BEST MANAGEMENT PRACTICES
FOR CAROLINAS GOLF COURSES

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BEST MANAGEMENT PRACTICES
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Construction, Watering, Fertilizing, Cultural Practices, and Pest Management Strategies for Sustainable Golf Course Turf Maintenance

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To those golf course superintendents who grow and maintain the best playing conditions and environmentally friendly courses in the world and to the students who should relentlessly pursue knowledge in turf management, personnel skills, and human relationships.

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Bob Bellinger and L.B. McCarty

PREFACE

Golf courses in North and South Carolina are among the finest in the world. Indeed some of the game's most famous courses, such as Pinehurst No. 2 and Harbor Town Golf Links, are in the Carolinas along with an array of facilities that are as affordable as they are accessible. All of these courses benefit from continued research to identify the most economically and environmentally sustainable operations of the day.

As a result, across the board, Carolinas golf courses are living examples of constantly advancing sophistication in terms of their design, construction, and ongoing management. Golf's environmental performance, like that of many industries, is subject to increasing scrutiny from the general public and regulatory agencies. This manual is intended as a reference guide to help ensure the game continues to withstand that scrutiny and remains a sound steward.

Golf course superintendents, assistant superintendents, club managers, green committee members, turfgrass students, and officers of regulatory agencies will find this manual helpful. It has been produced by authors with extensive expertise in specific areas of turfgrass and environmental science. At the time of publication, it is as complete and up-to-date possible.

However, management and pesticide recommendations are constantly being updated. New products, grasses, and management techniques continue to evolve, while older ones often disappear. It is imperative for those charged with maintaining golf courses to be in constant contact with State University turfgrass specialists, County Cooperative Extension Service offices, and relevant professional and trade associations. Information on the latest advances is also available at turfgrass field days and events such as the Carolinas Golf Course Superintendents Association annual Conference and Trade Show.

Golf course management budgets and intensity levels range from the very modest to exquisite, highly-maintained courses capable of hosting international and professional events. Regardless of the resources available or the nature of the clientele, the climate and geography of the Carolinas demands all courses employ a broad range of maintenance practices from season to season, and often from one area of the course to another. Even the briefest scan of the pages following will give the reader some idea of the complexity involved in presenting a golf course in quality condition for play on any given day.

Considerable resources are available to golf course superintendents in the Carolinas. Many are free or available at nominal cost. These resources include:

Web Sites:

http://www.clemson.edu/extension/horticulture/turf/pest_guidelines/

http://www.turffiles.ncsu.edu/

Publications:

- Diagnosing Turfgrass Problems: A Practical Guide
- More Turfgrass and Related Weeds: Beyond the Color Atlas
- Designing and Maintaining Bermudagrass Sports Fields in the United States, 2nd edition - EC 698
- Weeds of Southern Turfgrasses - EB 150
- Diseases of Turfgrasses in the Southeast - EB 146
- Pest Management Handbook (vol. 2), Turfgrass and Ornamentals - EC 695
- Sod Production in the Southern United States - EC 702
- Southern Lawns - EC 707

Call 864-656-3261 during weekday office hours or order online at: http://www.clemson.edu/psapublishing

Other Turfgrass Publications:

Common Turfgrass Weeds. An 84-slide set with narrative of the most common weeds in golf courses, home lawns, sports fields, & roadsides.

Sports Field Construction. A 70-slide set with narrative on designing, constructing, and maintaining all levels of sports fields. Both are available from: CSSA Headquarters Office, Attn: Book Order Dept., 677 South Segoe Road, Madison, WI 53711-1086, http://www.crops.org

Best Golf Course Management Practices (3rd edition). A complete text covering all agronomic practices for managing golf courses with minimum fertilizer and pesticide inputs. Order from www.prenhall.com; Amazon.com; GCSAA.com; or BarnesandNoble.com. 1-800-472-7878. ISBN 0-13-088359-X.

Color Atlas of Turfgrass Weeds (2nd edition). A complete text covering all major weeds occurring in Turfgrass and Ornamentals. Included are detailed biology, reproductive means, distribution ranges and control recommendations. ISBN 1-57504-142-1.

Managing Bermudagrass Turf. A complete text concerning Bermudagrass Turf, especially golf greens. ISBN 1-57504-163-4. Order these books from GCSAA.com; Amazon.com; or BarnesandNoble.com.

Weed Control in Turf and Ornamentals. A complete text on turf and ornamental herbicides, their chemistry, mode of action, and control of the most important weeds in each. ISBN 13-978-0-13-159122-6.

Applied Soil Physical Properties, Drainage, and Irrigation Strategies - A Practical Guide. A soil physics book which demystifies the complicated math used in many of the soil physics formulas and to concentrate on the applications of these. Included are numerous examples of how practitioners can successfully use the information covered in the book. Springer International Publishing, at www.springer.com/us/book/9783319242248.

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This manual was initiated by Bill Kennedy, CGCS, then-president of the Carolinas Golf Course Superintendents Association. It was supported by the Carolinas GCSA board of directors including David Lee, Adam Charles, Brian Powell, CGCS, Danny Allen, Billy Bagwell, Rob Daniel, III, CGCS, Chris DeVane, Scott Kennon, CGCS, Andrew Ramsey, Charlie Spears, Brian Stiehler, CGCS, and Matthew Wharton, CGCS. The executive director of the Carolinas GCSA, Tim Kreger also was a driving force for the publication. The manual was reviewed by the following golf course superintendents:

David Lee

Adam Charles

Don Garrett, CGCS

Brian Powell, CGCS

Danny Allen

Billy Bagwell

Rob Daniel, CGCS

Chris DeVane

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Steen Wansley

Corey Hall

Nate Stevely

Bill Kennedy, CGCS

Note: CGCS = Certified Golf Course Superintendent

President Kennedy, the board of directors, and executive director felt a manual outlining typical management practices necessary to maintain attractive, yet, economically viable golf courses with acute attention to pest management, wise and prudent water use, minimal management inputs, and using best adapted grasses for the particular regions of the Carolinas was needed.

Any project of such magnitude is definitely the result of the efforts of many competent, dedicated professionals. Philip Brown was a key reviewer and organizer of the manual while Trent Bouts was critical in its formatting and printing. Hopefully no one has been omitted from this list; if so, we apologize for the oversight.

DISCLAIMERS

The use of trade names in this publication is solely for the purpose of providing specific information. It is not a guarantee or warranty of the products named, and does not signify they are approved to the exclusion of others of suitable composition. Listing products or companies within this document does not constitute an endorsement of that product or company.

The pesticide recommendations presented in this publication were current with State and Federal regulations at the time of publication. The user is responsible for determining that the intended pesticide use is consistent with the directions on the product label being used. Use pesticides safely.

Labels change frequently; refer to the current pesticide label for specific application information. Never exceed the rates recommended on label of the specific product applied. Read and follow label directions as the label is the law.

ABOUT THE COORDINATING AUTHORS

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L.B. (Bert) McCarty is a Professor of Horticulture specializing in turfgrass science and management at Clemson University in Clemson, South Carolina. A native of Batesburg, SC, McCarty received a B.S. degree from Clemson University in Agronomy and Soils, an M.S. from North Carolina State University in Crop Science, and a Ph.D. from Clemson University in Plant Physiology and Plant Pathology. Dr. McCarty spent nine years as a turfgrass specialist at the University of Florida in Gainesville. While at the University of Florida, he oversaw the design and construction of a state-of-the-art research and education turfgrass facility named "The Envirotron." He also was author or co-author of the books Best Management Practices for Florida Golf Courses, Weeds of Southern Turfgrasses, and Florida Lawn Handbook. In 1996, he moved to Clemson University, where he is currently involved in research, extension, and teaching activities. He has published numerous articles dealing with all phases of turfgrass management and is in constant demand to conduct presentations, workshops, training sessions, and on-site visits concerning all phases of turfgrass establishment and management. He is currently author or co-author of the books: Color Atlas of Turfgrass Weeds (3rd ed.); Weed Control in Turf and Ornamentals; Southern Lawns; Managing Bermudagrass Turf; Applied Soil Physical Properties, Drainage, and Irrigation Strategies; and, Fundamentals of Turfgrass and Agricultural Chemistry. He is co-author for the Golf Course Superintendents Association of America workshops Weed Control; Advanced Weed Management; Managing Bentgrass Golf Greens in Heat Stress Environments; and, Managing Ultradwarf Bermudagrass Golf Greens. He also teaches an undergraduate/graduate course, Advanced Turfgrass Management, is active in a number of professional societies, and a Fellow of the Crop Science Society of America and Fred V. Grau Turfgrass Science award recipient.

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James P. (Jim) Kerns is an Associate Professor of Plant Pathology at North Carolina State University located in Raleigh. He earned a B.S. at NC State University; an M.S. at Texas A&M University; and Ph.D. at NC State University. For four years, he was an assistant Professor and Extension Specialist at University of Wisconsin-Madison. While at UW-Madison, Kerns developed a model that accurately predicted dollar spot development and developed highly successful snow mold management programs that were widely adopted by turfgrass managers in Northern climates. In 2012, Kerns moved to NC State University as the turfgrass pathologist with extension and research responsibilities. At NC State, his program focuses on etiology, epidemiology and management of diseases of both warm- and cool-season grasses. His research program focuses on understanding the biology of ultradwarf bermudagrass diseases, large patch of zoysiagrass, plant parasitic nematodes in turf and diseases of creeping bentgrass. He has published numerous articles on turfgrass disease management and is frequently asked to conduct presentations, workshops, training sessions and on-site visits concerning all aspects of turf disease management. He has co-authored two book chapters; Advances in Turf Pathology since 1990 in Turfgrass: Biology, Use, and Management, Agronomy Monograph, and Etiolation and Decline: An Enigmatic Condition in Creeping Bentgrass in Acidovorax as a Plant Pathogen. His program also houses the Turfgrass Diagnostic Lab, which receives 400 to 500 samples each year from the continental 48 states with most of the samples coming from the Southeastern U.S.

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FOREWORDS

As a golf course superintendent in the Carolinas, the publication of this best management practices manual gives me great satisfaction. While it stands as a road map for sound environmental and economic management of every golf course across the region, I am proud to say that road is already well traveled. Superintendents have long been busy with these BMPs.

What this manual does is bring the best of the best into one place to serve as a reference tool. We have worked hard to make it practical and user-friendly not just for superintendents but also for others interested in how we make decisions every day. It is my contention that golf is a far better environmental citizen than it is given credit for. I believe any party from any field who invests the time to study this manual will come to share that opinion.

As a past-president of the Carolinas GCSA, I am doubly proud that we raised the money not just to produce this manual but also some of the science within. Our association created the annual Rounds4Research auction of golf rounds that generates funds for turfgrass research. The auction, which is now conducted nationally, is one more example of how golf course superintendents are committed to being part of the solution.

Bill Kennedy, CGCS
Past-President (2015)
Carolinas Golf Course Superintendents Association

I have yet to meet the golf course superintendent who fell in love with the job before they fell in love with the outdoors. Many do enjoy the game but without exception their passion for the natural world led them to the work.

This manual is an extension of that relationship and a clear demonstration of their commitment to sound stewardship. To put it simply, golf course superintendents want to do the right thing.

There is further incentive in the fact that doing the right thing environmentally equates to economic success. It serves every golf course owner's business interests to minimize the use while maximizing the benefit of any resource whether that is water, labor or fertilizer.

The Carolinas GCSA is fortunate to be able to draw on the expertise of leading researchers in preparing this document. The manual has also been informed by collaboration with environmental and natural resource regulatory agencies in both North and South Carolina.

As a result, golf course superintendents have at their fingertips a road map to the best means available to conserve the environment in which the game is played and protect the nearly $7 billion in overall economic activity and close to 90,000 jobs that it supports in the Carolinas.

Tim Kreger
Executive Director
Carolinas Golf Course Superintendents Association

1 TURFGRASSES

1 TURFGRASSES

1.1 ECONOMIC IMPACT OF THE GOLF INDUSTRY

Golf courses in the United States provide the economy with an estimated $20 billion each year **(Figure 1–1)**. In South Carolina, the total economic yearly impact is $2.7 billion in output or sales, ~35,000 jobs, $875 million in personal income and over $300 million in federal, state, and local taxes. Green fees and club membership dues generate $13 million in admissions tax revenue alone, accounting for 38% of the state admissions tax collection (Jackson, 2012). In North Carolina, the 556 golf courses and related industries generate over $4.2 billion of economic activity, nearly 53,000 jobs, and $1.3 billion of wage income (Anonymous, 2013). Golf is comparable to other key industries such as agricultural crops ($2.5 billion), science, research and development ($2.9 billion) and electronic and semiconductor components manufacturing ($2.9 billion). More importantly, turfgrasses provide soil erosion control, dust stabilization, heat dissipation, noise abatement, air pollution control, wildlife habitat, safety to competitive athletic participants, increased property values, and are an integral component of the landscape **(Figure 1–2)**. Turfgrasses provide many of these benefits due to their high number of plant shoots and roots – 49 to 85 billion shoots per acre (123 to 213 billion per hectare), with up to 163 billion shoots per acre (408 billion per hectare) for putting greens and a combined root weight of up to 14,363 pounds per acre (16,000 kg/ha) for a lawn. Due to this high shoot and root mass, turfgrasses are often used as filter strips for mining operations, animal production facilities, and agricultural croplands. Research also demonstrates bare ground

Figure 1-1. Golf is a game enjoyed by all ages and is a major economic force in the Carolinas

Figure 1-2. The Carolinas is blessed with some of the finest golf facilities in the world.

loses almost 200 pounds of soil per acre (224 kg/ha) during a 3-inch (7.6 cm) rainstorm while turfgrass-covered ground loses between 9 and 54 pounds of soil per acre, or 10 to 60 kg/ha (Gross et al., 1991). In the Carolinas, the first golf course was built in Charleston in 1786.

1.3 ADAPTATION

Climate

Climate (or environment) is the primary factor determining the region of adaptation of turfgrasses **(Figure 1–3)**. Temperature and moisture are the major components of climate influencing adaptation. Light and wind are two additional climatic parameters influencing adaptation. Grasses evolve in nature through natural selection or naturalization in order to adapt to specific regions. This naturalization may involve mutations (rapid genetic changes), physiological adjustments over long periods, or most likely some combination of numerous change processes.

Cool Humid Zone. The cool humid zone consists of the higher elevations of Western North Carolina where rainfall quantities are often 80+ inches (2m+) yearly. The primary turfgrasses used in the cool humid area are the bentgrasses, bluegrasses, fescues, and ryegrasses. In the extreme southern portion of the cool humid area, tall fescue, zoysiagrass, and cold hardy bermudagrasses are sometimes used.

Warm Humid and Hot Humid Zones. The warm humid zone runs from southern Virginia through the Carolinas to central Texas. The hot humid zone includes the coastal areas of the southern-Atlantic states, all of Florida, and the

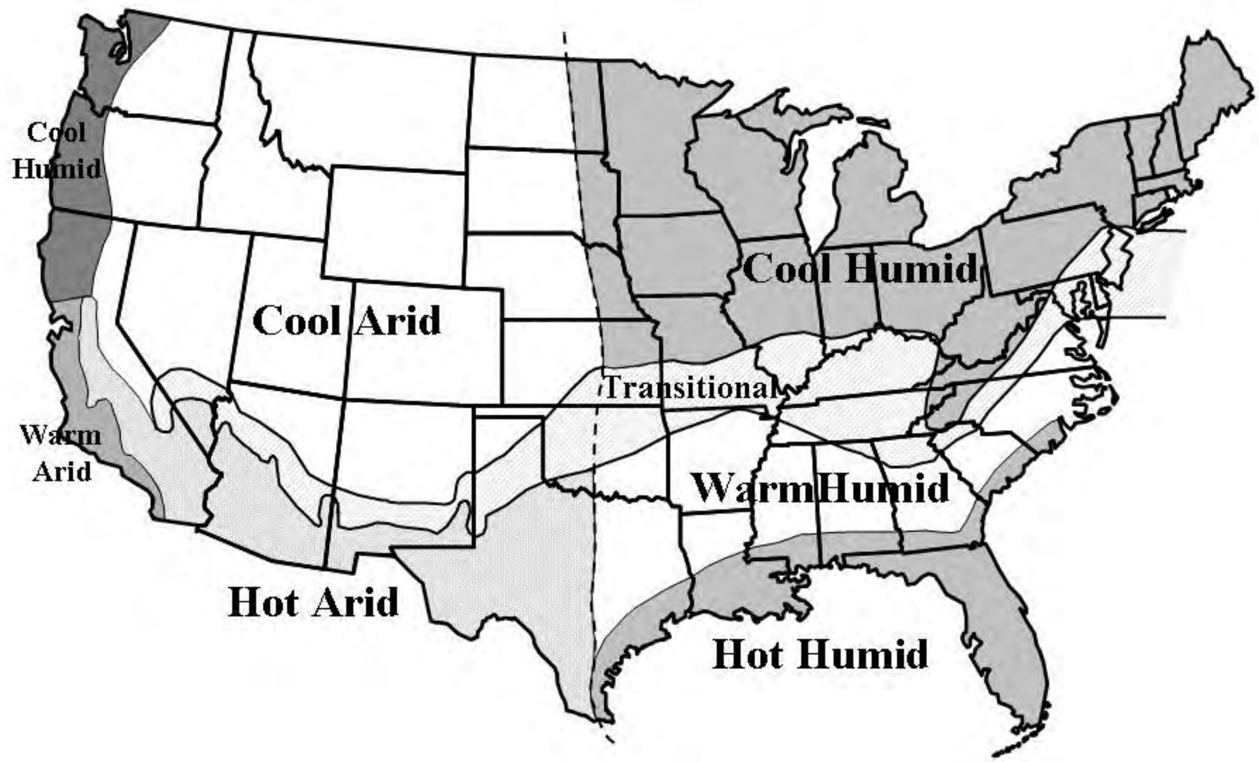


Figure 1-3. Climatic zones in the mainland United States. Up to four climatic zones occur in the Carolinas ranging from hot and humid along the coast to cool and humid in the mountains. These climatic zones largely dictate which turfgrasses can be grown long-term.

Gulf coastal regions to the southern tip of Texas. Many of these parts are considered subtropical. Humidity is usually high during summer months with rainfall ranges from a low of ~20 inches (~51 cm) in central Texas and western Oklahoma to a high of ~70 inches (~178 cm) along the Gulf coast and ~80 inches (~208 cm) in the southern western portion of the Appalachian Mountains.

The primary turfgrasses grown in these two regions include bermudagrass, zoysiagrass, bahiagrass, St. Augustinegrass, carpetgrass, and centipedegrass. Ryegrass is used for temporary winter overseeding. Kentucky bluegrass and tall fescue are used along the northern edge of the warm humid zone. Creeping bentgrass is often used on golf greens in the northern portions of the warm humid zone and on fairways at higher (e.g., >2,000 ft (610 m)) elevations. Seashore paspalum is also used along coastal areas in the hot humid zone, especially where poorer quality irrigation water is used.

Transition Zone. An imaginary line passing east to west at approximately 37° north latitude separates the temperate and subtropical zones in the eastern United States **(Figure 1–3)**. This line marks the center of a 200 mile wide (322 km) belt, called the **transition zone**, where cool-season and warm-season turfgrasses encounter the limits of their southern and northern adaptation, respectively. Many warm- and cool-season turfgrasses can be found growing together in the transition zone.

Turfgrasses often grown in the transition zone include bermudagrass, zoysiagrass, tall fescue, bentgrass, and Kentucky bluegrass. Some shade is generally needed in the transition zone to support permanent tall fescue and Kentucky bluegrass while full sunny conditions are needed for bermudagrass. It is typically too cold for most cultivars of St. Augustinegrass, carpetgrass, centipedegrass, and bahiagrass and too hot for the fine fescues and perennial ryegrasses as a permanent turf cover, unless grown at higher (e.g., >2,000 ft (610 m)) elevations.

1.4 CULTIVARS AND THEIR CHARACTERISTICS

Turfgrasses are divided into two groups based on their temperature requirements; warm-season and cool-season. Warm-season (or C4) grasses grow best at air temperatures between 80 and 95°F (26 and 35°C) and night temperatures in the high 60°F's (15.6°C's) to low 70°F's (21°C's). Warm-season grasses such as bahiagrass, bermudagrass, carpetgrass, centipedegrass, St. Augustinegrass, and zoysiagrass are better adapted in the southern (tropical and subtropical) regions but can grow further north into the transition zone **(Table 1-1)**. The main flush of growth of warm-season grasses occurs during spring into summer and will continue even at 55 to 60°F (12.8 to 15.6°C) but initiate dormancy at temperatures less than 50°F (10°C).

Table 1-1. General characteristics of warm-season turfgrasses used on Carolina Golf Courses (cultivar differences may occur).

Characteristic	Bahiagrass	Bermudagrass	Centipedegrass	Seashore Paspalum	St. Augustinegrass	Zoysiagrass
Establishment						
Planting method	seed/vegetative	seed/vegetative	seed/vegetative	seed/vegetative	vegetative	seed/vegetative
Rate of coverage	poor to intermediate	excellent (fast)	slow	slow	good	slow
Days to germination	21 to 35	14 to 21	35 to 40	na	na	21 to 28
Growth rate	slow	good-fast	slow-poor	slow-medium fast	medium fast	slow
Density	poor to fair	excellent	good	excellent	excellent	excellent
Leaf texture	coarse	fine to medium	medium	fine to coarse	coarse	fine to medium
Polystand compatibility	medium	medium	poor	poor	poor	poor
Cultural Requirements						
Maintenance intensity	low	high	low	medium	medium	medium
Mowing height (in.) [fairways]	3 to 4	0.5 to 1.5	1 to 2	0.75 to 1.5	2.5 to 4.0	0.75 to 2.0
Mowing frequency (days)	7 to 14	1 to 4	10 to 14	1 to 7	7 to 14	1 to 14
Irrigation requirements	low	low	medium	high	high	medium
Evapotranspiration (ET) (mm/day)	2.5 to 8.5	6 to 7	6 to 7	2.5 to 8.5	7 to 8.5	6 to 7
Nitrogen needs	low	high	low	low	medium	low to medium
Performance						
Heat tolerance	excellent	excellent	excellent	excellent	excellent	excellent
Cold tolerance	fair	good	fair	poor	poor to fair	good to very poor
Killing temperature (°F)	~23	~19	~11	~19	~23	~6
Drought resistance	excellent	excellent	poor	excellent	good	excellent
Shade tolerance	fair	poor	fair	fair to good	good to very good	fair to good
Wear tolerance	excellent	excellent	poor	good	medium	excellent
Recuperative potential	good	excellent	poor	good	good	good
Low mow tolerance	poor	excellent	fair	good	poor	good to excellent
Salt tolerance	poor	good	poor	excellent	fair to good	good
Soil pH range	5.0 to 7.0	5.5 to 8.0	5.0 to 6.5	5.5 to 8.0	6.0 to 8.0	6.0 to 8.0
Acid soil tolerance (below pH 5.5)	good	good	excellent	good	fair	fair
Thatch tendency	low	high	medium	medium	high	high
Disease tendency	low	low to medium	low	medium	medium	low to medium
Submersion tolerance	medium	excellent	poor	good	excellent	excellent

na = not available

Table 1–2. General characteristics of cool-season turfgrasses used on Carolina Golf Courses (cultivar differences may occur)

Characteristic	Annual bluegrass	Ky bluegrass	Creeping bentgrass	Perennial ryegrass	Red fescue	Poa trivialis	Chewings fescue	Tall fescue
Establishment								
Planting method	seed	seed/vegetative	seed/vegetative	seed	seed	seed	seed	seed/vegetative
Rate of coverage	very fast	slow	slow	very fast	medium	slow	very slow	medium
Days to germination	na	8 to 21	7 to 14	5 to 12	10 to 21	na	10 to 21	10 to 14
Growth rate	fast	fast	fast	fast	slow - medium	medium	slow - medium	fast
Density	excellent	good	excellent	very good	excellent	good	very good	good
Leaf texture	fine	medium	very fine	medium	very fine	very fine	very fine	medium-coarse
Polystand compatibility	low	good	medium	medium	good	medium	medium	medium
Cultural Requirements								
Maintenance intensity	high	medium	high	medium	low	high	low	medium
Mowing height (in.) [fairways]	0.3 to 1.0	1.5 to 2.5	0.25 to 0.5	0.75 to 2.5	1.5 to 2.5	na	1.5 to 2.5	1.5 to 3
Mowing frequency (days)	1 to 3	5 to 7	1 to 3	5 to 7	7	1 to 2	7	7 to 14
Irrigation requirements	high	medium	high	medium	low	high	low	low
Evapotranspiration (ET) (mm/day)	>10	>10	>10	8.5 to 10	7 to 8.5	>10	7 to 8.5	>10
Performance								
Nitrogen needs	medium	medium	high	medium	low	medium	low	medium
Heat tolerance	poor	fair	fair to good	poor to fair	fair	poor	fair	good
Cold tolerance	poor	very good	good	fair	good	good	good	good
Killing temperature (°F)	na	na	na	na	na	na	na	na
Winter performance	fair	fair	fair	excellent	very good	fair	very good	good
Drought resistance	poor	good	poor	good	very good	poor	excellent	excellent
Shade tolerance	poor	fair	fair to good	fair	excellent	fair	excellent	good
Wear tolerance	poor	good	fair	excellent	good	fair	fair	good
Recuperative potential	poor	good	good	poor	fair	fair	poor	good
Low mow tolerance	excellent	poor	excellent	very good	very good	excellent	good	fair
Salt tolerance	poor	poor	poor to excellent	good	good	poor	good	good
Soil pH range	5.5 to 6.5	6.0 to 7.0	5.5 to 6.5	6.0 to 7.0	5.5 to 6.5	5.5 to 6.5	5.5 to 6.5	4.7 to 8.5
Thatch tendency	medium	medium	high	low	medium	medium	medium	low
Disease tendency	high	medium	high	medium to high	medium	high	medium	low
Submersion tolerance	fair	medium	good	fair	fair	na	na	na

na = not available

Table 1–3. Characteristics of popular improved bermudagrass varieties. This list is very dynamic. Refer to your state turfgrass specialist or www.ntep.org for the latest varieties and their comparisons.

GREENS GRADE VARIETIES
These are used for golf greens, collars, approaches, and high-maintenance tees **(Figure 1-5)**. They all are vegetatively propagated with no available seed.
Aussie Green, Champion, Classic Dwarf, FloraDwarf, Jensen, Mini Verde, MS Supreme, Pee Dee 102, Quality Dwarf, Reesegrass, Sunday, Tifdwarf, TifEagle, Tifgreen (328), Tifgreen II.
VEGETATIVE PROPAGATED VARIETIES FOR FAIRWAYS, ROUGHS, AND TEES
Baby Bermuda, Bulls-Eye (MS Choice), Cardinal, Celebration*, FloraTeX, GN-1, Guymon, Latitude 36**, Midfield Midiron*, Midlawn*, Midway*, MS Express, MS Pride, NorthBridge**, Ormond, Patriot*, Plateau, Quickstand*, Santa Ana, Shanghai, Sunturf, Texturf 10, Tif No. 4, Tiflawn (57), TifSport*, TifTuf, Tifton 10 (or T-10), Tifway (419), Tifway II, Transcontinental, Windsor Green, Wintergreen.
SEEDED VARIETIES FOR FAIRWAYS, ROUGHS, AND TEES
Ashmore, Astro, Barbados, Blackjack, Blue-Muda, Bradley, Burning Tree, Casino Royal, Cheyenne, Common, Contessa, DelSol, GoldGlove, Guymon, Hollywood, Jackpot, Kashmir, LaPaloma, LaPrima (a blend of certified bermudagrasses), Majestic, Mercury, Mirage, Mohawk, Northshore SLT, NuMex Sahara, Panama, Paradise, Primavera, Primo, Princess 77, Pyramid 2, Riviera*, Royal Bengal, Sahara, Savannah, Shangri-La, Soliel, Sonesta, Southern Star, Sultan, Sunbird, Sundance II, Sundevil II, Sunsport, SunStar, Sultan, Sydney, Tif No. 1-4, Transcontinental, U-3, Veracruz, Yukon*, Yuma.

*Noted for cold tolerance. **Improved cold tolerance.

In spring when temperatures rise above 50°F (10°C), warm-season turfgrasses resume growth. The greatest stress period for warm-season grasses is winter due to potential low-temperature damage.

Cool-season (or C_3) grasses, such as bentgrass, fine fescue, tall fescue, rough bluegrass (or *Poa trivialis*), and Kentucky bluegrass, are adapted and grown in cooler temperatures and subarctic regions of the world, with optimum growth at temperatures between 60 and 75°F (15.5 and 24°C) **(Table 1–2)**. Their peak growth periods occur in spring and fall. Conversely, their growth is slow during summer and winter, often becoming dormant, and they can eventually die if management practices are not manipulated to better favor their growth and survival.

In the Carolinas, all major turfgrasses used for golf courses can be found with the exception of buffalograss [*Buchloe dactyloides* (Nutt.) Engelm.]. With much of the Carolinas in the transition zone, some seasons, locations, and years favor certain turfgrasses while other seasons, years and locations often favor other turfgrasses.

Warm-Season Grasses

Bermudagrass. Bermudagrass is a long-lived perennial grass originating from subhumid, open, closely grazed rangelands characterized by hot, dry summers around the Indian Ocean ranging from Eastern Africa to the East Indies. It is believed to have been introduced to the United States from Africa in 1751 or earlier.

Bermudagrass Cultivars. Prior to the mid-1940s, golf courses used common bermudagrass from tee to green. Common bermudagrass provided a course-textured, uneven, and thin putting surface. Many golf courses still had sand greens where a roller was used to smooth the ball line toward the cup and heavy oils or diesel fuel was used to pack the sand. Common bermudagrass seed was not certified until 1963 in an attempt to rid seed from a tall, rapid growing Giant bermudagrass (*Cynodon dactylon* var. *aridus*). This common bermudagrass was also called Arizona common since the production fields were in Arizona. The first recognized turf-type bermudagrass cultivar in the United States was "St. Lucie," a fine-textured dwarf plant used in Florida lawns. Table 1–3 lists some of the popular current bermudagrass varieties and their characteristics **(Figure 1–4)**. Consult www.NTEP.org for independent cultivar comparison.

Figure 1-4. Bermudagrass is a widely used warm-season turfgrass on many golf courses in the Carolinas.

Figure 1-5. An ultradwarf bermudagrass golf green in the Carolinas.

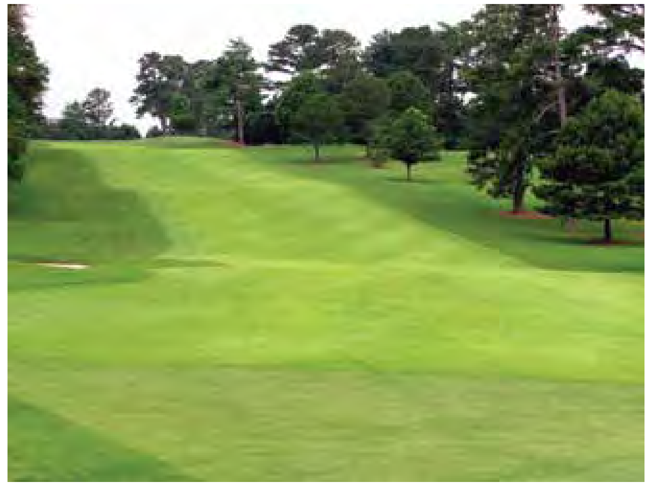


Figure 1-7. A zoysiagrass golf fairway.

Figure 1-6. In recent years, "off-types" have plagued some bermudagrass golf greens.

Bermudagrass Mutants or Off-Types

In recent years, considerable attention has been made toward the occurrence of mutants or off-types of grasses in previously pure bermudagrass stands. In addition to different color, texture, and density, off-types often have differential susceptibility to environmental stresses such as high temperature, humidity, and reduced sunlight intensity **(Figure 1–6)**. Additional stresses such as low mowing height or verticutting often delay recovery. When 30 to 40% of the total surface has become contaminated, it becomes difficult to provide consistent, acceptable playing conditions, especially during periods of stressful weather. When over 50% of the surface becomes contaminated, it is almost impossible to provide a quality playing surface.

It is believed off-types have arisen from the chance mutation of the parent material (least likely), "carry-over" plants not fully controlled prior to renovation (more likely), or possibly contamination via sprigs, through mechanical means or encroachment from collars (most likely). Mutations are abrupt inheritable changes brought about by alterations in a gene or a chromosome or by an increase in chromosome number. The rate of mutation occurrence can be increased artificially, but the results cannot be controlled. As they are usually recessive, mutations may be unexpressed for generations.

Mutations are produced by internal disorders, such as inaccurate gene duplication, and by natural external forces, such as severe temperature changes and sunlight radiation. They are induced experimentally by use of atomic radiation, X-rays, chemicals, and sudden temperature changes. Natural mutations appear very infrequently while artificial ones occur quicker. Tifway II, Tifgreen II, and TifEagle are induced mutations of original grasses created by exposing parent material to artificially high levels of radiation. Tifdwarf, FloraDwarf, and Pee Dee 102 bermudagrasses are believed to be natural mutants from Tifgreen bermudagrass.

Since Tifdwarf is a probable vegetative mutant from Tifgreen bermudagrass, it is possible an original planting of Tifdwarf can undergo another mutation to produce a different grass. Champion, Mini Verde, MS Supreme, and others are believed mutations of Tifdwarf bermudagrass. Mutations offer breeders new ways of introducing genetic variability into breeding lines but also may cause existing materials to be somewhat unstable; thus, they may produce undesirable off-types after several years of growth.

Zoysiagrasses

Zoysiagrasses, named after Karl von Zois, an 18th-century Austrian botanist, are warm-season grasses (2n=40) native to the hot, humid Southeast Asia/South Pacific region including China, Korea, Japan, and northern Australia. They were first introduced in the United States starting in the late 1890s but recently have become much more popular

Table 1–4. Partial listing of current zoysiagrasses used for fine turf purposes in the USA.

	Propagation method	
Zoysiagrass (common names)	Vegetative	Seeded
Zoysia japonica (Japanese, Chinese, or Korean Common)	Belair, BK-7, Carrizo, Chisholm, Crowne, El Toro, Empire, Empress, GNZ, Himeno, JaMur, Marion, Meyer (aka, Z52 & Amazoy), Miyako, Pali-sades, Royal, Serene, Southern Gem, Sunburst, UltimateFlora, VJ, Y2, Zoyboy	Cathay, Chinese Common, Compadre, Companion, Compatibility, J-36 & 37, Ming, SR 9150 & 9200, Sunrise, Suns-tar, Traveler, W3-2, Zen 100-300, Zenith, Zoysia japonica
Zoysia macrantha Desv. (Prickly Couch)	Icon, Nara	
Zoysia matrella (Manilagrass)	Cashmere, Cavalier, Diamond, Facet, L1F, Roll-master, Omni, PristineFlora, Shadow Turf, Zeon, Zorro	
Zoysia japonica x Z. matrella	Z-3	
Zoysia tenuifolia (syn. Z. pacifica) (Mascarenegrass, Templegrass, or Korean Velvetgrass)	common	
Z. japonica x Z. tenuifolia	Emerald, Geo, Pristine	
Z. japonica x (Z. matrella x Z. tenuifolia)	DeAnza, Victoria	
Z. sinica (Seashore Zoysiagrass)		J-14
Other cultivars	Links, Marquis	

due to their excellent wear tolerance, slow growth rate, improved winter hardiness, salt tolerance, unique green color during the summer, and golden brown color during winter months. Zoysiagrasses also have better shade tolerance than bermudagrass and lower fertility requirements. Zoysiagrasses are well-adapted for use on golf course fairways, tees, bunker faces, and collars as well as lawns in hot and warm climatic zones **(Figure 1–7)**.

Zoysiagrasses as a whole, however, are very slow-growing grasses; thus, they have slow recuperative potential which is an important consideration in high traffic areas such as par-3 tees and greens approaches. This slow lateral growth, however, is often an advantage as zoysiagrasses are often planted on the perimeter of sand traps, golf greens, and flower beds to greatly reduce or slow off-site lateral growth. They tend to develop thatch over time, and are susceptible to several diseases, most notably rust, dollar spot, leaf spot, and brown patch. Most improved zoysias have to be propagated vegetatively and are extremely slow in becoming established if plugged or sprigged. Other disadvantages include slow thatch decomposition; poor growth on acid, compacted, and perpetually wet soils; higher water requirements than most bermudagrasses; seedheads; susceptibility to bermudagrass invasion; and possible severe damage by nematodes, and hunting billbugs. Zoysiagrass, being native to coastal areas which naturally receive heavy yearly precipitation, also tends to be shallower rooting, and is weakened when grown in soils low in potassium. For maximum beauty, a reel mower should be used for cutting.

There are several species and varieties of zoysiagrasses used for golf courses **(Table 1–4)**. These varieties vary widely in color, texture, and establishment rate. Broadly speaking, two leaf texture types are used; fine and coarse. The finer textured zoysiagrasses generally have better shade tolerance but less cold tolerance compared to the coarser textured species. Consult www.NTEP.org for independent cultivar comparison.

Coarser Leaf Types

Zoysia japonica Steud.

This species, commonly called Japanese, Chinese, or Korean Common lawngrass, was introduced into the United States as seed in 1905 from Kokai, North Korea by Frank Meyer. It has a relatively coarse texture; hairy, light-green leaves; a relatively fast growth (spread) rate; and the best cold tolerance of the zoysias. Although cold tolerant (50% kill at ~11°F, -11.6° C), it quickly loses color with slight frost. *Zoysia japonica* is the only zoysiagrass for which seed is commercially available. Current seeded cultivars include Cathay, Chisholm, Compadre, Companion, Compatibility, J-36 & 37, Ming, SR 9150 & 9200, Sunrise, Sunstar, Traveler, W3-2, Zen 100-300, Zenith, and Zoysia japonica. Important vegetatively established cultivars of *Z. japonica* include Belair, BK-7, Carrizo, Crowne, El Toro, Empire, Empress, GNZ, Himeno, JaMur, Marion, Meyer (aka, Z52 & Amazoy), Miyako, Palisades, Royal, Serene, Southern Gem, Sunburst, UltimateFlora, VJ, Y2, and Zoyboy **(Table 1–4)**. Due to its superior cold tolerance, Meyer is a popular cultivar in full sunlight areas of the upper transition zone. However, other cold tolerant cultivars are being developed with Chisholm being one of the first. It also has a number of additional desirable traits.

Finer Leaf Types

Zoysia matrella (L.) Merr.

Also called Manilagrass since it was introduced from Manila, the Philippines around 1911, this species produces a finer and denser turf than *Zoysia japonica* but is less winter hardy (50% kill at ~17°F, -8.3° C). It has a similar brown patch tendency as Meyer but better shade tolerance (up to 60% continous shade, up to 90% shade + trinexapac-ethyl). Manilagrass resembles bermudagrass in texture, color, and quality and is recommended for a high-quality, high-maintenance turf where a slow rate of establishment is not a disadvantage. Most zoysiagrasses used on golf courses are *Z. matrellas* due to their finer leaf texture, excellent density, and desirable shade tolerance. Cultivars currently include Cashmere, Cavalier, Diamond, L1F, Matrella, PristineFlora, Shadow Turf, Zeon, and Zorro. Diamond and L1F are *Zoysia matrellas* currently being evaluated as possible putting surfaces **(Figure 1–8)**.

Figure 1-8. Diamond zoysiagrass golf green.

Zoysia japonica x Z. tenuifolia

Emerald zoysia is a selected hybrid between *Zoysia japonica* and *Z. tenuifolia* released in 1955 by the USDA, although recent DNA fingerprinting suggests it is possibly a cross between *Z. matrella* and *Z. tenuifolia* (syn. *Z. pacifica*). It, along with Meyer zoysiagrass, were the industry standards until the late 1980s. This hybrid combines the winter hardiness, dark green color, and faster growth rate of Z. japonica with the fine texture and density of *Z. tenuifolia*. Other *Z. japonica* x *Z. tenuifolia* selections include Pristine and Geo.

Miscellaneous Zoysias

Zoysia japonica x Z. matrella

The only reported cultivar of this cross is Z-3 in Hawaii. It is medium-textured, apple-green in color, and forms a tight mat. It develops less thatch than Emerald but somewhat more than El Toro.

Zoysia tenuifolia Willd. ex Trin.

Also called Mascarenegrass and Korean velvetgrass, this species is the finest textured, most dense, least winter hardy zoysiagrass available. It has good wear tolerance but is extremely slow to spread and develops excessive thatch, giving it a puffy appearance. It is mainly used as an ornamental grass ground cover, especially in rock gardens, due to its unique clumping or mounding appearance. Since it also is the least cold hardy zoysiagrass, *Zoysia tenuifolia* is best adapted only to tropical and subtropical climates. It is often seen growing along roadsides and other low maintenance areas in the Caribbean Islands.

Zoysia japonica x (Z. matrella x Z. tenuifolia).

Two cultivars released in 1993 from the University of California are DeAnza and Victoria. These hybrids include El Toro and other experimental lines as parents, which provide them with faster lateral growth than most traditional cultivars. Both also have a finer leaf texture, although not as fine as Emerald zoysiagrass.

Additional Zoysiagrass Cultivars

Much research is currently being conducted on breeding and selecting additional zoysiagrass cultivars for the turfgrass sector. Vegetative zoysiagrasses being developed and evaluated include Compadre (Companion), JaMur, Links, Marion, Miyako, Omni, Royal, Serene, Ultimate, VJ, ZoyBoy, and several numbered entries. A new turf-type seeded zoysiagrass (*Z. sinica* Hance) also is being investigated for turfgrass potential, especially in low-to-moderate maintenance saline areas. J-14 is a commercial variety of *Z. sinica*. Other zoysiagrass species being investigated for turf use include *Z. macrostaycha* Franch. et Sav. and *Z. korenia*, supposedly the most salt-tolerant zoysiagrass species.

Bahiagrass

Bahiagrass (*Paspalum notatum* Flugge.) is a very coarse-textured species originally from rangelands and forest fringes in Argentina and Brazil in South America. It was introduced into the United States in 1914 and forms a low to fairly dense turf. It has very tough leaves and spreads vegetatively by short stout rhizomes and stolons. Its inflorescence bears two racemes as opposed to three to five for dallisgrass (*P. dilatatum*) or seven to nine for vaseygrass (*P. urvillei*). It is best adapted to the warm humid and hot humid zones. Bahiagrass has excellent drought tolerance, due in part to an extensive root system. It has fair shade and good wear tolerance, does particularly well on infertile, droughty sands, and seems affected little by nematodes. Fertility requirements are minimum. A major drawback of bahiagrass, however, is the constant production of tall (2 to 4 feet, 0.6 to 1.2 m), V-shaped seedheads throughout the summer months. Salt tolerance is poor and a high mowing height (2 to 3 inches, 5 to 7.6 cm) is required to maintain an acceptable stand. Bahiagrass also often expresses iron chlorosis in spring and fall months. Often used as a roadside grass because of its toughness, bahiagrass frequently escapes into bermudagrass fairways and roughs. However, as water resources become more restrictive, fertilizer rates become reduced, and effective nematicides are lost, bahiagrass use may increase. Cultivars include Argentine, Common, Paraguay, Pensacola, RCP, Riba, and Wilmington.

Seashore Paspalum

Seashore paspalum (*Paspalum vaginatum* Swartz.) is a sexually reproducing, diploid (2n=20), dense, variable-textured species of relatively dark-green color, originally from South Africa and secondarily from Argentina north into Brazil, where it is often found growing along seashores (hence, its common name) and in brackish water. In the United States, it grows in coastal areas of the Southeast to Texas and southward into Mexico and Argentina. Due to self-incompatibility, seed production is inhibited; thus, seashore paspalum is mostly propagated vegetatively. Traditional selections include Excaliber (formerly Adalayd) and Futurf. New releases include Aloha, AP-10, Boardwalk, FWY-1, Neptune Salam (fairways), Seadwarf (greens), Sea-Green (greens), Sea Isle I (tees and fairways), Sea Isle 2001 (greens), SeaSpray (seeded), and SeaWay (fairways).

Advantages of seashore paspalum include:

- It has the highest salinity tolerance of all warm-season grasses—withstanding short irrigation duration with seawater (~35,000 ppm salts). However, the turf must be fully grown-in to withstand this and have excellent soil drainage available. With diligence, good soil drainage, and the right growing conditions, water with ~5,000 ppm salts can routinely be used.
- Compared to bermudagrass, seashore paspalum has better low-light and cool-temperature tolerance from shorter winter days, or cloudy, rainy, foggy, or smoggy conditions.
- Due to its good water-logging or low oxygen tolerance, seashore paspalum can be inundated for short intervals with minimal detrimental effects.
- Requires between 30 to 50% less nitrogen than bermudagrass. If fertilized similar to bermudagrass, seashore paspalum tends to thatch and then severely scalps.
- Minimal seedhead production with certain cultivars and does not readily produce viable seed. However, when stressed, seashore paspalum, like most grasses, produces a flush of seedheads.

Figure 1-9. Seashore paspalum golf fairway.

- Seashore paspalum has a shiny, glassy dark-green hue, similar to Kentucky bluegrass or perennial ryegrass, with similar striping capabilities **(Figure 1–9)**.

Limitations of seashore paspalum include:

- Poor shade tolerance, requiring about six to eight hours of full sunlight daily for acceptable performance, similar to bermudagrass.
- Limited cold-tolerance, thus, appears limited in geographic range: tropical areas, or coastal areas in subtropical zones.
- Although it has superior salt tolerance when established, seashore paspalum cannot be effectively and rapidly established with irrigation water high in salinity (>5,000 ppm total salts) due to suppression of root growth. Fresh water will be necessary during grow-in or extended time will be necessary to achieve this. Fresh water also is needed periodically during prolonged droughts. Salinity tolerance, however, substantially increases as the turf matures. Leaf tip burn can also occur following irrigation with high-salt containing water.
- Although salt tolerant, having a sandy profile with high percolation rates is virtually mandatory for proper salt management of seashore paspalum. Areas with poor-draining silty or clay soils, or severely compacted soils, will find it extremely difficult to maintain any grass, including seashore paspalum. Many rivers and salt-laden estuaries used to irrigate contain high levels of silt and clay, and with prolonged use may reduce the infiltration rates of soils.
- Irrigation heads have to be monitored constantly to ensure each sprinkler is operating properly. Additional heads are often needed to improve application uniformity. Granular calcium applications such as gypsum ($CaSO_4$), calcium nitrate, or possibly liquid potash are needed to displace the excess sodium (Na) in the soil. The sodium then is leached down below the turf root

system; hence, the need for a soil profile with high percolation capabilities. Soil compaction also needs to be avoided. An aggressive deep-tine aerification program will be needed in poorly draining soils. Other nutrients such as phosphorus, potassium, magnesium, and manganese also are critical for good turf performance, requiring constant tissue and soil testing and regular spoon feeding.

- Seashore paspalum appears very thatch prone; thus, it may require more grooming, verticutting, and topdressing for control. Also, due to paspalum's tougher leaves, mower bed-knives and reels dull quicker and need replacing more frequently.
- Few pesticides are labeled specifically for seashore paspalum.
- Bermudagrass and other grassy weeds can be very problematic. Currently, no selective herbicides are labeled to control most grassy weeds in seashore paspalum. Weed control, especially bermudagrass suppression, involves using less nitrogen to discourage the bermudagrass, using saline irrigation to slow bermudagrass more than the paspalum, and applying rock salt to infested areas. All planting stock should be certified bermudagrass free.
- Other sporadic pests include billbugs, armyworms, webworms, leaf spots, dollarspot, and patch diseases.
- Excess nitrogen leads to succulent growth and enhanced scalping, predisposing the grass to pathogen attack.
- Seedheads may persist with some cultivars during certain months of the growing season.

With these in mind, seashore paspalum is best grown in high-draining, high sand content environments where salinity or poor water quality is an issue and inadequate quality water is available.

St. Augustinegrass

St. Augustinegrass [*Stenotaphrum secundatum* (Walt.) Kuntze] is believed to be native to open-to-lightly shaded, high rainfall, and humid regions of coastal South and Central America including the West Indies. It spreads by thick, long stolons and forms a very coarse-textured turf of medium density. Due to the lack of cold tolerance, St. Augustinegrass use is restricted to mostly coastal areas of the lower Atlantic states, the gulf coast regions, all of Florida, and parts of southwest and southern California. Its drought tolerance is fair to good but often develops chlorosis (yellowing) when grown on alkaline soils. Certain cultivars have good shade and salt tolerance. Chinch bugs, gray leaf spot disease, St. Augustinegrass Decline (SAD) virus, and brown patch disease are problems. The mowing height ranges from 1.5 to 3 inches (3.8 to 7.6 cm). Its use on most golf courses is limited to shade areas or lower-quality roughs. Cultivars include Amerishade, Bitterblue, Delmar, DeltaShade, Emerald Blue, Floralawn, Floratam, Floratine, Gulf Star, Island, Jade, Levi, Mercedes, Palmetto, Raleigh, Raleigh-S, Sapphire, Seville, Sunclipse, Texas Common, Winchester, Woerner Classic, and 80-10.

Cool-Season Grasses

Bentgrasses. Bentgrass (*Agrostis* sp.) is native to the cool, moist climate of central Europe and is adapted to cool, humid environments from the Northeast to the Northwest in the United States. Bentgrasses, however, are used outside this climatic region predominantly only on small, highly maintained areas such as golf greens **(Figure 1–10)**. It provides a year-round green surface; not requiring yearly overseeding and transition in spring as bermudagrass does. Hot (temperatures >90°F, 32°C), humid summer conditions are unfavorable for its growth and development. Under such conditions it often becomes very shallow rooted due to the depletion of carbohydrate reserves and is very susceptible to stresses such as drought, traffic, and diseases, especially dollar spot. The microclimate surrounding the bentgrass grown in these areas is often altered to better favor its survival. This includes soil preparation, irrigation, surface and subsurface air circulation, shade, and other parameters **(Figure 1–11)**. Bentgrass, due to its aggressive stoloniferous growth, can become a serious weed in other cool-season turfgrasses such as fescue and Kentucky bluegrass.

Varieties. Creeping and colonial bentgrass are the two most widely used species for golf course purposes **(Table 1–5)**. Creeping bentgrass is a fine-textured, cool-season perennial with excellent cold tolerance and is stoloniferous; hence, the name "creeping." It has less wear tolerance than many other turfgrass species, poor soil compaction tolerance, and slow recuperative ability following damage or environmental stress. Creeping bentgrass also is a heavy thatch producer which must be controlled. It is the primary bentgrass used for cool-season golf greens in the temperate and transition zones of the United States. Currently,

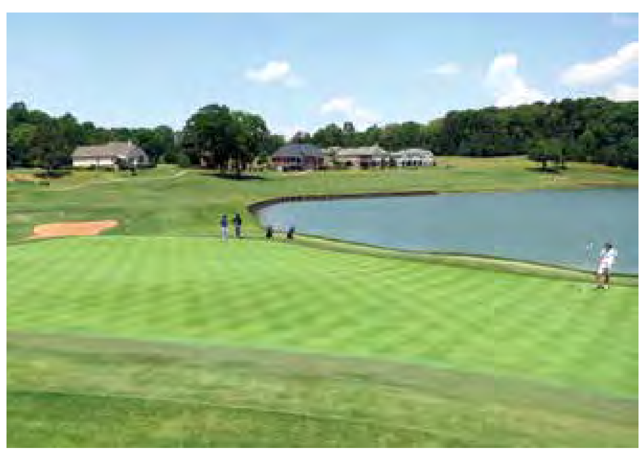


Figure 1-10. Creeping bentgrass golf green.

Figure 1-11. Above ground fans have largely revolutionized maintaining bentgrass golf greens in heat-stress environments often experienced in many areas of the Carolinas.

"Crenshaw," "Dominant," "SR 1019/1020," Penn "A" and "G" series, 007, and L-93 rapidly are being used in place of the old industry standard, Penncross. The fine-textured, aggressive-growing newer varieties are more susceptible to thatch buildup, scalping, and "puffiness;" thus, they need more aggressive management.

For tees and fairways, blends are often used to broaden the genetic base, thereby reducing disease occurrence. Two- and three-way blends containing Cato, Cobra, L-93, Penneagle, Pennlinks, Providence, or Seashore are currently popular.

Table 1–5. Bentgrass cultivars used for golf course purposes.

CREEPING BENTGRASS (*Agrostis palustris subsp. stolonifera L.*)
Penn A & G Series (A-1; A-4; G-1; G-2; G-4; G-6), Alpha, Authority, Backspin, Bardot, Barifera, Benchmark DSR, Bengal, Brighton, Carman, Cato, Century, CEO, Cobra 1-2, Crenshaw, Crystal BlueL-inks, CY-2, Declaration, Dominant (SR 1019 + SR 1020), Dominant Plus/Xtreme, Emerald, Grand Prix, 18th Green, Greenwich, Imperial, Independence, Inverness, Kingpin, L-93, Lopez, LS-44, Mackenzie, Mariner, Memorial, National, Ninety-Six Two, Penncross, Penneagle II, Pennlinks II, PLS, Princeville, ProCup, Prominent, Providence, Putter, Regent (Normark 101), Sandhill, Seaside II, Shark, Southshore, SR 1020, 1119, 1150, and 7150, T1, T2, Tendenz, Tiger II, Trueline, Tyee, Viper, 007.

Kentucky Bluegrass. Kentucky bluegrass (*Poa pratensis L.*) is the most widely used cool-season turfgrass and became popular due to its ability to survive summer drought through dormancy **(Figure 1–12)**. It is native to cool, open areas in Europe and was introduced during the 1600s. It possesses a vigorous rhizome system which forms a very dense cover, allowing it to recover from divots and traffic damage, and has fair-to-good drought tolerance. During extended heat and drought stress without irrigation, it will enter dormancy where the aboveground tissue ceases growth and can turn brown. With favorable growing conditions, new shoots are initiated from rhizomes and crowns. Kentucky bluegrass also has greater cold temperature tolerance than grasses such as perennial ryegrass or tall fescue. Overall, shade tolerance is only poor to fair, but breeding efforts are improving shade and low mowing height (<1 inch, 2.5 cm) tolerance. Under a high-maintenance program, thatch and diseases (e.g., summer patch, rust, powdery mildew, leaf spot) can be serious problems.

Kentucky bluegrass seed, compared to ryegrass, can be slow to germinate and become established and has weak seedlings. At warmer soil temperatures (>60°F, 15.6°C), germination occurs in about 10 days. Cooler temperatures (<55°F, 12.8°C) extends germination to 14 to 21 days. For good quality, density, and beauty, Kentucky bluegrass requires a moderate-to-high fertility (e.g., 3 to 4 lbs yearly N/1,000 sq.ft., 15 to 20 g N/m^2). Herbicide and PGR tolerance can be marginal. Summer patch and leaf spot are troublesome diseases. "Merion" was the first improved Kentucky bluegrass developed, primarily for its resistance to leaf spot disease. Over 200 cultivars currently exist; consult www.NTEP.org for independent cultivar comparison.

Figure 1-12. Kentucky bluegrass rough compared to a creeping bentgrass fairway.

Tall Fescue. Over 100 *Festuca spp.* are known. Generally, these are divided into two types: fine or coarse leaf fescues. Tall fescue (*Festuca arundinacea = Lolium arundinacea* Schreb.) is a coarse-textured, bunch-type species originally from southern Europe where summers are warmer and drier than in other European regions. Tall fescue forms a low-density turf with wider leaves than other cool-season turfgrasses. Although improvements have been made toward developing a rhizomatous cultivar, tall fescue has an overall bunch-type growth habit. Due to its clumping growth habit in warmer environments, tall fescue often requires reseeding every two to three years to maintain desirable turf density.

Tall fescue has very poor low-temperature hardiness, thereby limiting its use for those areas which experience severe winter temperatures. However, it has the best heat tolerance of the cool-season turfgrasses and is commonly grown in the transition zone, mid-Atlantic region, and the upper portion of the warm-humid zone. It also survives in arid climates when irrigated. Finer textured cultivars are available with good color and traffic tolerance. Due to its extensive root system, tall fescue also has excellent drought tolerance and disease and insect resistance. Shade tolerance is fair but will tolerate infertile, saline, alkaline, wet, and dry soil conditions. It is not as susceptible to gray leaf spot as perennial ryegrass and has good herbicide tolerance.

Tall fescue germinates quickly but not as fast as perennial ryegrass and its texture is coarser than Kentucky bluegrass and perennial ryegrass. When over-irrigated and/or -fertilized, tall fescue often becomes susceptible to leaf spot and brown patch diseases, as well as white grub damage. To maintain stand density and to avoid scalping, tall fescue is mowed at three-inches (7.6 cm). Due to its coarse leaf texture, low shoot density, and clumpy growth habit, tall fescue can be considered a serious weed in finer-textured monostand turfs such as Kentucky bluegrass. When seeded with Kentucky bluegrass, the seed mix on a weight basis should be at least 70% tall fescue. “Rebel” was the first introduced turf-type tall fescue and provided improved leaf width, stand density, color, and disease resistance. Over 200 cultivars are available with numerous new ones released yearly. Refer to www.NTEP.org for comparison of cultivars.

Fine Fescue. Fine fescue is a general term used for several fine-leafed *Festuca* species. Originally from the cool, forested European Alps, fine fescues have delicate and wiry leaves which are usually less than 0.5 mm wide and have a clumping, bristle-like appearance. These normally are maintained at two to three inches (5 to 7.6 cm) in height and should receive two pounds or less of nitrogen per 1,000 square feet (10 kg N/m^2) annually. Traffic and mowing should be withheld during heat or drought stress as turf injury or death often occurs. Due to short root systems, fine fescues tend to go dormant and turn brown in heat and drought conditions. Red fescue *(F. rubra L.* spp. *rubra* and ssp. t*ricolphylla*) and Spreading fescue (*F. pratensis Huds.*) have slow spreading rhizomes while Chewings fescue (F. rubra ssp. *commutata Gaud*.), Sheep fescue (*F. ovina L.*), Blue fescue (*F. ovina ssp. glauca*), and Hard fescue (*F. longifolia* auct. non Thuill.) have a bunch-type growth habit.

Hard fescue tends to have a deep-green color, whereas sheep fescues are bluish-green. Red fescue performs in shady conditions in humid regions whereas chewings, hard, and sheep fescues grow well in full-sun or partial shade, especially in the drier regions of the Midwest. These often are planted in shaded, low-traffic areas, poor soils, or in secondary roughs or out-of-play areas. If left unmowed, their leaf growth and seedheads often provide a low-maintenance, natural appearing area.

As a group, the fine fescues are noted for shade tolerance, winter hardiness, and adaptability to infertile and dry soil conditions. They do not tolerate wet, poorly drained soils well, but are particularly adapted to dry, shady conditions as well as to low-maintenance situations. Fine fescues rarely are used alone but are usually mixed with other cool-season grasses such as Kentucky bluegrass, perennial ryegrass, and colonial bentgrass. They tend to eventually dominate the stand when grown in shady conditions. They are also used in blends for winter overseeding of warm-season turfgrasses. Seeds tend to germinate in seven to 10 days under good environmental conditions.

Perennial Ryegrass. Perennial ryegrass (*Lolium perenne L.*) is a short-lived perennial with a medium leaf texture and good shoot density originating from open to fringed forest regions of southern Europe and western Asia to northern Africa. It has a non-spreading, bunch-type growth habit which makes it slow to recover from divots, good wear resistance, finer leaf texture, good soil compaction tolerance, good drought tolerance, good herbicide tolerance, fast establishment rate, and bright-green color. Perennial ryegrass tolerates lower mowing heights than Kentucky bluegrass or tall fescue. Perennial ryegrass, however, does

Figure 1-13. Overseeded perennial ryegrass to provide green color while the bermudagrass is dormant.

not tolerate low or high temperature extremes and has limited shade tolerance. It has become very susceptible to gray leaf spot disease which is expensive and troublesome to control. Perennial ryegrass also is susceptible to Pythium blight and has marginal cold tolerance. Perennial ryegrass is primarily used as a component in seed mixtures with other cool-season turfgrasses such as Kentucky bluegrass to broaden the resistance to various diseases and other pests. It is often used for overseeding purposes in bermudagrass and zoysiagrass for winter color **(Figure 1–13)**. Refer to www.NTEP.org for comparison of cultivars.

Annual Bluegrass. Annual bluegrass (*Poa annua L.*) is a highly variable species originating from Europe, it traditionally has been a very troublesome bunchgrass weed in most turfgrass situations and is found on every continent. This is due to its prolific seed production which disrupts the appearance and uniformity of the turf stand, its competitive growth habit, and poor heat and disease tolerance which often leaves bare or thin areas in the turf. Additionally, the annual biotypes have a bunch-type growth habit of low density, and are non-creepers. Selective herbicide control has also been marginal at best. Various forms or biotypes behave as true annuals while others have perenniated. Perennial or "creeping" biotypes (*P. annua ssp. reptans*) have recently been identified which have a more desirable putting characteristic. The perennial biotypes have a more prostrate, spreading growth habit with short stolons. These also form a high shoot density and much less seed production as it allocates more of its energies into vegetative growth as tillers than seed production. *Poa annua* (2n=28) is believed to have derived from hybridization of two Poa ancestors, *P. supina* and *P. infirma*. *Poa annua* biotypes adapted to turf areas restrict their flowering and seed production instead of favoring more vegetative growth. Breeding efforts are under way to identify potential permanent selections for golf greens. Peterson and True Putt creeping bluegrasses are improved perennial biotype bluegrasses for putting greens.

Other Cool-Season Turfgrasses. Numerous additional cool-season turfgrasses are available, with most having only a very small role on golf courses. Probably the most widely used of these is Roughstalk bluegrass (*Poa trivialis L.*) for overseeding warm-season grass greens and tees **(Figure 1–14)**. Poa trivialis typically provides a lighter green color which contrasts well with the darker green perennial ryegrass used to overseed collars, approaches, and fairways. Poa trivialis tends to provide easier transition in late spring back to the permanent warm-season grass, unlike lingering problems often associated with overseeded perennial ryegrass. Poa trivialis, however, has become a major weed in other cool-season turfgrasses, most notably, tall fescue.

Figure 1-14. A bermudagrass golf green overseeded with Poa trivialis to provide winter green color.

Selecting a Fairway/Rough Grass

Availability of a reliable irrigation system specifically designed for roughs is an initial question, if expectations are high for roughs. Primary choices of cool-season grasses for roughs are perennial ryegrass, Kentucky bluegrass, and turf-type tall fescues. In cool humid and arid regions and northern portions of the warm humid region, golf courses typically use cool-season grasses alone or blended with other cultivars or species for year-round color in fairways, roughs, and out-of-play areas. Kentucky bluegrass, perennial ryegrass, and/or the fescues (tall and fine fescues) are often used alone or as blends to reduce disease, insect, and summer stress problems. Bentgrass also is used for fairways but typically as a monoculture and mostly at higher-budgeted courses. In much of the northern United States and Canada, Kentucky bluegrass, bentgrass, and fine fescues are widely used. Tall fescue and perennial ryegrass are less winter hardy; thus, they are used more in the mid-central regions of the United States including the transition zone. **Table 1–6** lists the advantages and disadvantages of each. Cool-season grass cultivars constantly change as new selections are introduced and older ones become less important. Contact your state turfgrass specialist for the latest releases recommended in your area.

Current trends in cooler regions use predominantly pure perennial ryegrass stands in the upper transition zone and the cool semiarid zone, especially if the mowing height is maintained at or below one inch (2.5 cm) **(Table 1–7)**. With pure ryegrass, however, the disease grey leaf spot and winter kill periodically thin or weaken the stand. Courses try to overcome this by adding a small amount (e.g., 20 to 30%) of Kentucky bluegrass since it has better recuperative ability due to rhizomatous growth or by switching to bentgrass or zoysiagrass in more southern areas. However, if Kentucky bluegrass is used, the mowing height should be maintained above one inch (2.5 cm).

Table 1–6. Region of adaptation, advantages, and disadvantages of various turfgrasses used for golf course fairways and roughs.

Turfgrass	Region of adaptation	Advantages	Disadvantages
Bentgrass (*Agrostis spp.*)	Most cool-region zones (temperate regions) if irrigation is available.	• Tolerates close (<0.5 in., 1.3 cm) mowing. • Produces dense stands from stolons, has excellent recuperative ability, and doesn't require yearly interseeding. • Stripes easily, good color contrast with darker-colored blue-grass roughs. • Provides excellent playing sur-face.	• Generally intolerant of heat and drought. • Maintenance expense due to susceptibility to diseases such as *Pythium*, dollar spot, and brown patch. • Must control thatch. • Susceptible to winter desiccation. • *Poa annua* infestations require lightweight mowers, clipping removal, extra aerification, and continued herbicide/PGR use.
Bermudagrass (*Cynodon spp.*)	Tropical to subtropical regions into lower half of the transition zone, southern Illinois, Missouri, and Kansas.	• Adapted to poor soils, harsh (hot) climates. • Efficient water users. • Excellent wear tolerance. • Good pesticide options. • Rapid and cost effective to establish. • Low-cost option for fairways	• High nitrogen requirements. • Aggressive growth habit. • Shade intolerant. • Nematode susceptible. • Cold sensitive in northern locations. • Has dark tan/brown winter color which may need overseeding or painting. Poor spring playability. • Poor spring transition when over-seeded.
Fine fescue (*Festuca spp.*)	Shady areas in upper transition zone and northward.	• Withstands very low maintenance in terms of nutrient and water requirements. • Has slow vertical growth rate, requiring about half the mowings of taller-grown grasses. • Alternative to Kentucky blue-grass in unirrigated, infrequently mowed roughs.	• Goes dormant with warm summer temperatures. • All are bunch grasses except the rhizomatous creeping red fescue. • Slow recuperative rates. • Dollar spot and red thread susceptible.
Kentucky bluegrass (*Poa pratensis*)	Irrigated regions in the cool zones, midwest throughout Canada into Alaska.	• Excellent color, texture, and density. • Affordable seed. • Good recuperative ability from rhizomes. • Excellent cold tolerance.	• Slow establishment from seed. • Shallow root system, thus, poor water use. • Poor shade tolerance. • Poor tolerance to low (<1.5 in.) mowing heights. • Susceptible to diseases (e.g., summer patch).
Perennial ryegrass (*Lolium perenne*)	Lower temperate (cool, humid zone) into upper transition zone, also southern portions of Midwest.	• Inexpensive seed which establish rapidly. • Has bright-green color which stripes well. • Compatible with Kentucky blue-grass. • Good wear and drought tolerance • Good tolerance to low mowing. • Good tolerance to ethofumesate and other products for *Poa annua* control. • Good playability.	• Requires more frequent mowing than fine fescue or Kentucky blue-grass. • Thins out and turns stemmy at lower fertility levels. • High disease susceptible to *Pythium*, red thread, and grey leaf spot. • Slow to spread, slow recovery from divots. • Usually requires yearly interseeding. • Rapid spring and early summer growth. • Only fair cold tolerance, susceptible to ice damage in shaded, low-lying areas.

Turfgrass	Region of adaptation	Advantages	Disadvantages
Seashore Paspalum (*Paspalum vaginatum*)	Tropical to subtropical regions up to coastal Carolina.	• Excellent salt tolerance. • Has bright-green color which stripes well. • Stiff blades so golf balls sit up. • Low nitrogen requirements. • Forms excellent density. • Good wear tolerance.	• Limited cold tolerance. • Bermudagrass invasion. • Few herbicides labeled for use. • Eventually becomes thatchy. • Moderate to high disease potential. • Mostly vegetatively established.
Tall fescue (*Lolium arundinacea*)	Irrigated and non-irrigated lower maintenance courses throughout the temperate region.	• Good heat drought tolerance. • Easily established by seeding. • Compatible with Kentucky blue-grass and perennial ryegrass.	• Clumpy growth habit requires re-seeding to maintain density. • Intolerant to close (<2 in., 5 cm) mowing. • Slow to recover from damage. • Requires more-frequent mowing than other cool-season grasses. • Brown patch susceptible.
Zoysiagrass (*Zoysia spp.*)	Tropical and subtropical areas into the upper transition zone.	• Can be low maintenance after establishment. • Produces dense, weed-resistant turf, with good playability. • Best winter hardy warm-season grass. • Has light, attractive tan color when dormant.	• Expensive and slow to establish from sprigs or seed, slow to recover from divots. • Traffic restrictions when dormant. • Eventually becomes thatchy. • Winter damage in low areas holding water. • Bermudagrass invasion and brown patch susceptible.

Table 1–7. Common seed mixtures for cool-season grasses in the higher elevations of the Carolinas.

Fairways		Roughs				
Sunny, with higher fertility		Shaded, non-irrigated with low fertility	Sun	Shade	Grass bunkers	Low maintenance areas
Irrigated	Non-irrigated					
Mowing height >1 inch, 2.5 cm: 10 to 30% Kentucky bluegrass blend + 70 to 90% perennial ryegrass *or* 70 to 90% tall fescue	**Mowing height >1 inch, 2.5 cm:** 100% buffalograss *or* tall fescue *or* alkaligrass in salty environments	**Mowing height >1 inch, 2.5 cm:** 10 to 20% Kentucky blue-grass **+** 40 to 60% perennial ryegrass **+** 30 to 40% fine fes-cue	90% tall fes-cue + 10% Kentucky bluegrass *or* 60% Kentucky blue-grass + 20% perenni-al ryegrass + 20% chew-ings fescue	90% tall fescue + 10% Ken-tucky bluegrass *or* 65% chewings fescue + Kentucky bluegrass + 15% perennial ryegrass	100% tall fes-cue blend *or* 80% hard fescue + 20% chewings fescue	100% tall fescue blend *or* 80% hard fescue + 20% chewings fescue
Mowing height <1 inch, 2.5 cm, irrigated: 100% perennial ryegrass blend *or* 100% creeping bentgrass **In grey leaf spot infested areas:** 100% bentgrass						

Blends of approximately 85% tall fescue plus 15% Kentucky bluegrass work reasonably well. Often, sod is used to re-establish highly visible areas such as near green surrounds. For acceptable long-term rough turf, weed and insect control programs are necessary. Grub control products applied in early summer can provide season-long control. Fungicides also are being used more often in cool-season grass roughs and good fertility programs are needed to maintain thick, healthy grass. Finally, heavily trafficked areas, such as near greens, need special attention. This includes spreading wear to prevent concentrated traffic damage, additional nitrogen for recovery, aggressive aeration, and possibly walk mowing during periods of summer head stress or when soils are saturated.

In the southern United States, bermudagrass is used almost exclusively for fairways and roughs. Irrigated fairways use a hybrid bermudagrass while non-irrigated ones use an improved common bermudagrass. Zoysiagrass is being used more when shade and cold temperature damage are issues with bermudagrass or if courses desire a different hue or textured grass. Some golf course architects use other grasses such as centipedegrass or bahiagrass roughs with bermudagrass fairways to provide contrasting color and textural differences. However, in most cases, this is a maintenance mistake as many of the pesticides, especially herbicides, used on bermudagrass invariably are sprayed on these other turfgrasses, causing damage. Also, the higher nitrogen and watering requirements of bermudagrass usually weaken these other grasses.

In the upper areas of cool regions, winter kill periodically occurs to ryegrass and tall fescue; thus, Kentucky bluegrass is often used alone. However, the bluegrass should be mowed above one inch (2.5 cm) in these situations for best turf growth and hardiness. In addition, a blend of two or more bluegrass cultivars should be used to help in pest resistance. Fine fescues are used, especially in shady areas or areas without irrigation, but these tend to establish slowly and are susceptible to several diseases.

Figure 1-15. Using native or low maintenance grasses in deep rough areas to reduce maintenance costs.

Native Grasses

It has become popular to use native grasses in an attempt to reduce inputs such as water, fertilizer, and pesticides **(Figure 1–15)**. These are typically incorporated outside the primary play areas as most native grasses provide loosely knitted, blue-green colored turf stands when grown naturally. When placed under higher maintenance such as periodic irrigation and fertilizing, many of these become weakened and thin, become disease susceptible, and face invasion from other grasses and weeds. If used, native grasses should be maintained as close to their natural adaptation as possible; mow these high (>2 inches, 5 cm), fertilize only lightly (0 to 2 lbs N/1,000 sq.ft. annually, 0 to 98 kg N/ha), and only seldom water.

Several grasses native to the arid Great Plains regions of North America are occasionally used as a turfgrass. Most of these originated as pasture grasses, forage, or for roadside soil stabilization. They are occasionally used for low-maintenance roughs and out-of-play areas on golf courses due to their distinct characteristics such as seed-

Table 1–8. Native warm-season grasses used for low-maintenance sites.

Common name	Latin name	Growing height, ft (m)	Soil conditions	Moisture needs	Sunlight requirements
Big bluestem	*Andropogon gerardi*	5 to 8 (1.5 to 2.4)	Clay, loam, sand	Dry to moist	Full sun to light shade
Switchgrass	*Panicum virgatum*	6 (1.8)	Clay, loam, sand	Dry to moist	Full sun to light shade
Indiangrass	*Sorghastrum nutans*	5 to 8 (1.5 to 2.4)	Clay, loam, sand	Dry to moist	Full sun to light shade
Prairie cordgrass	*Spartina pectinata*	5 to 8 (1.5 to 2.4)	Clay, loam, sand	Moist to wet	Full sun
Broomsedge	*Andropogon virginicus*	1 to 3 (0.3 to 0.9)	Clay, loam	Dry to moist	Full sun
Side oats grama	*Bouteloua curtipendula*	1 to 3 (0.3 to 0.9)	Loam, sand	Dry to medium moist	Full sun
Little bluestem	*Andropogon scoparius*	1 to 3 (0.3 to 0.9)	Loam, sand	Dry to medium moist	Full sun
Prairie dropseed	*Sporobolus heterolepsis*	1 to 3 (0.3 to 0.9)	Loam, sand	Dry to medium moist	Full sun

Figure 1-16. Maintaining golf roughs as waste areas to mimic earlier golf conditions.

head height or plant color; these help provide distinct differences from the playing surface. Blends are often planted. However, if regularly watered, these grasses tend to lose their competitiveness and often become invaded by weeds and diseases. Weed control prior to planting, and for the first two years thereafter, is essential for success. Examples include the warm-season grasses buffalograss, gramagrass, switchgrass, bluestems, Indiangrass, and lovegrass **(Table 1–8)** and the cool-season grasses wheatgrass, Timothy, Redtop, orchardgrass, fine fescues, and alkaligrass. Most of these have a blue-green color and should be mowed relatively high, two to three inches (5 to 7.6 cm), only fertilized sparingly, e.g., zero to two pounds of nitrogen/1,000 square feet yearly (0 to 9.8 kg N/m^2), and watered only during establishment.

Some courses have opted to incorporate extensive areas with minimum vegetation to mimic earlier times when most resources such as irrigation and fertilizers were very limited **(Figure 1–16)**. Although inputs such as mowing, fertilization, and irrigation are obviously reduced or eliminated, dramatic increases in hand labor for weeding and maintaining area integrity often occur. Regardless, the uniquiness of these areas and potential to reduce artificial inputs have other courses considering similar trends.

Ornamental Grasses

With the desire to add unique color and textural characteristics to the golf landscape, a variety of ornamental grasses, sedges, and rushes are available. The foliage color can range from green to variegated yellow or white to red with textures varying from fine to heavy and coarse. These are used as specimen or accent plants or as mass plantings **(Figure 1–17)**. The height of these plants ranges from about two feet (0.6 m) to more than 10 feet (3 m). Some are stoloniferous while others have clumpy growth habits. Refer to **Table 1–9** for an overview of some of the available plants for various landscapes. New grasses and other landscape plants are constantly being introduced. Attend conferences, field days, visit websites, and ask for referrals to keep up with the latest introductions and their merits.

Figure 1-17. Using ornamental grasses (*Spartina* spp.) on a golf course.

Table 1-9. Common ornamental plants used in golf course landscapes.

Latin Name	Common Name(s)	General Descriptions	Potential Uses
Acorus sp.	Sweet Flag	Cool-season.	Good shade tolerance and for water gardens.
Andropogon gerardii	Big bluestem, turkeyfoot	Warm-season, tall, native to central USA.	Mass planting, mod- or background bed, screen, low maintenance.
Andropogon virginicus	Broomsedge	Weak clump forming warm-season perennial. Native to USA.	Blue-green spring and summer color, orange winter foliage, good for acid, nutrient-poor soils.
Arundinaria pygmaea	Dwarf Bamboo	Spreading perennial.	Good ground cover for shade.
Aruno donax	Reedgrass, giant reed, giant cane, carrizo	Warm-season, tall, coarse-textured, clump-forming.	Good accent plant, requires space, good near water's edge or for poor soils.
Bouteloua curtipendula	Side oats gramagrass	Low growth habit.	Good ornamental seedheads, good in dry soils and heavy foot traffic.
Carex and Cyperus sp.	Sedge	Warm-season, clump-forming, not cold or drought hardy.	Annuals for borders or mixed with container plants. Good shade and moist site tolerance.
Chasmanthium latifolium	Northern sea oat, wild oats, upland oats	Warm-season, clump-forming, native to USA, heavy seed producer.	Handsome bamboo-like quality, specimen, moderate shade tolerant, produces glittering seedheads in fall.
Cortaderia selloana	Pampasgrass	Warm-season perennial, large, upright clump-forming.	Excellent specimen in larger areas. Flowers late summer.
Deschampsia caespitosa	Tufted hairgrass	Cool-season.	Low maintenance, use in mid- or foreground bed, plant in front of dark background.
Eragrostis sp.	Lovegrass	Warm-season perennial, clump-forming, thin bladed.	Excellent drought tolerance, for dry, sandy sites.
Festuca glauca (F. amethystine, F. cinerea, F. ovina, F. ovina var. glauca)	Blue fescue	Cool-season, clump-forming, forms low-growing ground covering tufts.	Accent plant, foreground bed, ground cover.
Helictotrichon sempervirens	Blue oatgrass	Cool-season, moderate sized, clump-forming.	Blue-gray foliage, tolerates dry sites, use in the foreground of beds, specimen, ground cover.
Leymus arenarius Glaucus	Lymegrass, dune grass	Cool-season, stoloniferous.	Useful in large open areas as a groundcover or for erosion control perennial borders, dune plantings.
Miscanthus sinensis	Miscanthus, Chinese silvergrass, eulalia grass	Warm-season, numerous varieties available. Tall or short growing, clump-forming, good foliage color.	Good cold tolerance, variegated cultivars available, good fall color, site in masses, as specimens in a hedge or screen, in containers.
Panicum virgatum	Switchgrass, panicgrass	Warm-season, tall, clump-forming, native to USA.	Back of borders in sunny areas, perennial beds, erosion control, moist sites, mass plantings, not for refined landscapes.

Latin Name	Common Name(s)	General Descriptions	Potential Uses
Pennisetum sp.	Fountaingrass	Warm-season, numerous varieties available, clump-forming, purple flowers.	Good for low accent in annual or perennial borders or in containers, building foundations, use in masses, groups, or as single specimen.
Phalaris arundinacea Picta	Ribbongrass, gardener's garters	Cool-season, stoloniferous.	Spreads rapidly, useful in masses, as a groundcover or for erosion control in shaded areas.
Saccharum ravennae	Ravennagrass, plumegrass	Warm-season, tall, clump-forming.	Good accent plant, near water, tall screen or windbreak.
Schizachyrium or Andropogon scoparium	Little bluestem	Warm-season, short rhizomes, native to USA.	Good fall color, for dry, sand and rocky soils in full sun, not for formal gardens, goundcover, mid- or foreground bed.
Seslaria caerulea	Blue moorgrass	Cool-season, clump-forming, forms low-growing ground covering tufts.	
Sorghastrum nutans	Indiangrass	Warm-season, tall clump-forming, native to USA.	Specimen or in masses, screen, windbreak.
Spartina sp.	Prairie cordgrass/ dropseed	Warm-season, rhizomatous, native to USA.	Large open areas as a groundcover or for erosion control. Good for moist sites mid- or background bed.
Sporobolus heterolepis	Prairie dropseed	Warm-season, native to USA.	Good in dry, rocky sites.
Tripsacum dactyloides	Eastern gamagrass, Fakahatcheegrass	Warm-season, clump-forming native to the Southeastern USA.	Tall clumping, pest-free, ornamental grass to 6 ft (~2 m) and 4 ft (1.3 m) wide with spiky foliage and wine-colored anthers. Prefers sunny to partially shaded areas with moist to wet soils.

2 BEST GOLF COURSE ENVIRONMENTAL PROTECTION STRATEGIES

2 BEST GOLF COURSE ENVIRONMENTAL PROTECTION STRATEGIES

Golf courses offer many recreational, economical, and environmental benefits **(Figure 2–1)**. Turfgrasses are oxygen producers that help cool their surrounding environments, absorb sound and glare, prevent erosion, and are effective filters of natural and synthetic contaminants. They also provide areas for recreational activities, help increase property values, provide green space and wildlife habitats in urban areas, and provide an enormous economic impact in terms of jobs, tax base, and many side impacts such as being the site of vacation destinations and retirement communities. However, like any living plant, turfgrasses require certain inputs in terms of fertilizer, water, and in special situations, pesticides, to maintain their vigor and health. Golf courses often intersect with environmentally sensitive areas, and management strategies should be formulated that protect these areas.

Since golf courses exist as a small part of a complex and integrated biological and ecological system, best management practices (BMPs) consider the surrounding landscape, plant community, watersheds, and ecological regions. Best management practices are developed to protect water resources and other environmental concerns. Major issues that BMPs address include: (1) Potential pollution of groundwater and surface waters; (2) Soil erosion and sedimentation; (3) Thermal pollution; (4) Misuse of pesticides and other potential contaminants; and, (5) Fertilizer use. This protection involves removing, filtering, detaining, or rerouting potential contaminants before they enter water sources or other environmentally sensitive areas. An environmental monitoring program providing feedback to the golf course as to conditions and movement of materials also is beneficial. A well-developed management plan includes site description and evaluation, following sound golf course cultural practices including using best management practices and integrated pest management, educating personnel on safety regulations on storage, handling, disposal, and record keeping of pesticides related to worker protection, employee right-to-know and OSHA requirements, and assessing and evaluating existing programs and then adjusting for future use. Water conservation, wildlife and habitat management along with self-evaluation and education to local residents complement a holistic BMP program. The following sections discuss pesticides and nutrients in the environment and strategies for developing environmentally sound golf course design, construction, and maintenance practices.

Figure 2-1 . Golf courses offer many recreational, economical, and environmental benefits.

2.1 STRATEGIES FOR ENVIRONMENTALLY SOUND GOLF COURSE DESIGN

Pre-design Questions

Golf courses should be designed to integrate with the natural geography of the site. This means the golf course should complement the natural resources of the site and, in turn, the natural resources should help make the course unique. Although no two golf courses and the associated natural resources will be identical, certain questions concerning environmental issues should be addressed during the planning, review, and construction process. These questions include the following:

1. Does a golf course provide important open or green space by making use of a site that is currently undeveloped?
2. Will the proposed golf course maintain or expand wetlands and other sensitive environmental areas that may exist on the site **(Figure 2–2)**?
3. Are there significant historical or archaeological areas on the site that will be preserved by the golf course **(Figure 2–3)**?
4. What positive impact will the golf course have on the ecological systems of the site, such as plant life and wildlife habitat?
5. How will the golf course enhance the existing character of a site through alteration of the topography and vegetative cover?
6. How will potential earth disturbance and erosion be minimized during the construction of the golf course?
7. How will prudent irrigation design and efficient water use impact existing water supplies, especially in areas experiencing conditions that limit water resources?
8. How will the design and maintenance practices of the golf course be implemented to prevent water pollution from surface run-off or infiltration into the ground?

Figure 2-2. Protected wetlands on a golf course.

Figure 2-3. Preserving historical or archaeological sites on a golf course.

By addressing these issues during the planning stage, the developer can avoid deleterious environmental impacts as well as costly delays in the development process. The end result is a more successful design, development, and construction project that produces an enjoyable recreational facility that is aesthetically pleasing and environmentally compatible.

Team Approach

The most successful approach to ensure a successful project completion is to form a team of experts **(Figure 2–4)**. This team should include a golf course architect, golf course superintendent, engineer, landscape architect, water resources specialist, environmental specialist, marketing/economic consultant, ecologist, construction supervisor, and other consultants as dictated by the peculiarities of the golf course and the watershed in which it is sited. This team then works with the developer, community representatives, environmental groups, and regulatory agencies to determine the project goals.

During site selection and golf course design, the team must become intimately familiar with the environmental aspects of the site. Proposed site selection guidelines (Anonymous, 1993a; 1996a) include the following:

1. Have professionals assess the physical and economic viability of a golf course on a particular site. Identifying environmentally sensitive areas and other natural resources helps balance environmental concerns, playability, and aesthetics in the course design.
2. If possible, select sites outside of agricultural land use zones. Should agricultural land be the only option, follow local and state agricultural guidelines when selecting development sites.
3. Identify and respect existing ecosystems such as unique wetland qualities and other sensitive natural areas.

Figure 2-4. Using a 'team' approach to ensure a successful project and to keep community leaders informed.

Avoid the disturbance of these areas and incorporate these features into the design. This will help protect natural resources, improve course maintenance efficiency, and will likely minimize permit and site development costs.

4. Consider present or potential aggregate resources when determining location.
5. Ensure the project conforms with all state and local land use plans and zoning bylaws.
6. Ensure adequate water supply is available for all potable and irrigation needs of the golf facility and neighboring properties.
7. Be available to meet with the public and answer their concerns regarding the development site.

Developing the Design

The sum total of all reconnaissance and analysis should be a series of maps illustrating existing roads and property boundaries, water sources for both irrigation and consumption, topography, sensitive wildlife habitat, potentially high erosion areas (steep slopes), wetlands and required buffer areas, drainage patterns including flood plains, vegetative cover, historical or archaeological sites, right-of-ways or easements, utilities including power and sewer, scenic views and vistas, adjacent land uses, and other information critical to planning and designing the golf course. By overlaying all of these features onto one map, if often becomes evident which areas to avoid developing and those that could be considered. It is critical, at this point, to be intimately familiar with all local and state rules and regulations governing the construction and management of the golf course. This will help establish realistic goals and produce the most efficient planning and design. In particular, this approach will avoid costly revisions and delays during the review, permit, and construction process.

Additional suggested design considerations include the following:

1. Select plant species that are best suited to the local climate and require the minimum of inputs. Use of native or naturalized vegetation should be retained when appropriate in non-play areas.
2. Design the irrigation to efficiently use water only where and when needed.
3. Investigate the feasibility of alternative or supplemental sources of irrigation water (e.g., on-site storage reservoirs for storm water run-off collection or effluent). On-site retention of stormwater run-off should be considered on soils with low infiltration rates. Effluent water should be considered if it meets local health and environmental standards and it does not negatively affect sensitive surface water areas.
4. Maintain a non-treated vegetative buffer zone adjacent to all water sources to assist in filtering any nutrients or pesticides from storm run-off, to reduce intrusion from effluent water use, and to moderate water temperatures **(Figure 2–5)**.
5. Retain as much natural cover as possible and enhance vegetation through supplementary planting of trees, shrubs, and grasses, especially along fairways to provide wildlife habitat and along water courses supporting fish habitat.
6. Incorporate as many natural features and areas in the design as possible to minimize disturbance of the existing ecology. Seek to create and/or preserve habitat areas that enhance the area's ecosystem **(Figure 2–6)**.
7. Consider future maintenance requirements of all golf course design features. Low-maintenance features that require less-intensive management are preferred. Integrated plant management, including integrated pest management, plant nutrition, and overall plant health, should be emphasized to most efficiently use and protect available resources.

Figure 2-5. Using a grass filter strip adjacent a stream.

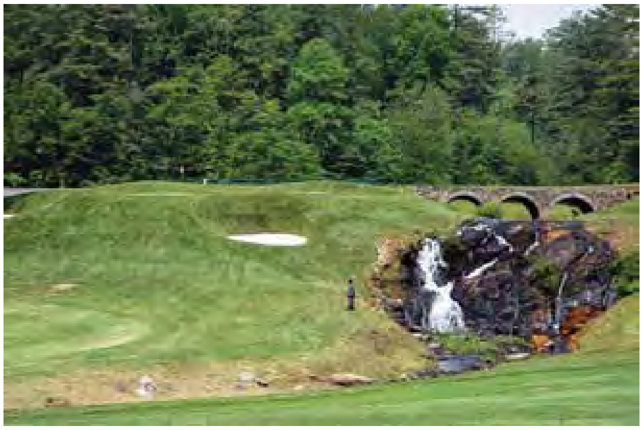


Figure 2-6. Incorporating a water feature in a golf design.

A well-balanced landscape design for the golf course results in a mix of shrubs, trees, grassy areas, and water features that sustain and encourage wildlife and plant diversity. This design should balance the correction of poor drainage and erosion with the need to maintain wetland habitats. Include areas for feeding, breeding, resting, and nesting, and remember that habitat is integrated both vertically and horizontally.

Wetland habitats are particularly critical not only for wildlife but also for water treatment, processing, and storage. Whenever possible, golf courses should be designed so irrigation and stormwater run-off move from the edges into the middle of the course. Drainage ditches should be bisected by small swales or even natural or constructed wetlands. These geographic features slow down water and allow for assimilation of both nutrients and pesticides by vegetation. These geographic features can be picturesque playing hazards that make the course more challenging.

Figure 2-7. An erected bird nesting site on a golf course.

When considering enhancing wildlife and their habitats, the core requirements include:

- providing adequate space,
- providing appropriate and sufficient food sources such as feeder boxes, food gardens (plots), or landscapes,
- cover or protection such as nesting boxes, natural (or no-mow) areas, wildflowers and native grasses **(Figure 2–7)**,
- sufficient quality water planted with wildlife friendly plants, sized and shaped properly, and surrounded with "no spray or treatment" buffers or zones.

In many locations, water quantity and quality may be the limiting factors in golf course development. A wise water-use plan might include the recapture and reuse of irrigation water as well as the use of secondary treated effluent water from a municipality or surrounding housing development for irrigation. Wetlands are extremely important for both their water-holding capacity and their water purification capacity. These features will increase water recapture by the golf course as well as help to alleviate fears of homeowners over the use of wastewater treatment effluent on the course.

Regulatory Considerations

Numerous regulatory permitting will be needed during the golf course design and construction, typically involving various federal, state, and occasionally, local level agencies. These most often involve various levels of environmental impacts, especially water quality, stormwater management, erosion and sedimentation, plus floodplains.

2.2 STRATEGIES FOR ENVIRONMENTALLY SOUND GOLF COURSE CONSTRUCTION

Construction Documents

Once the planning and design processes have been completed, the construction phase of development is initiated. The environmental issues concerning construction will have been addressed during the design of the golf course. The construction documents will vary depending upon the architect and local regulations, but typically include:

1. Using only qualified contractors experienced in the unique needs of golf course construction.
2. Staking plans to locate the key points of the golf course (tees, landing areas, and greens) in the field for review and construction **(Figure 2–8)**. This should emphasize protecting water sources, reducing wildlife and plant disruption, minimizing topsoil loss, and avoiding environmentally sensitive areas.
3. Erosion control and stormwater management plans show the location of features and methods of con-

Figure 2-8. Marking trees to remain during a golf course construction.

Figure 2-9. Using a variety of materials to avoid soil erosion during on a golf course construction site.

trolling stormwater and erosion on disturbed areas of the site during construction (**Figure 2–9**). Sediment traps and basins are constructed and established with plant materials to provide soil stabilization. Contractors should be in possession of all permits at all times.

4. Clearing plans to indicate the limits of clearing necessary for golf course construction. Specimen trees to be saved or areas of vegetation to be preserved will be shown on this plan or designated in the field.
5. Grading and drainage plans to show the overall plan for construction of the golf course and the earth work necessary to create features and produce the proper drainage. Long or steep slopes are broken with diversions to keep run-off velocities low and divert storm water runoff.
6. Golf green plans to provide details for the construction of each green complex.
7. Construction details and sections to show how the features (trees, bunkers, mounding, ponds, etc.) are to be constructed in conjunction with the grading and drainage plan.
8. Irrigation plans and details to provide the information for the type of irrigation system and pump station to be installed for the golf course.
9. Grassing plans to indicate the areas where specific turfgrasses and, in some cases, ornamental grasses are to be planted on the golf course.
10. Landscape plans to serve as a guideline of where plant material is to be installed to enhance the golf course design. As a part of this plan, conservation areas can be established throughout the golf course.
11. Specifications and bid documents outline the methods and details of construction for the course completion.

Construction Process

The golf course superintendent should be hired early in the design and construction process. The superintendent will inspect the construction process daily and serve as the on-site representative for the owner and the architect. During the construction process, site visits are made by the golf course architect, accompanied at times by other members of the consulting team, to inspect the work and see that the intended level of design and quality in the course is being accomplished. These visits ensure that the close interaction between the architect, design team, and the construction team will ultimately produce the distinctive features and character of the golf course. These visits also provide the opportunity to monitor the controls and management techniques in place for environmental protection (**Figure 2–10**).

The construction process starts with the stakeout of the golf course by a surveyor or engineer. This process is reviewed by the architect and minor field adjustments are made to improve the golf course by responding to existing terrain, by integrating natural features, by providing further protection for sensitive areas, and by the preservation of specific natural features such as specimen trees, rock outcroppings, and sand dunes in the design.

Figure 2-10. Designated conservation area on golf course.

Soil erosion control features are then installed and checked to ensure proper placement and installation prior to the clearing and grading of the site. It is critical these controls remain in place throughout the construction and stabilization of the disturbed areas (e.g., turf establishment). Stormwater management controls are also installed very early in the construction phase to control drainage of the site and avoid impacts to sensitive areas. This is the time when natural geographic features such as ponds, grass swales, and wetlands are incorporated into the water management plan. A key goal during construction is to keep the site as stable as possible, minimizing erosion.

The next step is grading the golf course. It is important to remember the objectives during grading the course should be to avoid excessive disturbance, produce the necessary drainage contours, and provide the features required by the golf course design. An irrigation system is installed after grading has been completed. The system must be complete and operational to support the planting of the golf course. Care should be taken to design the irrigation system so the spray is directed inward onto the course with little drift off the course. This is particularly important if fertigation or chemigation is planned or effluent water is used.

After grading and installing the irrigation system, the course should be prepared and planted with the specific types of turfgrass or ornamental grass required by the golf course design. Native species should be used to reestablish roughs and areas designed to make the course more visually pleasing **(Figure 2–11).** The overall landscape design should include specific areas designed to promote wildlife habitat. In addition;

1. Schedule construction to protect soils by minimizing the time ground is left without cover. Protect soils during construction through the use of mulching materials, hydro-seeding, or sod.
2. Monitor groundwater quality before and after construction.
3. Avoid construction near water courses, especially during fish spawning season. However, if construction is necessary, ensure adequate mitigative measures are in place to protect water quality, fisheries, and stream-side habitats. Contact the local regulatory agencies for guidance.

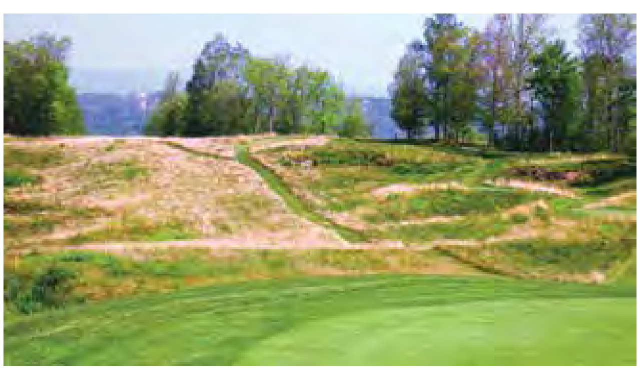


Figure 2-11. Using native or low maintenance grasses in out-of-play areas on a golf course.

Figure 2-12. Water feature on a golf course.

2.3 STRATEGIES FOR ENVIRONMENTALLY SOUND GOLF COURSE MANAGEMENT

Public concerns for the environment have led to the idea of best management practices (BMPs) for golf courses. The following sections detail management strategies golf courses should consider.

Water

Water is arguably, the most important component in golf course management **(Figure 2–12)**. The following sections will discuss the various uses of water on a golf course (e.g., irrigation, hazards, and aesthetics). Attention will be given to sources of water used in irrigation and subsequent management of possible run-off, as well as the management of both existing and man-made bodies of water found on the property.

Irrigation. Maintenance of optimal soil moisture levels is necessary for turfgrass growth and formation. Approximately 70 percent of water used for irrigation is from surface water sources (e.g., lakes, ponds, streams). Purchase of potable waters or secondary treated effluent make up less than 10 percent of irrigation waters used.

Lakes, ponds, and streams on the golf course may serve as an adequate source of irrigation water. However, in coastal areas, the salinity of these water bodies may be detrimental to turfgrass, thereby eliminating them as possible sources. Dilution of these brackish waters with potable or other freshwaters can reduce the need for purchasing water for irrigation purposes.

Purchasing potable water is another option. This may be done as a sole source or simply as a means of augmenting another supply source. In either case, this source of water can be expensive.

Figure 2-13. Effluent water storage facility on a golf course.

The push for water conservation has resulted in the management technique of using secondary treated effluent for irrigation **(Figure 2–13)**. This practice can be beneficial for all involved. Nutrient levels in the effluent will supplement the application of fertilizers, thereby reducing the amount of fertilizers purchased and applied. In coastal areas in particular, the sand content of the soil also serves to filter out bacteria and other contaminants found in the effluent. This then decreases the possible chances of groundwater pollution. However, the use of effluent for irrigation is strictly regulated. Refer to the chapter on Water Management for additional information on effluent water use.

Lakes/Ponds/Streams. Flood control of existing water bodies and those constructed on the course is a very important issue to be addressed. All drainage structures should be maintained so as to ensure the proper control of excess water. In part, these aspects of management are built into the golf course at the design and construction phase. However, as a golf course ages, erosion should be curbed and drains often need some attention. A small sedimentation or settling pond upstream may be necessary to reduce erosion, especially if significant development or logging occurs upstream of the main golf course lakes or ponds. In most situations, lakes and ponds on the course will be used to collect run-off and will be able to hold nearly all input. It is the run-off into creeks and streams that is of most concern. The planting of aquatic macrophytes in these areas may help slow flow and filter contaminants. Lakes and ponds should maintain a minimum depth of 15 feet (~4.6 m) at its deepest point to allow some sunlight penetration along the shore line but prevent total bottom rooted plants, plus provide cooler waters to mix with warmer surface waters.

Water quality should be monitored in all bodies of water subject to the effects of golf course management. The most common problem superintendents face in managing water quality is fluctuations in dissolved oxygen. A decline in dissolved oxygen can initially be minimized by controlling algal blooms, which are the major contributor to oxygen consumption in early morning hours, and then by directly treating the problem **(Figure 2–14).** The addition of an aerator in ponds and lakes receiving nutrient-rich run-off will help quench the extreme dissolved oxygen shifts. Assimilation of excess nutrients by wetlands is a management technique used to improve water quality, which is discussed later. An unfertilized buffer zone surrounding lakes and ponds should be considered, especially on steep-sloped edges or edges with soils such as clays that do not readily allow water infiltration.

Common groups of algae include blue-green, green, diatoms, dinoflagellates, and euglena. Algae form the base of an aquatic food chain; thus, they are important to the overall system's health. However, algal blooms require management at various times of the year. This is an area of management that can be addressed at the design/construction phase of a golf course. The use of existing or constructed wetlands and riparian zones can reduce the total loading of nutrients into aquatic systems, subsequently decreasing the growth rate of algae.

Aquatic macrophytes such as duckweed, widgeon grass, and cattail can play a large role in the assimilation of chemical input to aquatic systems as well as serve to control erosion. Nuisance macrophyte growth can be controlled by various means. Mechanical means may be employed to physically remove the plants, or biological controls (e.g., grass carp) may be used. A limited number of herbicides can also be used to control aquatic plants.

Pond food chains. The food chain in a pond directly influences the amount of oxygen produced in the pond. **Phytoplankton algae** form the base of the food chain in a pond system. These are microscopic plants living suspended in the water. Through photosynthesis, phytoplanktonic algae provide needed oxygen for fish and other aquatic organisms. Oxygen also is supplied by wave and wind action and by rainfall. Next higher in the food chain are **zooplankton**,

Figure 2-14. Pond algae on a golf course largely from insufficient aeration or fresh water intake.

tiny insectlike animals floating in the water and feeding on phytoplankton. Bream then feed on zooplankton and other aquatic insects. The top of the food chain in most ponds are bass. Bass feed on bream and help control their populations. In fact, ponds lacking a satisfactory bass population will be overcrowded with small bream. However, overstocking or using the wrong kind of fish could cause long-term fish kill. Consult a fisheries scientist before stocking any fish to determine how much and which kind(s) of fish are needed for a particular site.

Pond regions. Ponds can be divided into various regions or areas, including the **littoral region** and **open water regions**. The shore area or interface zone between the land of the drainage basin and open water is the **littoral region (Figure 2–15)**. This is generally where most sunlight will penetrate to the bottom of the pond often forming a ring of plants around the shore area according to water depth and wave action. The littoral region extends from the shoreline to the point where sunlight fails to penetrate to the pond's bottom, thus, aquatic plants no longer grow. Typical plants growing in this ring-like region are cattails or rushes, water lily or lotus, and submersed plants such as pondweeds. The littoral region is also the area in which over 90 percent of all algal species are found attached to macrophytes. These contribute significantly to the pond's productivity and provide habitats for microflora, as well as larger invertebrates and vertebrates. Typically, the littoral region is the most challenging region of a pond to manage. Shallow ponds (<6 feet, 2 m) are an even greater challenge to manage as the entire depth has sunlight penetration and thus, warms, producing abundant plant and algae growth.

Beyond the littoral region is the **open water region** (also called the **limnetic zone**), an area where an upper layer of warm, well-lit, and relatively high oxygen levels and a lower layer of cooler, poorly lit, and lower oxygen water levels occur. The water in ponds gets colder the deeper one goes. Plants and animals in the open water region include water lilies, submerged pondweed, planktonic algae, zooplankton, invertebrates, and fish. Typically, this region is the easiest to manage.

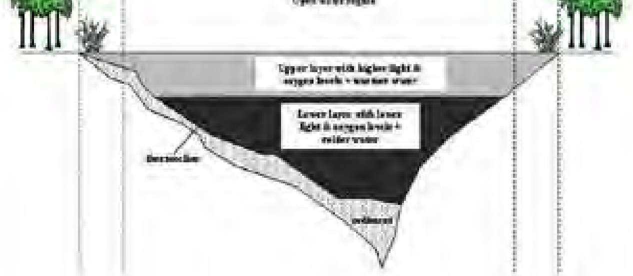


Figure 2-15. Cross-section illustration on a typical pond showing the littoral and open water regions and the upper and lower water layers.

Managing Lakes/Ponds/Streams. Managing a pond involves controlling or manipulating three significant parameters:

1. Light and temperature,
2. Nutrients, and
3. Oxygen.

Sunlight is the primary source of energy in pond dynamics. It fuels photosynthesis, which in turn, regulates oxygen levels, as well as warms the water. As temperatures rise, the pond's surface warms, becoming lighter (less dense). **Thermal stratification** begins, allowing the water to "layer," with warm water being separated from the deeper cooler water. Upper levels of ponds may become much warmer (termed the **epilimnion layer**) than the cold-water bottom (termed the **hypolimnion layer**). In small ponds (e.g., <15 acres, 6 ha), the warm layer extends down to about six feet (2 m) where a **thermocline**, the dividing line between the two layers, occurs. As water temperatures increase, the ability of water to hold oxygen decreases. For example, water at 80°F (27°C) holds less than 40% of oxygen than water at 52°F (11°C). Most of the oxygen-producing phytoplankton live in the warmer upper layer; thus, most of the oxygen for fish to breathe also resides here. During stratification, lower waters are not exposed to photosynthesis and wave action, the two main sources of dissolved oxygen in a pond. Little oxygen occurs below this warm layer; thus, it does not support aquatic life very well, sulfides are converted to hydrogen-sulfide, insoluble iron is converted to soluble forms, suspended solids increase as decomposition of waste materials on the pond bottom decrease, and this then becomes a less-than-ideal source of irrigation water for turf.

The **benthic zone** is the bottom of a pond that is normally nutrient enriched and oxygen starved. Undecomposed debris accumulates on the bottom as sludge and gradually decreases the depth of the pond. This sediment or sludge buildup can accumulate at a rate of one- to five-inches (2.5 to 12 cm) annually in temperate climates and up to eight-inches (16 cm) annually in tropical regions. For example, if a three-inch (7 cm) accumulation occurs per year, a one surface acre (4000 m^2) pond loses about 80,000 gallons or 300 m^3 of water storage capacity.

Thermal stratification must be interrupted or **eutrophication** will occur, where excess dissolved nutrients occur with insufficient dissolved oxygen. "Turnover" of a pond often occurs when the surface is cooled from rain or cold temperatures. The temperature of the top layer then equals the bottom layer and the two water layers will mix. As the two layers mix, the oxygen will diffuse from the top of the pond to the bottom, leaving insufficient oxygen to support fish life **(Table 2–1)**. Turnover of ponds may also occur as aquatic plants receive insufficient sunlight for normal photosynthesis during cloudy weather, and dissolved oxygen becomes deficient in the system. Oxygen levels are generally safe when all regions of a pond have

Table 2-1. Warning signs of oxygen depletion in ponds.

WARNING SIGNS OF OXYGEN DEPLETION IN PONDS.
1. Fish swimming at the surface are gulping for air, especially in late night or early morning.
2. Water rapidly turns from light green to dark brown to black in color.
3. A rotten or putrid odor is detected.
4. Sudden algal death.
These conditions are most likely after extended hot, cloudy weather is interrupted by a summer rain storm.

at least four ppm (or mg/L). With depleted oxygen, a cold rain may mix the warm and cold layers, breaking down the thermocline and depleting the pond of what little dissolved oxygen remains in the upper levels. Less-desirable odoriferous anaerobic bacteria then take over. Without oxygen, microorganisms, invertebrates, and fish die. Oxygen levels also tend to decline over time as ponds lose some of their holding capacity when sludge or sediment buildup occurs.

Oxygen depletion is from many situations. Most commonly this occurs: (1) during pre-dawn hours; (2) on cloudy and windless days; (3) on hot and humid days; (4) when water nutrient content is high; and (5) after extensive death and subsequent decomposition of aquatic plants. Algae occurrence often indicates poor quality water. Blooms of microscopic and filamentous algae are unsightly and disrupt full use of the water. Planktonic algae are single cell plants at or near the surface, typically light green in color, creating the common "pea-soup" appearance. The bloom of these algae typically occurs on cloudy, hot days or during pre-dawn hours, and they consume all the available oxygen in the water. Fish-kills and massive algae die-off follows. Cold weather, lack of sunlight, or a chemical application may cause this algae die-off. The water then quickly changes from the light green to a brown color.

Ponds often naturally turnover in fall when temperatures begin to cool. The major difference between a fall turnover and a summer turnover is the cooler water temperatures. Cold water will hold more oxygen than warm water, so when a pond turns over in the fall there is more oxygen available in the epilimnion layer, and fish do not normally die.

Cultural eutrophication such as sewage disposal, land drainage, and fertilization may result in excess nutrient enrichment in ponds. A direct correlation exists with the level of available nutrients and the populations of algae and aquatic weeds. High nitrates and phosphates cause algal blooms, aquatic weeds follow, and water turbidity, pH, alkalinity, and dissolved oxygen are adversely affected in eutrophic ponds. Vegetative life and sediment at the lake bottom are the primary sources of nutrients. The second most common source of nutrients is run-off from surrounding turf, roads, farms, and other outlying areas and through inlet waters. Inlet waters can originate from effluent sewage, wastewater treatment facilities, and leaching from septic systems. These waters often have minimal oxygen and are high with phosphorus. A 30 foot (10 m) band or "no fertilizer or pesticide treated zone" is suggested be implemented to help eliminate nutrient run-off into the water. Using slow release fertilizers also helps minimize run-off as well as a slightly elevated swale or berm around the pond. Balancing a pond's ecosystem must provide fewer destructive primary producers such as periphytic algae and manageable aquatic vegetation. Biodiversity of plants and animals is best for golf course ponds, resulting in as many levels of the food chain as possible. Strategically placed wetlands also capture unwanted nutrients prior to entering ponds.

Monitoring ponds should consist of measuring turbidity, total ammonia-nitrogen, phosphorous, temperature, pH, and dissolved oxygen **(Table 2–2)**. Pond nutrients are most prolific during the summer, leading to foul odors. Aerobic bacteria digest algae and other nutrients seven times faster than anaerobic bacteria. When aerobic bacteria run out of oxygen, the less-desirable anaerobic bacteria take over.

Aeration. Adequate circulation and aeration are needed for odor and algae control; therefore, electrical service should be provided to all open water bodies in the course design. Aeration helps attack the cause(s) of poor water quality while other methods such as dyes and algaecides treat the symptoms—algae. Artificial aeration helps provide oxygen when natural wind and wave action cannot provide sufficient levels **(Table 2–3)**. Aerators introduce oxygen into a larger volume of water while fountains create an attractive display or spray pattern **(Figure 2–16)**. Aerators use propellers to move a large volume of water and introduce a larger volume of oxygen. In fountains, a centrifugal pump usually creates an attractive display while volume is

Table 2-2. Desired levels of quality for open bodies of water.

Characteristic	Desired Level
Dissolved oxygen (prior to sunrise)	>4 mg/L (or ppm)
Biological oxygen demand (or BOD)	<5 mg/L
pH	6 to 9
Alkalinity	>50 mg/L
Chlorophyll	<2 mg/L
Suspended solids	<5 mg/L
Fecal coliform	<200 per 100 ml (no human contact if >400/100 ml)
Total nitrogen	<5 mg/L
Total phosphorus	<0.05 mg/L (<0.1 mg/L to prevent algae blooms)

Figure 2-16. Example of a number of means of artificially introducing oxygen into a water feature.

sacrificed to obtain the necessary pressure to achieve these heights and shapes.

Aerators need to be matched for the size of the pond or lake. A one-acre (0.4 ha) pond three feet (1 m) deep contains about 1 million gallons (3.8 million liters) of water. For aerations, 800 to 1,400 gallons (3000 to 5300 L) per minute (gpm) should be propelled into the atmosphere for a water surface area 0.5 to 1.5 acres (0.2 to 0.6 ha) in size. For smaller, 0.1 to 0.5 acre (0.04 to 0.2 ha) areas, 350 to 500 gpm is acceptable. If the lake is bigger, multiple smaller units generally distribute oxygen more evenly than one unit of larger horsepower. If the aerator cannot move sufficient amounts of water, then disappointing benefits will be seen.

Surface spray aerators can pump water from lower parts of the pond through the thermocline and into the air, where it can pick up oxygen. Short, wide, full volume water pumped at lower speeds maximizes recycling of water and injection of oxygen into water. Running fountain surface sprayers and subsurface aerators are maximized at night for oxygen benefits. A balanced pond will typically contain at least four ppm of oxygen. Oxygen levels are typically lowest just before dawn. Increasing the oxygen content in lakes can help reduce nutrient levels, limit thermal stratification, and decrease algae growth.

Beneficial algae. *Periphytic algae* is the general category of predominantly beneficial green algae found growing on or attached to submerged structures in fresh water. These can outcompete problematic blue-green and filamentous algae but require a submerged surface area to live. The usage of barley straw to control algae and clarify ponds was developed in England in the 1990s; however, mixed results have occurred since its effect on planktonic algae is less than on filamentous algae. The straw is believed to inhibit algae growth through a chemical exuded from the decomposing barley straw; by a metabolic product produced by fungi that decomposes the barley straw, preventing algae growth; or by the barley tying up excessive nitrates (NO_3^-). As a starting use rate, barley straw bales are applied at 225 pounds per acre (252 kg/ha) in shallow (4 to 5 feet, 1.2 to 1.5 m, deep) ponds or one two × four foot (0.6 × 1.2 m) bale per 5,000 square meters of water, which is repeated twice yearly. Other structures used to encourage beneficial

Table 2-3. Types of pond aerators.

TYPES OF POND AERATORS.	
1. Floating fountains (also called display fountains)	These electrically charged floating devices with a motor or pump/motor send jets or fountains of water into the atmosphere which dissolve oxygen and, through wave action following surface impact, support aerobic bacteria. Although spectacular, fountains normally do not move the same volume of water as true aerators.
2. Aerating fountains	This combination of an aerator and a fountain generally creates a spray pattern shaped as the flare of a trumpet or tuba.
3. Floating surface aerators	These devices, similar to the floating fountains, do not create a fountain-type spray pattern when this is not desired. They agitate the surface in the form of a bubbling or boiling effect and is best in water less than 15 feet (5 m) deep.
4. Aspirating aerators	These devices do not create a fountain pattern but blow oxygenated bubbles directionally into the water body, deep below the surface. The units create artificial currents in long narrow ponds or canals. The pond's bottom needs to be equipment-friendly, so as not to upset and mix the silt and any sludge throughout the pond and "islands" minimized to prevent normal channel flow. Aspirating aerators can be either floating or fixed base mounted and are good for water bodies three to 12 feet (1 to 4 m) deep.
5. Pond bottom aerators	These completely submerged units use a propeller water transport system where bottom water is circulated to the surface. This cooler, denser water absorbs oxygen as it spreads across the pond and returns through the stratified layers.
6. Diffused air or compressed air systems	These systems involve a shore-mounted compressor that pumps oxygen through tubing into the pond. It requires quality weighted tubing and self-cleaning diffusers but offers superior aeration, circulation, and de-stratification. These are the most unobtrusive aerators and are most effective in water depths 15 feet (5 m) or deeper.

Figure 2-17. Sign indicating a protected environmentally sensitive area on a golf course.

algae are rocks, rooted plants, Christmas trees, and other organic materials. Commercial mats are also available that provide enormous surface area for these beneficial algae.

Ponds should be continually monitored, measuring turbidity, ammonia (NH_4), phosphorous, temperature, pH, and dissolved oxygen. Small ponds are more prone to stagnation when water temperatures rise as aquatic plants die and consume dissolved oxygen; strong odors and aquatic death result. However, small ponds allow regular turnover of water; the fresher the water, the less problems occur.

Use of a filter system also is suggested to reduce algae that may enter the sprinkler system and clog nozzles. Even distribution by the irrigation system also helps prevent build-up of any harmful substances.

Pond enhancements. Algae are well-adapted to high nutrient concentrations, particularly phosphorus, warm water, and sunshine. Their ability to reproduce exponentially can result in an algal bloom distinguished by a "pea-soup" appearance.

Prevention of algal blooms often requires controlling nutrients in the pond. If not prevented, restoring ponds after an algal bloom can be costly and time-consuming. Ways to enhance pond health, attract wildlife, and prevent algal blooms include:

- Have a minimum pond basin depth of 15 feet (~4.6 m). This depth prevents full sunlight penetration and discourages bottom rooted plants plus provides cooler subsurface water to mix with surface waters.
- Create islands and shallow water areas by adding rocks and logs. These help protect and provide nesting sites for various small creatures and create basking sites for turtles.
- Provide shelter for fish by sinking trees.
- Provide food and safe access to wildlife by planting a vegetative buffer around the edge of ponds. These plants also help filter run-off to improve water quality.
- Plant emergent vegetation to provide food and cover for various birds, mammals, amphibians, and insects.
- Plant submergent vegetation to provide cover for various aquatic life and to help maintain healthy oxygen levels.
- Have a no-treatment buffer zone around the pond to act as a filter of surface-applied material **(Figure 2–17).**

Herbicides. Herbicides often are the fastest way to control weeds, but may not provide long-term control. Decaying weeds from herbicide control also often create oxygen depletion as the bacteria that decompose the weeds are oxygen consumers, leaving insufficient levels for fish. If using aquatic herbicides, treat in early spring when water temperatures are cooler, thereby holding more oxygen. If ponds need to be treated in summer, treat one-fourth of the pond at a time. If the whole pond is treated in summer, dissolved oxygen levels are reduced by the decomposing bacteria, causing fish kills.

Additional water treatment means to reduce aquatic plants and algae are (1) ozone injection; (2) adding beneficial bacteria to lower nutrient levels, especially in effluent water; (3) stocking grass carp such as the White Amur or Triploid Grass Carp; (4) use of dyes to alter the wavelength reaching aquatic plants, reducing their photosynthetic capability; and, (5) sediment dredging.

2.4 WETLANDS AND RIPARIAN ZONES

Geographic features such as wetlands and riparian zones are valuable natural resources. Wetlands are currently one of the most valuable natural resources in the United States **(Figure 2–18)**. They serve many purposes in nature, ranging from habitat for wildlife to a means of water quality improvement. Golf course developers, managers, and scientists are recognizing that wetlands and other geographic features may be essential to environmentally sound golf course management.

Natural Wetlands

Natural and constructed wetlands and riparian zones may be incorporated into golf course design **(Figure 2–19)**. These features, when fully integrated into the water management strategy, act as natural filters to remove nutrients, pesticides, and suspended particulates (e.g., soil, microorganisms) from run-off water. Many courses in coastal areas are fortunate to have an abundance of natural wetlands and riparian zones. These geographic features provide a critical wildlife habitat. In turn, the wildlife and the wetlands significantly contribute to the aesthetics of the course itself.

The key is to create a hydrologic design that begins with irrigation and rainfall; follows run-off from tees, fairways, and greens; and treats this run-off with vegetative

Figure 2-18. Incorporating extensive wetlands in a golf facility.

Figure 2-19. An example of a typical wetland on a golf hole.

filter strips, wetlands, and riparian zones. Collection of this treated run-off into ponds and lakes may provide a much-needed source of clean irrigation water for reuse on the course.

Constructed Wetlands

Some principles of ecological engineering suggested by Mitsch and Gooselink (1993) that can be applied to the construction and restoration of wetlands for non-point-source chemical run-off include the following:

1. Design the system for minimum maintenance. The system of plants, animals, microbes, substrate, and water flows should be developed.
2. Design a system that utilizes natural energies, such as the potential energy of streams, as natural subsidies to the system.
3. Design the system with the landscape, not against it. Floods and droughts should be expected. Outbreak of plant diseases and invasion of alien species are often symptomatic of other stresses and may indicate faulty design rather than ecosystem failure.
4. Design the system with multiple objectives, but identify at least one major objective and several secondary objectives.
5. Design the system as an ecotone. This means including a buffer strip around the site, but it also means the wetland site itself is often a buffer system between upland and aquatic systems. Stabilize and maintain stream banks and limit fertilizer and pesticide use near wetlands.
6. Give the system time. Wetlands do not become functional overnight and several years may lapse before nutrient retention or wildlife enhancement is optimal. Strategies that try to short-circuit ecological succession or overmanage are doomed to failure.
7. Design the system for function, not for form. If initial plantings and animal introductions fail but the overall function of the wetland, based on initial objectives, is intact, then the wetland has not failed.
8. Do not overengineer wetland design with rectangular basins, rigid structures and channels, and regular morphology. Ecological engineering recognizes natural systems should be mimicked to accommodate biological systems.

Wetlands can be located almost anywhere on a golf course. This utility facilitates the integration of a challenging whole design with water and chemical management. Wetlands can be incorporated into streams by adding control structures. Blocking the entire stream is a reasonable alternative only in low-order streams. This approach is usually not cost effective and is particularly vulnerable during high flow and flooding. An alternative would be to provide another channel for high flow periods. This would preserve the integrity of the wetland during intense storm events and flooding.

Riparian wetlands are those adjacent to flooding streams. These wetlands periodically receive flood waters and, in natural systems, may be seen as bottomland hardwood forests. Forested riparian zones adjacent to small creeks and drainage ditches are extremely useful for water and chemical management. For example, run-off from a playing surface may be directed via drain pipe or shallow depressions to a riparian ditch. This ditch, with a gentle to steep slope depending on the terrain, then empties into a wetland immediately upstream from a lake or larger-order stream. When designing the complete golf course hydrologic plan, the use of several small wetlands instead of a few larger wetlands should be considered. There are several advantages to locating several small wetlands in the upper reaches of the golf course (but not in the streams themselves) rather than fewer larger wetlands in the lower reaches. A particularly useful design might be the construction of multiple small wetlands in the landscape to intercept small streams and drainage tiles prior to reaching the stream. The stream itself is not diverted; the wetlands receive water, nutrients, and golf course chemicals from small tributaries, swales, and overland flow. In addition, drain tiles can be located so that they provide significant amounts of water to the wetlands. These tile drains are often the sources of highest chemical concentrations such as fertilizers.

The size and shape of the wetland should be dictated by other phonographic features such as slope. Short, wide wetlands might be appropriate for intercepting diffuse overland flow in areas with gentle slopes; long, narrow wetlands might be more appropriate for ditches, swales, and streams in areas with steeper slopes. In extreme cases of the latter, terraced wetlands placed into the watershed in a stair-step style are most appropriate.

Turf

Best Golf Course Management Practices (BMPs) combine cultural management factors for sustained productivity, course profitability, and the integrity of ecosystems on and in the vicinity of the golf course. Critical components of BMPs include: (1) selection of turfgrass species and cultivars; (2) soil management practices; (3) clipping and cultivation practices; (4) nutrient management; (5) irrigation and drainage management; and (6) chemical, biological, and cultural pest management. The goal of a BMP approach is to balance costs, benefits, and human and environmental health while sustaining an acceptable playing surface.

Fertilizers. The first and most important principle when managing turfgrass systems is to use optimum rates of nitrogen and phosphorus to maintain appropriate nutrient levels and avoid losses to run-off or leaching. Soil and tissue tests frequently determine specific levels and possible needs. Improving uptake efficacy will also minimize nutrient losses. For example, core aerify compacted soil before fertilizing to allow better penetration by the fertilizer; water-in soluble fertilizer sources after application; use slow-release sources when feasible, especially in sandy soils; use minimum rates on severely sloping or highly erodible soils; use iron as a supplement to nitrogen for improved turf color; recycle grass clippings; and avoid fertilizer application in bodies of water by using a drop spreader near these. Also, applications of fertilizers should coincide with the growth requirements of the specific turfgrass species. Traffic patterns and intensity should be monitored and taken into account in calculating the potential for run-off. Selecting different application techniques can also reduce losses, as can variations in the formulations used. In addition, it is necessary to have properly calibrated equipment. Some measure of quality control and quality assurance needs to be conducted in order to assess the efficacy of the nutrient management plan.

Pesticides. Foremost in the superintendent's mind when planning pesticide management should be the safety of the workers and golfers.

Control of Other Pests. (what other pests – none mentioned previously) Other pests such as raccoons, armadillos, groundhogs, wild hogs, deer, geese, and other birds should be controlled according to local regulations. Trapping or harvesting these pests, humanely, may be effective. Care should be taken when handling wild animals as they are vectors for various diseases, such as rabies.

Audubon International Cooperative Sanctuary Program. Audubon International began its Audubon Cooperative Sanctuary Program (ACSP) in 1991 to "educate people about environmental stewardship and motivate them to take action in their daily lives which will enhance and protect wildlife and their habitats and conserve natural resources." The ACSP has devised four programs tailored for homeowners, businesses, schools, and golf courses.

A golf course can become certified in the ACSP in six areas:

- Environmental planning
- Wildlife and habitat management
- Chemical use reduction and safety
- Water conservation
- Water quality management
- Outreach and education

If a course successfully becomes certified in all six categories, it receives a Certified Audubon Cooperative Sanctuary **(Figure 2–20)**. Once a course is certified, it must be recertified after two years. This involves completing a case study, site assessment, and environmental planning. For further information on this sanctuary program, contact Audubon International at:

Audubon International
46 Rarick Road
Selkirk, NY 12158
Phone: (518) 767-9051
Fax: (518) 767-9076
www.audubonintl.org

Figure 2-19. Sign on a golf course door indicating it's a Certified Signature Sanctuary by the Audubon International.

3 WATER MANAGEMENT AND CONSERVATION IN TURF

3 BEST WATER MANAGEMENT AND CONSERVATION STRATEGIES

Plants typically contain between 75 to 85% water by weight and begin to die if their water content drops to 60 to 65% within a short period of time. Unfortunately, rainfall does not occur frequently enough in most cases to provide adequate water to sustain turfgrasses, especially with the limited root systems associated with most closely-mowed turf areas and sand-based soils with low water-holding capacity. This situation is further intensified by warm weather and the high aesthetic demands of clientele. To ensure efficient watering, turf facilities require well-designed irrigation systems based on soil infiltration rates, soil water-holding capacity, anticipated annual rainfall, plant water-use requirements, depth of rootzone, conveyance losses from the surrounding area, and desired level of turfgrass appearance and performance **(Figure 3–1)**.

Water loss from a turf area occurs through evaporation, transpiration, run-off, leaching, and conveyance losses. Turf managers have a degree of control over these water-loss mechanisms; therefore, they should have a good understanding of each mechanism in order to maximize water conservation. In addition to water quantity, water conservation also encompasses irrigation water quality which will also be covered in this chapter.

Figure 3-1. A properly designed and operating irrigation system is the life-line for golf facilities. Most are computerized and synchronized with weather stations and/or soil moisture probes to efficiently use irrigation water.

Figure 3-2. Turf turning a characteristic bluish-green color, indicating soil and plant moisture stress.

3.1 TURFGRASS WATER USE

Determining When to Irrigate

There are a number of methods used to determine how much water turf requires at any given time, under any given environment. Several are indirect and base their estimates on measuring soil moisture, others simulate evapotranspiration from the canopy, while yet others make direct soil measurements.

Visual Symptoms

A simple method used to determine when to irrigate is to observe visual symptoms of moisture stress **(Figure 3–2)**. Moisture-stressed grass appears blue-green or grayish-green in color, recuperates slowly (>1 minute) after walking or driving across it ("foot-printing"), or wilts continuously. These symptoms occur when plant moisture is insufficient to maintain turgor pressure, due to more water being lost than absorbed. As a result, the plant rolls its leaves to minimize exposed leaf surface and wilts to conserve moisture. Golf course managers should avoid prolonged moisture stress, especially on greens. This method is best used for low-maintenance turf such as golf course roughs, out-of-play sports fields, or home lawns.

Table 3-1. Crop coefficient (Kc) values for a Class A Evaporative Pan or the Penman-Monteith equation.

Grass	Class A-Evaporative Pan Kc Values	Penman-Monteith Kc Values
Bermudagrass	0.55 to 0.65	0.70 to 0.80
Tall Fescue	0.65 to 0.75	0.75 to 0.95
Perennial Ryegrass	0.65 to 0.75	0.80 to 1.0
Kentucky Bluegrass	0.70 to 0.80	0.85 to 1.0
Creeping Bentgrass	0.75 to 0.90	0.95 to 1.0

Evaporatory Pans

Another method of irrigation scheduling is the use of evaporatory pans. A United States Weather Service Class A Evaporatory Pan is 122 cm in diameter, 25 cm deep, and is supported 15 cm above the ground. Evaporatory pans are filled with water and placed in a representative location, where water loss is measured over time. The amount of water evaporating from the pan correlates to that lost by evapotranspiration (ET). This correlation is generally accurate except during windy conditions which tend to exaggerate the amount of water lost by the evaporatory pan compared to actual ET rates.

The water quantity lost through evaporation correlates with turfgrass ET, but is not exactly the same; turfgrasses use less water than the amount evaporated from the pan. A crop coefficient (Kc) value is needed to adjust this correlation **(Table 3-1)**. Warm-season grasses use 55 to 65%, and cool-season grasses use 65 to 90%, of pan evaporation. Thus, if the evaporative pan shows a one-in (2.5-cm) water loss, a bermudagrass turf would actually have lost approximately 0.60-in (1.5 cm) while bentgrass would have lost approximately 0.85-in (2.2 cm).

Soil Moisture Measuring Devices

Soil moisture measuring devices have been developed with the goal of indicating how much moisture is available to plants. Soil moisture is measured by two distinctly different methods - *quantitatively* (or *volumetric*), the actual amount of moisture in the soil, and *qualitatively* (or *tensiometric*), how tightly water is held by soil. Though numerous means of measuring these exist, the most common ones include gravimetric water content, TDR, tensiometers, and FDR (or hand-push) probes.

The water content of different soils varies due to large differences between soils in their total particle surface areas. For example, moisture levels at field capacity for sands may be as low as 7% whereas clays may have as much as 40% moisture content at field capacity. In another example, the permanent wilting point volumetric water content may range from 1 to 2% for sandy soils to 25 or 30% for clay (finer-textured) soils. This variation demonstrates that a measure of soil water (volumetric) content does not necessarily indicate the amount of water available to plants. A better indicator of a plant's soil-water availability is the energy status of water (called tensiometric or water potential) which measures the relative amount of work (or energy) needed to remove a unit of water from a particular soil.

Quantitative Methods

Quantitative methods for measuring soil moisture include gravimetric sampling, neutron probe (or scatter), and dielectric constant (Time Domain and Frequency Domain Reflectometry, TDR and FDR) probes **(Figure 3–3)**. The most accurate is the gravimetric water content method where a volume of soil is weighed, dried, and then reweighed **(Table 3–2)**. This method measures how many grams of water there are per gram of soil (or kg water kg^{-1} soil), which gives a very useful measure to work with. Gravimetric water content can quite easily be changed to volumetric water content by multiplying the gravimetric water content by the soil's bulk density. Volumetric water content is a measure of the volume of water per volume of soil and is commonly seen as $m^3\ m^{-3}$ or $cm^3\ cm^{-3}$. Often times when you see soil water described as a percentage, it is in fact describing volumetric water content; this is largely accepted but slightly misleading. The impracticality of sampling for gravimetric water content and expense (>$5,000) for neutron probes have led to the development of other techniques.

Dielectric constant methods measure the soil's ability to transmit electricity (electromagnetic waves or pulses) with the value increasing as the water content of the soil increases. The permittivity constant for air is approximately 1; dry soil between 3 and 5; and about 80 for water. Values are related through calibration to known soil moisture content determined using either a neutron probe or the gravimetric sampling technique. The equipment consists of an electronic meter connected to two to four rods placed

Figure 3-3. Using a highly accurate TDR probe to measure soil moisture levels.

into the ground. The instrument sends an electrical signal through the soil and the rods serve as the transmitter and receivers. TDR and FDR probes are currently the most commonly used dielectric devices. Although these devices are able to detect the amount of moisture in the soil, they do not determine how much of it is available to plants.

Advantages of using dielectric devices to quantify soil moisture include:

- ability to leave soil moisture sensors in place to continuously monitor soil moisture content,
- repeatability of measurements,
- sensitivity to small changes in soil moisture content,
- precise resolutions with depth due to the narrow vertical zone of influence.

Disadvantages include:

- need for soil specific calibration for best accuracy,
- relatively small zone of measurement,
- possibility of soil salinity influencing probe reading,
- sensitivity to air gaps,
- probe length should equal rooting depths.

Time Domain Reflectometry (or TDR). These systems measure the travel time of an electromagnetic wave between sending the pulse and receiving it, and is the preferred tool for researchers. With TDR, a pair of parallel metal rods connected to a signal receiver is inserted into the soil. The rods serve as conductors while the soil is the dielectric (a non-conductor of electricity). The presence of water (higher dielectric constant) proportionally slows the speed of the electromagnetic wave. Traditionally, TDR instruments were more expensive due to the advanced electronics needed to provide this series of precisely-timed electrical pulses and ability to read them. However, recent technology has allowed TDR moisture sensors to be priced closer to the less accurate FDR based alternatives.

Frequency Domain Reflectometry (or FDR). These are also known as *hand-push probes* and as *dielectrical capacitance probes*. Like TDR systems, FDR are also dielectric sensors as their electrodes are separated by the dielectric (soil). One or two pairs of electrodes (either an array or parallel spikes or circular metal rings) form a capacitor, with the soil acting as the dielectric in between. This capacitor works with the oscillator to form a tuned circuit and

Table 3-2. Comparison of common techniques of soil moisture content measurement.

Technique	Measurable Range	Advantages	Disadvantages
Gravimetric water content. - Measures soil moisture by weighing-drying-reweighing.	Full range of water content (%).	- simple equipment needs, - highly accurate, - easy interpretation.	- destructive sampling, - labor intensive, - collection, transport, & time restraints.
Time Domain Reflectometry (TDR). - Measures time for an electromagnetic wave to travel using soil medium as a dielectric. Moisture slows this down.	Up to 50% volumetric water content (0.50 kg water kg^{-1} soil)	- accurate, - minimal soil disturbance, - soil specific-calibration is optional, - relatively insensitive to temperature, - also estimates, with limited accuracy, soil EC.	- expensive, - accuracy decreases in high saline (>25 ds m^{-1}) conditions or heavy clay soils, - relatively small sensing volume (about 1-in., 2.5- cm, radius around probe).
Frequency Domain Reflectometry (FDR) or Hand-push probes. - Measures the change in frequency of a capacitor using soil medium as a dielectric.	Up to 70% volumetric water content (0.70 kg water kg^{-1} soil) or to -7.0 MPa	- relatively inexpensive, - can be automated with irrigation, - stable in different soil types and over a large range of moisture contents.	- needs soil-specific calibration for accuracy, - samples small volume of soil (about 4-in., 10-cm, radius around probe), - sensitive to soil air gaps, saline soils & temperature.
Tensiometers. - Measure how tightly (the "tension") water is held by soil.	0 to -0.08 MPa or 0 to 80 kPa	- direct readout of soil water potential (or tension), - inexpensive, - can be automated with irrigation, - relatively reliable, - good accuracy, - unaffected by soil salinity.	- soil moisture retention curve needed to relate to soil water content, - samples a small area near cup, thus, multiple samples are needed in larger areas, - doesn't measure soil salinity content, - exposed gauges, sensitive to disturbance & soil air gaps.
Unit Conversions: 1 bar ≈ 1 atm = 14.7 psi; 1 kPa = 0.001 MPa = 0.01bar = 1 cb			

changes in soil water content are detected by changes in the reflected frequency. Most of these sensors operate at low frequencies (100 MHz or less) compared with a higher (~250 MHz) operating frequency for TDR probes. The high frequency used for TDR probes allows less dependency on soil specific properties like texture, salinity or temperature. The greater the soil moisture content, the smaller (or greater change in) the frequency. The dielectric reading is then converted to volumetric water content (m^3 water m^{-3} soil or θ_v) with a readout in percentage (% volume).

In general, FDR probes perform best in coarser-textured, non-saline soils, and often require specific soil calibration, limiting their use or comparison from different soils or locations. Less precise electronics are needed vs. TDR, thus FDR probes are cheaper. All electronic resistance probes are influenced by temperature, soil composition and bulk density, and the solute concentration (EC) of the soil solution and since moisture content is a non-linear curve, calibration equations are required for specific soils. Probes should also be at least 6-in (15-cm) in length to reduce wavelength reflection which produces erroneous readings as do EC levels at and above 25 dS m^{-1}.

Electrical Conductivity Probes. These are a commonly available low-cost means of measuring soil moisture based on the soil's ability to pass a current of electricity between two probes. In many ways the concept is similar to resistance blocks but the probes (electrodes) have direct contact with the soil and are not buffered as with resistance blocks (discussed below). The more moisture in soil the better the conductivity or the lower the electrical resistance. This method is very sensitive to probe spacing as well as being influenced by soil type and salts, primarily in the form of fertilizers. Because of this strong correlation, these probes are more commonly used to measure salt content in soils.

Qualitative Methods

These methods measure how tightly soil moisture is held by soil particles but do not directly measure the quantity of water contained. As the tension increases, water extraction becomes more difficult for the plant. Tensiometers and porous blocks (i.e., gypsum, ceramic, nylon, and fiberglass) are qualitative methods.

Tensiometers. These are sealed, water-filled tubes with a vacuum gauge on the upper end and a porous ceramic tip on the lower end. Water in the tensiometer comes to equilibrium with water in the soil and provides an indication of how difficult it is (or tension required) for the plant to obtain water from the soil, but does not directly provide information on soil water content. To obtain this, a soil moisture release curve is needed. A lower reading indicates more available water. Though very accurate when scheduling irrigation, tensiometers are often not practical in turfgrass applications as their presence disrupts play and/or maintenance practices.

Electrical Resistance Blocks. Electrical resistance blocks measure soil moisture tension with two electrodes imbedded in a porous material such as gypsum, nylon, fiberglass, or a sand-ceramic mixture. Gypsum or similar material is used to buffer against salts that would affect resistance readings. Moisture is allowed to move in and out of the blocks as the soil dries or becomes moist. The electrodes measure resistance to electric current when electrical energy is applied. The more moisture in the block, the lower the resistance reading indicating more available moisture. These are accurate when measuring low soil moisture content and can be left in place for extended periods. They are, however, sensitive to saline conditions, and, like tensiometers, measure soil moisture only at the area immediately surrounding them. They also are not as accurate in predominantly sandy soil.

Predictive Models or Evapotranspiration Feedback

Predictive models, such as the modified Penman-Monteith ET (also known as FAO 56) model, based on weather station data and soil types also are available **(Figure 3–4)**. These are often referred to as Irrigation, or ET, Controllers in the industry. They estimate or predict ET of the turf. These are relatively accurate and applicable, especially as long-term predictors of yearly turf water requirements. Models, however, are only as effective as the amount of data collected and the number of assumptions made. Weather data such as rainfall, air and soil temperature, relative humidity, and wind speed are incorporated into certain model formulae, and estimated soil moisture content is calculated. Accessible weather data, as well as specialized computer equipment and programs, must be available.

Evapotranspiration feedback strategies are also used to schedule irrigation. Weather station or evaporative pan data can be used to calculate water use. This value is referred to as potential ET (ET_p) and is used as a reference point. Actual turf water use usually is not quite as high as ET_p, so a factor called the **crop coefficient** (K_c) is used to convert ET_p to actual turf ET (as discussed in the previous section on evaporative pans). Crop coefficients are fairly constant for a given species, but vary considerably between species **(Table 3-1).** For example, the Kc of bermudagrass is about 0.75. This means bermudagrass will use about 75% as much water as is predicted from using environmental data to calculate ETp. If environmental data indicates the theoretical reference crop used 2.2-in (5.6 cm) of water for a given week in the summer, multiply 2.2 by 0.75 indicates 1.65-in (4.2 cm) of water is actually used by bermudagrass. Most cool-season grasses have a Kc of approximately 0.85, indicating cool-season grasses actually require 1.87-in (4.75 cm) of water in the previous situation. These calculated water use rates are the "feedback" used to determine irrigation rates. Using the site information and weather data, ET feedback controllers run a "water balance" that keeps track of how much water is in the soil. Controllers

Figure 3-4. An on-site weather station which measures environmental conditions which in-turn are used to predict irrigation needs.

then adjust the run timers (or amount) of water applied to the turf.

Atmometer

The atmometer (also referred to as the "ET gauge" or Bellani plate) also can be used to estimate evaporative demand. This relatively inexpensive device consists of a water reservoir connected to a porous plate covered by green fabric designed to simulate a leaf surface. Water from the reservoir is wicked through the plate to the fabric, where it evaporates. The drop in the reservoir is then easily measured on a daily basis, much like checking a rain gauge. Rates of water loss are directly related to weather conditions, especially temperature, wind, and humidity, and have been found to correlate very well with turfgrass water demand. Atmometers may be an attractive alternative to the more costly weather station-based system while still supplying similar information.

The atmometer should be located in a sunny turf-covered area representative of the majority of the golf course. Additional units may be necessary for varying microclimates such as shady, windy, or stagnant areas, and irrigation rates should be adjusted accordingly. Atmometers require calibration and provide only an estimation of watering needs.

3.2 TURFGRASS EVAPOTRANSPIRATION RATES

Plants absorb water from the soil and lose water to the atmosphere. Only about 5% of all water consumed by turf is used in photosynthesis, carbohydrate synthesis, and other metabolic reactions. About 95% of this water is lost as vapor from the leaves, to the atmosphere, by the process of **transpiration**. Water is also lost by **evaporation** from soil and leaf surfaces. Evaporation is typically much lower than transpirational losses in a mature turf. The combined total of water lost through transpiration and evaporation is termed **evapotranspiration**, abbreviated ET. Evapotranspiration is usually expressed in inches or millimeters per day, week, or month. Since ET is the total water lost from the turf system, it represents the water demand, or the total amount that must be replaced to maintain a healthy turf. Environmental parameters largely controlling ET are light intensity and duration, relative humidity, wind velocity, and temperature. Increasing solar radiation, temperature, and wind increases ET, while increasing relative humidity decreases ET. Other parameters affecting ET to a lesser extent include soil-water content, turf-root system development, inherent turf water needs and dehydration avoidance mechanisms, and turf cultural practices.

Turfgrass Water-Use Rates

Water-use rates are usually expressed in inches or centimeters of water lost per day or per week. In general, warm-season grasses use less water due to their greater resistance to water stress compared to cool-season grasses **(Table 3–3)**. This ranges between 35 and 50% less water required to maintain desirable warm-season grass color compared to cool-season grasses. Bermudagrass ET is between 0.3 and 0.9 cm water day^{-1}, while tall fescue water use ranges from 0.4 to 1.3 cm day^{-1}. Lower values are associated with cooler or more humid regions of the United States, while higher values are typical of warm arid regions. Tall fescue has the highest potential ET rates, but avoids drought stress due to its deep and extensive root system and ability to go dormant for short periods without lethal consequences.

Potential Evapotranspiration (ET_p) Rates

As previously discussed, another method to schedule irrigation is the development of ET feedback systems based on an estimate of the potential ET (indicated as ET_p) developed from climatic data or weather pan evaporation. The ET is then adjusted to actual plant ET use with an appropriate crop coefficient (K_c) that more accurately reflects actual ET for the particular turfgrass under irrigation:

$$ET_p = K_c \times \text{pan evaporation}$$

Currently, K_c for warm-season grasses ranges from 0.60 (moderate stress) to 0.90 (non-stressed) and from 0.80 to

Table 3-3. General mean summer turfgrass evapotranspiration (ET) rates. Low values within a range represent humid conditions; high values are for arid conditions (modified from Beard, 1985; Carrow, 1995a). ET rates during non-summer months generally are much lower.

SUMMER ET RATES				
Turfgrass	**in day^{-1}**	**mm day^{-1}**	**in wk^{-1}**	**cm wk^{-1}**
Bahiagrass	0.25	6.2	1.75	4.4
Bermudagrass	0.12 to 0.30	3.1 to 8.7	0.84 to 2.10	2.1 to 5.3
Buffalograss	0.20 to 0.30	5.3 to 7.3	1.40 to 2.10	3.6 to 5.3
Centipedegrass	0.15 to 0.33	3.8 to 8.5	1.05 to 2.31	2.7 to 5.9
Creeping bentgrass	0.19 to 0.39	5.0 to 9.7	1.33 to 2.73	3.4 to 6.9
Kentucky bluegrass	0.15 to 0.26	3.7 to 6.6	1.05 to 1.82	2.7 to 4.6
Perennial ryegrass	0.15 to 0.44	3.7 to 11.2	1.05 to 3.08	2.7 to 7.8
Seashore paspalum	0.25 to 0.31	6.2 to 8.1	1.75 to 2.17	4.4 to 5.5
St. Augustinegrass	0.13 to 0.37	3.3 to 9.6	0.91 to 2.59	2.3 to 6.6
Tall fescue	0.15 to 0.50	3.6 to 12.6	1.05 to 3.50	2.7 to 8.9
Zoysiagrass	0.14 to 0.30	3.5 to 7.6	0.98 to 2.10	2.5 to 5.3

0.85 for cool-season grasses. General estimates of ET_p may be calculated using the following values for Kc:

Warm-season grasses: ET_p = 0.75 x pan evaporation

Cool-season grasses: ET_p = 0.85 x pan evaporation

Scheduling Irrigation Based on ET Rates

Potential ET rates can be calculated from a variety of equations. In general, by using historical climatological data as a reference and incorporating this in the modified Penman or McCloud equation to determine specific ET rates, potential ET rates have been calculated at various locations throughout the country. From this, normal net irrigation requirements to maintain low-to-medium maintenance grass are estimated.

When using any predictive equation to determine ET rates or net irrigation requirements to maintain grass, a series of assumptions must be made. These assumptions influence actual amounts of net irrigation requirements since each location and golf operation is designed and built differently. Allowances are needed to account for these and to adjust for any differences.

1. The net irrigation requirement is affected by irrigation system efficiency or **distribution uniformity** (designated DU). To determine the actual irrigation quantity needed to provide the minimum intended amount uniformly across the turf, the following equation is used:

$$\text{actual irrigation needed} = \frac{ET_p}{\text{Distribution Uniformity}}$$

   For example, if 1-in (2.54-cm) of water is needed as determined by multiplying pan evaporation rate by K_c to achieve ET_p with a 75% efficient (or DU) system, then 1.33-in (1.0 ÷ 0.75) of total “applied” water is required to uniformly apply this minimum 1-in (2.5-cm) over the whole turf area.
2. Environmental parameters at the time of application also influence the amount of water delivered to plants. Applications made during hot, windy conditions, with low relative humidity, and fine mist irrigation nozzles, can result in extensive evaporation (up to 30 to 50%) of irrigation prior to it reaching the turfgrass. Irrigation should not be scheduled during such periods. However, special practices such as establishing new turf areas, and watering-in fertilizer or pesticide applications, often necessitate irrigation during adverse conditions.
3. Net irrigation requirements listed are for taller-mowed grass. Closely maintained grass, such as golf greens and tees, have significantly less rooting depth compared to taller-mowed plants; thus, they require more frequent, shallow irrigations and have less room for error if not properly and adequately watered during periods of heat and drought stress.
4. Rainfall amounts used in these calculations are averages based on historical climatological data. Deviations from these averages usually occur, and net irrigation amounts during exceptionally dry years will have to be increased to compensate for this. Values listed also assume even rainfall distribution over the entire period. If uniform rainfall distribution does not occur, irrigation amounts higher than those listed in **Table 3–3** are required.
5. “On-site” computer-assisted ET-predicted models calculate water needs based on local conditions. Generally, a range of ET models are used that estimate between 0.8 and 1.2 of actual ET.

3.3 IRRIGATION STRATEGIES

With potential shortages of irrigation water, it is in the best interest of a turf facility to conserve water whenever possible and to design irrigation programs that provide quality turf with minimum water use. Irrigating too heavily not only wastes valuable water, but invites the potential for increased disease incidence, turf thinning, shallow rooting, reduced stress tolerance, and increased soil compaction and turf wear. Inefficient use of electricity and excessive wear and tear on the irrigation pumps and other components of the system also are reasons to make the most of all water use.

Playing conditions are also influenced by watering practices. Overwatered golf courses tend to play much longer and have slower putting greens. Conversely, drier turf results in quicker putting surfaces and more bounce and roll; in effect, shortening the course. However, if allowed to dry excessively, this increases the risk of losing turf from moisture stress and causing a reduction in aesthetic quality. Many courses also are restricted in the amount of water they can use and may be mandated to irrigate based on ET data, soil moisture levels, or other water need indicators.

Steps in formulating an irrigation strategy include:

1. Calibrate an irrigation system's output and distribution uniformity (or DU).
2. Determine daily ET rates or soil moisture status by one of the methods discussed earlier. A reasonable estimate of daily summer mean ET rates for various grasses is provided in **Table 3–3**.
3. Accurately track daily rainfall and ET rates so a water budget can be set-up and followed.
4. When irrigation is needed, use the appropriate crop coefficient to find daily ET rate and incorporate distribution uniformity (DU) of the irrigation system as shown earlier and below.
5. Make adjustments for rainfall, varying microclimates, and forecasted weather.

Irrigation System Calibration

The first step in irrigation scheduling is to determine how much water the irrigation system applies, typically expressed as inches per hour (in hr^{-1}). This information is central to water management. The easiest and most common way to determine application rate is by "canning" the turf area. For small areas, a dozen or so empty tin cans are placed in a grid system across the turf with the location of each catch-can recorded. It is important the cans are the same size, have a consistent cross-section, and are fairly tall; soup or vegetable cans work well **(Figure 3–5)**. The irrigation system is then activated for a timed period, usually 15 to 30 minutes, to let the cans collect ¼- to ½-in (6.4 to 13 mm) of water. The amount of water in each can is then measured with a ruler and adjusted to the amount

Figure 3-5. Using a 'jar-test' to accurately measure the distribution uniformity of an irrigation system.

of water caught per hour. These cans are all emptied into a single can and the water depth is measured with a ruler. The depth is then divided by the total number of cans to get the average depth per can. This value must be divided by the time period to calculate the application rate. For example, assume 12 cans were used to collect irrigation for a 30-minute period. The total depth of all cans was 4.4-in (11 cm). Dividing 4.4-in (11-cm) by 12 gives 0.37-in (0.94-cm) per can. Now multiply the average depth, 0.37-in (0.94-cm) per one-half hour, by 2 to calculate the application rate of 0.74-in hr^{-1} (1.9-cm hr^{-1}).

The canning method also helps indicate the distribution uniformity (DU) of the irrigation system which is the ratio of under-watered area to the average applied within the sprinkler coverage area. The most common measure of distribution uniformity is the "low-quarter" method. With this method, distribution uniformity is determined by identifying the depth of irrigation applied to the driest 25% of the test area and dividing it by the mean depth of water in all cans. The equation of DU involves:

$$\text{distribution uniformity (DU)} = \frac{\text{average } \textbf{least} \text{ amount of water depth collected in 25\% of all cans}}{\text{average depth of water collected for all cans}}$$

Typical DU values range from 55 to 80%; even rainfall is not 100% uniform. The lower the value, the less uniformity with which an irrigation system applies water; thus, the more water and energy requirements are needed to uniformly meet plant needs. Obtaining 80% DU is considered excellent (achievable), 70% as good (minimum) and 55% or less as poor. Means of improving existing DU values include: (1) changing sprinklers and worn sprinkler nozzles; (2) pressure changes (increases); (3) changing sprinkler spacing; and, (4) maintaining level irrigation heads. The Center for Irrigation Technology is a resource for testing and selecting irrigation heads (www.fresnostate.edu/jcast/cit/index.html).

Example:

1. Determine the distribution uniformity (DU) of the following conditions. A can test was performed with 20 cans evenly spaced 5 ft (1.5 m) apart in a grid system. After a 15-minute run cycle, the average depth in the five **least**-filled cans was 0.2-in (0.5-cm). The average depth measure in all cans was 0.33-in (0.84-cm). The irrigation rate is then adjusted from inches per 15-minutes to inches per hour by multiplying the 0.33-in (0.84-cm) and 0.2-in (0.5-cm) by 4 to achieve 1.32-in hr^{-1} (3.36-cm hr^{-1}) and 0.8-in hr^{-1} (2.0-cm hr^{-1}) respectively. The DU value is then determined:

$$\text{distribution uniformity (DU)} = \frac{\text{average \textbf{least} amount of water depth collected in 25\% of all cans}}{\text{mean depth collected for all cans}}$$

$$= \frac{0.8\text{-in}}{1.32\text{-in}}$$

$$= 0.61 \text{ (or 61\%)}$$

2. How much water would be needed to apply 0.5-in (1.3-cm) over the entire area?

$$\frac{0.5\text{-in}}{0.61\text{ DU}} = $$ 0.82-in (2.1-cm) of irrigation needed to 0.61 DU apply at least 0.5-in (1.3-cm) over the area.

3. How long would the irrigation system need to run to apply 0.88-in (2.2-cm)?

   From the above information, it was determined the irrigation system delivered 1.32-in hr^{-1} (3.4-cm hr^{-1}), therefore,

$$0.88\text{-in} \times \frac{1\text{ hr}}{1.32\text{-in}} \times \frac{60\text{ min}}{\text{hr}} = 40\text{ min}$$

   Irrigation system calibration, but not DU, can also be determined by knowing the amount (gal) of water applied per irrigation head, the sprinkler spacing (ft), and by using one of the formulas listed in **Table 3–4**. Different formulas are needed depending on whether the sprinkler head design is on square spacing, triangular spacing, or single row design. For example, to determine inches of water applied per hour for an irrigation system designed with triangular spaced heads 50 ft apart that apply 30 gal min^{-1} of water per head, use the following equation from **Table 3–4**.

inches water applied per hour

$$= \frac{96.3 \times \text{gal min}^{-1} \text{ per head}}{(\text{sprinkler spacing, ft.})^2 \times 0.866}$$

$$= \frac{96.3 \times 30 \text{ gal min}^{-1} \text{ applied per head}}{(50\text{ ft})^2 \times 0.866}$$

$$= 1.33\text{-in hr}^{-1} \text{ (3.4-cm hr}^{-1})$$

Table 3-4. Irrigation application rates per head based on the head spacing pattern.

Square spacing head design
$\frac{96.3 \times \text{gal min}^{-1} \text{ applied per full circle head}}{(\text{sprinkler spacing, ft})^2}$ = in applied hr^{-1}
Triangular spacing head design
$\frac{96.3 \times \text{gal min}^{-1} \text{ applied per full circle head}}{(\text{sprinkler spacing, ft})^2 \times 0.866}$ = in applied hr^{-1}
Single row spacing head design
$\frac{96.3 \times \text{gal min}^{-1} \text{ applied per full circle head}}{\text{sprinkler throw diameter (ft)} \times 0.80 \times \text{sprinkler spacing (ft)}}$ = in applied hr^{-1}

Example:

1. If 46 ac (18.6 ha) of turf were to receive 1-in (2.5-cm) of water, what is the total amount of water, in gallons, needed? From **Table 3–5**, 1 ac-in of water equals 27,154 gal; thus, 27,154 gal × 46 ac = 1,249,084 total gal water needed (47 million liters).
2. If water costs are three cents per cubic foot of water, what is the total cost of this volume? From Table 3–5, 1 ft3 equals 7.48 gal of water; thus,

$$\frac{1\text{ ft}^3}{7.48\text{ gal}} \times 1{,}249{,}084 \text{ gal total} \times \frac{\$0.03}{\text{ft}^3} = \$5{,}010$$

Determining Irrigation Rates and Frequency

In addition to the application rate and uniformity, the turf manager should know how much water the turf is using. This can be determined using reference ET from a weather station/computer system plus a crop coefficient specific for the turf species from data in **Table 3–4**, or with data from an atmometer or other devices as previously discussed. Historical weather information may also provide reasonable estimates of average water use. Managers also need to know where the roots are in the soil profile and approximately how much available water is held by the soil.

As previously noted, evaporation during hot, windy, and dry periods can reduce irrigation efficiency. Superintendents can avoid this by irrigating early in the morning before the temperature rises and humidity drops. Early morning irrigation also removes dew from the leaves, and helps prevent diseases favored by irrigating in the evening.

Water Budgeting

Budgeting water is analogous to handling money in a checking account **(Figure 3–6)**. There are inputs (deposits), outputs (withdrawals), and a certain amount of water in the soil (standing balance). The flow of water (money) into and out of the “checking account” (the rootzone) is simply followed over time. If the roots penetrate 12-in (30-cm), the checking account is the water held in 12-in (30-cm) of soil. If the roots penetrate only 2-in (5-cm), the checking account is considerably smaller. Irrigation is

Table 3-5. Conversions and calculations for determining turfgrass irrigation needs.

1 ac-in (amt. of water needed to cover 1ac to the depth of 1-in)	= 27,154 gal	1 ac-ft (amt. of water needed to cover 1 ac to the depth of 1 ft)	= 325,851 gal
	= 43,560 in^3		= 43,560 ft^3
	= 3,630 ft^3		
1-in 1,000 ft-2	= 623.33 gal	7.48 gal	= 1 ft^3
	= 83.33 ft^3		= 1,728 in^3
1 gal	= 0.134 ft^3	1 ft^3	= 7.4805 gal
	= 231 in^3		
	= 8.34 lb water	1 psi	= 2.31 ft of head
1 pound of water	= 0.1199 gal	1 ft of head	= 0.433 psi
	= 27.7 in^3	1 million gal	= 3.07 ac-ft

applied to wet the rootzone, no more, no less. Generally, most of the roots on putting greens and tees are in the top 6-in (15-cm) of soil, whereas roots on fairways and roughs often penetrate 12-in (30-cm) or more.

Consider a silt-loam soil at field capacity, which has roughly 2.0-in (5-cm) of water per foot of soil. A 12-in (30-cm) deep bermudagrass root system growing in this soil will have access to 2.0-in (5-cm) of available water. Weather station data and a predictive model estimate over a six-day period that 1.8-in (4.6-cm) of water was used by the theoretical reference crop. Correcting this reference value using a Kc of 0.7 for bermudagrass, estimates the turf actually uses about 1.3-in of water (1.8 × 0.7 = 1.26-in., 3.2-cm). Subtracting this from the original 2.0-in (5-cm) of available water gives about 0.7-in (1.8-cm) of water left in the soil. Should the turf go another day before irrigating? No, it's time to water, since it is never a good idea to deplete most of the available water. Approximately 1.5-in (3.8-cm) of irrigation should be applied to replace the 1.3-in (3.3-cm) lost from the system. The soil is returned to field capacity without irrigating excessively and wasting water.

For most turfgrass examples, the amount of water in the soil at wilting point is negligible. Turfgrass rooting depth should be used instead of soil rootzone depth since most moisture obtained by plants in a reasonable time frame will be in the rooting depth and not below it.

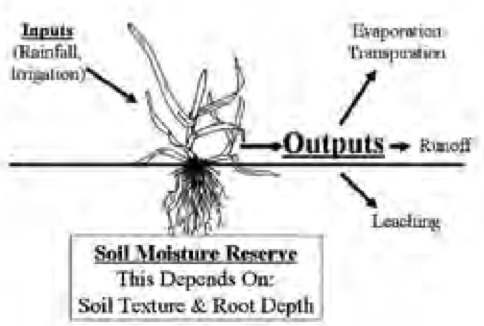


Figure 3-6. Water budgeting is like managing a checking account with inputs, reserves, and outputs. These are constantly measured to determine when soil moisture is insufficient to sustain desirable turf.

Determining Approximate Intervals (in days) Between Irrigation Cycles

$$\text{irrigation interval (days)} = \frac{\text{soil water content at field capacity x rooting depth (in)}}{\text{daily ET rate (in day}^{-1})}$$

Example:

Determine the time between irrigation cycles for a sand soil with a volumetric water content of 15% at field capacity, a rooting depth of 4-in (10-cm), and a summer daily ET rate of 0.20-in day^{-1} (5 mm day^{-1}):

$$\frac{0.15 \text{ x } 4\text{-in}}{0.20\text{-in day}^{-1}} = \text{3 days between irrigation cycles, which brings the soil back to field capacity}$$

If rainfall occurs and it is more than the amount of water depleted during the period (1.3-in, 3.3-cm), the rootzone is returned to field capacity and any excess is ignored since it will drain and not be stored in the rootzone. If it rains less than actual ET, the running deficit is calculated over several days, and irrigation is scheduled when ET has depleted the soil moisture to a bit more than 50% of the 0.6-in (0.15 x 4-in) of available water. A good rain gauge is needed to keep track of precipitation, and it is a good idea to use automatic pump shutdown switches to prevent irrigation after a significant precipitation. Conversion factors in **Table 3–5** indicate gallonage required to apply certain amounts of irrigation.

Example:

From the use of a hand-held TDR probe, determine a soil moisture management program, including when to irrigate and how much water is needed to return the total moisture levels to field capacity for two sands with $\theta fc = 0.32$ cm^3 cm^{-3} and 0.22 cm^3 cm^{-3} and $\theta wp = 0.02$ cm^3 cm^{-3} and 0.01 cm^3 cm^{-3} for sands 1 and 2, respectively. The TDR probe measures moisture in the top 10-cm (4-in) of the soil profile.

Step1: Determine available water for each sand using the equation:

D_w = soil depth x (θfc - θwp)

where: D_w = equivalent depth of available water in the top 10-cm (4-in),

θfc = volumetric water content at field capacity,

θwp = volumetric water content at wilting point

For sand 1: D_w = soil depth (θfc - θwp) = 10 (0.32 - 0.02) = 3.0 cm (1.18-in)

For sand 2: D_w = soil depth (θfc - θwp) = 10 (0.22 - 0.01) = 2.1 cm (0.83-in)

Step2: If the effective rootzone is 10-cm (4-in) deep and the turfgrass being used has an average ET rate of 0.2-in day^{-1} (0.5-cm day^{-1}), the days between watering for each sand would be:

sand 1:

$$3.0 \text{ cm rootzone moisture} \times \frac{1 \text{ day}}{0.5 \text{ cm moisture used}} = 6 \text{ days}$$

sand 2:

$$2.1 \text{ cm rootzone moisture} \times \frac{1 \text{ day}}{0.5 \text{ cm moisture used}} = 4.2 \text{ days}$$

Therefore, for sand 1, 3.0 cm of water would be needed every 6 days while for sand 2, 2.1 cm of water would be needed every 4.2 days to return each to field capacity.

With information on ET rates and sprinkler calibration available, each sprinkler's run time can be calculated by dividing the daily ET rate by the sprinkler output. For example, if the day's ET rate is 0.3-in (7.6 mm) and the sprinkler output is 0.01-in min^{-1} (0.25 mm min-1), the irrigation time needed would be 30 minutes. However, this is adjusted according to the appropriate crop coefficient (e.g., 0.85 for bentgrass); therefore, 30 minutes is multiplied by 0.85 to give 25 minutes of run-time needed. Distribution uniformity considerations should then be incorporated to ensure enough water is being applied uniformly across the turf area.

Example:

Water use engineers employed at a municipality require a golf course to justify their water use permit in terms of total amount of water requested and how they determined this value (modified from Green, 2005).

A. Determine average yearly ET rate from one of the methods listed previously. In this example, 56.37-in (4.7 ft, 1.4 m) is used,

B. Determine normal yearly precipitation rate. In this example, 10.67-in. (27 cm) is used,

C. Area of irrigated turfgrass. In this example, 110 ac is used (3.1 ac for greens, 3.7 for tees, 43.7 for fairways, and 59.5 for roughs),

D. Determine the irrigation efficiency (DU). In this example, 70% is used.

	Greens	Tees	Fairways	Roughs
E. Turf Area (ac)	3.1	3.7	43.7	59.5
F. Turfgrass	Bentgrass	Bermuda overseeded Oct – May	Bermuda overseeded Oct – May	Bermuda
G. K_c (crop coefficient)	0.8	0.75	0.75	0.65
H. Turf Water Use [A x G] (which is ET x K_c)	45.1	42.3	42.3	36.6
I. 25% precipitation (in): [B x 0.25]*	2.7	2.7	2.7	2.7
J. Water use adjusted for 25% precipitation (in): [H-I]	42.4	39.6	39.6	33.9
K. Irrigation water use (in): [J/D]	60.6	56.6	56.6	48.4
L. K converted to feet: [K/12] (12-in = 1 ft)	5.1	4.7	4.7	4.0
M. Annual irrigation use (ac-ft): [E x L]	15.8	17.4	205.4	238.0
N. Annual irrigation water use: [sum of M for all turf areas]		477 ac-ft (or 155,430,927 gal)		
*Water use regulators often use a precipitation efficiency adjustment value to reflect the amount (percentage) of usable precipitation by plants. Rainfall is often at inefficient amounts (too high or low) or at the wrong agronomic time.				

In the above example, to compare calculated annual irrigation use to the overall formula, ET x area, the following was determined:

O. ET x 110 ac: A (ft) x C (total turfgrass area) or 4.7 ft x 110 ac = 517 ac-ft predicted by the simple formula,

P. Calculation efficiency for water budget: N/O x 100 or (477 ac-ft ÷ 517 ac-ft) x 100 = 92%. This value indicates the simple formula of ET x area overestimated water needs by 8% compared to the Water Budgeting process above.

3.4 MANAGING IRRIGATION WATER QUALITY PROBLEMS

Wells, ponds, retention ponds, canals, streams, rivers, lakes, and waste treatment plants are common water sources for irrigation. Turf facilities are increasingly using poorer quality irrigation sources. Water from waste treatment plants may contain elevated nutrient and trace element concentrations **(Figure 3–7)**. Successful irrigation management requires regular monitoring of both soil and water chemistry, especially salt content. The following tests provide information concerning soil and water quality:

- **Water soluble salts** (or **Salinity drought hazard**) - Total salt content as measured by the electrical conductivity (ECw) or total dissolved salts (TDS) of water. Excessive salts produce plant physiological drought,
- **Sodium status** – Soil sodium level proportionally to Ca and Mg ions as measured by sodium adsorption ratio (SAR), exchangeable sodium percentage (ESP), or adjusted SAR (Adj. SAR). SAR also is used to assess the sodium levels of water. Excessive sodium causes soil structure deterioration,
- **Specific ions toxicity** - Toxic ion levels, especially boron, chloride, fluoride, sulfate and nitrate-nitrogen,
- **Alkalinity** - Bicarbonates and carbonates as measured by residual sodium carbonate (RSC),
- **pH and lime requirement**,
- **Suspended solids**, as measured by total suspended solids (TSS),
- **Soil nutrient imbalance based on:**
- Sufficiency levels of available nutrients and cation ratio,
- Soil cation exchange capacity (CEC),
- Percent base saturation,
- Percent organic matter.

Figure 3-7. Purplish-pink pipe indicating effluent water which is an increasing source of irrigation for many golf facilities.

Salts

A salt is a combination of positively charged ions (cations) and negatively charged ions (anions). Cations include calcium, magnesium, sodium, ammonium, and potassium; while anions include carbonates, bicarbonate, nitrate, sulfate, chloride, and boron. Table salt (sodium chloride) is found in some soils. Insoluble salts (i.e., gypsum and lime) occur in soils, but excessive soluble salts are the primary impediment to plant growth. High soluble salts in the soil solution reduce water availability, causing the turfgrass to be prone to drought stress. This is the most important or most common salt problem involved with turfgrasses.

The amount of salt in water determines the degree of salinity and, to a large extent, the overall water quality. The following equation determines the amount of salt applied when irrigating with saline water:

lbs salt applied $acre^{-1}$ =

$$\text{irrigation water salinity level (ppm or mg L-1)} \times \text{2.72 million lb (weight of water per ac-ft)} \times \text{ac-ft water applied}$$

Example:

How much salt is applied, if 1-in (2.5-cm) of water with salinity levels of 640 ppm is used? 1-in = 0.083 ft.

$$\frac{640}{1{,}000{,}000} \times \frac{\text{2.72 million lbs}}{\text{ac-ft water}} \times \text{1 ac-in water} \times \frac{\text{1 ft}}{\text{12-in}}$$

$$= \text{144 lbs salt applied per acre}$$

To determine the amount of salt applied per 1,000 ft^2, divide 144 lb salt per acre by 43.56 = 3.3 lb salt applied per 1,000 ft^2, when 1-in (2.5-cm) of irrigation water with a salinity level of 640 ppm is used.

Two types of salt problems exist: (1) those associated with the total salinity, and (2) those associated with sodium. Water with high salinity becomes toxic to plants and poses a **salinity hazard (Figure 3–8)**. As mentioned, soil salt accumulation is the most common cause of plant injury from poorer quality water but normally must occur over an extended period of time before this is seen. Combinations of saline irrigation use, low precipitation, poor soil drainage, and the use of cool-season turfgrasses increase the likelihood of salinity problems. Salty soils may cause direct injury to turfgrass growth or indirect injury due to soil physical properties. Direct stresses include moisture stress as roots are unable to absorb tightly held soil moisture, ion toxicity, or nutrient (ion) imbalances. In saline soils, water moves from an area of lower salt concentration (plant roots) to an area of higher salt concentration (the soil). This causes plant water stress and wilt even though the soil may be wet. Indirect stress occurs from high soil sodium by destroying soil structure, thus, reducing water infiltration, drainage, and soil oxygen levels. Salinity problems are less likely to develop with high rainfall and cooler climates, the use of salt-tolerant warm-season grasses, and

Figure 3-8. Brown turf indicating salt damage from high tide intrusion across a golf course fairway.

in well-drained soils.

Salts also can move upward from groundwater; water is drawn to the surface when evaporation exceeds the amount of water being applied and is deposited on the soil and plant surface through the process of capillary rise. Formation of a white crust on the soil surface indicates salt accumulation, as does shoot browning **(Figure 3–9)**. Many arid and semi-arid soils, especially when annual rainfall is <15 in (38 cm), are salt affected due to insufficient leaching to remove salts that accumulate from the weathering of minerals, groundwater, and rain. In arid and semi-arid regions, sodium and sulfate salts (Na_2SO_4, K_2SO_4, $CaSO_4$, and $MgSO_4$) usually dominate, reflecting the composition of the soils parent material.

Figure 3-9. Turf replacement from salt damage in low, poorly drained areas on a golf green.

Measuring and Classifying Irrigation Salinity

Salinity hazard is determined by measuring the ability of water to conduct an electrical current. Salty water is a good conductor of electrical current, whereas pure water is a relatively poor conductor. Salinity is expressed in two different ways, either as **electrical conductivity** (EC_w) or **total dissolved salts** (TDS) (also reported as total soluble salts, TSS). There are several units commonly used to express EC_w: deciSiemens per meter (dS m^{-1}), millimhos per centimeter (mmhos cm^{-1}), or micromhos per centimeter (µmhos cm^{-1}). The relationship between these units is:

$$1 \text{ dS m}^{-1} = 1 \text{ mS cm}^{-1} = 0.1 \text{ S m}^{-1} = 1 \text{ mmhos cm}^{-1} = 1{,}000 \text{ µmhos cm}^{-1} = 640 \text{ ppm TDS}$$

Total dissolved salts are expressed in parts per million (ppm) or milligrams per liter (mg L^{-1}) and are generally not measured directly, but calculated from an EC_w measurement.

$$\text{TDS (mg L}^{-1}\text{ or ppm)} = EC_w \text{ (mmhos cm}^{-1}\text{ or dS m}^{-1}) \times 640$$

Individual components of salinity (such as sodium) may also be reported in milliequivalents per liter (meq L^{-1}). To convert ppm to meq L^{-1}, divide the ppm of the ion by its equivalent weight. The ratio of total dissolved salt to EC_w of various salt solutions ranges from 550 to 740 ppm per dS m^{-1}. The most common salt in saline water, sodium chloride, has a TDS of 640 ppm at an EC_w of 1 dS m^{-1}. Most laboratories use this relationship to calculate TDS from EC_w, but some multiply the amount by 700.

Example:

1. An irrigation source has an EC_w of 0.53 mmhos cm^{-1}. What would the EC_w be in dS m^{-1}, µmhos cm^{-1}, and ppm TDS?

   a. Since 1 dS m^{-1} = 1 mmhos cm^{-1}, then 0.53 mmhos cm^{-1} = 0.53 dS m^{-1}

   b. Since 1 mmhos cm-^{1} = 1,000 µmhos cm^{-1}, then

$$0.53 \text{ mmhos cm}^{-1} \times \frac{1{,}000 \text{ µmhos cm}^{-1}}{1 \text{ mmhos cm}^{-1}} = 530 \text{ µmhos cm}^{-1}$$

   c. To convert mmhos cm^{-1} to ppm, multiply by 640:

$$0.53 \text{ mmhos cm}^{-1} \times 640 = 339 \text{ ppm TDS}$$

2. The salt content of a water sample is 1,121 mg L^{-1} TDS. What is the salt content in dS m^{-1} and µmhos cm^{-1}?

   a. To convert TDS (mg L^{-1} or ppm) to dS m^{-1}, divide by 640:

$$1{,}121 \text{ mg L}^{-1} \div 640 = 1.75 \text{ dS m}^{-1}$$

   b. To convert dS m^{-1} (or mmhos cm^{-1}) to µmhos cm^{-1}, multiply by 1,000:

$$1.75 \text{ dS m}^{-1} \text{ (or mmhos cm}^{-1}) \times 1{,}000 = 1{,}750 \text{ µmhos cm}^{-1}$$

3. Convert 100 ppm Ca to meq L^{-1}. The equivalent weight of Ca^{+2} is 20.

$$100 \text{ ppm Ca} \div 20 = 5 \text{ meq L}^{-1} \text{ of Ca}$$

Water sample salinities are often compared to those of seawater with an average EC_w of 54 dS m^{-1} or about 34,500 ppm dissolved salts.

Irrigation water is classified based on the salinity hazard, which considers the potential for damaging plants and the level of management needed for utilization as an irrigation source **(Table 3-6)**. Water with EC_w readings of less than 0.75 dS m^{-1} is suitable for irrigation without problems. Successful use of water with EC_w values above 0.75 dS m^{-1} depends upon soil conditions and plant tolerance to salinity. Generally, higher salinity levels can be used on sandy soils where salts can be flushed. The use of water with similar salinity values on poorly draining clay soils may cause problems. Under typical summer stress, EC_w of turfgrass irrigation should ideally not exceed 1.25 dS m^{-1} soluble salts. Salinity levels above 3.0 dS m^{-1} are unsuitable for any length as an irrigation source.

Water Sodium Hazard

The primary cause of sodic or saline-sodic soil is using high sodium (Na^+) content irrigation water. While EC_w is an assessment of all soluble salts in a sample, **sodium hazard** (termed sodic or saline-sodic soil) accounts for sodium's specific detrimental effects on soil physical properties. The potential for irrigation water to have poor infiltration properties or sodium hazards is assessed by determining the **sodium adsorption ratio** (SAR) and the electrical conductivity (EC_w) of the water. The sodium adsorption ratio relates the concentration of sodium to the concentration of calcium and magnesium. Calcium and magnesium counter the negative effects of sodium on soil structure. The higher the sodium level in relation to calcium and magnesium, the higher the SAR, the poorer the water infiltration, and the more increased problems with soil deflocculation (deterioration - swelling, dispersion, and permeability reduction). The collapse of aggregates from dispersion of clay tends to clog large pores, particular at the soil surface. Salt concentration and exchangeable sodium percentage then become problems with the loss of permeability. Calcium will hold soil together (or flocculate), while sodium pushes (or disperses) soil particles apart. The dispersed soil readily crusts and poses water infiltration and permeability problems.

SAR is defined as:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}}$$

Ion concentrations in the equation above are expressed in milliequivalents per liter (meq L^{-1}) while those in the equation above right are expressed in millimoles per liter (mmoles L^{-1}). Milliequivalents describe the molecular weight adjusted for the valence number (number of positive charges) of the ion. The SAR is determined by the number of milligrams per liter (mg L^{-1} or ppm) of Na^+, Ca^{+2}, and Mg^{+2} in a water sample. To convert parts per million (or mg L^{-1}) to meq L^{-1}, use the following equation and equivalent weights for Na^+, Ca^{+2}, and Mg^{+2} of 23, 20, and 12.2 mg meq^{-1}, respectively. Use of the saturated paste extract method, rather than other soil test extraction methods, is necessary for determining soil Na^+, Ca^{+2}, and Mg^{+2} levels for the SAR equation.

$$\text{meq L}^{-1} = \frac{\text{concentration (ppm or mg L}^{-1})}{\text{equivalent weight (mg meq}^{-1})}$$

Example:

A water sample test reports 1,000 mg L^{-1} Na^+, 200 mg L^{-1} Ca^{+2}, and 100 mg L^{-1} Mg^{+2}.

Find the SAR value in meq $L.^{-1}$

Step 1: Calculate the concentration (meq L^{-1}) of each ion:

Na^+ : 1,000 mg L^{-1} ÷ 23 mg meq^{-1} = 43.5 meq L^{-1}

Ca^{+2} : 200 mg L^{-1} ÷ 20 mg meq^{-1} = 10 meq L^{-1}

Mg^{+2} : 100 mg L^{-1} ÷ 12.2 mg meq^{-1} = 8.2 meq L^{-1}

Step 2: Place these values into the SAR equation:

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}} = \frac{43.5}{\sqrt{\frac{10 + 8.2}{2}}}$$

$$= 14.4 \text{ meq L}^{-1}$$

Example:

A water analysis indicates a sodium concentration of 85 meq L^{-1}, a calcium concentration of 33.3 meq L^{-1}, and a magnesium concentration of 7.1 meq L^{-1}. What is the SAR value for this water?

$$SAR = \frac{Na^+}{\sqrt{\frac{Ca^{+2} + Mg^{+2}}{2}}} = \frac{85}{\sqrt{\frac{33.3 + 7.1}{2}}}$$

$$= 18.9 \text{ meq L}^{-1}$$

Since salts and sodium do not act independently, the effect of sodium on soil particle dispersion, thus permeability, is counteracted by high concentrations of soluble salts (measured as EC_w) in the irrigation water. The effects of high SAR on irrigation water infiltration are dependent on the electrical conductivity of the water **(Table 3-7)**.

Table 3-6. General guidelines for irrigation water quality concerning total salinity, sodium hazard, and ion toxicity (modified from Ayers and Westcot, 1985; Harivandi, 2007; Huck, 2000; McCarty, 2011).

ITEM	UNITS	MINOR PROBLEMS	INCREASING PROBLEMS	SEVERE PROBLEMS
Water salinity hazard (influences water availability to plants)				
ECw (saturated paste extract)	mmhos/cm or dS/m	<0.75	0.75 to 3.0	>3.0
SAR (sodium adsorption ratio)	meq/L	<10	10 to 18	>18
	mg/L or ppm	<70	70 to 200	>200
TDS (total dissolved salts)	mg/L or ppm	<500	500 to 2,000	>2,000
Soil and water sodium/ion hazard (influences soil water infiltration and soil structure properties)				
SAR [sodium adsorption ratio]	meq/L	<10	10 to 18	>18
	mg/L or ppm	<70	70 to 200	>200
Adjusted SAR	meq/L	<6.0	6.0 to 9.0	>9.0
ECe (1:1 soil-water saturated paste extract)	dS/m or mmhos/cm	<1.5	1.6 to 3.9	>4.0
ECe (1:2 dilution)	dS/m or mmhos/cm	<0.80	0.80 to 2.4	>2.4
SAR = 0 to 3 & ECw =	dS/m or mmhos/cm	>0.7	0.7 to 0.2	<0.2
SAR = 3 to 6 & ECw =		>1.2	1.2 to 0.3	<0.3
SAR = 6 to 12 & ECw =		>1.9	1.9 to 0.5	<0.5
SAR = 12 to 20 & ECw =		>2.9	2.9 to 1.3	<1.3
SAR = 20 to 40 & ECw =		>5.0	5.0 to 2.9	<2.9
TDS (total dissolved salts)	mg/L or ppm	<2,500	2,500 to 7,500	>7,500
ESP (exchangeable sodium percentage)	%	<13	13 to 15	>15
pH	1 to 14	6.0 to 7.0	7.0 to 8.0	>8.0
Bicarbonate (HCO3-)	mg/L or ppm	<120	120 to 180	>180
	meq/L	<1.5	1.5 to 3.0	>3.0
Carbonate (CO3-2)	mg/L or ppm	<15	15 to 50	>50
	meq/L	<0.5	0.5 to 1.65	>1.65
RSC (residual sodium carbonate)	meq/L	<1.25	1.25 to 2.50	>2.50
TSS (total suspended solids)	mg/L or ppm	<5	5 to 10	>10
Water hardness (Ca + Mg)	mg/L or ppm	<200	200 to 400	>400
($CaCO_3$)	mg/L or ppm	<50	50 to 300	>300
Calcium (Ca)	mg/L or ppm	<25	25 to 250	>250
Magnesium (Mg)	mg/L or ppm	<20	20 to 40	>40
Chloride (Cl-)	meq/L	<2	2 to 10	>10
	mg/L or ppm	<70	70 to 350	>350
Boron (B)	mg/L or ppm	<1	1 to 2	>2

ITEM	UNITS	MINOR PROBLEMS	INCREASING PROBLEMS	SEVERE PROBLEMS
Foliar ion toxicity for turfgrass				
Calcium (Ca)	mg/L or ppm	<60	60 to 100	>100
	meq/L	<3	3 to 6	>6
Fluoride (F)	mg/L or ppm	<0.25	0.25 to 0.5	>0.5
Iron ($Fe+^{2 \text{ or } +3}$)	mg/L or ppm	<0.3	0.3 to 5.0	>5.0
Magnesium (Mg)	mg/L or ppm	<25	25 to 50	>50
	meq/L	<3	3 to 6	>6
Nitrogen (N)	mg/L or ppm	<11	11 to 23	>23
Phosphorus (P)	mg/L or ppm	<0.40	0.40 to 1.0	>1.0
Potassium (K)	mg/L or ppm	<20	20 to 50	>50
Sodium (Na)	meq/L	<3	>3	---
Sulfates (SO_4^{-2})	mg/L or ppm	<100	100 to 200	>200
Soil ion hazard for sensitive ornamentals				
Boron (B)	meq/L	<1.0	1.0 to 3.0	>3.0
	mg/L or ppm	<1.0	1.0 to 3.0	>3.0
Chloride (Cl^-)	meq/L	<3	3 to 10	>10
	mg/L or ppm	<100	100 to 300	>300
Sodium (Na)	mg/L or ppm	<70	70 to 200	>200
	SAR (meq/L)	<3.0	3 to 9	>9
Foliar ion toxicity for sensitive ornamentals				
Ammonium-N (NH_4^-N)	mg/L or ppm	<5	5 to 30	>30
Bicarbonate (HCO_3^-)	meq/L	<1.5	1.5 to 8.5	>8.5
-Unsightly foliar deposits	mg/L or ppm	<90	90 to 500	>500
Chloride (Cl^-)	mg/L or ppm	---	---	<100
	meq/L	<3	>3	---
Residual chlorine (Cl_2)	mg/L or ppm	<1.0	1 to 5	>5
Sodium (Na)	meq/L	<3	>3	---
	mg/L or ppm	<70	>70	---
Manganese (Mn)	mg/L or ppm	<0.2	---	>0.2
Nitrate-N (NO_3^-N)	mg/L or ppm	<50	50 to 100	>100
Nitrate (NO^{3-})	mg/L or ppm	<45	45 to 150	>150
Copper (Cu)	mg/L or ppm	<0.2	---	>5
Fluoride (F)	mg/L or ppm	<1.0	1.0	>1.0
Zinc (Zn)	mg/L or ppm	<2.0	---	>2.0
pH	1 to 14	<8.4	---	>9.0
Potential algal blooms				
Phosphate (PO_4^-P)	mg/L or ppm	<1.2	1.2 to 2.4	>2.4

Table 3-7. SAR values, categories, and precautions for irrigation sources with EC_w >1 dS m^{-1}.

SAR OR ADJ SAR (MEQ L^{-1})	CATEGORY	PRECAUTION
0 to 10	low sodium water	Little danger from structure deterioration to almost all soils. For ornamentals, water SAR values should be <10.
10 to 18	medium sodium water	Problems on fine-textured soils and sodium-sensitive plants, especially under low-leaching conditions. Soils should have good permeability.
18 to 26	high sodium water	Problems with sodium accumulation on most soils. Good salt-tolerant plants are required along with special management, such as good drainage, the use of gypsum, and leaching. Generally, high and very high EC water should not be used for irrigating turfgrasses long term.
>26	very high sodium water	Unsatisfactory except with high salinity (EC_w> 2.0 dS m^{-1}), high calcium levels, and the use of gypsum.

For a given SAR, the lower the EC_w, the greater dispersion or poorer infiltration properties; the higher the EC_w, the better the infiltration. For example, irrigation water with a SAR = 15 meq L^{-1} has poor infiltration properties with an EC_w = 0.5 dS m^{-1}, but good infiltration properties with an EC_w = 2.0 dS m^{-1}. As a rule-of-thumb, if the SAR is more than 10 times greater than the EC_w, then poor water infiltration is likely to occur. When the EC_w = 0.5 dS m^{-1} or less, the water has very few minerals to flocculate soil particles. Thus, irrigating with this **pure water** strips minerals from cation exchange capacity (CEC) sites, causing dispersed particles to settle closely next to each other. The result is a compacted soil surface which forms a thin crust layer, impeding water flow into the soil. Problems can develop quickly when EC_w < 0.2 dS m^{-1}. In the case of pure water, the problem exists regardless of the SAR value since very few minerals are present to begin with.

Clay-textured soils can have structural permeability problems if a water with an SAR >9 meq L^{-1} is used over an extended period as it reduces infiltration, percolation, and drainage, often causing low soil oxygen problems. In the earlier example where the water sample had an SAR of 14.4 meq L^{-1}, problems could occur if this water source was used long term on finer-textured soils.

Example:

A superintendent has two water sources to choose from based on their sodium hazard.

Sample 1. SAR = 5.0 and EC = 0.5.

Sample 2. SAR = 5.0 and EC = 1.5.

Which one is more suitable?

Sample 1. Water infiltration problems may occur, especially on finer-textured clay or silt-based soils.

Sample 2. This sample is less likely to cause soil water infiltration problems.

Soil Sodium Permeability Hazard

Although high sodium levels in irrigation water can be directly toxic to plants (especially ornamentals), its most deleterious effect is on soil structure. Since sodium ions (Na^+) are monovalent (have only one positive charge), two sodium ions are needed to displace divalent (two positive charged) ions such as calcium (Ca^{+2}) or magnesium (Mg^{+2}) on soil exchange sites. Sodium ions are also relatively large compared to calcium and magnesium ions. This along with the greater number of ions required to replace calcium and magnesium mean that the soil colloids, which are usually attracted to each other, are forced apart, dispersing them. This concern is greater on fine-textured soils such as clays and silt loams. Salts often accumulate in high, exposed sites such as hilltops while low areas may accumulate salts from runoff.

High soil sodium causes finer-textured soil and organic matter to disperse (termed **deflocculation**) breaking down aggregates into smaller units; the smaller clay minerals and organic particles plug soil pores, reducing water infiltration and soil aeration. Soil then seals and becomes hard and compacted, reducing soil water and oxygen movement. The higher the clay and organic matter content of the soil, the greater the effects of sodium. Typically, for soil structure breakdown, sodium levels exceed calcium levels by more than 3 to 1. These soils are characterized by pools of standing water after irrigation. To counteract the negative effects of sodium, increasing calcium and magnesium concentrations in clay soils will cause the soil to flocculate (have good structure). A key management step is to prevent soil structure breakdown.

Soil structure can be destroyed by continued use of water containing high levels of sodium. This results in reduced water infiltration, drainage, and soil oxygen. The sodium ions replace calcium and magnesium ions on the clay CEC sites, destroying its structure, reducing pore continuity, and thus reducing infiltration, percolation, and drainage.

Assessing Soil Salinity

Saline soils are classified based on two criteria: (1) the **total soluble salt** or s**alinity content** based on electrical conductivity of a saturated extract (ECe), and (2) **exchangeable sodium percentage** (or, more recently, **sodium adsorption ratio**). Additional information is also often used, such as carbonate content and potential toxic ions.

Soluble salts are measured in soils by the same basic method as used for water samples. A conductivity instrument measures electrical conductivity in an extract (EC_e) either from a saturated paste (preferred method) or from a **soil:water dilution**. As total salt concentration increases, EC_e also increase. The SAR is a calculated value from a saturated paste extract sample based on milliequivalents per liter of Ca, Mg, and Na. The saturated paste extract is the most precise method to determine soil EC, SAR, and boron levels. A soil sample is brought just to the point of saturation using the irrigation source, allowing it to equilibrate for several hours, and then is subjected to vacuuming to extract the soil solution through filter paper. Spectrophotometers and other analytical equipment are then used to quantify the soil solution. Using the saturated paste extract, soils with EC_e readings <1.5 dS m^{-1} are considered to have low salt levels. Soils with EC_e readings of 1.6 to 3.9 dS m^{-1} have medium levels. When soil readings are above 4.0 dS m^{-1}, soils are considered to have high salt levels and only salt-tolerant turfgrasses normally survive.

Soil water dilution ratios are either a 1:2 dilution (one part dry soil:two parts water) or a 1:5 dilution (one part dry soil:five parts water). Electrical conductivity readings from these three methods are not comparable, so the method used must be known in order to interpret the EC_e reading. Soil testing laboratories frequently use a 1:2 dilution method because it is more rapid than obtaining a saturated paste extract. The EC_e of a 1:2 extract is on average 20% of the EC_e of a saturated paste extract on sand-based greens. To estimate the EC_e of a saturated paste from a 1:2 extract, multiply the ECe of the 1:2 extract by 5.

Assessing Soils for Sodium Problems

Sodicity refers to high concentration of sodium (Na^+) while **salinity** refers to high concentrations of total salts including NaCl, CaSO4 & MgSO4. Salt-affected soil can be classified as **saline, sodic,** and **saline-sodic** soils. **Saline soils** are the most common type of salt-affected soil and the easiest to reclaim. Saline soils are plagued by high levels of soluble salts, primarily containing chloride (Cl^-), sulfate (SO_4^{-2}), and sometimes nitrate (NO_3^-). Salts of low solubility, such as calcium sulfate or gypsum ($CaSO_4$) and calcium carbonate ($CaCO_3$), may also be present. Because exchangeable sodium is not a problem, saline soils are usually flocculated with good water permeability. Saline problems generally occur when: (1) insufficient rainfall leaches salts through the soil profile, (2) drainage is impaired, or (3) water contains high levels of salts.

Sodic soils, or soil structure deteriorated soils, have high levels of exchangeable sodium, low total soluble salt content, HCO3 >120 mg L^{-1} or CO_3^{-2} >15 mg L^{-1}. These soils tend to disperse, reducing water infiltration. Sodic soils also have a pH between 8.5 and 10 and are often called black alkali soils because the organic matter in the soil tends to disperse creating black-colored puddles. Calcium and magnesium ions in sodic soils tend to form insoluble calcitic lime, leaving low soluble calcium and magnesium levels to displace sodium ions. The high sodium concentration of a sodic soil not only injures plants directly, but also degrades the soil structure, termed "sodium hazard." Sodic soil cannot be improved by leaching the sodium from the soil profile alone. Soil amendments containing calcium are required to replace the sodium in the soil in conjunction with leaching with acidified water.

Saline-sodic soils contain both high soluble salts and high exchangeable sodium. Saline-sodic soils, like sodic soils, are best reclaimed by adding a calcium-containing amendment and then leaching to remove excess soil sodium ions.

Two laboratory measurements are used to assess whether soils contain excessive sodium levels and if poor drainage and aeration are likely to occur. These measures are the **exchangeable sodium percentage** (ESP) and the sodium adsorption ratio (SAR). The ESP identifies the degree or portion of the soil cation exchange capacity (CEC) occupied or saturated by sodium, reported as meq 100 g^{-1} or cmol kg^{-1}, and is calculated as follows:

$$\text{ESP (\%)} = \frac{\text{exchangeable sodium (meq 100 g}^{-1})}{\text{cation exchange capacity (meq 100 g}^{-1})} \times 100$$

ESP does not consider the quantity of calcium and magnesium ions relative to sodium ions present like SAR does.

Example:

A soil test indicates the Na^+ content of a soil is 6.9 meq 100 g^{-1} and the cation exchange capacity (CEC) of the soil is 17.3 meq 100 g^{-1}. Find the exchangeable sodium percentage (ESP) of this soil.

$$\text{ESP} = \frac{\text{exchangeable sodium (meq 100 g}^{-1})}{\text{cation exchange capacity (meq 100 g}^{-1})} \times 100$$

$$= \frac{6.9 \text{ meq 100 g}^{-1}}{17.3 \text{ meq 100 g}^{-1}}$$

$$= 40\%$$

Soil SAR is a second, more easily measured property, analogous to the irrigation water SAR discussed earlier which considers calcium and magnesium ion content in the soil. Soil SAR is calculated from soil-test extractable levels of sodium, calcium, and magnesium (expressed in meq 100 g^{-1} or mmol L^{-1}).

ESP indicates the probability a soil will disperse, thereby reducing the permeability of soil to water and air. In the environment, salts and sodium do not act independently; high-soluble salt concentration can negate the soil particle dispersal (thus, impermeability) effects of sodium. Usually, few or only minor problems occur when ESP values are less than 13 to 15%. An ESP >15% or a soil SAR >13 meq L^{-1} indicates a **sodic** soil, where sodium causes soil colloids to disperse and plug the soil's drainage pores, thereby reducing the permeability of the soil to water and air. Sodic soils become saturated with sodium ions compared to calcium and magnesium ions, especially if bicarbonate ions are present. Symptoms of reduced permeability include waterlogging, reduced infiltration rates, crusting, compaction, disease occurrence, weed invasion, and poor aeration. Sodic soils often have considerable amounts of clay that is sticky due to the sodium. ESP and SAR are related and can be estimated by using the following formula:

$$ESP = \frac{1.475 \times SAR}{1 + (0.0147 \times SAR)}$$

Managing Poor Quality Water Use Sites

Managing salinity, sodicity, and alkalinity problems requires constant attention **(Table 3–8)**. Management practices that aid in remedying these problems include:

1. Site assessment to determine which, if any, water and soil treatments are best,
2. Utilizing salt-tolerant grasses – warm-season turfgrasses generally are less salt-sensitive compared to cool-season turfgrasses, while most ornamentals are more salt-sensitive,
3. Diluting or blending poor quality water with good quality water,
4. Flushing excess salts by applying extra water,
5. Modifying soils with various amendments to replace and leach sodium from the soil,
6. Amending irrigation water to correct sodium and bicarbonate problems,
7. Enhancing soil drainage by using sands and installing subsurface tile drainage, plus intensive cultivation to enhance infiltration, percolation, and drainage of salt-laden water (see earlier),
8. Using cytokinin and iron-containing biostimulants as salt-stressed plants often exhibit low cytokinin activity, as well as using wetting agents and appropriate fertilizers,
9. Raising the mowing height to promote more stress-tolerant plants,
10. Routine use of wetting agents to help maintain good water infiltration and percolation to flush salts and sodium below the rootzone.

Blending Water Sources for Reducing Salinity

High salinity water that is unacceptable for use can be made suitable as an irrigation source by diluting it with non-saline water. Enough non-saline water must be available to create a mixed water of acceptable quality (e.g. not making a less-saline water that is still unacceptable). The quality of a poor water source should improve proportionally to the mixing ratio with better quality water. For example, a water source with an EC_w = 5 dS m^{-1} mixed equally with a source with an EC_w = 1 dS m^{-1} should reduce salinity in the blend to approximately 3 dS m^{-1}. A chemical analysis of the blend should be performed to confirm this. The salinity of the mixture can be calculated with this equation:

Table 3-8. Water and soil salinity problems with potential management solutions.

SOIL SALINITY PROBLEM	POTENTIAL SOLUTIONS
Total Irrigation Salt Content (EC)	Leaching; blending water sources; increase drainage and aeration; use salt tolerant varieties.
Soil SAR/Adj. SAR	Apply calcium amendment; apply sulfur alone (in calcareous soils) plus lime (in acidic soils); blending water sources; acid or sulfur irrigation injection in severe cases.
Exchangeable Sodium Percentage (ESP)	Apply calcium amendment such as gypsum; apply sulfur alone (in calcareous soils) plus lime (in acidic soils); or sulfur irrigation injection in severe cases.
Soil Residual Sodium Content (RSC)	Irrigation acid injection; sulfur generator; sulfur application in calcareous soils; blending water sources.
Soil Infiltration/Permeability (EC_w plus SAR)	Gypsum additions to either: (a) low EC_w plus low SAR water; or, (b) low to moderate EC_w plus high SAR water; blending water sources.
Specific Ion Toxicity	Establish tolerant varieties (especially ornamentals); blending water sources.
Total Suspended Solids	Irrigation line filtration; use of settling ponds.
Nutrient Imbalances	Adjusting fertility programs.

$$EC_w \text{ (blend)} = \frac{\text{volume (water A)} \times EC_w \text{ (water A)} + \text{volume (water B)} \times EC_w \text{ (water B)}}{\text{volume (water A)} + \text{volume (water B)}}$$

Example:

Two water sources are available for irrigation. One has an EC_w of 3.0 dS m^{-1} and the other, 0.6 dS m^{-1}. The water will be blended in equal amounts. What would the resulting EC_w of the blended water be?

$$ECw \text{ (blend)} = \frac{\text{volume (water A)} \times ECw \text{ (water A)} + \text{volume (water B)} \times ECw \text{ (water B)}}{\text{volume (water A)} + \text{volume (water B)}}$$

$$= \frac{[1 \text{ gal} \times 3.0 \text{ dS m}^{-1}] + [1 \text{ gal} \times 0.6 \text{ dS m}^{-1}]}{1 \text{ gal} + 1 \text{ gal}}$$

$$= \frac{3.6 \text{ dS m}^{-1}}{2}$$

$$= 1.8 \text{ dS m}^{-1}$$

Mixing of irrigation sources can occur in irrigation ponds or within the irrigation system itself. When mixing water sources in irrigation ponds, the non-saline water should be added immediately prior to being used so as to reduce evaporative losses. Evaporation of surface water is not only an inefficient use of water, but it also increases the salinity of the water remaining in the pond. If blending is not an option, alternating irrigating with effluent followed by fresh water helps leach salts.

Leaching or Flushing Soils to Remove Salts

Salt buildup from salt-laden irrigation water occurs when rainfall is low and evaporative demand is high. As water evaporates from the soil surface, salt deposits are left behind. Applying water in an amount greater than ET to cause the applied water to flow (or leach) through the rootzone and wash away salts is the goal of leaching salt-laden soil. Steps involved when leaching or flushing soils to remove salts include:

1. Perform soil and water tests to determine the extent of salinity levels present,
2. Aerify or vent the soil. Soils which do not drain well will not benefit greatly from flushing as the salts must be removed by leaching. Also, standing water in summer is often detrimental to certain plants, such as bentgrass. Aerifying or venting the soil by slicing are two ways of improving internal soil drainage. If drainage is still inadequate, then "pulse" irrigation may work. Pulse irrigation is a series of short-run irrigation cycles where water is to match infiltration rates or added until puddling occurs. Once the surface water drains, another pulse of irrigation is applied.
3. Apply gypsum (calcium source) to replace soil sodium ions removed and also add wetting agents to improve water infiltration and assist in soluble salt removal from the rootzone.
4. Perform leaching or flushing. Several techniques to determine the amount of water needed to accomplish the goal(s) of leaching/flushing are presented in the following text.
5. Add leached nutrients. Leaching/flushing to remove salts also often removes other elements, especially nitrogen and potassium. Add a scheduled fertilizer following leaching/flushing to ensure sufficient potassium levels are maintained to help combat future added sodium ions.

Measuring the EC of the soil is the best way to determine the extent of salt accumulation. When the EC exceeds the tolerance level of the turfgrass, the soil should be leached to move the salt below the root-zone. For example, 6-in (15-cm) of water is required to leach 80% of salt out of the top 1 ft (30 cm) of a sand loam soil and about 1.5 ft (45 cm) of water is required to leach 80% of the salt out of the top 1ft (30 cm) of a clay loam. Typically, a course with potential salinity problems should plan on an additional 10 to 20% of water needed yearly to provide water for adequate leaching for turf growth.

Frequent flushing of the soil with good quality irrigation water or rainfall is the best method of preventing excessive salt accumulation **(Figure 3–10)**. Unfortunately, low salinity irrigation sources are not always available and frequently saline irrigation water must be used to manage soil salinity. However, as long as the salinity of the irrigation water is acceptable, it can be used to leach accumulated salts from the turf rootzone. The goal is to maintain a soil salinity level that is not increased through salts added by irrigation yet can support turfgrass growth. The use of soil amendments, such as gypsum, should be considered in conjunction with leaching irrigation applications in saline-sodic soils.

Figure 3-10. "Flushing" a golf green of accumulated salts. Excellent soil drainage is necessary for this strategy to work.

If saline water is used to reduce the salt level of the soil, irrigation must be applied at rates exceeding evapotranspiration to leach (or flush) excess salts out of the rootzone. Leaching of soluble salts in the soil solution is much more rapid and easier than removing sodium on the CEC sites of sodic soils. On sodic soils, the sodium is chemically bonded and must be replaced by calcium, magnesium, or another cation before the sodium can be leached from the soil solution. Soluble salts are already in the soil solution, thus, are more easily leached. To determine the amount of excess water required to leach salt below the rootzone, the following **leaching requirement** equation is often used.

Leaching requirement is the amount of extra water needed to leach salts from the rootzone and is defined as:

$$\text{leaching requirement} = \frac{EC_w}{ECd_w} \times 100\%$$

ECw is the electrical conductivity of the irrigation water and ECdw is electrical conductivity of a saturated paste extract that can be tolerated by the turfgrass being grown.

Example:

An irrigation water source has a salinity level of 2 dS m^{-1}. The turfgrass being grown has a tolerance of 4 dS m^{-1}. What would be the recommended amount of water needed to leach salt from the rootzone?

Step 1: Determine the leaching requirement for this sample and turfgrass.

$$\text{leaching requirement} = \frac{ECw}{ECdw} \times 100\%$$

$$= \frac{2}{4} \times 100\%$$

$$= 50\%$$

Step 2: Fifty percent more water than is normally applied would be needed to leach the salt from the soil. If 2 in (5 cm) of water is normally used, adding 50% would equal 3 in (7.6 cm). Table **3–9** lists these irrigation guidelines for leaching salts from soil with saline water.

Leaching requirements depend on the salt levels of the irrigation water, ET rates, and the salt tolerance of the affected plants. As the irrigation water becomes saltier or the soil heavier, the leaching requirement becomes larger, meaning more water must be added for leaching to avoid salt accumulation. A guideline is for about 70% of the total soluble salts to be removed by leaching, 3 in (7.6 cm) of water is needed per 12 in (30 cm) of soil depth of a sandy soil, 6 in (15 cm) of water per 12 in (30 cm) of a medium-textured loam soil, and 9 in (23 cm) of water per 12 in (30 cm) of a clay (fine-textured) soils. Leaching Na+ also removes nutrients such as K, Mg and others. These should be monitored and replaced, if necessary, following leaching. Heavy Ca+2 applications may also cause other cations imbalances, such as K or Mg, thus they may need replacing. It generally is better to have periodic leaching events (i.e., 2 to 4 times monthly at 0.2 to 0.4 in, 0.5 to 1.0 cm, per application) compared to heavier, infrequent events (i.e., once monthly), which may cause puddling.

If saline water is the only source of water available for irrigation, it is helpful to predict how the leaching fraction of known irrigation water salinity will influence soil salinity over an extended period of time (Table 3–9). Applying a leaching fraction of 10% will lead to an ECe of ECw x 2.1, 15-20% will lead to an ECe of ECw x 1.5, and 30% will lead to an ECe = ECw.

Finally, plants tolerate higher soil salinity levels if water stress is avoided by maintaining soil moisture. Adequate surface moisture also prevents capillary rise of subsurface water and salts.

Flushing Steps

1. Aerify to break hardpans or organic zone surface tension.
2. Add greens grade gypsum at 7 to 12 lb 1,000 ft^{-2} (3.4 to 5.9 kg 100 m^{-2}).
3. Start flushing, usually for about an hour. If puddling occurs, stop, allow it to percolate, then resume.
4. Assess flushing length of time by measuring EC_w of discharged water with a portable meter. Once readings are stabilized or fall below pre-set thresholds, stop.
5. Afterwards, N and K may need to be added as they are commonly stripped by flushing.

Table 3-9. Irrigation guidelines for leaching salts from soil with saline water.

IRRIGATION WATER ECW (DS M^{-1})	MAXIMUM PLANT EC_{DW} TOLERANCE LEVEL, MEASURED		
	4 (low)	8 (medium)	16 (high)
	(inches of water to replace weekly ET losses and provide adequate leaching in rootzone)*		
0.00	1.5	1.5	1.5
1.00	2.0	1.7	1.6
2.00	3.0	2.0	1.7
3.00	6.0	2.4	1.8

*Multiple inches by 2.54 to convert to cm.

Figure 3-11. Water remaining in a golf pin indicating poor soil drainage.

Good Soil Percolation and Drainage. As previously mentioned, leaching works well only with soils possessing good drainage. If compacted zones or abrupt changes in soil texture exist, less leaching occurs as water movement through the soil is reduced **(Figure 3–11)**. Soil drainage can be improved through modifying rootzones, increased deep tine aerification, and the use of drain lines. Drain lines, spaced no more than 20 ft apart (6.1 m), are used on golf greens for this purpose. Aerification also initiates deep root development prior to summer heat and increases tolerance of salt stress by reducing soil compaction and disrupting soil layering. Native (or push-up) greens often fail when effluent water is used, unless these techniques are aggressively incorporated.

For fairways, deep aerification has become standard on effluent-using courses to increase soil drainage and provide deep channels for incorporation of soil amendments. On tees and greens, deep aerification in spring and fall are typical along with supplemental monthly venting by spiking, slicing, quadratining, hydrojetting, or other techniques. For soils with limited infiltration properties, pulse irrigation is more effective where water is applied and allowed to infiltrate before reapplying.

Clay type also influences the sodium tolerance of a soil. Different clay types have different cation exchange capacities and swelling properties. Clays with high CECs such as Montmorillonite can adsorb more sodium on their exchange sites and therefore can become more dispersed. In addition to this Montmorillonite is a 2:1 expanding clay, when it is dry large cracks form allowing rapid infiltration but as it gets wet the clay swells and closes the cracks, reducing the infiltration rate. Kaolinite on the other hand has a low CEC meaning less sodium can be adsorbed to its exchange sites and therefore its degree of dispersal is lower. Kaolinite is a 1:1 non-expanding clay and as such doesn't shrink and swell. Illite is a 2:1 clay, but has a moderate CEC and tends to fall between the others in its degree of dispersal by sodium.

Salt damage also is typically experienced in low-lying areas where water accumulates. Drain line installation helps remove this excessive water, preventing toxic accumulation of salts and sodium. Sand topdressing of fairways is also becoming more prevalent to improve playing conditions, degrade thatch, and to help remove excess surface water.

Leaching is typically performed monthly during high-stress summer months but soils should be checked periodically if problems develop. Soil salinity levels should be monitored before and after leaching to determine if salts have been sufficiently moved below the rootzone. Finally, routine leaching will also remove certain soil nutrients such as nitrogen and potassium. Although most effluent sources contain small levels of these and others, monitoring of soil nutrients should occur following a leaching cycle.

3.5 WATER CONSERVATION

Daily water conservation practices integrate many of the previously mentioned practices and technology. Using computerized irrigation systems to better pinpoint irrigation needs for various soil types or turfgrass use, utilizing weather stations to determine daily ET rates, installing soil moisture sensors to monitor soil moisture levels, and using automatic pump shutdown switches when significant rainfall occurs are examples of water conservation techniques **(Figure 3–12)**.

A holistic approach to water conservation is required. If not, turf water conservation will probably be mandated by governing bodies and may include: (a) changing the grass species, (b) allowing only native grasses and Xeriscape designs, (c) reducing the area of irrigated turf, or (d) improving (updating and expanding) current irrigation

Figure 3-12. A typical computerized irrigation system using the most energy efficient variable frequency drive pumps.

designs to become more efficient. Steps to develop best management practices (BMPs) for turfgrass water conservation include:

1. Site assessment and initial planning (i.e., documenting grasses, soils, microclimate, and existing management practices).
2. Evaluating and implementing water conservation strategies.
3. Analyzing benefits and costs of water conservation measures.

Site Assessment and Initial Planning

An extensive irrigation/water audit is needed to assess current water usage rates and efficiencies. This includes identifying currently implemented water conservation measures, estimating their costs to implement, and how they have improved water-use efficiency for the facility. This helps demonstrate to regulatory agencies that water conservation BMPs have been in place and the course is committed to as efficient use of available resources as possible. Examples of current conservations measures can include:

- Irrigation scheduling based on scientific principals and experiences which measure plant water requirements.
- Providing educational and demonstration opportunities for the crew and course membership.
- Irrigating in early morning or at night to reduce wind losses and to take advantage of efficient water pressure.
- Using required irrigation backflow preventers, valves, heads, and permit requirements as per local code.
- Periodically checking valve boxes for leaks or disconnected wires and open and close valves manually to confirm proper operation. Also, inspecting for and eliminating pipe leakage.
- Use a pilot tube and gauge to check pressure at the head to ensure maximum efficiency and to regulate water use.
- Periodically check the height of heads to prevent mower and other equipment damage and to check coverage, water-discharge patterns, and to raise low heads.
- Use low-maintenance turf, landscape plants, and native grasses whenever possible.
- Use mulch (>3 in, 7.6 cm deep) around landscaping to reduce evaporation and weeds.
- Use drip irrigation or low emitter heads for landscapes.
- Use multiple irrigation cycles to allow infiltration without surface run-off.
- Have water harvesting and collection sources feeding into irrigation ponds.
- Having access to color weather radar or other devices to track and predict local showers.
- Matching the application rate to the soil infiltration rate.
- Using an irrigation company with local service support and readily available parts.
- Identifying cultivation programs (i.e., mowing heights, fertility programs, aerifications) and equipment which improve water infiltration and enhance rooting.
- Use of appropriate soil amendments and wetting agents to provide efficient water infiltration, water retention, and to minimize run-off.
- Reducing or eliminating irrigation in low priority play areas.

Following identification of existing water conservation measures, the next step is to assess the current resources and infrastructure available. This can be a time-consuming and costly assessment, especially if alternative irrigation sources are explored or when major irrigation system design changes are needed.

- Hire an irrigation design specialist.
- Use an irrigation system design that provides uniform application to minimize wet and dry areas and limits run-off or leaching.
- Identify and provide cost considerations of alternative water sources such as reclaimed water.
- Identify irrigation design changes necessary for improved efficiencies.
- Assess current soil, microclimatic, and plant conditions affecting irrigation system design including zoning and scheduling issues.
- Add sufficient wire in the irrigation system to accommodate future expansions or added heads per zones.
- Provide single-head irrigation control.
- Use a variable frequency drive (VFD) pump to gradually reduce water flow after pump shut-off and gradually increase water flow when turned on to reduce strain on the pipe. These motors only expend enough energy to meet the demands of the pumps.
- Have an on-site weather station or access to regional weather information to calculate daily ET rates and possibly use soil moisture sensors to monitor irrigation efficiency.
- Safeguard against water hammer when systems are pressurized by installing check values where water drains from low heads to prevent damage.
- Consider using ductile fittings and gasketed joints which have a longer life expectancy than glue.
- Consider looping the irrigation system to allow watering from two directions.
- Use multi-row irrigation design systems compared to single rows with single, heavy-use cycles.

- Zone irrigation heads of similar areas together (greens, tees, bunkers, fairways, and roughs).
- Isolate as many areas of the golf course as possible with individual shut-off valves from the main line.
- Use low-volume heads when possible and low trajectory heads in windy areas.
- Use the biggest irrigation pipe that is affordable—ideally, pipes should be sized for water velocities of about 3 ft s^{-1} (0.9 m s^{-1}).
- Mainline pipe should be a minimum of 4 to 6 in (10 to 15 cm) in diameter, preferably larger. Successive branches of an irrigation line should be reduced by 2 in (5 cm).
- Have controller flexibility to develop the most efficient irrigation program.
- Avoid placing heads in a depressed area as seepage or bleeding may occur. Use seals if this is unavoidable.
- Use part-circle pattern heads and proper design to place water only on intended turf areas and not on unintended natural areas, mulched areas, water bodies, edges of fairways or primary rough, off-property, and other such areas.
- Incorporate efficient drainage designs that allow water harvesting or recapturing in ponds or catch basins.
- Consider a remote (radio) controller to enable quicker response time to a problem.
- Use appropriate soil amendments which are known to help retain soil moisture without negatively affecting the turf.
- Use pressure-regulating stems on spray heads to prevent water waste when operated outside the designated window of pressure.

Evaluating and Implementing Water Conservation Strategies

Once existing and potential irrigation practices have been identified, they must be sorted through and the ones practical for a specific course can be implemented. These strategies are generally site-specific, driven by water-allowances and conservation goals, member expectations, and of course, financial and other resources available or required. Key components of water conservation strategies include:

- Alternative irrigation water sources, their availability, costs, quality, reliability, use requirements, suitability for a particular site, and long-term effects. Probably the major problem with effluent water is not quality but quantity. Courses find themselves having to accept a certain amount per day, whether it is needed or not. Storage of this water is a concern and must be addressed early in the planning process of using effluent water.
- Practical extent of implementing efficient irrigation design, scheduling, operations, and monitoring devices as discussed previously.
- Considerations on selecting turfgrass and landscape plants, such as the quality they can produce, their water use requirements, and quality of water needed.
- Changes in management practices which enhance water conservation as discussed previously.
- Holistic course water conservation, including landscaped areas, clubhouse use, pool water conservation, etc.
- Educating the crew, owners, and membership on water conservation and management plans.
- Developing a formal written water BMP conservation plan for the course and for regulatory agencies.
- Monitoring and revising the conservation plan periodically to assess the success of the plan and to identify limiting factors to achieving water conservation goals.
- Inform members, owners, crew, and concerned citizens of water conservation efforts with proper signage and other communication avenues.

Assessment of Water Conservation Costs and Benefits

To track costs and benefits, which is critical information to demonstrate the facility has developed and is implementing long-term BMP water conservation efforts, a follow-up detailed review and documentation phase is necessary. Costs include labor, facility costs as outlined in evaluating and implementing water conservation strategies section, and costs associated with more stringent water restrictions, such as revenue loss, job loss, reduced and possible hazardous turf quality, etc.

The following are example of questions to answer when developing Best Management Practices for Water for a particular golf facility (modified from the Georgia Golf Course Superintendents Association; 2015, http://www.ggcsa.com/-best-management-practices-for-water-conservation).

Best Management Practices for Water Use and Conservation

1. Site Assessment for greens, tees, fairways, roughs, landscapes, and club grounds, including:
    a. Area size involved, (ft^2, ac, m^2, or ha),
    b. Turf (plant) species involved,
    c. General factors such as mowing height, soil type, special technology, other pertinent information.
    d. Irrigation Audit:
        - Pump station – year, type, pump size(s), gallonage, safety features, condition, maintenance schedule, other information,

- Controls – year, system type, number of field controllers, condition, other information,
- Irrigation system – year, type, valves, output and distribution efficiency (DU) for greens, tees, fairways, roughs, plus other information.

2. Overall Water Needs
   a. Metering – number of meters, location(s), other information,
   b. Record keeping – yearly usage, scheduling, other information (attach one year of records)
   c. Water testing – schedule, other information (attach most recent tests),
   d. Reservoir – size, type of water, source of water, other information,
   e. Alternative water sources (yes or no), if yes, explain,
   f. Future needs – explain in detail.

3. Best Management Practices and Current Conservation Measures
   a. Current Irrigation Control/Costs – for pump station, controllers/computer, irrigation system components (sprinklers, pipe, valves, fittings, etc.), preventive maintenance of all these, other,
   b. Staffing Control/Maintenance Costs – supervisor time, irrigation technician time, other assistance time (include diagnosis, repairs, recordkeeping, inventory, scheduling, etc.),
   c. Scouting Costs – daily scouting time (explain),
   d. Hand Watering Costs – daily hand watering time (explain),
   e. Night Watering Capability – explain how this reduces loss and reduces disease occurrence,
   f. Rain, Leak Loss Costs,
   g. Traffic Controls/Costs – daily traffic control time (explain),
   h. Management for Water Conservation (describe each):
      - Mowing heights,
      - Soil cultivation (number times yearly for greens, tees, and fairways),
      - Evapotranspiration utilization – List source for monitoring weather data to schedule irrigation events based on ET values,
      - Landscape material selection explanation,
      - Natural areas,
      - Fertilization – yearly rates, slow vs. quick release, stress nutrient use,
      - Pest management (explain IPM programs),
      - Wetting agent use (explain products, timings, etc.),
      - Soil moisture sensors – calibrating and determining thresholds (saturation, field capacity, wilting point).
   i. Record Keeping:
      - Scouting labor hours and costs,
      - Hand watering hours and costs,
      - Irrigation repair hours and costs,
      - Repair parts costs,
      - Water usage weekly, monthly, and yearly,
      - Water quality tests,
      - Pesticide and fertilizer applications (in relation to irrigation)
      - Other methods.
   j. Irrigation Methods – combination of plant based, soil based, atmosphere based, and budget report.
   k. Goal Setting – explain.

      Education: for example,
      - Benefits of Golf Course and Turf – i.e., economic contributor, carbon dioxide exchange for oxygen, temperature moderation, erosion control, water filtering for improved water quality, wildlife sanctuary, recreational benefits, community outreach (i.e., First Tee programs), others.
      - Publish this Best Management Plan for use at club – articles in the club newsletter or web page explaining proper water use and efforts towards water conservation.
   m. During drought, display water conservation plans (posters) in the pro shop and locker rooms and distribute to patrons for use at home.

4. Water Conservation Plan
   a. List reasons for water conservation, for example:
      - Proper water management dictates that over-watering is unacceptable,
      - Economic considerations - inefficient watering costs money,
      - Depleted water supplies and reduced water quality,
      - Other reasons.
   b. List measures implemented by the course to reduce drought effects, for example:
      - Raise mowing heights where possible,
      - Reduce or stop mowing non-irrigated areas,
      - Increase hand watering and wetting agent use,
      - Improve uniformity by improving pressure regulation, leveling heads, etc.
      - Other reasons.

c. Irrigation upgrades implemented by the course for improved water conservation
   - List possible options and costs.

d. List and describe actual plans for water conservation at various mandated drought levels

5. Attachments, for example:
   - Pump station records,
   - Most recent water quality test results,
   - Man-hour records,
   - Budgets,
   - Repair records,
   - Copies of publications.

3.6 HYDROPHOBIC SOILS AND THEIR MANAGEMENT

Hydrophobic Soils

Hydrophobic (or "water-hating") soils such as those associated with localized dry spots, occur as organic matter decomposes and humic and fulvic acids (nonpolar) produced eventually coat individual sand grain particles **(Figure 3–13)**. Sands are more prone to develop water repellency than finer soil textural classes due to the low or smaller surface area to volume ratio of sand particles. Certain fairy ring fungi also produce a mat of below-ground hyphae which often becomes hydrophobic. These acids have extruding non-polar ends which repel water particles, much like wax, leading to the dry spots. These conditions can be so severe that normal irrigation is often ineffective in restoring adequate soil moisture. Repeated wet and dry soil cycles aggravate hydrophobic soils. Other potential sources of organic acids which coat soil particles include exudates from turfgrass roots, lipids from decomposing organic matter, surface waxes from cuticles of turfgrass plant leaves, and fungal or soil microbial by-products.

Figure 3-13. Localized dry spots on a bermudagrass golf green.

Table 3-10. Degree of soil hydrophobicity (or repellency) based on the water drop penetration test.

WATER DROP PENETRATION TIME (SECONDS)	DEGREE OF REPELLENCY
0 to 5	none
5 to 60	slight
60 to 600	moderate to high
600 to 3,600	severe
>3,600	extreme

Hydrophobic soils can cause problems on golf courses (especially golf greens) and other turf areas, in nurseries and greenhouses, and in open fields. Localized dry spots tend to be a surface phenomenon, in the top 2 in (5 cm), but can occur up to 6 in (15 cm) deep. Nursery operators sometimes encounter hard-to-wet media in pots and greenhouse beds. Farmers who work organic soils or "salt-and-pepper" soils complain that the soil wets too slowly, reducing crop productivity. Problems with hydrophobic soils are also commonly associated with citrus production areas, where mine spoils have been deposited, and with burned-over forestland and grassland.

If water cannot readily penetrate and wet the soil, the availability of moisture to plants is reduced, decreasing the germination rate of seeds, the emergence of seedlings, and the survival and productivity of plants. Lack of sufficient water in the soil also reduces the availability of essential nutrients to plants, further limiting growth and productivity. In addition, water that cannot penetrate the soil runs off the surface and increases soil erosion.

A soil water repellency water drop penetration test is used to measure how hydrophobic a soil may be. Droplets of water are placed every inch down a soil core and the time required for the droplet to penetrate the soil reflects the soil's degree of repellency **(Table 3-10)**.

Adjuvants

An adjuvant is a spray additive that helps modify the surface properties of liquids to enhance their performance and handling. Adjuvant is a broad term and includes surfactants, wetting agents, crop oils, crop oil concentrates, activators, antifoaming agents, detergents, drift control agents, emulsifiers, fertilizers, spreaders, sticking agents, dispersing agents, penetrants, pH modifiers and compatibility agents.

Surfactants

Surfactants are adjuvants that produce physical or chemical changes at the interface of a liquid and another liquid, solid, or gas. These typically lower the surface tension of a liquid, allowing easier spreading, and lower the interfacial tension between two liquids. Since this occurs at the surface, the term surfactant is short for surface active agents. These facilitate emulsifying, dispersal, wetting, spreading, sticking, penetrating, or other surface-modifying properties of liquids into plants and soil. Surfactants are widely used in everyday life in medicines, medical care, fire extinguishers, paints, inks, adhesives, waxes, laxatives, hair conditioners, and agriculture. Surfactants include emulsifiers, detergents, dispersants, penetrants, soaps, spreaders, stickers, and wetting agents.

To understand how surfactants work, it helps to understand how water works. Each water molecule is bipolar, meaning it has a negative and a positive charge, similar to a magnet. When several water molecules come into contact with each other, these positive and negative forces attract each other. This attraction of water molecules to each other is termed cohesion. The molecules on the surface of a water droplet are held together with more force than those of the interior water molecules. This causes surface tension, which causes the droplet to behave as if a thin, flexible film covered its surface, tending to keep the water molecules apart from other substances, and can prevent many things from going into solution and getting wet. This surface tension is the tendency of the water surface molecules to be attracted toward the center of the liquid, causing a water droplet with a dense, elastic membrane around it. Wetting agents help break this surface tension, thus the water droplets breakdown allowing dispersal. Adhesion, the attraction of water molecules to other substances, is the force causing water molecules to adhere to other objects, such as soil particles.

The effects of these forces can be illustrated by placing a drop of water on a napkin and another drop on a piece of waxed paper. On the napkin, the force of adhesion between the water molecules and the paper molecules is greater than the force of cohesion that holds the water molecules together. As a result, the water droplet spreads out and soaks into the paper. Certain organic substances such as wax, however, do not have an adhesive force for water. On the waxed paper, therefore, the water "beads up"—that is, the droplet remains intact. The water molecules are not attracted to the wax that coats the paper's surface; instead, the water molecules cohere to each other. When the adhesive forces between water molecules and an object are weaker than the cohesive forces between water molecules, the surface repels water and is said to be hydrophobic **(Figure 3–14)**.

Figure 3-14. Localized dry spots on a bentgrass golf green.

Figure 3-15. Use of a wetting agent to combat localized dry spots and fairy ring.

Surfactants are composed of two parts, a water-soluble end which is polar or hydrophilic, meaning it is attracted to water, and an oil soluble hydrocarbon chain which is lipophilic or nonpolar, meaning it is attracted to oil and not water. Water forms bonds with polar molecules but does not bond to non-polar molecules, and is repelled by them. Chemists manipulate the ratio of the hydrophilic (polar) portion of the molecule to the lipophilic (non-polar) to produce different surfactants, with different molecular weights, and different characteristics. Thousands of potential combinations exist, thus the reason for the hundreds of surfactants available. These components of a surfactant molecule help break water surface tension, allowing the solution to be more evenly dispersed on a surface and to reach its target. Two major types of surfactants are emulsifiers and wetting agents.

Wetting Agents

Wetting agents are a type of adjuvant that reduce interfacial tensions and cause a liquid to spread more easily over, or to penetrate, a solid surface, thus increasing the contact with treated surfaces **(Figure 3–15)**. They can reduce this surface tension by 50 to 60% or more. In plant and soil sciences, wetting agents have a number of uses including reducing soil hydrophobicity (i.e., localized dry spots), reducing dew and frost formation, firming bunker sand, improving irrigation efficiency, reducing vehicle path dust, improving soil water infiltration, improving pesticide efficacy, and others.

Wetting agents are classified based on how they ionize or separate into charged particles in water. Four types of wetting agents are:

1. **Anionic** – negatively charged. These are often used for dispersion of clays in wettable dry granulars as well as detergents, and degreasers. They may burn plants.
2. **Nonionic** – neutrally charged. Also referred to as polyoxyethylene (POE) or alkylphenol ethoxylate (APE). Often used to enhance water movement into soil.
3. **Cationic** – positively charged, often used as biocides (disinfectants), soaps, shampoos, and fabric softeners. Strongly adsorbed to soil particles with high plant burn potential. Rarely used.
4. **Amphoteric** – charge is pH dependent of the solution. Little use.

Nonionic surfactants do not ionize, thus remain uncharged. This is the most commonly used type of surfactant and is compatible with most pesticides. They are unaffected by water containing high levels of calcium, magnesium, or ferric ions. They also can be used in strong acid solutions. Anionic wetting agents ionize with water to form a negative charge while cationic ones ionize with water to form a positive charge. Anionic wetting agents may deleteriously impact soil structure (negative soil charges repel the negatively charged anionic wetting agents) and are often phytotoxic to plants. Amphoteric surfactants can be either anionic or cationic depending on the acidity of the solution. Cationic materials are strongly adsorbed to soil particles and may become ineffective. If used in hard water, anionic and cationic surfactants can cause an insoluble precipitate, or foam, to form. These are only occasionally used. Soaps and detergents are types of surfactants but typically are anionic and react with salts in hard water and form a precipitate (scum), foam, or are phytotoxic to plants.

As mentioned, chemists are able to manipulate the ratio of the hydrophilic (polar) portion of the molecule to the lipophilic (non-polar) to produce different surfactants, with different molecular weights, and different characteristics. Within the nonionic surfactant chemistry, two main groups of wetting agents are currently available: soil penetrants and water retainers.

1. *Soil Penetrants.* These are often characterized as "water-moving" chemistry, characterized by having ethylene oxide terminal functional groups. Ethylene oxide groups are hydrophilic, being able to attract or disperse water molecules. Soil penetrating wetting agents generally increase water infiltration and percolation through the rootzone, providing more uniform soil moisture distribution within the profile leading to fast and firm playing conditions.

2. *Soil water retainers.* These are often characterized as "water-holding" chemistry, containing propylene oxide terminal functional groups. Propylene oxide groups are hydrophobic, thus repel water molecules. These are used where moisture retention is needed, especially sand-based rootzones with little organic matter and high infiltration and percolation rates. These are especially useful to help retain moisture during drought periods.

To take advantage of both types of wetting agents, many newer commercial products are blends of each. Extensive research has been conducted on hydrophobic soils and on the effectiveness of wetting agents **(Figure 3–16)**. Localized dry spots in turf grown on naturally sandy soils, and on formulated materials high in sand content, become a serious turf management problem during the summer months, especially during periods of drought, windy weather, and low humidity. Despite frequent irrigation, the soil in these spots resists wetting, resulting in patches of dead or severely wilted turf. The water applied wets the turf but does not adequately penetrate the soil surface to reach the rootzone. Wetting agents or surfactants do not aid in decomposing thatch, alleviating black layer, or reducing soil compaction.

When a wetting agent is applied, their non-polar ends react (or align) with the non-polar ("water-hating") ends of the acid coated sands. The polar ("water-loving") ends of the wetting agent then are exposed outward and can attract water, restoring wettability. Wetting agents, however, do not substantially remove the hydrophobic acid coating. For most products, to minimize phytotoxicity, irrigation after wetting agent application is critical as well as not treating when temperatures are extreme. When soil organic matter content exceeds 3.5%, this organic matter may dry down slower when treated with a wetting agent. Increasing the use rates above label recommendations generally does not increase the longevity or effectiveness of products and increases the chance of plant damage. Wetting agents can improve the efficiency of irrigation and when water repellent soil conditions occur, wetting agent use may improve root growth and survival. Efficacy differences and length of control does vary between wetting agents. Soil organisms naturally breaking down the materials eventually occurs,

Figure 3-16. Localized dry spots on turf treated with a wetting agent (right) compared to untreated (left).

Figure 3-17. Lack of dew formation from areas previously treated with a wetting agent.

causing the need for repeat applications for extended results. When treating golf greens, it generally is best to treat the whole green versus just treating the hot spots. Wetting agents do not solve a subsurface drainage problem but may help leach salts from the rootzone under certain situations.

In general, studies have shown that the extent of improvement in infiltration rate is affected by the type of wetting agent used, its dilution, previous use of wetting agents on the soil, and the water content of the soil at the time water is applied **(Figure 3–17)**. Several studies have shown that the infiltration rate of a hydrophobic soil, once it has been wetted, remains higher than it was before it was wetted, even if it is allowed to dry out again. Applying wetting agents often reduces the severity of the condition, but best use is in combination with coring—making small holes in the soil surface to allow water to pass through the hydrophobic surface layer. Also, keeping the soil moist seems to be the best defense against the development of dry spots. Allowing the soil to dry out intensifies the problem. For maximum efficiency, if your goal is to re-wet a dry, hydrophobic soil, the area should be aerified, followed by pre-wetting the area, applying the wetting agent or soil surfactant, and then watering it rapidly and liberally into the soil profile.

4 TURF FERTILIZATION STRATEGIES

4 TURF FERTILIZATION STRATEGIES

Proper fertilization is essential for turfgrasses to sustain desirable color, growth density, and vigor; to better resist diseases, weeds, and insects; and to provide satisfactory playing conditions **(Figure 4–1)**. Grasses may survive in some soils without added fertility, but it is unlikely the turf will be dense enough to support continued play or resist pest invasion. Turfgrass plants need 17 elements that are divided into two categories: **macronutrients** and **micronutrients (Table 4–1)**. Macronutrients typically are found at concentrations greater than 500 to 1,000 ppm in plant tissue while micronutrients are generally found at concentrations less than 100 ppm.

Macronutrients can further be subdivided into **primary nutrients** (nitrogen, phosphorus, and potassium) and **secondary nutrients** (calcium, magnesium, and sulfur). Carbon (C), hydrogen (H), and oxygen (O) are macronutrients obtained from air and water, and are the building blocks for the process of photosynthesis. These three nutrients, when combined in the presence of chlorophyll and light through the process of photosynthesis, form carbohydrates, the sugars used to provide plant growth. Plants, therefore, do not obtain their food through the soil; rather, they manufacture this via photosynthesis utilizing the raw materials—mineral nutrients from the soil—as components of this food.

4.1 NUTRIENT UPTAKE BY ROOTS

Large amounts of nutrients are stored in soil organic matter; as the organic matter decomposes, these nutrients are released. Up to 80 percent of the soil sulfur, 95 percent of the soil nitrogen, and over 50 percent of the total soil phosphorus are stored in soil organic matter. Other nutrients, such as boron (B), molybdenum (Mo), and iron (Fe) and aluminum (Al) oxide reserves, are also held in organic matter.

Roots are the principal means in which nutrients and water enter plants. The root system is usually very large and extensive, allowing the plant to make contact with a tremendous volume of soil. Root hairs greatly increase the surface area of roots and are the principal site of nutrient and water uptake.

Since active absorption is the primary mechanism for element uptake by plants, roots must be growing in an aerobic medium—that is, oxygen must be present. If oxygen is not present, respiration will cease and element absorption will not occur. Under these conditions, plants may develop nutrient deficiency symptoms. If the anaerobic conditions continue, the plant will eventually die. Any soil condition that affects soil aeration, such as compaction or continuous moisture saturation, will negatively influence root growth and nutrient uptake.

Figure 4–1. To maintain healthy and aesthetically pleasing turf, a proper fertilization program is required.

Table 4–1. Elements, their most common available forms for plant uptake, and primary functions in turfgrass growth.

	ELEMENT (CHEMICAL SYMBOL)	MOST COMMONLY USED FORM(S) BY PLANTS	FUNCTION IN PLANT GROWTH
		Macronutrients	
Obtained from air and water	Oxygen (O) Carbon (C) Hydrogen (H)	CO_2 CO_2 H_2O	Through photosynthesis, these elements are converted to simple carbohydrates, and finally into amino acids, proteins, protoplasm, enzymes, and lipids.
Obtained primarily from fertilization	Nitrogen (N)	NO_3– (nitrate) NH_4+ (ammonium)	A mobile element within the plant used in the formation of amino acids, enzymes, proteins, nucleic acids, and chlorophyll. It generally increases color and shoot growth. Conversely, excessive nitrogen generally reduces heat, cold, and drought hardiness; disease and nematode resistance; wear tolerance; and root growth.
	Phosphorus (P)	H_2PO^{4-} HPO_4^{-2} (phosphates)	A plant mobile element that is a constituent of phospholipids and nucleic acids. These are involved in a carbohydrate transport system that moves energy to all parts of the plant for vital growth processes. This function in root development is most vital. Phosphorus also hastens plant maturity, and is needed for glycolysis, amino acid metabolism, fat metabolism, sulfur metabolism, biological oxidation, and photosynthesis. In addition, phosphorus influences maturation, establishment, and seed production.
	Potassium (K)	K	A mobile element used by plants in large quantities, second only to nitrogen. Potassium is essential for the control and regulation of various minerals; adjustment of stomatal movements and water relation; promotion of meristematic tissue and rooting; activation of various enzymes; synthesis of proteins; and carbohydrate metabolism. Potassium helps increase heat, cold, and drought hardiness; wear tolerance; and increases disease and nematode resistance.
		Secondary Nutrients	
Present in some fertilizer formulations; available in most soils, and/or as part of conditioners such as lime, dolomitic lime, and gypsum.	Calcium (Ca)	Ca^{+2}	An immobile element required for cell division (mitosis); important in cell membrane permeability; activates certain enzymes; provides chromosome stability and structure; enhances carbohydrate translocation and formation, and increases protein content of mitochondria. It influences absorption of other plant nutrients, and also strongly influences soil pH and can improve soil structure, water retention, and infiltration by displacing sodium ions.
	Magnesium (Mg)	Mg^{+2}	A mobile element which is a component of chlorophyll; assists in the stabilization of ribosome particles, and activates several plant enzyme systems such as carbohydrate and phosphate metabolism and cell respiration. It serves as a specific activator for a number of enzymes.

*Threshold level ranges commonly used in research by universities. Numbers are not absolute as the health of the turf and environmental conditions substantially influence these. na = data not available.

	ELEMENT (CHEMICAL SYMBOL)	MOST COMMONLY USED FORM(S) BY PLANTS	FUNCTION IN PLANT GROWTH
	Sulfur (S)	SO_4^{-2}	A partially mobile element required for the synthesis of sulfur-containing amino acids—cystine, cysteine, and methionine; required for protein synthesis and activation of certain enzymes and hormone constituents.
	Micronutrients		
Most premium fertilizers contain these.	Iron (Fe)	Fe^{+2} (ferrous) Fe^{+3} (ferric) $Fe(OH)^{2+}$	An immobile element necessary for chlorophyll, heme, and cytochrome production, and in ferredoxin, which participates in cellular respiratory (oxidation-reduction or electron transfer reactions) mechanism; an essential component of iron enzymes and carriers. Generally increases color, and shoot and root growth.
	Manganese (Mn)	Mn^{+2}, organic salts	An immobile element that activates enzymes such as manganoenzyme; needed in photosystem II of photosynthesis; connected with carbohydrate (nitrogen) metabolism, chlorophyll synthesis, oxidation-reduction process, phosphorylation reaction, and the citric acid (or TCA) cycle.
	Copper (Cu)	Cu^{+2} (cupric) Cu^{+} (cuprous)	An immobile element connected with the light reaction during photosynthesis as a constituent of oxidation-reduction or electron transfer enzymes; found in cytochrome oxidase that is essential for plant (carbohydrate) metabolism, and is used for production of the enzyme polyphenol oxidase; and catalyze plant metabolism.
	Chlorine (Cl)	Cl^{-} (chloride)	An immobile element possibly required for photosynthesis of isolated chloroplasts and as a bromide substitute. It is believed to influence osmotic pressure and balance cell cationic charges. It also affects root growth.
	Zinc (Zn)	Zn^{+2} $Zn(OH)^{+}$	A mobile elemental component of the enzyme dehydrogenase, which is needed for RNA and cytoplasmic ribosomes in cells, proteinases, peptidases, and IAA (auxin) synthesis. It is involved in the conversion of ammonium to amino nitrogen and is necessary for chlorophyll production and promoting seed maturation and production.
	Boron (B)	H_3BO_3 (boric acid) HBO_3^{-2} B_4O7^{-2} BO_3^{-3}	An immobile element that facilitates sugar transport through membranes; involved in auxin metabolism in root elongation, protein, and phosphate utilization; influences cell division (growth) by control of polysaccharide formation. Boron is a non-metal and is one of two non-metallic micronutrients called **metalloids**.
	Molybdenum (Mo)	MoO_4^{-2} (molybdate)	An element required for the assimilation and reduction processes in nitrogen fixation to produce amino acids and proteins.
	Sodium (Na)	Na^{+}	An element that regulates stomatal opening and nitrate reductase. Toxic levels are generally more of a concern than deficiencies.
	Nickle (Ni)	Ni^{+2}	An element most noted as a component of the enzyme urease which is needed for the conversion of urea to ammonia in plant tissue.

Temperature also influences nutrient uptake. Higher temperatures usually mean increased root growth; therefore, the plant encounters more soil nutrients. Warmer temperatures also increase leaf transpiration which provides the "pull" for water (and dissolved nutrient) uptake.

If water levels are inadequate, nutrient absorption decreases since water mass flow decreases. Inadequate water around soil particles, combined with plant transpiration, may "pump dry," breaking the columns of water from the root surfaces to the surrounding soil area.

Adequate soil nutrient levels also are needed for uptake by plants. The amount of an element in the soil solution is affected by the total concentration of the element in the soil, the soil pH, the concentration of other elements in the soil and soil solution, the extent of biological activity, and soil temperature. The composition of soil solution can be altered by liming, fertilizing, draining, irrigating, and mechanically manipulating a soil.

Mineral Mobility and Deficiencies

Nutrients are **mobile** if the plant can transport them from one tissue to another. They tend to show deficiency symptoms in older tissue first, as plants will withdraw them to support new growth. Mobile elements include nitrogen, phosphorus, potassium, magnesium, and zinc, while sulfur has limited mobility. **Immobile** elements show deficiencies in new growth as they are not transferred from older growth if external supplies are inadequate. Immobile elements also must be continuously applied if plants are foliarfed. Immobile elements include calcium, iron, boron, manganese, and copper.

Plant deficiencies for nutrients often occur due to external conditions that prevent their uptake rather than them actually lacking in soil. Soil and tissue testing, therefore, should be used to ascertain if sufficient supplies are in the soil and if plant tissue is able to obtain them. Restricted root and tissue growth from improper soil pH, inadequate or excessive moisture, or temperatures outside the optimum growth range are several common reasons nutrient deficiency symptoms in plant tissue may occur, even though tests indicate adequate soil levels.

4.2 PRIMARY NUTRIENTS AND FERTILIZERS

Nitrogen, phosphorus, and potassium receive a great amount of attention because they are typically deficient in soils and must be regularly applied. These elements are required in the greatest amounts, and are therefore referred to as the **primary (or essential) nutrients or elements**. The numerical designation on a fertilizer bag refers to the percentage of nitrogen, phosphorous (expressed as P_2O_5), and potassium (expressed as K_2O). Thus, a bag of 10-10-10 would contain 10% nitrogen, 10% P_2O_5, and 10% K_2O.

Figure 4–2. Research plots examining various rates and types of fertilizers for golf courses.

Nitrogen

Nitrogen (designated as N) is the key element due to its influence on color, growth rate, density, pest occurrence, and stress tolerance **(Figure 4–2)**. Turfgrasses consist of between 20 and 60 grams of nitrogen per kilogram of plant tissue (or 2 to 6 percent of the total dry matter) while soil organic matter typically contains about 5 percent nitrogen. In plants, nitrogen is used primarily for chlorophyll production, plant proteins, and nucleic acids. It is the most applied element and is required in larger quantities than any other element except carbon, hydrogen, and oxygen. Problems, however, may develop if excessive nitrogen is used. An amount that is considered excessive may vary based on species, plant health, and intended use. Excessive nitrogen increases shoot growth and selective diseases, as well as lowers stress tolerance to heat, cold, drought, and traffic; most importantly, root and lateral shoot growth also are reduced.

Nitrogen Carriers

Turfgrass fertilizer carriers are available in an array of forms such as granules, pellets, liquids (or solutions), powders, and suspensions. Granules are the most popular and range in size from coarse (1 to 3 mm in diameter) to fine, greens grade (<1 mm).

Chemically, nitrogen sources are classified as either (1) **quick release** (also called **soluble source, quickly available, readily available, fast-acting,** and other terms) forms that are water soluble and available as liquids or granules, or (2) **slow release** (also called **water-insoluble, controlled release, slow acting, delayed release**, and other terms) forms, which are either coated products, control-release reacted products, or a combination of both, available as granules, powders, or suspensions. **Table 4–2** lists the most widely used nitrogen-containing turfgrass fertilizers and their characteristics while **Table 4-3** lists advantages and disadvantages of various nitrogen fertilizer sources.

Table 4–2. Primary nutrient sources and characteristics used in turf fertilizers.

NITROGEN SOURCE [FORMULA]	APPROXIMATE NUTRIENT CONTENT ($N\text{-}P_2O_5\text{-}K_2O$)	WATER-INSOLUBLE N%	SALT INDEX (FOLIAR BURN POTENTIAL) RELATIVE TO SODIUM NITRATE (100)	COMMENT
		Soluble or Inorganic Solids		
Ammonium nitrate [NH_4NO_3]	34-0-0	0	105 (v. high)	Water soluble; half N is ammonium form, the other half is the nitrate form; high burn potential; potential fire and explosive hazard; very hygroscopic (water loving) unless coated; medium acidifying effect.
Ammonium sulfate [$(NH_4)2SO_4$]	21-0-0	0	69 (high)	Water soluble; contains 24% S; often used in flooded soils. Highest acidifying effect of listed sources.
Calcium nitrate [$Ca(NO_3)_2$]	15-0-0	0	53 (high)	Very hygroscopic unless stored in airtight containers; contains 19% Ca and 1.5 % Mg; fast acting with high burn potential; nitrogen release is not temperature dependent; used on sodic soils to displace Na; has alkalinity effect.
Monoammonium phosphate (MAP) [$(NH_4)HPO_4$]	10-50-0	0	34 (low)	Soluble N and P source; preferred to DAP when applied to alkaline soils; medium acidifying effect.
Diammonium phosphate (DAP) [$(NH_4)_2HPO_4$]	18-46-0	0	30 (low)	Soluble N and P source; ammonia losses can occur on alkaline soils; medium acidifying effect.
Potassium nitrate [KNO_3]	13-0-44	0	74 (high)	Also known as saltpeter or nitre. Water-soluble K source with supplemental N; low salt concentration, low chloride, fire hazard; has alkalinity effect.
Nitrate of soda (sodium nitrate) [$NaNO_3$]	16-0-0	0	100 (v. high)	Water soluble; has highest burn potential of all materials; has alkalinity effect. Imported from Chile.
Urea [$CO(NH_2)_2$]	46-0-0	0	75 (high)	Contains 12 to 20% S; water soluble; rapid release; may volatilize if surface applied, especially under alkaline conditions; may leach rapidly if rainfall occurs immediately after application; medium acidifying effect.
		Slow, Controlled Release, or Water Insoluble Solids		
Sulfur-coated urea (or SCU) [$CO(NH_2)_2$ + S]	[31 to 37]-0-0	0	25 (low)	Contains 10 to 20 % S; slowly soluble; N release rate is temperature and coating thickness dependent; has minor acidifying effect. *SCU* is a commercial source.
Polymer sulfur-coated urea (or PCSCU)	[39 to 43]-0-0	0	25 (low)	Slowly soluble; N release rate is temperature and coating thickness dependent; low acidifying effect. *Poly-Plus, Poly-S, TriKote, Poly-X Pro, XCU.*
Methylene ureas (or MU)	40-0-0	14.5	—	Sprayable powder, dispersible granulars, and suspension formulations (18-0-0) are available. *Nutralene; MU40; METH-EX40; Chip; Contec DG, Nutri DG*. Additional nutrients may also be included.
Urea formaldehyde (or UF) [$CO(NH_2)_2 CH_2]_n CO(NH_2)_2$	[18 to 38]-0-0	~27	10 (low)	Slowly soluble; N release rate is temperature and formulation dependent; low acidifying effect. Sprayable powder formulations are available. *Nitroform; MethEx38; UF38; Powder Blue.*

NITROGEN SOURCE [FORMULA]	APPROXIMATE NUTRIENT CONTENT (N-P_2O_5-K_2O)	WATER-INSOLUBLE N%	SALT INDEX (FOLIAR BURN POTENTIAL) RELATIVE TO SODIUM NITRATE (100)	COMMENT
Isobutylidene Diurea (or IBDU) $[CO(NH_2)_2]2C_4H_8]$	31-0-0	27	5.0 (low)	Slowly soluble; N release rate is not temperature dependent but depends on moisture availability and particle size; low acidifying effect. Sprayable powder formulations are available. *Slo-Release; IBDU.*
Reactive Layer Coating (RLC)/Resin Coated Urea (RCU)	[37 to 44]-0-0	0	25 (low)	Slowly soluble; has various thickness of resin or polymer coating. Coating thickness and soil temperatures control N release rate. *Polyon, Duration, ESN, Nutricote, Multicote, Osmocote, GoldCotes.*
Meth-Ex Sulfate of Ammonia	[30 to 40]-0-0	11 to 67	low	A homogeneous mixture of quickly available ammonium sulfate and urea plus water insoluble methylene urea. Sulfur content typically ranges from 12 to 24%.
		Natural organics		
Milorganite	5-2-0	5.5	0.04 (low)	Activated sewage sludge; N release rate increases with higher temperatures; contains micronutrients, especially Fe; low acidifying effect.
Ringer Turf, Nature Safe, Earthworks, Sustane, Actinite, Hynite, + others	[5 to 18]-[1 to 6]-[5 to 6]	variable	~3.5 (low)	N is from urea, methylene ureas, ammoniacal sources, and hydrolyzed poultry feather meal, bone meal, leather tankage, fish meal, and blood; low acidifying effect.
		Solutions		
Methylol urea + urea (formaldehyde + urea)	30-0-0	30	low	*RESI-GROW GP-4340 (30-0-0); GR-4341 (30-0-2), and GR-4318; FLUF; Form-U-Sol; Homogesol-27; Slo-Release; Flormolene; CoRoN (28-0-0); Nitro-26 (26-0-0).*
Methylene ureas + urea	28-0-0	28	low	Also formulated as a suspension as 18-0-0 with 4.5% water insoluble N.
Methylene ureas + triazone	30-0-0	18	low	Nitamin. An approximate 60% combination of methylene urea + triazone with 40% urea.
Triazones + urea (formaldehyde + ammonia + urea)	28-0-0	28	low	Commercial sources include: N-Sure; Trisert; Formolene-Plus.
Ammoniated solutions	[37 to 41]-0-0	—	—	—
Ammonium polyphosphate	10-34-0	10	low	—
Ammonium sulfate	21-0-0	0	high	Contains 24% S, has acidifying effect.
Ammonium thiosulfate	12-0-0	12	high	Contains 26% S.
Ammonium nitrate	20-0-0	0	high	—
Aqueous (or Aqua) ammonia	[20 to 23]-0-0	0	high	—
Urea-ammonium nitrate	[28 to 32]-0-0	0	high	Used in colder climates where salting (precipitating) may occur.
Calcium ammonium nitrate	17-0-0	0	—	Contain 9% Ca.
Potassium nitrate	13-0-40	0	high	Has alkalinity effect.

NITROGEN SOURCE [FORMULA]	APPROXIMATE NUTRIENT CONTENT ($N_-P_2O_5-K_2O$)	WATER-INSOLUBLE N%	SALT INDEX (FOLIAR BURN POTENTIAL) RELATIVE TO SODIUM NITRATE (100)	COMMENT
Urea solution	[20 to 23]-0-0	0	—	Generally, most effective foliar N source.
Urea sulfuric acid	[10 to 28]-0-0	0	—	Contains 9 to 18% S.
Suspensions				
Methylene ureas (or MU)	18-0-0	5	24 (low)	—

Table 4–3. Advantages and disadvantages of various nitrogen fertilizer sources.

ADVANTAGES	DISADVANTAGES
Soluble (liquid), quick-release sources	
• Rapid initial color and growth response	• High potential for foliar burn, especially at higher application rates, low water volumes, and high temperatures.
• High in total nitrogen	
• Odorless	• Potentially undesirable growth surge.
• Maintain satisfactory nitrogen levels if applied frequently in small amounts	• Relatively short residual plant response; therefore, frequent applications are needed.
• Minimum temperature dependence for availability	• Greater nitrogen loss potential to volatility, leaching, and run-off.
• Low cost per unit of nitrogen	• Often difficult to handle.
• Versatile in terms of being applied as a granular or as a liquid	• Due to slower release rates, more mower removal prone.
Synthetic slow-release sources	
• Slow-release liquid sources available	• High cost per unit of nitrogen.
• High in total nitrogen	• Release rates can be confusing, depending on temperature, moisture, and soil microorganisms.
• Low potential for foliar burn	
• Potential slow-release rates over extended time; product dependent	
Organic slow-release sources	
• Controlled release rates extending color response	• Often have inconsistent release rates.
• Low potential for foliar burn	• May have unpleasant odor.
• Other nutrients (e.g., P, K, and micronutrients) often included	• High cost per unit of nitrogen.
• Viewed as a more "environmentally friendly" source	• May contain high salt or metal content (e.g., chicken manure).
• Dark color may help warm soils	

Nitrogen release (or availability) to plants from a particular carrier is facilitated by one of several mechanisms. The two most common release mechanisms include hydrolysis (dissolving of fertilizer with water) or microbial (**Table 4–4**). Microbial release (through **mineralization**) is very dependent on environment. Extreme weather conditions (too hot, cold, or dry) may reduce or delay nitrogen release from microbial degradation.

Slow-Release Nitrogen Sources. In an attempt to overcome some of the disadvantages of soluble nitrogen sources, fertilizer manufacturers have developed an array of slow or control-released nitrogen sources where the nitrogen is either slowly soluble, slowly released, or held in a natural organic form. To qualify as a slow-release fertilizer, at least 15% of the nutrient must be slowly released over a period of time. Slow-release sources are placed in one of three broad categories:

1. Organic nitrogen
2. Coated nitrate, urea, or ammonium (slowly released)
3. Chemically reacted urea to make it more slowly available

Table 4–4. Release means for the major turfgrass fertilizers.

NITROGEN SOURCE	HYDROLYSIS (MOISTURE)	MICROBIAL (TEMPERATURE) DEPENDENT[a]
Isobutylidene diurea (IBDU)	yes	—
Organic sources	—	yes
Milorganite	—	yes
Urea formaldehyde (UF)	—	yes
Poly (or resin)-coated urea (PCU)	—	yes
Methylene urea (MU)	—	yes
Sulfur-coated urea (SCU)	yes	—
Ammonium nitrate/sulfate	yes	—
Urea	yes	—
Mono- or diammonium phosphate	yes	—
Calcium nitrate	yes	—

[a]*Microbial nitrogen release generally increases with increasing temperatures, soil moisture, oxygen levels, and near-neutral soil pH.*

These sources generally provide a more uniform growth response and longer residual plant response. They also have less potential for nitrogen loss, and allow a higher application rate than readily soluble sources. In addition, their burn potentials are lower because of their low salt index values. The application rate at which these sources release nitrogen may vary with fertilizer timing, source, temperature, moisture, pH, and particle size.

Drawbacks of slow-release nitrogen sources include high per-unit cost and slow initial plant response. Some sources also are not adaptable to liquid application systems. General characteristics of several slow-release nitrogen sources are listed in **Table 4–5**.

Natural Organic Nitrogen Sources. Natural organic nitrogen sources usually involve various levels of plant composted or waste (either human or animal) materials **(Figure 4–3)**. Manure, sludges, bone meal, humates, and composted plant residues are traditional natural organic nitrogen sources **(Table 4–6)**. Nutrient contents are typically low—1 to 8 percent nitrogen; 0.2 to 6 percent phosphorus; and 0.5 to 6 percent potassium. Once applied, all organic nitrogen forms must be converted first to the ammonium form (NH_4^+) and then to the nitrate (NO_3^-) form by soil microorganisms prior to plant use. Advantages of these include low burn potential due to limited water-insoluble nitrogen, little effect on pH, and low leaching losses. Other advantages include a variety of nutrients included in addition to nitrogen, and certain organic sources that may possibly

Table 4–5. General characteristics of several slow-release nitrogen sources.

CHARACTERISTICS	SULFUR-COATED UREA (SCU)	POLYMER-COATED UREA (PCU)	UREA FORMALDEHYDE (UF)	METHYLENE UREA (MU)	ISOBUTYLIDENE DIUREA (IBDU)	NATURAL ORGANIC
Percent nitrogen	37% N	37 to 44% N	38% N	40% N	31% N	2 to 10% N
Immediately available nitrogen	3.9% N	0% N	11% N	26% N	3.1% N	10% N
Release time	6 to 8 weeks	8 to 36 weeks	2 years	8 to 12 weeks	12 to 16 weeks	8 to 52 weeks
Release mechanism	coating breakdown	osmosis	microbial	microbial	hydrolysis	microbial
Release requirements	moisture	moisture	moisture & soil temperature	moisture & soil temperature	moisture	moisture & soil temperature
Best response season	all seasons	summer	summer	summer	spring & fall	summer
Initial response	medium	slow	medium-slow	medium	medium-slow	slow
Residual effect	extended	extended	extended	extended	extended	extended
Water solubility	low	low	medium-low	medium	medium-low	low
Foliar burn potential	low	low	low	low	low	low
Soil temperature release dependence	low	medium	high	medium	low	high

Figure 4–3. A "natural" or "organic" fertilizer used on a golf course.

improve the physical condition of soils, especially sandy ones. In addition, depending on the local source, natural organic nitrogen sources may readily be available at competitive prices.

Some issues to consider before using these traditional organic sources include low nitrogen release during cool weather due to reduced microbial activity and low nitrogen content, which can result in large amounts of material having to be applied. Other considerations include greater costs on a per pound of nutrient basis than with soluble sources, and the fact that natural organic nitrogen sources may be difficult to store and to uniformly apply. This is especially true when the turf is already established. Depending on the source, some natural organic sources produce objectionable odor after application and contain undesirable salts, heavy metals, and weed seeds. In general, natural organic sources such as manures and composted crop residues should not be used on golf greens because of potential soil drainage hindrance from the large amounts of material applied and from inorganic ash such as sand, silt, and clay remaining after the organic matter is combusted. As some of the handling and application problems are resolved, future use of municipal refuse and sewage sludge in turf production will probably increase.

Table 4–6. Approximate amounts of macronutrients often found in common organic fertilizer sources.

	NITROGEN (N)	PHOSPHATE (P_2O_5)	POTASH (K_2O)
NUTRIENT SOURCE	%		
Animal byproducts			
Dried blood	13	2	1
Blood meal	10 to 14	1 to 2	0.6 to 1.
Bone meal, steamed	3	25	0
Dried fish meal	10	7	0
Tankage, animal	7	8.5 to 10	0.5 to 1.5
Excreta			
Cattle manure	2 to 5	1.5	2
Guano, bat	8.5	5	1.5
Horse manure	2 to 8	1 to 3	2 to 7
Poultry manure	5 to 15	3	1.5
Sewage sludge, dried	2	2	—
Sewage sludge, activated	6	3	0.5
Swine manure	7	4	6
Plant residues			
Alfalfa meal	2	1	1
Cottonseed meal	7	3	2
Garbage tankage	2.5	3	1
Linseed meal	5.5	2	1.5
Rapeseed meal	5.5	2.5	1.5
Soybean meal	7	1.5	2.5
Tobacco stems	2	0.5	6
Turkey/Rice hull litter	1.8	2.7	1.9

4.3 LIQUID FERTILIZERS AND FERTILIZATION

Foliar liquid fertilization (commonly referred to as foliar feeding) involves the use of a soluble nutrient form for plants **(Figure 4–4)**. This concept is over 100 years old and provides quicker utilization of nutrients. It also permits correction of deficiencies in less time than soil treatments. However, the response is often temporary. Due to the small amounts required, micronutrient applications have traditionally been the most prominent use of foliar sprays. A difficulty in applying sufficient amounts of macronutrients such as nitrogen, phosphorus, and potassium without leaf burn also has been a problem. Other advantages and disadvantages of foliar liquid fertilization include:

Advantages

1. It has no segregation of particles, as is common with granulars.
2. It provides nutrients directly to plants and is not influenced by soil properties.
3. It contains water-soluble forms of nutrients, which quickly correct plant nutrient deficiencies.
4. Co-application with pesticides is possible.
5. It is generally easier to handle and quicker to apply, with a greater flexibility in timing and rate use.
6. It utilizes a lower cost of energy, labor, and equipment.

Disadvantages

1. More difficult to monitor application amounts - the number of bags cannot be counted, requiring the operator and meter to be trusted.
2. Some solutions may salt-out at lower temperatures, especially when used with water high in calcium, magnesium, and bicarbonate.
3. Problems with sufficient application amounts without causing severe leaf burn.
4. Frequent applications at low rates may be necessary because turf response is temporary and low rates prevent leaf burn.
5. Fertilizer distribution depends on water-distribution patterns.
6. Ammonium nitrogen sources may volatilize.
7. Some foliar applied nutrients are immobile in plants (e.g., Ca^{+2}, Fe^{+3}, Mn^{+2}, Si) while others are only partially mobile (e.g., S, Zn^{+2}, Cu^{+2}, Mo, B). Granular forms of these nutrients should be applied to ensure plant availability. Tissue sampling should also be performed to track nutrients in the plants and identify any deficiencies.

Figure 4–4. Applying a liquid fertilizer at low rates to prevent unwanted growth surges and to help preserve natural resources.

Foliar feeding involves using low fertilizer rates (e.g., 1/8 lb N or Fe per 1,000 sq.ft., 0.6 g/m^2) in low water application volumes (e.g., 0.5 gal per 1,000 sq.ft., 2 L/100 m^2) compared to higher application volumes for liquid fertilization. Low nutrient and spray volumes are used to minimize costs and to supplement the normal fertilization program with nutrients absorbed directly by turfgrass leaves. Urea is a popular nitrogen form used for foliar application. Because of its water solubility, urea is the most widely used fertilizer material and is often mixed with ammonium nitrate or potassium nitrate **(Table 4–2)**. Liquid urea is characterized by a quick response in terms of turf color and a medium-to-high burn potential. However, to reduce burn, foliar feeding should be limited to low light intensities, mild (<85°F, 29°C) temperatures, and when the plant surface is dry at the time of application. The remaining soluble nitrogen sources are mixtures of urea and water-soluble short-chain methylene ureas. Nitrogen release from these methylene ureas is by rapid microbial degradation. This provides a quick plant response, and has less potential for foliar fertilizer burn. These also are sometimes called controlled-release nitrogen forms.

Liquid fertilization involves using higher spray volumes (e.g., 3 to 5 gal per 1,000 sq.ft., 12 to 20 L/m^2), to wash the fertilizer off the leaves, increasing root absorption. With liquid fertilization, fertilizers and pesticides often are applied together.

Phosphorus

Phosphorus (P), the third-most essential element for plant growth (behind N & K), is involved in the transfer of energy as the organic compound, adenosine triphosphate (ATP), during metabolic processes. It also is an essential component of DNA, RNA, and cellular membranes **(Table 4-1)**. Phosphorus content may range between 0.10 to 1.00

Figure 4–5. Bluish-purple turf indicating phosphorus deficiency.

percent by weight, with sufficiency values from 0.20 to 0.40 percent in newly mature leaf tissue. Phosphorus is considered deficient when tissue levels are below 0.20 percent and excessive above 1.00 percent. The highest concentration of phosphorus is in new leaves and their growing point, but it is readily mobile in plants.

Since phosphorus is fairly mobile within plants, deficiency symptoms initially occur in older tissue. Symptoms of phosphorus deficiencies include slow growth, as well as weak and stunted plants possessing dark-green lower, older leaves **(Figure 4–5)**. These older leaves eventually show a dull blue-green color with a reddish-purple pigmentation along the leaf blade margins due to sugar accumulation in phosphorus-deficient plants. Eventually, leaf tips turn reddish, and may then develop in streaks down the blade.

Phosphorus deficiency symptoms normally occur when root growth of turf plants is restricted, and when soil temperatures and oxygen levels decrease. Since roots are a principal site for energy (carbohydrate) storage, they are very dependent on adequate phosphorus levels. Early spring and fall are two seasons in which root growth is slowed; hence, phosphorus in the soil is not readily encountered. Similarly, phosphorus deficiencies often occur during turfgrass establishment, resulting from the initial restricted rooting of new seedlings. Establishment in sandy soils also may also cause problems due to phosphorus deficiencies. Research indicates a 1:2:1 or 1:2:2 ratio of N–P–K as best for turfgrass establishment.

The first phosphorus fertilizer was manufactured in England around 1830 from treating ground bones with sulfuric acid (H_2SO_4) to increase the solubility (or availability) of the phosphorus. Today, the most common phosphorus fertilizers used in turf include superphosphate, triple (or treble) superphosphate, and monoammonium and diammonium phosphate (MAP and DAP, respectively) **(Table 4–7)**. Superphosphate consists of calcium phosphate and gypsum. It is produced by reacting rock phosphate with sulfuric acid or phosphoric acid (H_3PO_4). Triple superphosphate is calcium phosphate formed when rock phosphate is treated with phosphoric acid, while ammonium phosphates are produced by reacting anhydrous ammonia with phosphoric acid. Ammonium polyphosphates are used primarily in liquid fertilizer and are formed by reacting ammonia with superphosphoric acid.

The available phosphorus content in fertilizers is expressed as P_2O_5, which is ~44% phosphorus. To determine the actual phosphorus content from the percent P_2O_5 in a fertilizer, the following conversion is needed:

percent P_2O_5 as expressed on fertilizer bag x 0.44 =
percent phosphorus in fertilizer bag

Phosphorus does not move or leach readily in soils due to its low solubility in the soil solution; therefore, phosphorus applications are not needed as regularly as nitrogen applications. A soil test is probably the best indicator of phosphorus levels in a soil. Indiscriminate phosphorus applications can form unhealthy, high levels of phosphorus. Iron deficiencies, for example, often result from high phosphorus-containing and/or alkaline soils. Phosphorus is most readily available to plants with the soil pH range of 5.5 to 6.5. At low pH (<5.0), soils containing iron and aluminum form an insoluble complex with phosphorus, resulting in neither nutrient being easily available to the grass. For example, with aluminum and/or iron, phosphorus at low pH can react to form variscite [$Al(OH)_2H_2PO_4$] from aluminum or strengite [$Fe(OH)_2H_2PO_4$] from iron.

Potassium

Potassium (K) is an essential element not normally associated with a prominent visual response in terms of shoot color, density, or growth. However, it helps plants overcome some of the negative effects of excessive nitrogen fertilization such as decreased stress tolerance to cold, heat, drought, diseases, and wear **(Figure 4–6)**. Potassium is often called the "health" element since an ample supply increases the plant's tolerance to these stresses ***(Table 4–1)***.

The critical level of potassium in plants is about fourfold that of phosphorus and almost the same as nitrogen. Dry matter of leaf tissue consists of 1.0 to 5.0 percent potassium. Sufficient values range from 1.0 to 3.0 percent in recently matured leaf tissue. Potassium deficiency occurs when tissue levels are less than 1.0 percent and excessive when greater than 4.0 percent. However, most plants can absorb more potassium than needed; this is often referred to as **luxury consumption**. Also, an inverse relationship exists between potassium, magnesium, and calcium in plants. As potassium levels increase, magnesium deficiencies are the first to show, while calcium deficiencies occur at higher concentrations. In saline soils, an inverse relationship can occur where calcium, magnesium, or sodium ions compete with potassium for plant uptake.

Table 4–7. Primary phosphorus sources and characteristics used in turf fertilizers.

SOURCE	APPROXIMATE NUTRIENT CONTENT ($N\text{-}P_2O_5\text{-}K_2O$)	SALT INDEX (FOLIAR BURN POTENTIAL) RELATIVE TO SODIUM NITRATE (100)	COMMENT
Monoammonium phosphate (MAP) [$(NH_4)H_2PO_4$]	10-50-0	34 (low)	Soluble P source that also provides N; preferred to DAP when applied to alkaline soils; contains 1 to 2 % sulfate (SO4-); medium acidifying effect.
Diammonium phosphate (DAP) [$(NH_4)_2HPO_4$]	18-46-0	30 (low)	Soluble P source containing higher N than MAP while also reducing soil pH; preferred to MAP on acidic soils. Significant ammonia losses on alkaline soils can occur; medium acidifying effect.
Superphosphate [$Ca(H_2PO_4)2$ + $CaSO_4$]	0-20-0	8 (low)	Soluble P source often used in mixed fertilizers; contains Ca (18 to 21%) and S (12%) as gypsum; neutral acidifying effect.
Triple (or treble) superphosphate [$Ca(H_2PO_4)_2H_2O$]	0-46-0	10 (low)	Concentrated P source containing Ca (13%); neutral acidifying effect.
Ammonium polyphosphate [$NH_4H_2PO_4 + (NH_4)_3HP_2O_7)$]	10-34-0	2 (low)	A liquid P and N solution source; used in fluid fertilizers. Grades of 11-37-0, 8-24-0, and 9-30-0 are also available.
Phosphoric acid [H_2PO_4]	0-55-0	— (high)	Very caustic. Primarily used to make triple superphosphate, ammonium phosphate, and in fluid fertilizer.
Milorganite	6-2-0	3 (low)	Activated sewage sludge; N release rate increases with higher temperatures; contains micronutrients, especially Fe; low acidifying effect.
Colloidal phosphate	0-8-0	—	Contains 20 percent Ca; low P availability; best used as a powder on acid soils; neutral acidifying effect.

Deficiencies may occur in soils low in micas (the more-soluble mineral source), soils low in clay (fewer exchange sites), and soils high in sand, which are prone to leaching. Potassium deficiency symptoms include interveinal yellowing of older leaves, and the rolling and burning of the leaf tip. Leaf veins finally appear yellow and margins appear scorched (called necrosis). The turf stand will appear thin with spindly growth of individual plants. Potassium is a mobile element within plants; thus, it can be translocated to younger meristematic tissues from older leaves if a shortage occurs, while necrotic spots may form a unique pattern on the leaf margin in certain plants. Although similar in appearance, plant salinity damage differs by affecting newer leaves compared to older leaves with potassium deficiency.

Muriate of potash (potassium chloride) is the most often used potassium-containing fertilizer **(Table 4–8)** and originates from potassium salt deposits that have been mined and processed. These deposits developed where seawater once occupied the surface. Sodium chloride from this seawater normally is found as a contaminant of the potassium mines. Magnesium salts also are often found concurrently with potassium salts. As seawater evaporated, potassium salts crystallized to become beds of potassium chloride. A white soluble grade is used as a fluid source. Potassium sulfate forms when potassium chloride is reacted with sulfuric acid, and potassium nitrate forms when it is reacted with nitric acid. These forms are used to reduce the salt index compared to potassium chloride and are also carriers of sulfur and nitrogen, respectively.

Figure 4–6. Weed infested, unhealthy appearing turf indicating potassium deficiency.

The soluble potassium content in a fertilizer is expressed as K_2O, which is ~83% potassium. To determine the quantity of actual potassium supplied in a fertilizer source, the following conversion is used:

percent K_2O as expressed on the fertilizer bag x 0.83 = percent potassium in the fertilizer bag

Competition exists for plant uptake between potassium, calcium and magnesium. Soils high in either or both calcium and magnesium will need additional potassium fertilization in order to satisfy plant needs. In sandy soils, or where turf clippings are not returned, a 2:1 or 1:1 ratio of nitrogen to potassium may be required to maintain adequate potassium supply. Frequent, light potassium treatments with these ratios should be considered with each nitrogen application.

Table 4–8. Primary potassium sources and characteristics used in turf fertilizers.

SOURCE	APPROXIMATE NUTRIENT CONTENT ($N\text{-}P_2O_5\text{-}K_2O$)	SALT INDEX (FOLIAR BURN POTENTIAL) RELATIVE TO SODIUM NITRATE (100)	COMMENT
Muriate of potash (potassium chloride) [KCl]	0-0-[50 to 63]	116 (high)	Most common K source; water soluble granular; high burn potential; contains ~46 percent Cl; neutral acidifying effect.
Sulfate of potash (potassium sulfate) [K_2SO_4]	0-0-[40 to 54]	46 (moderate)	Soluble granular source containing 17% S; used instead of potassium chloride where chlorine is not desirable, to reduce foliage burn potential, and to provide sulfur; may not leach as rapidly as potassium chloride; neutral acidifying effect. Made by reacting KCl with sulfuric acid.
Potassium-magnesium sulfate (or K-Mag or Sul-Po-Mag) [$K_2SO_4 \cdot 2MgSO_4$]	0-0-[18 to 22]	43 (moderate)	Contains 11 percent magnesium and 23 percent sulfur; also known as langbeinite; neutral acidifying effect.
Potassium nitrate [KNO_3]	13-0-[37 to 45]	74 (high)	Also known as saltpeter or nitre; produced by reacting KCl with nitric acid (HNO3); K source with supplemental N; water soluble; low salt concentration, low chloride, fire hazard; has alkalinity effect. Used as a foliar source.
Potassium carbonate [K_2CO_3]	0-0-[34 to 48]	—	Granular and liquid forms available

4.4 SECONDARY PLANT NUTRIENTS

Secondary elements consist of calcium, magnesium, and sulfur. Dolomitic limestone provides calcium and magnesium to deficient soils while sulfur is added by sulfur-containing fertilizers. Sulfur is also provided by acidifying materials to lower soil pH, such as elemental sulfur; by desalinization materials such as gypsum; by rainwater containing the air pollutant sulfur dioxide; or from salts of nitrogen, magnesium, potassium, and various micronutrients.

Calcium

Calcium (Ca), magnesium (Mg), and **sulfur (S)** are elements required in almost the same quantities as phosphorus. Calcium functions include strengthening cell walls to prevent their collapse; enhancing cell division; encouraging plant growth, protein synthesis, carbohydrate movement; and balancing cell acidity **(Table 4–1)**. Calcium also improves root formation and growth.

Plants only use the exchangeable calcium ion, Ca^{+2}. Deficiencies occur most often in sandy soils with low cation exchange capacity (CEC), extremely acidic (<5.0 pH) soils, or soils saturated with sodium. Long-term use of effluent water high in sodium or aluminum may also induce calcium deficiency, as can heavy applications of ammonium, potassium, or magnesium fertilizers.

Calcium is an immobile nutrient within plants. It does not move from older leaves to new ones and must be continuously supplied or young leaves will show deficiency symptoms early. It also does not move appreciably in the plant when foliar applied. Calcium is usually added in a liming program, by irrigation with high-calcium-containing water, or naturally through high pH soils. Commercial sources of calcium include calcitic and dolomitic limestone, gypsum, superphosphates, calcium nitrate, shells, slags, and water-treatment residue **(Table 4–9)**. When lime is not needed, gypsum or some other calcium source should be considered.

Magnesium

Magnesium is essential for chlorophyll production in plants, as chlorophyll molecules contain approximately 7 percent magnesium. Magnesium also is essential for many of the energy reactions, such as sugar formation. It acts as a carrier of phosphorus and regulates uptake of other plant

Table 4–9. Primary calcium and magnesium sources and characteristics used in turf fertilizers.

	APPROXIMATE NUTRIENT CONTENT	
SOURCE	N-P_2O_5-K_2O	COMMENT
Gypsum (calcium sulfate) [$CaSO_4 \cdot 2H_2O$]-anhydrite	0-0-0	Contains 23% Ca + 19% S; neutral effect on soil pH; used to displace soil sodium.
-hydrated	0-0-0	Contains 19% sulfur and 33% calcium oxide; has little effect on soil pH; used to displace soil sodium.
Calcium nitrate [$Ca(NO_3)_2$]	16-0-0	Very hygroscopic; contains 24% Ca and 1.5% Mg; fast acting with high burn potential; N release is not temperature dependent; used on sodic soils to displace sodium.
Dolomitic limestone [$CaMg(CO_3)_2$]	0-0-0	Used to increase soil pH; contains 22% Ca and 13% Mg; very slowly available; low salt hazard.
Superphosphate [$Ca(H_2PO_4)_2 + CaSO_4$]	0-20-0	Soluble P source often used in mixed fertilizers; contains Ca (18 to 21%) and S (12%) as gypsum.
Triple (or treble) superphosphate [$Ca(H_2PO_4)_2H_2O$]	0-46-0	Concentrated P source also containing Ca (13%).
Calcitic limestone (calcium carbonate) ($CaCO_3$)	0-0-0	Contains 40% Ca; used to raise soil pH; very low salt hazard.
Magnesium sulfate (or Epsom salt) [$MgSO_4$]	0-0-0	Contains 13 to 23% S and 10 to 17% Mg; water soluble; neutral salt with little effect on soil pH.
Potassium magnesium sulfate (or Sul-Po-Mag or K-Mag) [$K_2SO_4 \cdot 2MgSO_4$]	0-0-[18 to 22]	Contains 23% S and 11% Mg; water soluble.
Magnesium oxide (or Magnesia) [MgO]	0-0-0	Contains 55% Mg; high salt hazard.

nutrients. Deficiencies occur mostly in acidic sandy soils with low CEC or soils of extremely high pH, especially when clippings are continuously removed. Deficiencies can occur in soils with less than 40 pounds per acre (4.5 g/m^2) of Mehlich-I extractable magnesium. Magnesium generally constitutes about 4 to 20 percent of a soil's CEC, compared with up to 80 percent for calcium and 5 percent for potassium. High calcium and potassium levels tend to reduce magnesium uptake.

Magnesium is a mobile element in the plant and is easily translocated from older (bottom-most) to younger plant parts as needed. Symptoms of deficiency include a general loss of green color starting at the bottom (older) leaves. Interveinal chlorosis then occurs; veins remain green, and older leaf margins turn a blotchy cherry-red with a striped appearance of light yellow or white between the parallel veins. Necrosis eventually develops. Interveinal chlorosis can be caused by other deficiencies, but happens more so in neutral-to-alkaline soils. Therefore, a simple soil pH test can help narrow the potential deficiency problem to magnesium. Magnesium deficiency can occur when (1) the soil pH is less than 5.5; (2) an imbalance occurs among the other major cations, potassium (K^+) and calcium (Ca^{+2}); and, (3) plants are under stress for an extended period such as the soil being too wet, dry, or cold, and when root growth is limited. Sources of magnesium include dolomitic limestone, sulfates of potash and magnesium, magnesium sulfate (Epsom salt), oxide, and chelates **(Table 4–9)**. When lime is not needed, magnesium sulfate should be considered. A practical test to determine if magnesium deficiency is occurring on your turf is to apply one pound (454 g) of Epsom salts in three to four gallons of water over 1,000 square feet (12 to 16.3 L/m^2). If the turf greens up within 24 hours or so, magnesium deficiency should be suspected.

Balance Between Potassium, Calcium, and Magnesium. Soils should have a balance of these three major cations and if this balance is not maintained, the availability and uptake of one or more of these can be limited. Soils have a good balance if the total cation exchange capacity is about 60 to 80% Ca, 10 to 15% Mg, and 2 to 5% K.

Table 4–10. Primary sulfur sources and characteristics used for turf fertilizer.

SULFUR (S) CARRIERS [FORMULAS]	APPROXIMATE NUTRIENT CONTENT		COMMENT
	SULFUR (S)	OTHERS	
Gypsum (calcium sulfate) [$CaSO_4 \cdot 2H_2O$]	16 to 24	20% Ca	Granular source; commonly used on sodic soil.
Elemental sulfur [S]	up to 99	—	Oxidizes to sulfuric acid and lowers pH; foliage burn potential; available as a granular or suspension; slow acting; requires microbial oxidation; eye irritant.
Epsom salts (magnesium sulfate) [$MgSO_4$]	13 to 23	10 to 17% Mg	Granular and liquid forms available; neutral salt with little acidifying effect.
Ferrous sulfate [$FeSO_4 \cdot 7H_2O$]	19	21% Fe	Water soluble; usually applied foliarly.
Ferrous ammonium sulfate [$(NH_4)_2$ $FeSO_4 \cdot 6H2O$]	15	14% Fe + 7 % N	Water soluble; usually applied foliarly.
Ammonium thiosulfate [$(NH_4)2S_2O_3 + H_2O$]	26	12% N	Most widely used sulfur source in clear liquid fertilizers; foliage burn potential.
Potassium thiosulfate [$K_2S_2O_3$]	17	25% K_2O	Liquid form.
Potassium magnesium sulfate (or K-mag or Sul-Po-Mag) [$K_2SO_4 \cdot 2MgSO_4$]	22	22 % K_2O + 11% Mg	Commonly used on alkaline soils.
Ammonium sulfate [$(NH_4)2SO_4$]	24	21% N	Water soluble granular; high acidifying potential.
Sulfur-coated urea (or SCU) [$CO(NH_2)_2 + S$]	10 to 20	32% N	Slowly soluble.
Superphosphate [$Ca(H_2PO_4)_2 + CaSO_4$]	12	20% P_2O_5 + 20% Ca	Soluble P that contains gypsum (calcium sulfate); has little acidifying effect.
Potassium sulfate (or sulfate of potash) [K_2SO_4]	17	50% K_2O	Granular and liquid forms; used instead of potassium chloride to reduce foliage burn potential and to supply S.
Sulfuric acid [H_2SO_4]	20 to 33	—	Liquid injection in irrigation water; corrosive and caustic.
Urea-sulfuric acid [$CO(NH_2)2 \cdot H_2SO_4$]	9 to 18	10 to 28% N	Liquid injection in irrigation water; corrosive and caustic.

Table 4–11. Micronutrient forms, deficiencies, and sources for turf managers.

NUTRIENT	DEFICIENCY OCCURRENCE	DEFICIENCY SYMPTOMS	FERTILIZER SOURCES
Iron (Fe)	Iron levels in soils often are sufficient; however, soil conditions often render them unavailable. Deficiency occurs with excessive soil pH (>7.0), calcium, zinc, manganese, phosphorus, copper, and bicarbonates (HCO3) levels in irrigation water; poor rooting, poor soil drainage, thus, have low soil oxygen levels, and cold soils also are associated with deficiency. Often seen in summer on wet soils following rainfall. At low soil pH, phosphorus can combine with iron to form insoluble (unavailable) iron phosphate while at high pH, excessive phosphorus uptake by plants may inactivate absorbed iron. For each increase in pH, there is a 100-fold decrease in soluble Fe^{+2}. A plant tissue ratio of phosphorus-to-iron at 29:1 also provides healthy turf while a phosphorus-to-iron ratio of 40:1 often expresses iron deficiency. An iron-to-manganese ratio of 2:1 in plant tissue also has been suggested. Heavy metals and/or bicarbonates from effluent water or sewage sludge as a soil amendment may also compete with iron for plant uptake. Deficiency symptoms are most severe during warm days/cool nights (e.g., early spring and fall) when root growth is insufficient to support shoot growth.	Chlorosis resembling nitrogen deficiency except iron chlorosis is interveinal (e.g., between leaf veins) and first occurs in the youngest leaves since iron is immobile within plants. Older leaves are affected later. Nitrogen deficiency causes the entire leaf, including veins, to simultaneously yellow. Iron-deficient leaves finally turn white. Iron chlorosis tends to be in random scattered spots, creating a mottled appearance, and appears more severe when closely mowed. Nitrogen deficiency develops uniformly over a large area and appears unaffected by mowing. Management practices which help reduce Fe deficiency include lowering soil pH, improving drainage, reducing phosphorus fertilization, and applying Fe-containing foliar sprays. Excessive iron levels can induce manganese deficiency and leaf blackening. Anaerobic, acidic, poorly drained soils can produce toxicity levels of soluble iron. Soil and tissue tests are often poor indicators for Fe deficiency. Apply a solution of 2 oz (57 g) iron sulfate in 3 gallons (11 L) of water and spray the turf to the drip point to indicate if Fe deficiency is occurring.	**Ferrous sulfate** [$FeSO_4 \bullet 7H_2O$] (19 to 21% Fe and 19% S); usually foliarly applied; low acidifying effect; water soluble. **Ferric sulfate** [$Fe_2(SO_4)_2 \cdot 4H_2O$] 23% Fe; water soluble. **Ferrous ammonium sulfate** [$FeSO_4 \bullet (NH_4)2SO_4$] (5 to 14% Fe, 16% S, and 7% N); usually foliarly applied; also provides some nitrogen; medium acidifying effect; water soluble. **Ferrous ammonium phosphate** [$Fe(NH_4)PO_4 \bullet H_2O$] 29% Fe, water soluble. **Chelated iron** [Fe salts of -EDTA, -HEDTA,-EDDHA, or -DTPA] (5 to 14% Fe); longer greening effect than the other iron sources; low acidifying effect; water soluble. **Iron frits** (14% Fe). **Ferrous oxide** [FeO] 77% Fe. **Ferric oxide** [Fe_2O_3] 69% Fe. **Iron Humate** [FeH] 15 to 45% Fe + humic and fulvic acids; slow release; byproduct of potable water treatment.
Zinc (Zn)	Alkaline soils decrease solubility and availability, as does excessive soil Cu^{+2}, Fe^{+2}, and Mn^{+2} and excessive soil moisture, nitrogen, and phosphates. Zinc solubility increases 100-fold for each decreased pH unit. Above pH 7.7, zinc becomes $Zn(OH)^+$. Lower light intensities reduce root uptake. Sands also are likely to have lower zinc levels than clays. Some mine spoils and municipal wastes may contain high levels of zinc.	Interveinal chlorosis in both younger and some older leaves; mottled-chlorotic leaves, rolled and thin leaf blades; stunted, shortened internode growth; dark, desiccated-looking leaves (starting with the youngest ones); leaves finally turn white in appearance. Excessive zinc may inhibit root and rhizome development and induce iron and magnesium deficiencies.	**Zinc sulfate** [$ZnSO_4 \bullet H_2O$] (35% Zn and 12% S); water soluble, foliarly applied. **Zinc chelate** [NaZnEDTA] (9 to 14% Zn); foliarly applied. **Zinc oxide** [ZnO] (78% Zn); water soluble, foliarly applied. **Zinc frits**; (4 to 7% Zn). **Zinc carbonate** [ZnCO3], 53% Zn. Zinc nitrate [$Zn(NO_3)_2 \bullet 6H_2O$], 22% Zn, 9% N). **Soil applied zinc chloride** [$ZnCl_2$], 48% Zn, water soluble. Certain fungicides (e.g., chlorothalonil-Zn).

NUTRIENT	DEFICIENCY OCCURRENCE	DEFICIENCY SYMPTOMS	FERTILIZER SOURCES
Manganese (Mn)	Deficiencies occur in sand, peat, and muck soils (insoluble complexes are formed), alkaline soils high in calcium (for each increase in pH, there is a 100-fold decrease in soluble Mn^{+2}); at low temperatures; and in poor drainage. Excess iron, copper, zinc, potassium, and sodium in low cation exchange capacity soils can reduce manganese adsorption. An iron-to-manganese ratio in leaf tissue should be at least 2:1. Adjusting soil pH to below 7.0 usually reduces manganese deficiencies.	Yellowing (chlorosis) between veins (interveinal) of the youngest leaves, with veins remaining dark-green to olive-green in color since manganese is an immobile element within the plant; small, distinct necrotic leaf spots develop on older leaves; leaf tips may turn grey to white, droop, and wither. On closely mowed turf, mottled or blotchy appearance develops, with little or no response to nitrogen occurring. Toxicity can occur with anaerobic soils with pH < 4.8. Excessive manganese levels can induce iron, calcium, or magnesium deficiencies. Apply 1 oz (28 g) of manganese sulfate (techmangum) in 2 gallons (7.6 L) water to the point of drip for diagnosis purposes.	**Manganese sulfate** [$MnSO_4$•H_2O] (26 to 28% Mn and 13%S); foliarly applied. **Manganese oxide** [MnO] (33 to 77% Mn). **Mancozeb fungicides**; (16% Mn and 2% Zn); water soluble. **Manganese chelates** [Na_2Mn EDTA] (5 to 12% Mn); water soluble. **Tecmangam**: (20 to 25% Mn). **Manganese frits** (3 to 6% Mn). **Manganese chloride** [$MnCl_2$] (17% Mn); water soluble.
Copper (Cu)	Deficiency mostly occurs in sand, peat, muck, and high (>5%) organic soils due to their tight binding properties for copper. Excess iron, nitrogen, phosphorus, and zinc, highly leached soils, and high soil pH encourage deficiency. Toxic levels can result from excess sewage sludge applications, use of poultry manures, copper sulfate, and copper-containing pesticides such as Bordeau mixture. Liming to pH 7.0 is often the simplest means of overcoming copper phytotoxicity. Reducing nitrogen fertilization may also help.	Deficiencies are rare. Deficiency symptoms include yellowing and chlorosis of younger leaf margins; leaf tips initially turn bluish, wither, and droop, eventually turn yellow, and die; youngest leaves become light-green, and necrotic; plant dwarfing with inward rolling of leaves that develop a blue-green appearance; symptoms progress from the leaf tips to the base of the plant. Toxicity symptoms of excessive levels include reduced shoot vigor, poorly developed and discolored root systems, and leaf chlorosis resembling iron deficiency. Excessive copper levels suppress uptake of iron, manganese, zinc, and molybdenum.	**Copper sulfate** [$CuSO_4$•$5H_2O$] (13 to 53% Cu and 13% S); foliarly or soil applied. **Copper oxide** [CuO] (40% Cu); foliarly or soil applied. **Copper chelates** [CuEDTA] (9 to 13% Cu); foliarly applied. **Copper chloride** [$CuCl_2$], 47% Cu), foliarly or soil applied.
Boron (B)	Organic matter is the principal source of boron; availability increases with decreasing soil pH; deficiencies are most common in high (>6.5) pH, leached, or very dry, sandy soils. Calcium also decreases translocation of boron in plants. Liming acidic soils frequently causes a boron deficiency. Excessive levels (> 6ppm) may occur with high boron containing irrigation water, arid and semi-arid soils, and some composts.	Thickening, curling, and chlorotic leaves develop on dwarf (rosette) plants; chlorotic streaks develop in the interveinal areas. Leaf tips turn pale green. Plants develop a "bronze" tint. Boron is immobile within the plant; symptoms, therefore, first appear in meristematic tissues and young leaves. Deficiencies are infrequent in turf.	**Borax** (sodium borate) [$Na_2B_4O_7$•$10H_2O$] (11% B and 9% Na). **Boric acid** [H_3BO_3] 10 to 17% B. **Fertilizer borate** [sodium tetraborate, $Na_2B_4O_7$•$5H_2O$, 14 to 21% B; **Sodium pentaborate**, $Na_2B_{10}O_{16}$•$5H_2O$, 18% B]. **Solubor** [$Na_2B_4O_7$•$4H_2O$ + $Na_2B_{10}O_{16}$•$10H_2O$] (20% soluble B). **Ammonium pentaborate** [$NH_4B_5O_6$•$4H_2O$] (20% B).

NUTRIENT	DEFICIENCY OCCURRENCE	DEFICIENCY SYMPTOMS	FERTILIZER SOURCES
Molybdenum (Mo)	Availability increases with increasing soil pH; deficiencies are most common in acid sands or highly weathered soils; excess copper, iron, manganese, or sulfate may reduce Molybdenum utilization by plants. Deficiencies often occur in ironstone soils of Australia, New Zealand, and Holland.	Resembles mild nitrogen deficiency with pale yellow-green stunted plants; mottled yellowing of interveinal areas then appear in older leaves. Deficiencies are rare. Lime acid soils.	**Ammonium molybdate** [$(NH_4)_2MoO_4$] (54% Mo); liquid. **Sodium molybdate** [Na_2MoO_4•H_2O] (40% Mo); water soluble. **Molybdenum trioxide** [MoO3] (66% Mo). Molybdic oxide (47% Mo). Molybdenum frits (fritted glass), 2 to 3% Mo.
Chlorine (Cl)	Less available in alkaline soils, or soils high in NO_3^- and SO_4^{-2}; very mobile in acid-to-neutral soils. Toxic levels reduce water availability to plants; cause premature leaf yellowing, leaf tip, and margin burning; and leaf bronzing and abscission.	Chlorosis of younger leaves and wilting of plants; not mobile within plants and accumulates in older parts. Deficiencies are rare. Chlorine is most commonly applied in large quantities along with the potassium source in fertilizers.	**Ammonium chloride** [NH_4CL] (66% Cl, 25% N); acid-forming fertilizer. **Calcium chloride** [CaC_{l2}] (65% Cl). **Magnesium chloride** [MgC_{l2}] (74% Cl). **Potassium chloride**: [KCl] (47% Cl, 60% K). **Sodium chloride** [NaCl] (60% Cl, 40% Na).

Sulfur

Sulfur is essential for the selective amino acids cystine, cysteine, and methionine. It is used as a building block of proteins and chlorophyll, and also reduces diseases. The acidifying effect of sulfur also may increase the availability of essential elements such as iron, manganese, zinc, and phosphorus, as well as help reclaim sodic soil. Sulfur content in leaf tissue ranges from 0.15 to 0.50 percent of the dry weight. Most plants use comparable sulfur quantities as phosphorus and magnesium.

The sulfate anion (SO_4^{-2}) is the primary available form found in soil solution. Like nitrate, the sulfate ion can leach from soil. Deficiencies may occur when soil organic matter is low, grass clippings are removed, excessive watering occurs, and non-irrigated (no sulfate from water) and sandy soils predominate. Deficiency symptoms resemble nitrogen deficiency and include an initial light yellow-green color, with yellowing being most pronounced in younger leaves, since sulfur has limited mobility in plants. Older leaves become pale, then turn yellowish-green, in interveinal areas. Leaf tips are scorched along the margins. Roots tend to be longer than normal and stems become woody. Tissue testing is often necessary to distinguish between sulfur and nitrogen deficiencies. Grass grown in sandy soils has been shown to respond to sulfur applications.

Sulfur sources include gypsum (16 to 24% S); elemental sulfur (up to 99% S); ferrous sulfate (19% S, 20% Fe); liquid form ammonium thiosulfate (26% S, 12% N); potassium magnesium sulfate (or K-Mag or Sul-Po-Mag, 22% S, 22% K, 11% Mg); ammonium sulfate (24% S, 21% N); sulfur coated urea (10 to 17% S, 32% N); and potassium sulfate (17% S, 50% K) **(Table 4–10)**.

In poorly drained waterlogged soils, sulfur-containing materials can be reduced to toxic hydrogen sulfide (H_2S) by sulfate-reducing bacteria. Excessive applications of elemental sulfur to golf greens also may encourage hydrogen sulfide buildup. In addition, insoluble sulfides may form by reacting with soil iron or manganese.

Turf soils containing toxic levels of hydrogen sulfide or iron sulfate are acidic and commonly form a "black layer" several inches below the soil surface. They typically are characterized by the distinct hydrogen sulfide (e.g., sewer or rotten egg) smell. Low soil oxygen also has reduced states of manganese, copper, and iron and result in gray and blue-colored subsoils. This often occurs in poorly drained, anaerobic soils.

4.5 MICRONUTRIENTS

Micronutrients, as previously discussed, are essential elements needed in relatively small (e.g., <50 ppm) amounts. These include boron (B), chlorine (Cl), copper (Cu), iron (Fe), manganese (Mn), molybdenum (Mo), and zinc (Zn) **(Table 4-11)**. Many soils supply sufficient levels of micronutrients to the point they do not need to be added. In other cases, enough micronutrients are supplied in fertilizers as impurities. Deficiencies in micronutrients can become a problem, especially in areas with sandy and peat or muck soils; pockets of high pH and phosphorus-containing soil; and poor drainage or periods of extended, heavy rainfall **(Table 4-12)**. Due to the high sand content of many golf greens and extremes in soil pH, micronutrient management is important for superintendents **(Figure 4–7)**. For example, as soil pH is increased, iron changes from its available (soluble) ionic form (Fe^{+3}) to hydroxy ions ($Fe(OH)^{+2}$), and finally to insoluble or unusable hydroxide ($Fe(OH)_3$), or oxide (FeO^-) forms.

Soil pH probably influences plants most by affecting the availability of important nutrients (Figure 4-2). For example, at lower pH values (<5), aluminum, iron, and manganese are highly soluble and may be present in sufficient quantities to actually be toxic to plants. High levels of aluminum can also reduce plant uptake of phosphorus, calcium, magnesium, and iron. At higher pH values (>7.0),

Table 4–12. General plant nutrient deficiency symptoms.

I. LEAF CHLOROSIS EVIDENT	DEFICIENT NUTRIENT
1. Entire leaf is chlorotic	
(A) Only older leaves are chlorotic, then necrotic, then drop; growth noticeably slows; symptoms develop uniformly over the whole turfgrass area.	nitrogen
(B) Initially, young leaves turn a light yellow-green color; eventually, all leaves are affected; appears similar to nitrogen deficiency symptoms.	sulfur
2. Interveinal leaf chlorosis	
(A) Only older and recently mature leaves show symptoms; leaf veins remain green; older leaf margins turn cherry-red.	magnesium
(B) Only young leaves show interveinal chlorosis; leaves finally turn white; usually only patches of turf are affected.	iron
(C) Tan or gray necrotic spots also develop in chlorotic areas; leaf veins remain dark-green to olive color.	manganese
(D) Leaf tips remain green, then turn bluish, wither, and die.	copper
(E) Young leaves are dwarfed, dark, and desiccated-looking; shortened internodes; plants appear rosette.	zinc
II. LEAF CHLOROSIS NOT DOMINANT	
1. Symptoms appear at plant base on older growth	
(A) All leaves appear dark green, then possibly yellow; growth stunted; purple coloring in older (bottom-most) leaves from increased anthocyanin development; leaf tips turn reddish.	phosphorous
(B) Margins and tips of older leaves appear chlorotic, then scorched; small, whitish spots may be scattered over older leaves; turf stand composed of thin, spindly individual plants.	potassium
2. Symptoms on new plant growth	
(A) Terminal buds die, resulting in dwarf (rosette)plants.	boron
(B) Margins of young leaves do not form; young leaves twisted or deformed; these do not, or only partially, unfold; young leaf margins turn reddish brown; roots are short and bunched; leaf tips and margins eventually wither and die.	calcium

Figure 4–7. Light colored turf indicating iron deficiency.

nutrients such as iron, manganese, copper, and zinc are less soluble and, therefore, relatively unavailable for plant uptake, although molybdenum (Mo) availability actually increases at high pH. The availability of phosphorus and boron also may be hindered by pH values greater than 7.0.

Chelates

Chelates, chelating agents, or **sequestering agents** are cyclic structures of a normally non-soluble divalent metal atom and an organic component that, when held together, become soluble in water. The chelation process allows nutrients to move through the soil solution to the plants without being tied-up with other soil chemicals. However, the activity of the metallic ion decreases in the aqueous solution. For example, in the absence of chelation and the addition of an inorganic ion such as ferric sulfate to calcareous soil, most of the iron becomes unavailable by reacting with hydroxide ions (-OH) to form iron hydroxide (FeOOH). However, if the iron is chelated (from the Greek *chele*, meaning claw), it remains available for plant uptake.

Commercially available sequestered metallic ions are iron, copper, zinc, and manganese. Organic compounds that have the ability to chelate or sequester these metallic ions include ethylenediaminetetraacetic acid (EDTA); diethylenetriaminepentaacetic acid (DTPA); cyclohexanediaminetetraacetic acid (CDTA); ethylenediaminedi (*o*-hydroxyphenylacetic acid) (EDDHA); citrate; and, gluconate.

Table 4–13. Solution used to spot treat for micronutrient deficiencies applied in 1 gallon of water per 1,000 sq.ft. (4 to 12 L/100 m2).

		RATE	
DEFICIENT MICRONUTRIENT	FERTILIZER SOURCE	FLUID OUNCE/ GALLON/1,000 SQUARE FEET (ML/L)	POUND ELEMENT/1,000 SQUARE FEET (KG ELEMENT/HA)
Iron	iron sulfate (20% Fe)	2(16)	0.025 (1.2)
Manganese	manganese sulfate (27% Mn)	0.75(6)	0.0125 (0.6)
Zinc	zinc sulfate (35% Zn)	0.5(4)	0.010 (0.5)
Copper	copper sulfate (25% Cu)	0.2(1.6)	0.003 (0.15)
Boron	boric acid (17% B)	0.2(1.6)	0.002 (0.1)
Molybdenum	sodium molybdate (47% Mo)	0.04 (0.3)	0.001 (0.05)

Urea and humic acids also are used as chelating agents. Their stability fluctuates with various soil pH levels. For example, EDDHA is best for soil pH from 4 to 9, EDTA at soil pH <6.3, and DTPA at soil pH <7.5.

Non-essential Elements

Sodium, aluminum, arsenic, and silicon are non-essential elements for turfgrass growth and development. These, in general, become toxic when levels are excessive and should not be applied in supplemental fertilizers, although calcium silicate use may suppress certain diseases (e.g., dollar spot) through the physical effects of silica deposits in leaves and through enhanced biochemical defense mechanisms.

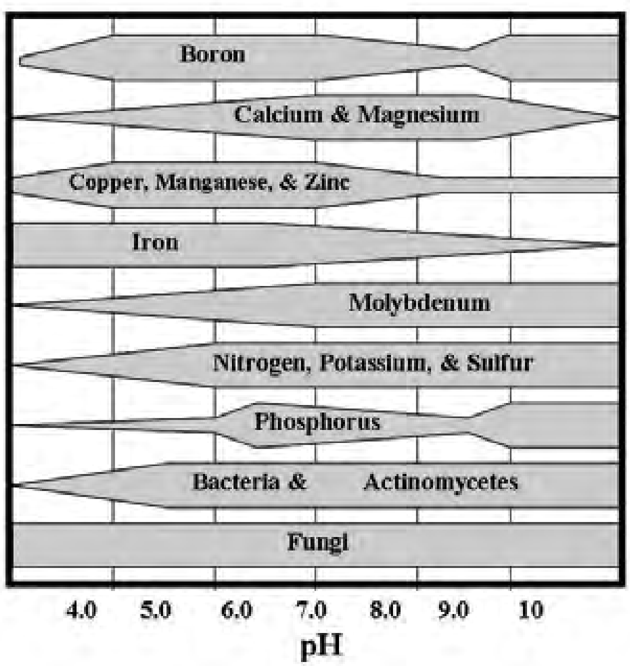


Figure 4–8. The availability of most soil nutrients is largely dependent on the soil pH levels.

4.6 DEVELOPING BEST TURF FERTILIZER PROGRAMS

Turfgrasses require regular fertilization to promote recovery from traffic, provide a pleasing green color, and replace nutrients lost by clipping removal **(Figure 4–8)**. Furthermore, many courses in the Carolinas are located in areas with extended growing seasons, high annual rainfall, and predominantly sandy soils that increase nutrient use and the need for a well-planned fertilization program. For these and other reasons, no one single fertilization schedule or program will sufficiently meet the needs of every golf course or even every area on a golf course. In addition, excessive quality expectations and playing standards are often demanded by professional players. Club members, in turn, place much undue pressure on their superintendents to duplicate conditions viewed on television. This often results in lush, unhealthy plant growth that can drive up maintenance costs and potentially waste natural resources.

Questions to consider when developing a turfgrass fertility program include:

1. What are the aesthetic quality expectations of the area being maintained?
2. What is the use or playing requirements and recovery needs of this area?
3. What is the current nutritional status of the soil and plant?
4. What fertilizer source (carriers) and rates will best meet the aforementioned goals?
5. What fertilizer rate, application timing, and frequency should be used?
6. What type of fertilizer equipment or delivery method will be used to provide these results?

Table 4–14. Air temperatures and soil temperatures at 4 inches (10 cm) affecting turfgrass shoot and root growth.

	SHOOT GROWTH		ROOT GROWTH	
TURFGRASS	MINIMUM	OPTIMUM	MINIMUM	OPTIMUM
	°F (°C)			
Warm-season grasses	55 (13)	80 to 95 (27 to 35)	50 to 60 (10 to 16)	75 to 85 (24 to 29)
Cool-season grasses	40 (4)	60 to 75 (16 to 24)	33 (1)	50 to 65 (10 to 18)

4.7 GENERAL NUTRITIONAL REQUIREMENTS

Steps when developing a fertility program include:

1. Annual nutrient needs depending on turf species, desired quality, budgets, length of growing season, clipping removal, soil types, irrigations/rainfall amounts and frequency, etc.
2. Schedule approximate application dates and rates.
3. Select appropriate fertilizer carrier(s).
4. Determine other nutrient and pH needs by soil tests in addition to nitrogen needs.
5. Other considerations such as price, availability, quality, ease of application, fuel costs, labor, etc.
6. Plan the program by developing tables indicating application dates, rates, carriers, etc.
7. Adjust the program as needed due to weather, pest outbreaks, traffic, etc.

Timing

Timing of nutrient applications is based predominantly on the growth cycle of the grass. Greatest nutrient needs are when shoots and roots are actively developing. **Table 4–14** lists growth temperatures for cool- and warm-season turfgrasses. If temperatures are outside the growth range of the grass, fertilizer applications will be inefficiently utilized.

In general, light (e.g., ¼ to ½ lbs of N/1,000 ft^2, 1.2 to 2.4 g/m^2) applications of fertilizer of cool-season grasses should commence in early spring and be stopped or severely curtailed prior to the elevated temperatures of summer (Figure 4–9). With cool-season grasses, the majority of the annual nitrogen fertilizer (approximately 60 to 75%) should be applied in the fall. This application begins in late summer/early fall as temperatures begin to cool, encouraging renewed growth. A final fertilization application, high in potassium, just after the turf has stopped growing in the late fall and prior to freezes, improves future turf quality.

Fertilizer applications of warm-season grasses should begin during spring "green-up" after the last killing frost. This generally continues through the summer and early fall, with the last application timed approximately 30 days before the first fall killing frost.

Nitrogen Rates

A general yearly range of nitrogen needs for bermudagrass golf greens in the Carolinas is from 4 to 12 pounds of nitrogen per 1,000 square feet (29 to 88 g N/m^2). Seashore paspalum, zoysiagrass, bentgrass and bentgrass/*Poa annua* greens annually require 3 to 8 pounds of nitrogen per 1,000 square feet (15 to 39 g N/m^2). Courses with sufficient resources, low-CEC soils, longer growing seasons, excessive traffic, pest problems, and elevated player expectations would use the higher rate range. Those courses interested in maintaining a less-intensive playing surface, or those with limited labor and financial resources, should use nitrogen rates in the lower range or apply very small doses frequently to ensure sufficient nutrient availability. Exceptions to these ranges may occur depending on various conditions or needs. For example, courses recovering from excessive traffic, pest or low-temperature stresses, or that are establishing new greens, may require higher (approx. 25% more) nitrogen than listed until their grass is sufficiently dense and mature.

Frequency

Bermudagrass. The percentages of nitrogen fertilizer applied to warm- and cool-season turfgrasses during the year are listed in Table 4–15. In general, to maintain optimum color and density during periods of active growth, highly maintained bermudagrass golf greens need approximately ¼ to ⅓ pound soluble nitrogen per 1,000 square feet (1.2 to 1.6 g N/m^2) every 7 to 14 days. On intensively maintained courses, higher rates (e.g., 1 lb N per 1,000 sq.ft. every 7 to 14 days, 5 g N/m^2) may be necessary to encourage quicker turf recovery during times of heavy play. However, these higher rates often lead to other problems. Excessive thatch/mat can quickly accumulate, especially on new ultra-dense cultivars like TifEagle, Mini-Verde, and Champion. This often results in slower ball roll and putting speeds since more leaf area will be produced, and a decrease in turfgrass rooting often follows.

Bentgrass and Poa annua. The total amount of nitrogen used for bentgrass or bentgrass/Poa annua greens generally ranges from 3 to 8 pounds nitrogen per 1,000 square feet annually (15 to 39 g N/m^2). Typically, 4 to 6 pounds (20 to 30 g/m^2) are used annually for bentgrass in areas with longer growing seasons such as the lower transition zone. Meanwhile, 3 to 6 pounds are typically used per 1,000

Table 4–15. Percentages of nitrogen fertilizer applied to turfgrass during the year.

	COOL-SEASON GRASSES		WARM-SEASON GRASSES	
SEASON	GREENS/TEES	OTHER	OVERSEEDED	NON-OVERSEEDED
	%			
Fall (Sept., Oct., Nov.)	40 to 75	45 to 75	15	10 to 15
Winter (Dec., Jan., Feb.)	0 to 30*	0 to 45	15	0
Spring (Mar., Apr., May)	10 to 20	10 to 20	25	35
Summer (June, July, Aug.)	10 to 20	0 to 10	45	50 to 55

**Nitrogen use stops during winter in areas where soils routinely freeze.*

square feet (15 to 30 g N/m^2) in shorter-growing-season cool humid or cool arid regions.

The timing for these applications is based on the temperatures affecting shoot and root growth **(Table 4–14). Table 4–15** lists the general rule-of-thumb of the percentage of these total nitrogen amounts applied during the various seasons of the year. The majority of nitrogen (40 to 75%) should be supplied during the autumn months.

Superintendents, in an effort to more closely regulate and maintain consistent growth and color, often alternate between using granular and liquid fertilizer sources. Granular fertilizers are predominantly used in fall through mid-spring to encourage turf recovery and rooting. Foliar applied liquid sources are popular during summer stress months as a means of precisely controlling nutrient application rates in an effort to minimize soluble salts, and reduce growth surges, while also providing consistent color and desirable playing conditions.

Seashore Paspalum and Zoysiagrass. Seashore paspalum fertility programs are heavily influenced by the water quality used. Rates and timings must be adjusted monthly based on water, tissue, and soil test results. Depending on the length of the growing season, seashore paspalum and zoysiagrass greens should receive between 3 to 8 lbs of nitrogen per 1000 ft^2 per year (15 to 39 g N/m^2). Monthly applications should be made at 0.5 lbs N per 1000 ft^2 (2.5 g N/m^2) using a fertilizer high in potassium (e.g., 15-2-15 or 15-2-22). To help offset salinity stress, potassium should be applied on a weekly to biweekly basis at 1.5 to 3 times the rate of nitrogen. Tissue analysis sufficiency values should range from 2.0 to 4.0%. Phosphorus should be applied at moderate to high levels, and in areas that are prone to high leaching rates should be increased by 25 to 50%. High salinity levels will alter the availability of some micronutrients. Calcium is an essential element when using poor water quality. Tissue test results should yield 0.25-1.50% Ca; 0.25-0.60% Mg; 0.20-0.60% Mn for healthy turf.

Other Nutrients

Potassium. Potassium (K) often is referred to as the “health” element and, without a relatively available supply, turfgrasses will be more susceptible to environmental and pest stresses. Root growth also is related to potassium availability. Excessive potassium, however, may increase soil salinity levels, especially if the leaching capability is limited. Potassium also competes for occupancy on the soil cation exchange sites and may displace other essential elements like calcium or magnesium. The following are guidelines for potassium fertilization (Carrow et al., 2001):

1. For native or unamended soils, use soil testing to determine available soil potassium levels and to base potassium fertilization needs. On intensively managed turf, a high K soil test level should be maintained. On moderate to lower maintained turf, a medium K soil test level is normally sufficient.
2. On heavily leached sands:
    a. Apply a 1:1.5 ratio of nitrogen to potash (K_2O) when annual nitrogen rates are 1 to 3 pounds of nitrogen per 1,000 square feet (4.9 to 15 g/m^2). In other words, for every pound of nitrogen used per 1,000 square feet (4.9 g/m^2), apply 1.5 pounds (7 g/m^2) of K_2O.
    b. When annual nitrogen rates are 3 to 6 pounds per 1,000 square feet (15 to 29 g/m^2), use a 1:1 nitrogen to potash ratio.
    c. When annual nitrogen rates are >6 pounds per 1,000 square feet (29 g/m^2), use a 1:0.75 or 1:0.5 nitrogen to potash ratio to avoid the potential of salt buildup.
    d. In summer, apply ¼ to ½ pound potash per 1,000 square feet (1.2 to 2.5 g/m^2) every two to six weeks.

Phosphorus. Soil phosphorus (P) levels tend not to fluctuate as readily as nitrogen or potassium. Soil-test results should be used to determine the amount needed for a particular turf area. Usually 4 pounds or less phosphorus per 1,000 square feet (20 g P/m^2) are needed yearly. Phosphorus is generally not very water soluble; therefore, if needed, its efficiency is increased if applications follow core cultivation. This allows the material to be placed more directly in the rootzone where roots can access the nutrient. Over time, P levels may actually increase near the soil surface, especially where clippings are returned during mowing.

During establishment, P needs are often greatest due to the shallow and low density root systems associated with young seedlings or recently installed sod. An efficient means of utilizing phosphorus is applying soil-test recommended rates prior to planting followed by tilling to the anticipated rooting depth of the turfgrass.

Tees

Tees, like greens, should be fertilized sufficiently to sustain vigorous recuperative growth, but not to the point where wear tolerance is sacrificed. Often this is associated with succulent leaf growth or increased disease incidences. Tees, in general, are maintained almost as intensively as golf greens. This is especially true for sand-based tees and heavily used par-3 tees receiving excessive traffic and significant divoting. For par-3 tees, especially undersized small tees, the fertilization program should range between three-fourths to equal that used for greens. For most par-4 and par-5 tees, the fertilization program can be reduced to approximately one-half that used for golf greens **(Table 4–16)**. Potassium applications should be approximately one-half of nitrogen applications except where clippings are removed or when sand-based tees are constructed. In such cases, potassium application rates should equal those of nitrogen.

Fairways and Roughs

Fairways generally are maintained with fewer fertilizer inputs than golf greens or tees. This is due to clippings being returned during mowing, resulting in more nutrients being recycled. Fairways also are typically grown on finer (heavier)-textured native soils that retain nutrients better than sand-based root-zones used for greens and tees. In addition, higher mowing heights promote deeper rooting, which improves plant nutrient acquisition. Less irrigation is normally applied to these areas, minimizing nutrient leaching. For bermudagrass, nitrogen and potassium fertilization rates should range between 45 and 260 pounds of nutrient per acre (50 to 290 kg/ha) per year **(Table 4–16)**. Zoysiagrass and cool-season grasses such as turf-type tall fescue and perennial ryegrass need between 45 and 135 pounds of nitrogen per acre (50 to 151 kg N/ha) each year. Annual rates for bentgrass and Kentucky bluegrass

Table 4–16. Typical nitrogen application rates, frequency, and yearly total amounts for golf course tees, fairways, and roughs.

	TEES			FAIRWAYS			ROUGHS		
GRASS	SINGLE RATE[1] (LB N/1,000 FT²)	FREQUENCY[2] (WEEKS)	YEARLY TOTAL (LB N/1,000 FT²)	SINGLE RATE[1] (LB N/ ACRE)	FREQUENCY (WEEKS)	YEARLY TOTAL (LB N/ ACRE)	SINGLE RATE[1] (LB N/ ACRE)	FREQUENCY (WEEKS)	YEARLY TOTAL (LB N/ ACRE)
Annual bluegrass	0.25 to 0.5	2 to 4	2 to 8	25 to 45	4 to 12	90 to 180	25 to 45	4 to 12	45 to 90
Bentgrass	0.25 to 0.5	2 to 4	2 to 8	25 to 45	4 to 12	90 to 180	25 to 45	4 to 12	45 to 90
Bermudagrass	0.5 to 1	2 to 4	4 to 12	25 to 45	4 to 16	45 to 180	45	8 to 16	0 to 90
Fine-fescue	0.25 to 0.5	2 to 4	2 to 8	25 to 45	4 to 12	45 to 135	25 to 45	8 to 16	45 to 90
Kentucky bluegrass	0.25 to 0.5	2 to 4	2 to 8	25 to 45	4 to 12	60 to 180	25 to 45	4 to 12	45 to 90
Ryegrass	0.25 to 0.5	2 to 4	2 to 8	25 to 45	4 to 12	45 to 135	25 to 45	4 to 12	45 to 90
Seashore paspalum	0.25 to 0.5	2 to 4	2 to 8	25 to 45	4 to 12	90 to 180	25 to 45	4 to 12	45 to 90
Zoysiagrass	0.5 to 1	4 to 8	2 to 8	45	4 to 16	45 to 135	45	8 to 16	0 to 90

[1] *Rates listed are typical for single applications. Single application rates, frequency, and yearly total nitrogen rates vary considerably between individual golf facilities, geographical regions, and desired results. Lower rates are acceptable for most golf facilities, especially for those turf areas not irrigated. Slow-release or control-release fertilizer sources should be considered with higher rates. Soluble sources should be used at lower rates and applied more frequently. Multiply lb/1,000 ft2 by 4.9 to obtain g/m2; multiply lb/acre by 1.12 to obtain kg/ha.*

[2] *Frequency represents fertilizing only during periods of active growth for each respective grass. The highest application rates should be reserved for optimum growth seasons of each grass. Typically this is late summer through early spring months for cool-season grasses and late spring through late summer/early fall for warm-season grasses. Fertilizer applications should be minimized or possibly eliminated during periods of natural slowed growth or where soils freeze.*

may need to be slightly higher (e.g., 60 to 180 lbs N/acre, 67 to 202 kg N/ha) to promote sufficient plant vigor and resist pest damage. These annual needs are normally split between two and four applications at between 25 and 45 pounds of nitrogen per acre per application (28 to 50 kg N/ha) **(Table 4–16)**. A range is suggested because local weather conditions, insect and disease severity, soil types, turfgrass quality, player expectations, overseeding practices, and so on, influence exact rates and timing. Phosphorus needs should be based on yearly soil test results.

Since roughs are mowed at higher cutting heights than fairways, and clippings are returned, fertilization requirements for roughs are lower **(Table 4–16)**. Roughs are usually fertilized one to three times a year to provide color and recuperation from pest or traffic damage. Forty pounds of a soluble nitrogen source, or eighty pounds (45 to 90 kg N/ha) of an insoluble source, are usually applied per acre per application. A complete fertilizer should be used at each treatment. Obviously, as fertilization amounts increase, so do maintenance expenditures in terms of mowing and trimming costs.

4.8 SOIL NUTRIENT ANALYSIS

A variety of analytical tools are available to assist turfgrass managers in developing an effective, efficient, and environmentally responsible nutrient management program for every area of the golf course. These test results indicate what is available to plants via a soil test and what is actually in plants by a leaf tissue test. The need for conducting either of these tests varies depending upon management intensity, quality expectations, environmental conditions, turfgrass species, and geographic location.

Soil Testing

Soil testing is one of the fundamental practices of turfgrass management. Soil sampling depends on several parameters: (1) type of rootzone, (2) uniformity of soil test results from replicated seasons, (3) turfgrass performance, and (4) turf maturity. Native soil "push-up" greens should be tested at least annually while sand-based greens are tested two or more times annually. When sampling at initial establishment, a depth of six inches (15 cm) should be used. When sampling mature turf, soil should be sampled to a depth of two to four inches (5 to 10 cm) or to the depth where the majority of plant roots are located.

Soil analysis provides information on relative levels of nutrients, organic matter, pH, soluble salts, and cation exchange capacity. However, significant variations often occur in reported values and nutrient recommendations between testing laboratories. This is primarily due to geographical differences in soil types, nutrient extraction solutions and analysis techniques, as well as philosophical differences in data interpretation. The ranking of the nutrient level, however, should be somewhat similar regardless of the extractant used. **Table 4-17** lists the most commonly performed soil test for turfgrass managers.

A turf manager should select a particular laboratory, preferably an accredited laboratory that has experience analyzing samples from turfgrass sites, and stick with one laboratory. The chances of a lab switching analytical methods are minimal, and nutrient recommendations will be more consistent from year to year. In many cases, laboratories with only limited experience with turfgrass samples tend to overestimate phosphorus requirements and underestimate potassium needs. Since no single soil test analysis is applicable to all soils, it is best to use a lab located in your general geographic area.

Soil Analysis Report

Two major philosophies for interpreting soil test results currently exist. They are the sufficiency level of available nutrients concept (SLAN) and the basic cation saturation ratio (BCSR) or nutrient maintenance concept. Although both philosophies measure the nutrient status of soil, they differ in how analytical results are interpreted and expressed on reports. This can be confusing if the laboratory uses a combination of both concepts to make nutrient recommendations. Consequently, if a golf course manager regularly switches laboratories or is not familiar with reading and interpreting a soil test report, the information can be confusing, and inconsistency in a fertilizer program may result.

Table 4–17. Soil testing option based on the desired objectives.

OBJECTIVE	SOIL TEST
Soil reaction and lime requirements	Water, salt and buffer pH
Nutrient element status	*Major elements:* P, K, Ca, Mg, NO_3, SO_4
Toxic elements	*Micronutrients:* B, Cl, Cu, Fe, Mo, Ms, Zn
Physical and chemical characteristics	*Other elements:* Al, Na
Mechanical analysis	*Trace elements and heavy metals:* As, Cd, Co, Cr, Cu, Mn, Pb, Ni
Drainage potential	Organic matter content
Total salts	Soil texture classification
	Saturated hydraulic conductivity
	Soluble salts

Table 4–18. Predicting plant response to nutrient application using soil test index values.

SOIL TEST INDEX		PROBABLE PLANT RESPONSE TO NUTRIENT APPLICATIONS				
Range	**Rating**	**Phosphorus**	**Potassium**	**Manganese**	**Zinc**	**Copper**
0 to 10	very low	very high	very high	very high	very high	very high
11 to 25	low	high	high	high	high	high
26 to 50	medium	medium	medium	none	none	none
51 to 100	high	none	low–none	none	none	none
>100	very high	none	none	none	none	none

Source: North Carolina Department of Agriculture, Agronomic Division.

Table 4–19. Range in extractable Phosphorus, Potassium, Calcium, and Magnesium (lbs element per acre) by soil test ratings.

SOIL TEST INDEX RATING	PHOSPHORUS	POTASSIUM	CALCIUM	MAGNESIUM
	Pounds element/acre*			
Very low	0 to 10	0 to 24	0 to 200	0 to 10
Low	11 to 30	25 to 70	201 to 400	11 to 32
Medium	31 to 60	71 to 156	401 to 800	33 to 60
High	61 to 120	157 to 235	801 to 2000	>60
Very high	121 to 240	>235	>2000	>60

**Multiply values by 1.12 to obtain kg/ha.*
Source: Clemson University Soil Testing Laboratory.

Sufficiency Level of Available Nutrient (SLAN) Concept. The SLAN philosophy assesses the actual levels of plant-available macronutrients, calcium, magnesium, potassium, phosphorus, sulfur, and micro-nutrients, iron, manganese, zinc, copper, and boron, in a soil sample and its ability to supply nutrient to plants. The SLAN attempts to correlate turf response to extractable soil nutrients and is based on the traditional concept that as the soil test index level for a given nutrient increases, the turfgrass plant response to the nutrient will increase up to a given critical level or threshold. The quantities of individual nutrients are typically expressed in terms of low, medium, high, or very high (**Tables 4–18 and 4–19**). Based on this method, for example, if a soil test index indicates phosphorus is low, then a phosphorus application will probably improve plant growth. Conversely, if the soil test indicates phosphorus is present at high or very high levels, then a plant response is not expected and further applications on very high testing soils may even lead to other nutrient imbalances. Specific laboratory values for these criteria have been established by decades of field and greenhouse soil test calibration research on various crops over various soil types. The state lab in NC presents a variation of the SLAN concept. It uses an index value to represent ranges in plant-available nutrients (**Table 4-18**).

Basic Cation Saturation Ratio (BCSR) Concept. This philosophy is based on the concept of an "ideal" ratio of "basic" cations (primarily calcium, magnesium, and potassium) for the given soil or crop occurring that occupies the majority of cation exchange sites in soil. This approach requires an accurate measurement of a soil's CEC. Soil testing laboratories often suggest a balanced "ideal" soil will have a total base saturation of approximately 80 percent. This will be comprised of 65 percent of the exchange sites being occupied by calcium, 10 percent magnesium, 5 percent potassium, with less than 2 percent sodium, and 3 percent trace cations, with the remainder being hydrogen (10% or less). These percentages are a 13:2:1 ratio of Ca:Mg:K. When these soil nutrient levels are "balanced," "ideal" nutrient ratios for plant growth have been suggested: Ca:Mg of 6:1; Ca:K of 15:1; 3:1 Ca:H; and, Mg:K of 2:1. Once the cations are in "balance," these soils are purported to possess better aggregation, which improves water infiltration and percolation. Furthermore, microbial activity increases due to increased oxygen availability that improves fertilizer use efficiency. Unfortunately, research in this area of soil science is limited and the long-term benefit of fertilizing according to the BCSR philosophy is largely unproven. Additionally, many soil testing methods on calcareous soils often overestimate the true CEC due to the abundance of free calcium solubilized by some nutrient extracting solutions.

The primary focus of BCSR is on "fertilizing the soil" rather than "fertilizing the plant" like with the SLAN concept. With BCSR, annual soil tests are conducted to assess the presence of various nutrients on the cation exchange sites and normally recommend large quantities of calcium, magnesium, and potassium which, in turn, may significantly raise soil pH. Adjustments are suggested whenever nutrient ratios become out of "balance." The concept appears to work for many weathered, low-pH soils. However, applying additional calcium and magnesium to naturally high pH soils where calcareous sands are used for putting greens, and/or soil tests indicate 90 percent calcium in soil, appears unnecessary. High calcium and magnesium rates may reduce the availability of phosphorus and other critical cations which in turn may lead to unnecessary fertilizer applications which may lead to nutrient deficiencies and an undesirable pH.

Test Results. Soil test reports often contain both types of data. SLAN data includes extractable nutrient levels using the appropriate extraction technique and results are reported as parts per million (ppm = mg/kg), pounds of nutrient per acre, or milliequivalent of nutrient per 100 g soil (meq/100 g). Nutrients routinely reported by SLAN include phosphorus, potassium, calcium, magnesium, sulfur, iron, manganese, zinc, copper, and sodium. BCSR information provided on a routine soil test report includes CEC and ratios of the cations, Ca:Mg, Ca:K, and Mg:K.

When reported as ppm, nutrient levels can be converted to pounds per acre. An acre of mineral soil, six to seven inches (15 to 18 cm) deep, weighs approximately two million pounds (900,000 kg). To convert ppm to approximate pounds per acre, simply multiply by two based on the following assumption:

$$\text{ppm} = \text{mg/kg}$$

$$\frac{\text{mg}}{\text{kg}} \times \frac{\text{lb}}{454{,}000 \text{ mg}} \times \frac{0.454 \text{ kg}}{\text{lb}} \times \frac{2{,}000{,}000 \text{ lbs}}{\text{acre (0.5 ft deep)}} \approx 2$$

To determine kg/ha, multiply mg/kg (or ppm) by 2.25.

Soil cations, such as calcium, magnesium, potassium, and hydrogen, are expressed by their relative ability to displace other cations. For example, one meq of potassium is able to displace exactly one meq of magnesium. The unit of measure meq/100 g serves this purpose. Cation exchange capacity and the total amounts of individual cations may be expressed using these units. To convert milliequivalent (meq) per 100 g of soil to pounds of nutrient per acre furrow slice, the equivalent weight of the cation is used.

$$\frac{3 \text{ meq}}{100 \text{ g}} \times \frac{\text{cation equivalent}}{2 \text{ (valence no.)}} \times \frac{1 \text{ eq}}{1000 \text{ meq}} \times \frac{2{,}000{,}000 \text{ lbs}}{\text{acre}} = \frac{\text{pounds nutrient}}{\text{acre}}$$

Example:

Convert 3 meq Ca^{+2} per 100 g soil to pounds Ca^{+2} per acre.

$$\frac{3 \text{ meq}}{100 \text{ g}} \times \frac{40 \text{ g } Ca^{+2}}{2 \text{ (valence no.)}} \times \frac{1 \text{ eq}}{1000 \text{ meq}} \times \frac{2{,}000{,}000 \text{ lbs}}{\text{acre}} = \frac{1{,}200 \text{ lbs } Ca^{+2}}{\text{acre furrow slice}}$$

From these reported nutrient levels, most soil test readings using the SLAN concept are assigned a fertility rating level with the division between medium and high being the critical value. Above this level, there is little expected plant response to added fertilizer as sufficient nutrients are in the soil, while below this value, increasing amounts of fertilizer are needed to produce a desirable plant response. Table **4–20** cross lists the amount of an element extracted from the soil related to its fertility rating level. **Tables 4–21** through **4-23** list the recommended yearly amounts of phosphate (P_2O_5) and potash (K_2O) based on the current extractable phosphorus and potassium from the soil.

Interpreting a Soil Analysis Report

A soil analysis report supplies a wealth of information concerning the nutritional status of a soil and may aid in the early detection of problems that limit turfgrass growth or desirable color. This is particularly important during the initial establishment or renovation of a turfgrass site. A typical soil analysis supplies information relative to cation exchange capacity, soil acidity, lime requirements, and soil phosphorus, potassium, calcium, and magnesium status. Nitrogen content is rarely determined because of its dynamic status due to environmental conditions and microbial transformations. Additional information can be requested from lab reports such as soil organic matter content, soluble salts, and irrigation water analysis. **Table 4–24** lists the results from a typical soil and plant tissue report. Recommendations, in terms of lime and nutrients, are usually listed at the end of the report.

Various Ratios of Elements. Ratios of various elements can be important for certain soil chemical reactions and influence nutrient availability. One of the most important ratios in turf management is the carbon-to-nitrogen ratio of organic amendments like peat moss, composts, or other organic materials used for improving soil structure. The carbon-to-nitrogen ratio will influence organic matter decomposition and is an indicator of nitrogen availability. Generally, a carbon-to-nitrogen ratio between 10 and 12:1 for most organic amendments is desirable. Ratios greater than 20:1 may have an inefficient breakdown of organic matter due to the lack of nitrogen necessary to sustain soil organisms responsible for decomposition. When excessive carbon is present, soil microorganisms will immobilize all available nitrogen for their own metabolic activity. This

Table 4–20. Recommended fertilizer amounts for bermudagrass and zoysiagrass golf course fairways based on existing extractable soil phosphorus and potassium levels.*

	SOIL POTASSIUM LEVELS				
SOIL PHOSPHORUS LEVELS	LOW	MEDIUM	SUFFICIENT	HIGH	EXCESSIVE
	Pounds of N - P_2O_5 - K_2O recommended per acre				
Low	120-100-80	120-80-60	120–100-30	120-80-0	120-100-0
Medium	120-50-80	120-40-60	120–50-30	120-40-0	120-50-0
Sufficient	120–25–80	120–25–60	120–25-30	120-25-0	120-25-0
High	120-40-80	120-40-60	120–0-30	120-0-0	120-0-0
Excessive	120-0-80	120-0-40	120–0-30	120-0-0	120-0-0

**Apply one-half of the nitrogen with phosphate and potash in spring and in late summer. Apply additional nitrogen as needed in mid-summer at 60 pounds per acre per application. Multiply values by 1.12 to ob-tain kg/ha.*
Source: Clemson University Soil Testing Laboratory.

Table 4–21. Recommended fertilizer amounts for bermudagrass golf course greens and tees based on existing extractable soil phosphorus and potassium levels.*

	SOIL POTASSIUM LEVELS				
SOIL PHOSPHORUS LEVELS	LOW	MEDIUM	SUFFICIENT	HIGH	EXCESSIVE
	Pounds of N - P_2O_5 - K_2O recommended per 1,000 sq.ft.				
Low	9.2- 4.6-4.6	9.2-4.6-2.3	9.2-4.6-1.4	9.2-4.6-0.7	9.2-4.6-0
Medium	9.2-2.3-4.6	9.2-2.3-2.3	9.2-2.3-1.4	9.2-2.3-0.7	9.2-2.3-0
Sufficient	9.2-1.1-4.6	9.2-1.1-2.3	9.2-1.1-1.4	9.2-1.1-0.7	9.2-1.1-0
High	9.2-0-4.6	9.2-0-2.3	9.2-0-1.4	9.2-0-0.7	9.2-0-0
Excessive	9.2-0-4.6	9.2-0-2.3	9.2-0-1.4	9.2-0-0.7	9.2-0-0

**Nitrogen applications should be alternated with complete fertilizers and modified to maintain desired growth and color. Multiply values by 49 to obtain g/m2.*
Source: Clemson University Soil Testing Laboratory.

Table 4–22. Recommended fertilizer amounts for bentgrass golf course greens and tees based on existing extractable soil phosphorus and potassium levels.*

	SOIL POTASSIUM LEVELS				
SOIL PHOSPHORUS LEVELS	LOW	MEDIUM	SUFFICIENT	HIGH	EXCESSIVE
	Pounds of N - P_2O_5 - K_2O recommended per 1,000 sq.ft.				
Low	6.9-4.6-4.6	6.9-4.6-2.3	6.9-4.6-1.4	6.9-4.6-0.7	6.9-4.6-0
Medium	6.9-2.3-4.6	6.9-2.3-2.3	6.9-2.3-1.4	6.9-2.3-0.7	6.9-2.3-0
Sufficient	6.9-1.1-4.6	6.9-1.1-2.3	6.9-1.1-1.4	6.9-1.1-0.7	6.9-1.1-0
High	6.9-0-4.6	6.9-0-2.3	6.9-0-1.4	6.9-0-0.7	6.9-0-0
Excessive	6.9-0-4.6	6.9-0-2.3	6.9-0-1.4	6.9-0-0.7	6.9-0-0

**Nitrogen applications should be alternated with complete fertilizers and modified to maintain desired growth and color. Multiply values by 49 to obtain g/m2.*
Source: Clemson University Soil Testing Laboratory.

Table 4–23. Recommended fertilizer amounts for Kentucky bluegrass, ryegrass, and/or fescue golf course fairways based on existing extractable soil phosphorus and potassium levels.*

	SOIL POTASSIUM LEVELS				
SOIL PHOSPHORUS LEVELS	LOW	MEDIUM	SUFFICIENT	HIGH	EXCESSIVE
	Pounds of N - P_2O_5 - K_2O recommended per acre				
Low	160-80-100	160-80-80	160-80-60	160-80-40	160-80-0
Medium	160-60-100	160-60-80	160-60-60	160-60-40	160-60-0
Sufficient	160-40-100	160-40-80	160-40-60	160-40-40	160-40-0
High	160-0-100	160-0-80	160-0-60	160-0-40	160-0-0
Excessive	160-0-100	160-0-80	160-0-60	160-0-40	160-0-0

**Multiply values by 1.12 to obtain kg/ha.*
Source: Clemson University Soil Testing Laboratory.

condition is evident through chlorosis or yellowing, symptoms consistent with a nitrogen deficiency. Certain sawdust sources have a C:N ratio as high as 400:1. Turf managers who use these as soil amendments should add some readily available nitrogen, like urea, to the mixture.

A trend currently exists in applying composts to golf course fairways and roughs to improve soil structure, especially on heavy clay soils. Many superintendents are producing composts on-site using collected grass clippings and woody debris. For composts, a carbon-to-nitrogen ratio of less than 30:1 is desirable before it is applied to the turf. When in doubt regarding the suitability of a particular compost for turf use, many soil testing laboratories also determine the carbon-to-nitrogen ratio. Coincidentally, a similar condition regarding sulfur availability also could occur if the nitrogen-to-sulfur ratio exceeds 20:1.

Though not well-defined, certain soil nutrient ratios appear beneficial for plant growth. As mentioned previously, Ca:Mg ratios of 6:1, Ca:K at 15:1, 3:1 Ca:H; and, Mg:K at 2:1 seem to be beneficial under certain conditions. Plant tissue analysis with a P:Fe ratio greater than 40:1 may have iron deficiency symptoms while a Fe:Mn ratio of 2:1 appears beneficial.

Table 4–25 summarizes recommended ranges for nutrient levels using various extractant procedures. The reader should note that differences occur between plants, soils, locations, management practices, and laboratory extraction techniques. Multiple sampling years, consistent use of a particular soil testing laboratory, and practical observations are required to establish the "critical" nutrient levels for each individual area on a golf course.

A soil test report utilizing SLAN can be used to determine the approximate amount of nutrient needed to be added to raise it into the medium range. From a SLAN soil test report, subtract the nutrient value listed (as ppm) from the desired (or medium) range listed in **Table 4-25.** If the value is negative, supplemental fertilization is not needed. However, if this value is positive, multiply it by 2 to convert it to pounds of nutrient per acre. Finally, divide the resulting value by 43.56 to indicate the pounds of nutrient per 1,000 sq.ft. needed to be added to correct the deficiency.

Example:

If a SLAN based soil test report indicates 30 ppm potassium, is additional potassium needed, and if so, how much per 1,000 sq.ft.?

step 1: Subtract the reported value from the desired (or medium) value listed in **Table 4–25**.

50 ppm **(from Table 4–25)** – 30 ppm (from the soil test report) = 20 ppm K deficit

step 2: Multiply the deficit value by 2 to determine its pounds per acre value (or by 2.25 to determine kg/ha).

20 ppm (from step 1) x 2 = 40 pounds of K per acre (or 45 kg K/ha) needed to correct the deficit.

step 3: To determine the approximate amount of potassium needed per 1,000 sq.ft., divide the step 2 value by 43.56 (or divide kg/ha by 100 to obtain g/m^2).

40 pounds K/acre needed ÷ 43.56 = 0.92 lbs K needed per 1,000 sq.ft. (or 4.5 g K/m^2) to correct the deficit.

Table 4-24. An example of a soil and tissue analysis laboratory report.

Grower: ____

Received: ____ Processed: ____________________________

Sample ID: _______________________________________ Grass: ________________________________

Phone:______________________ Fax: ________________________ E-mail: __________________________

ELEMENT	PLANT TISSUE	SOIL LEVELS (LB/A)	TEST RATINGS P=PLANT S=SOIL — DEFICIENT / LOW / MEDIUM / HIGH
Nitrogen (N)	3.13 %	—	PPPPPPPPPPPPPPPPPPPPPPPPP
Phosphorus (P)	0.32 %	129	PPPPPPPPPPPPPPPPPPPPPPPPPPPP SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
Potassium (K)	1.61 %	111	PPPPPPPPP SSSSSSSSSSSSSSSSSSSSSSSSS
Calcium (Ca)	0.47 %	584	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPPPP SSSSSSSSSSSSSSSSSSSSSSSSSS
Magnesium (Mg)	0.35 %	196	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPP SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
Sulfur (S)	0.12 %	46	PPPPPPPPP SSSSSSSSSSSSSSSSSSSSSSSSSSSS
Boron (B)	5 ppm	0.20	PPPPPPPPPPPPPPPPPPPPPPPPPPP SSSSSSSSSSS
Copper (Cu)	7 ppm	0.80	PPPPPPPPPPPPPPPPPPPPPPPPPPP SSSSSSSSSSSSSSSSSSSSSSSSSSS
Iron (Fe)	106 ppm	103	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPP SSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSSS
Manganese (Mn)	38 ppm	10	PPPPPPPPPPPPPPPPPPPPPPPPPPPPPP SSSSSSSSSSSS
Zinc (Zn)	24 ppm	4.0	PPPPPPPPPPPPPPPPPPPPPPP SSSSSSSSSSSSSSSSSSSSSSSSSSSS
Sodium (Na)	—	11 ppm	SSS
Soluble Salts	—	0.080 mmho/cm	SSS
Soil pH (or active acidity): 6.7			
Buffer pH (or lime index): 7.9		%K: 2.5	%H: 66.7
Organic Matter: 1.1%		%Ca: 24.0	%Na: 0.8
Calculated CEC: 6.0 meq/100g		%Mg: 6.5	
Lime and Fertilizer Recommendations:			
1. Lime (lbs/1,000 sq.ft.) ______ 2. Nitrogen (lbs N/1,000 sq.ft.) ______ 3. Phosphate (lbs P2O5/1,000 sq.ft.) ______		5. Other ______ 4. Potash (lbs K2O/1,000 sq.ft.) ______	

To convert tissue nutrient analysis from % to g/kg, multiply % values by 10.
To convert micronutrient tissue analysis from ppm to mg/kg, multiply ppm by 1.
To convert pounds nutrient per acre for a 6-inch furrow slice to mg/kg (or ppm), multiply lbs/acre by 2.
To convert pounds nutrient per acre for a 6-inch furrow to g/m2, multiply lbs/acre by 2.25.
To convert soil ppm P to lbs P2O5/acre, multiply ppm P by 4.6.
To convert soil ppm K to lbs K2O/acre, multiply ppm K by 2.4.
Conversely, to convert from pounds nutrient per acre to ppm, divide pounds nutrient per acre by 2.
Cation Exchange Capacity is determined by summing the major cations:

CEC (meq/100g) = Ca+2 + Al+3 + K+ + H+ + Mg+2

% Base Saturation is determined by:

$$\%BS = \frac{\text{meq of } Ca^{+2}, Mg^{+2}, K^{+}, \text{and } Na^{+}}{CEC} \times 100$$

Table 4–25. Relative response range of soil elements analyzed by indicated extractant techniques* (modified from Carrow et al., 2004b; Jones, 2001; McCarty, 2011).

ELEMENT (ABBREVIATION)	COMMENTS	
Nitrogen/organic matter (N/OM)	Typical levels are <5%. Due to its readily changing status in soils, nitrogen availability is hard to predict. Often, the percent OM serves as a reserve for nitrogen. Labs, therefore, list an estimated N release figure based on the percentage of OM present to estimate the N released over the season. OM content is determined by loss-on-ignition.	
Phosphorus (P)	P availability is greatest between a soil pH of 5.5 to 6.5. Desired P values for various extractant procedures include:	
	Extraction technique	Desired P Range (ppm)
	Morgan	10 to 20
	Bray P1	20 to 40
	Bray P2	40 to 60
	Mehlich I	15 to 30
	Mehlich III	25 to 55
	Olsen	12 to 28
	Ammonium bicarbonate-DTPA	8 to 45
Potassium (K)	Generally, higher K levels are required in high clay or organic matter containing soils. Soils with high levels of Mg may also require higher K applications. Sandy soils require more frequent, light K applications compared to heavier ones. A fertilizer ratio of N to K should be 3:2 or 1:1. Due to luxury consumption and leaching loss, levels above medium as reported by soil testing are mostly unnecessary. Desired K values for various extractant procedures include:	
	Extraction technique	Desired K Range (ppm)
	Mehlich I	
	Sands/most soils	50 to 100
	Fine-textured (>35% clay)	90 to 200
	Mehlich III	
	Sands/most soils	50 to 116
	Fine-textured (>35% clay)	75 to 175
	1M Ammonium acetate (pH 7.0)	
	Sands/most soils	75 to 175
	Fine-textured (>35% clay)	100 to 235
	Olsen	155 to 312
	Morgan	120 to 174
Calcium (Ca)	Extraction Technique	Desired Range (ppm)
	Mehlich I	200 to 350
	Mehlich III	500 to 750
	Ammonium acetate, pH 7.0	500 to 750
	Morgan	500 to 750

ELEMENT (ABBREVIATION)	COMMENTS		
Magnesium (Mg)	Extraction Technique	Mg in sands (<4 meq/100 g CEC)	Mg in clays (>4 meq/100 g CEC)
	Mehlich I	30 to 60	50 to 100
	Mehlich III	60 to 120	70 to 140
	Ammonium acetate, pH 7.0	100 to 200	140 to 250
	Morgan	>100	>100
	Comments. With most soils, liming with dolomite to ensure an adequate soil pH for proper plant growth will provide adequate Ca and Mg. Their deficiencies are more common in sandy, acidic, and/or low organic matter containing soils. Calcareous sands and most soils in the Midwestern states will not require Ca additions. Use gypsum (calcium sulfate) if Ca is needed when soil pH is too high. Consider using magnesium oxide, magnesium sulfate (Epsom salt), or sulfate of potash-magnesia (Sul-Po-Mag) if soil tests are low in Mg and lime is not required. Calcium deficiencies are uncommon; however, Mg deficiencies often occur in acidic soils low in CEC and subject to frequent leaching. Heavy liming with calcium carbonate (calcite) lime or heavy use of K also may induce Mg deficiency. Apply magnesium sulfate (Epsom salts) to test for Mg deficiency. Guidelines for Mg:K and Ca:K ratios based on saturation percentages on the soil CEC include:		
	Cations	Ratio	Possible Deficiency
	Ca:K	<10:1	calcium deficiency may occur
		>30:1	potassium deficiency may occur
	Mg:K	<2:1	magnesium deficiency may occur
		>10:1	potassium deficiency may occur
	Ca:Mg	<3:1	calcium deficiency may occur
		>8:1	magnesium deficiency may occur
Soil pH	Soil pH should ideally be between 5.5 and 6.5. Soil pH less than 5.5 becomes highly acidic and can produce toxic elements to the turf. Alkaline soil pH (>7.0) often limits the availability of many minor elements. For most elements, their maximum availability occurs between a pH 5.5 to 6.0.		
Cation exchange capacity (CEC)	A CEC between 5 and 35 meq/100 g is desired. CEC measures a soil's ability to hold the cations Ca, Mg, K, H, and Na. Increasing CEC generally occurs with increasing soil OM or clay content. Generally, the higher the CEC value, the more productive the soil. A suggested range of the total makeup of a soil's CEC is 65 to 75 percent Ca, 12 to 18 percent Mg, and 3 to 5 percent K.		
Percent base saturation	Percent base saturation refers to the proportion of the CEC occupied by the cations Ca, Mg, K, H, and Na. Ideally, 80% or more base saturation is from Ca, Mg, and K ions.		
Iron (Fe)	Soil iron levels should be between 12 and 25 ppm when using Mehlich extraction. Soil pH and relative levels of other elements such as P are important when interpreting Fe soil tests. Generally, iron becomes less available in alkaline or extremely acidic soils, cool soil temperatures or when roots become dysfunctional due to heat or diseases, and soils with excessive P or moisture levels. See copper for additional information.		
Manganese (Mn)	Soil levels of Mn should be between 2 and 10 ppm when using Mehlich extraction. Levels where a plant response to applied Mn may occur include: 3 to 5, 5 to 7, and 7 to 9 ppm for mineral or organic soils with pH 5.5 to 6.0, 6.0 to 6.5, and 6.5 to 7.0, respectively. Deficiencies are more prone on coarse, sandy, acid soils receiving excessive water. See copper for additional information.		
Zinc (Zn)	Soil levels of Zn should be between 1 and 3 ppm when using Mehlich extraction. Levels where a plant response to applied Zn may occur include: 0.5, 0.5 to 1.0, 1 to 3 ppm for soils with pH 5.5 to 6.0, 6.0 to 6.5, and 6.5 to 7.0, respectively. Zinc interactions with P and soil pH can alter needed application rates. See copper for additional information.		

ELEMENT (ABBREVIATION)	COMMENTS		
Copper (Cu)	Levels where a plant response to applied Cu may occur include: 0.1 to 0.3, 0.3 to 0.5, and 0.5 ppm for mineral soils with pH 5.5 to 6.0, 6.0 to 6.5, and 6.5 to 7.0, respectively. Copper deficiencies can occur on alkaline soils, high organic matter (peat and muck) soils, soils heavily fertilized with N, P, and Zn, and when flatwood soils are first cultivated. Toxic conditions may exist when Cu levels exceed 2 to 3, 3 to 5, and 5 ppm in mineral soils with pH of 5.5 to 6.0, 6.0 to 6.5, and 6.5 to 7.0, respectively. Additional levels used by many laboratories for micronutrient availability include:		
	Extraction technique		
Micronutrient	DTPA	Mehlich III	Ammonium bicarbonate-DTPA
	Desired range (ppm)		
Iron	2.6 to 5.0	50 to 100	3.1 to 5.0
Manganese	1 to 2	–	0.6 to 1.0
- sand soils	–	4.0 to 6.0	–
- clay soils	–	8.0 to 12.0	–
Zinc	0.6 to 1.0	1.1 to 2.0	1.0 to 1.5
Copper	0.2 to 0.4	0.3 to 2.5	0.3 to 0.5
Boron (B)	Soil B levels should be between 1 and 2 ppm when using Mehlich extraction. Boron deficiencies occur more commonly on sandy, low organic matter soils and alkaline soils. Boron is most soluble (available) under acid soil conditions.		
Sulfur (S)	Soil sulfur levels, like N, are dependent on soil organic matter levels, are erratic to measure, and the results are often meaningless. Soils that are low in organic matter, well-drained, have low CEC values, and are fertilized with excessive N can develop low S levels. Acceptable S ranges are 10 to 20 ppm for $Ca(H_2PO_4)_2$, 30 to 60 ppm for ammonium acetate (pH 7.0), and 15 to 40 ppm for Mehlich III extraction. Foliar application of magnesium sulfate (Epsom salt) will indicate if S deficiencies exist by greening up within 48 hours after application.		

** Refer to the specific soil testing facility and report to determine which nutrient extractant procedure was used and what the generated values actually represent. Multiply ppm values by 2 to obtain pounds nutrient per acre (lb/a) and by 2.24 to obtain kg/ha approximately 7 inches (18 cm) deep.*

4.9 LEAF TISSUE ANALYSIS

Leaf tissue analysis, in addition to a soil analysis, is another tool turfgrass managers can use to help develop or improve nutrient applications. It is most useful for intensively managed areas like golf greens and/or where the rootzone was constructed using a sand-based system having a relatively low nutrient-holding capacity. Tissue analysis, along with the overall turfgrass appearance and a soil analysis report, can be used as a means of diagnosing problems and determining the effectiveness of fertilization programs, especially for micronutrient deficiency. A tissue test determines if hidden nutrient deficiencies exist and determines how closely nutrients absorbed by the turf correlate with the soil test value.

Primary and secondary nutrients occur in relatively large quantities within plants—their concentrations are usually expressed in grams (g) of the element per kilogram (kg) of plant dry weight or percentages. Micronutrients occur in relatively small quantities—their concentrations are usually expressed in milligrams (mg) of the element per kilogram of plant dry weight, which is also ppm. **Table 4–26** provide general guidelines for appropriate nutrient concentrations in leaf tissue for the common turfgrasses used on golf courses.

Table 4–26. Specific ranges for nutrients from various turfgrass tissue analysis (modified from Carrow et al., 2001; Jones et al., 1991; McCarty, 2011).

BERMUDAGRASS							
		GREENS/TEES			FAIRWAYS		
Element		**Low**	**Desired**	**High**	**Low**	**Desired**	**High**
		%					
Primary nutrients	N	3.50 to 3.99	4.00 to 4.50	>6.00	2.50 to 2.99	3.25 to 4.00	>5.00
	P	0.15 to 0.24	0.25 to 0.35	>0.60	0.12 to 0.14	0.25 to 0.35	>0.50
	K	1.00 to 1.49	1.50 to 2.00	>4.00	0.70 to 0.99	1.45 to 1.75	>4.00
Secondary nutrients	Ca	0.30 to 0.49	0.50 to 0.60	>1.00	0.30 to 0.45	0.45 to 0.50	>1.00
	Mg	0.10 to 0.30	0.30 to 0.40	>0.40	0.10 to 0.12	0.25 to 0.35	>0.50
	S	0.15 to 0.50	0.50 to 0.60	>0.60	0.12 to 0.14	0.45 to 0.50	>0.50
		ppm					
Micronutrients	Al	—	<1,500	—	—	<1,500	>1,500
	B	4 to 5	15 to 20	>30	4 to 5	10 to 20	>30
	Cu	3 to 4	10 to 20	>50	3 to 4	10 to 15	>50
	Fe	40 to 49	300 to 4,00	>400	40 to 49	250 to 450	>450
	Mn	16 to 24	80 to 100	>300	16 to 24	80 to 100	>300
	Zn	15 to 40	40 to 80	>250	15 to 19	40 to 80	>250

		CREEPING BENTGRASS				PERENNIAL RYEGRASS		
Element		**Low**	**Desired**		**High**	**Low**	**Desired**	**High**
			Spring	**Summer**				
Primary nutrients	N	<4.5	5.00 to 6.00	4.00 to 5.25	>6.00	4.00 to 4.49	4.50 to 5.00	>5.00
	P	<0.3	0.35 to 0.40	0.35 to 0.60	>0.60	0.30 to 0.34	0.35 to 0.40	>0.40
	K	1.8 to 2.1	2.00 to 3.00	2.25 to 3.00	>3.00	0.70 to 1.99	2.00 to 2.50	>2.50
Secondary nutrients	Ca	<0.45	0.45 to 0.60	0.45 to 0.60	>0.75	0.20 to 0.24	0.25 to 0.30	>0.30
	Mg	<0.25	0.30 to 0.40	0.30 to 0.40	>0.40	0.13 to 0.15	0.16 to 0.20	>0.20
	S	<0.30	0.50 to 0.60	0.50 to 0.60	>0.70	0.22 to 0.26	0.27 to 0.32	>0.32
		ppm						
Micronutrients	Al	—	<1,500	<1,500	>1,500	—	—	—
	B	<8	15 to 25	15 to 25	>25	<9.0	9 to 17	>17
	Cu	<8	10 to 20	10 to 15	>30	4 to 5	6 to 7	>8
	Fe	<100	300 to 450	300 to 450	>450	<40	40 to 60	>60
	Mn	<50	90 to 130	90 to 130	>150	<2.0	2 to 10	>10
	Zn	<25	50 to 80	50 to 80	>80	10 to 13	14 to 20	>20

		KENTUCKY BLUEGRASS			TALL FESCUE		
Element		**Low**	**Desired**	**High**	**Low**	**Desired**	**High**
		%					
Primary nutrients	N	2.01 to 2.59	2.60 to 3.50	>3.50	2.50 to 3.39	3.40 to 3.80	>3.80
	P	0.18 to 0.27	0.28 to 0.40	>0.40	0.24 to 0.33	0.34 to 0.45	>0.45
	K	1.50 to 1.99	2.00 to 3.00	>3.00	2.20 to 2.99	3.00 to 4.00	>4.00
Secondary nutrients	Ca	5 to 12.5 g/kg			5 to 12.5 g/kg		
	Mg	2 to 6 g/kg			2 to 6 g/kg		
	S	2 to 4.5 g/kg			2 to 4.5 g/kg		
		mg/kg or ppm					
Micronutrients	Fe	35 to 100 mg/kg (or ppm)			35 to 100 mg/kg (or ppm)		
	Mn	25 to 150 mg/kg			25 to 150 mg/kg		
	Zn	20 to 55 mg/kg			20 to 55 mg/kg		
	Cu	5 to 20 mg/kg			5 to 20 mg/kg		
	B	10 to 60 mg/kg			10 to 60 mg/kg		
	Mo	2 to 8 mg/kg			2 to 8 mg/kg		

		ST. AUGUSTINEGRASS	SEASHORE PASPALUM	ZOYSIAGRASS
Element		**Desired**	**Desired**	**Desired**
		%		
Primary nutrients	N	1.90 to 3.00	2.80 to 3.50	2.70 to 3.50
	P	0.20 to 0.50	0.30 to 0.60	0.11 to 0.39
	K	2.50 to 4.00	2.00 to 4.00	0.38 to 1.51
Secondary nutrients	Ca	0.30 to 0.50	0.25 to 1.50	0.31 to 0.54
	Mg	0.15 to 0.25	0.25 to 0.60	0.11 to 0.25
	S	0.20 to 0.45	0.20 to 0.60	0.20 to 0.45
		mg/kg or ppm		
Micronutrients	Fe	50 to 300	50 to 500	35 to 100
	Mn	40 to 250	50 to 300	25 to 150
	Zn	20 to 100	20 to 250	20 to 55
	Cu	10 to 20	5 to 50	5 to 20
	B	5 to 10	5 to 60	10 to 60
	Mo	2 to 8	0.5 to 1.0	2 to 8

5 CULTURAL PRACTICES FOR GOLF COURSES

5 CULTURAL PRACTICES FOR GOLF COURSES

Golf courses require daily cultural practices to maintain quality playing surfaces and an aesthetically pleasing turf. Frequent maintenance practices such as mowing, watering, fertilizing, and aerifying are necessary, and a well-defined and well-conceived short- and long-term maintenance plan often elevates a course from others without that level of foresight. Courses typically begin to decline when necessary practices such as aerifying or topdressing are curtailed. This chapter outlines contemporary cultural practices and considerations for timings and frequencies courses can use when developing their master maintenance program.

5.1 MOWING

Mowing is the most basic, yet most important, cultural practice to provide desirable turf **(Figure 5–1)**. Other cultural practices and many aspects of turf quality are affected by mowing including density, texture, color, root development, and wear tolerance. Failure to mow properly usually weakens the turf resulting in poor density and quality.

Turfgrasses can be mowed relatively close to the ground due to their terminal growing point (crown) being located at or just below the soil surface. Re-growth from cell division and elongation takes place from growing points located below the height of the mower blade. In contrast, upright growing dicot plants have their meristematic tissue (growth points) at the top or tip of their stems. Consequently, mowing removes this growing point and many upright dicot weeds are eliminated since they do not have enough recuperative potential to recover.

Figure 5-1. Mowing is the most basic, yet most important cultural practice which provides a desirable turf.

Mowing Height

Mowing heights for golf course turf are mainly governed by the grass variety and the intended use **(Figure 5–2)**. For example, golf greens are mowed below 0.25 inch (6.4 mm) to provide the smooth, fast, and consistent playing surface that golfers desire. The turf species being mowed also influences height. For example, bentgrass generally withstands a shorter height than bluegrass. Mowing height also is influenced by cultivar (e.g., TifEagle bermudagrass tolerates shorter mowing than Tifgreen bermudagrass), while the newer creeping bentgrasses (e.g., L-93, A's and G's, etc.) tolerate closer mowing than Penncross bentgrass. Other factors influencing mowing height include mowing frequency, shade versus full sun-grown turf, mowing equipment, time of year, root growth, and moisture or temperature stress. Recommended mowing heights for each grass species and use are listed in **Table 5–1**.

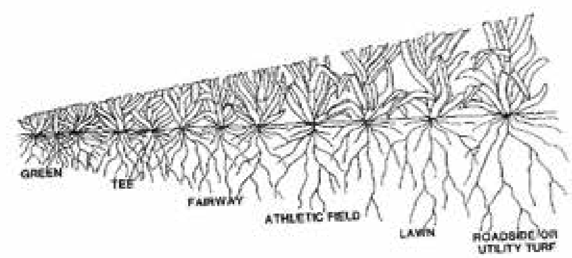


Figure 5-2. A direct correlation exists between mowing height and resulting turfgrass rooting. Generally, turf should be mowed as high as possible to encourage deeper rooting.

Mowing Frequency

Besides using properly maintained equipment, the most important aspect of mowing management is the frequency of cut—the more often, the better. Also, the shorter a grass is maintained, the more frequently it must be mowed. Mowing frequency often is a compromise between what is best for the turf and what is desired or practical for man. For example, daily mowing would be best for most turf, whether it is a golf green, tee, fairway, or even a sports field. However, this is impractical except for smaller, highly maintained areas such as greens.

The growth rate of the grass should determine the frequency of cut. Growth rate is influenced primarily by

Table 5-1. Recommended mowing heights for turfgrass species and their use.

SPECIES	MOWING HEIGHT (INCH)*		MOWINGS PER WEEK	
Greens				
"Ultradwarf" bermudagrass	1/8** to 3/16		5 to 7	
Tifdwarf bermudagrass	5/32 to 3/16		5 to 7	
Tifgreen (328) bermudagrass	3/16 to 1/4		5 to 7	
Creeping or Colonial bentgrass/Poa	1/10 to 3/16		5 to 7	
Tees				
Creeping or Colonial bentgrass	1/4 to 1/2		3 to 5	
"Ultradwarf" bermudagrass	1/4 to 1/2		3 to 5	
Tifdwarf bermudagrass	1/2 to 3/4		2 to 3	
Kentucky bluegrass	3/4 to 1		3 to 5	
Kikuyugrass, Zoysiagrass	7/16 to 5/8		2 to 5	
Perennial ryegrass, Fine fescue	3/8 to 1		3 to 5	
Seashore paspalum	5/16 to 1/2		3 to 5	
Zoysiagrass	7/16 to 5/8		2 to 5	
Fairways				
Creeping or Colonial bentgrass	3/8 to 5/8		3 to 5	
Common bermudagrass	3/4 to 7/8		2 to 4	
Hybrid bermudagrass	7/16 to 5/8		3 to 5	
Kentucky bluegrass	1 to 1 1/2		1 to 2	
Kikuyugrass	1/2 to 3/4		3 to 5	
Perennial ryegrass, Fine fescue	1/2 to 7/8		2 to 4	
Seashore paspalum	7/16 to 5/8		2 to 5	
Tall fescue	1 1/4 to 2 1/2		1 to 2	
Zoysiagrass	1/2 to 3/4		2 to 3	
ROUGHS	**INTERMEDIATE**	**PRIMARY**	**INTERMEDIATE**	**PRIMARY**
Common bermudagrass	0.75 to 1.25	1.5 to 3	2 to 3	1 to 2
Carpetgrass, Centipedegrass	1.0 to 2	2 to 3.0	2 to 3	1 to 2
Hybrid bermudagrass	0.75 to 1.25	1.5 to 2.0	3 to 4	1 to 3
Kentucky bluegrass	1.25 to 2	2.0 to 4	2 to 3	1 to 2
Kikuyugrass	1 to 1.5	1.5 to 2	2 to 3	1 to 3
Ryegrass	1 to 1.75	1.5 to 3	2 to 4	1 to 2
Seashore paspalum	0.75 to 1.25	1.5 to 2	2 to 3	1 to 2
Tall fescue	1.25 to 2	2.5 to 4	2 to 3	1 to 2
St. Augustinegrass, Bahiagrass***	—	2 to 3	—	1
Wheatgrass	—	2.5 to 4	—	1
Zoysiagrass	0.75 to 1.5	1.5 to 2	2 to 3	1 to 2

*Multiply inches by 25.4 to obtain millimeters (mm) or by 2.54 to obtain centimeters (cm).
**Tifgreen and Tifdwarf bermudagrass mowing heights below 3/16 inch (0.48 cm) are recommended only for short-term durations such as during tournament play. Newer ultradwarf bermudagrass cultivars are more tolerant to long-term lower mowing heights but should be raised by late summer due to shorter day lengths and typically cloudy conditions.
***Long-term mowing heights below three inches (7.6 cm) may weaken certain cultivars of St. Augustinegrass and bahiagrass.

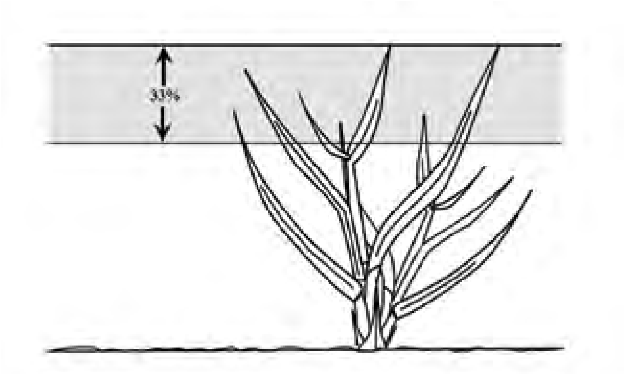


Figure 5-3. Mowing frequency should ideally be performed when the turf height is one-third higher than the desired height.deeper rooting.

the amount and source of nitrogen fertilizer applied and by season or temperature. With warm-season grasses, higher levels of either result in faster top growth, thereby requiring an increased mowing frequency. By raising the mowing height, the frequency of cut is reduced, which helps compensate for faster growing turf. When considering cool-season grasses during summer in warm climates, higher temperatures do not result in faster growth rates. Depending on the species, peak growth occurs around 70°F (21°C) for cool-season grasses. Extreme temperatures above this will slow growth, thereby reducing the need for mowing.

One-Third Rule. The traditional rule is to mow often enough so as not to remove more than one-third of top growth at any one time **(Figure 5–3)** since this decreases the recuperative ability of plants due to extensive loss of the leaf area needed for photosynthesis. This reduction in photosynthesis (food production) can result in weakening or death of a large portion of the root system since carbohydrates in roots are then used to restore new shoot tissue. Consequently, root growth may stop for a period following severe defoliation since the regeneration of new leaves (shoots) takes priority over sustaining roots for food reserves. However, when only one-third or less of shoot growth is removed during one mowing, enough carbohydrates are available to simultaneously sustain shoot-and-root growth without significantly reducing either. **Table 5–2** lists typical mowing heights and the resulting mowing frequency needed during active growing periods to maintain turf within the one-third rule-of-thumb. A golf course rough maintained at three inches (7.6 cm) needs to be mowed infrequently (once every 10 to 14 days) compared to a golf green mowed at 0.125-inch (3.2 mm), which requires daily mowing to prevent more than one-third of the height (0.04 inches, 1.0 mm) from being removed at any one period. Again, frequency is dependent on the grass growth rate.

Scalping. Scalping occurs when the turf has grown above the one-third maintenance height and is then mowed **(Figure 5–4)**. Excessive growth most often is from excessive nitrogen use, environmental conditions that favor rapid growth, and/or weather conditions that prevent normal mowing. If turf becomes excessively tall, it should not immediately be mowed down to the intended height. The resulting severe scalping may stop root growth for extensive periods. Also, since scalping removes the majority of plant leaf tissue, sunlight more readily reaches the soil surface and weeds typically become more problematic.

Figure 5-4. Scalping of a golf course from too infrequent mowing, dropping the height excessively at one time, and/or from excessive thatch which is susceptible to indentations from mowers.

Table 5-2. Typical mowing frequencies during periods of active growth needed for a given height to remove one-third of the leaf surface.

DESIRED HEIGHT (INCHES)*	HEIGHT REACHED ABOVE THE DESIRED CUTTING HEIGHT BEFORE MOWING	APPROXIMATE FREQUENCY (DAYS)
<1/4	3/8	daily
1/2	3/4	2 to 3
1	1 1/2	4 to 5
2	3	7 to 10
3	4 1/2	10 to 14

Figure 5-5. Yellow turf from being smothered by excessive clipping debris.

Figure 5-6. Weak, thin turf in late summer from insufficient aeration (coring) the previous spring.

Grass Clippings

Clippings are often composed of 3 to 5 percent nitrogen on a dry weight basis and also contain significant amounts of phosphorus and potassium. Clippings, therefore, serve as an important source of nutrients. If clippings are removed, additional fertilization is required to compensate for those nutrients. Removing clippings also poses a disposal problem for many superintendents since most municipal landfills no longer accept them, or if they do, an additional fee is assessed. Emptying the catcher or raking the clippings also requires additional time and labor. Under normal conditions, clippings should be allowed to fall back to the turf. Only when clippings are so heavy they smother the grass or interfere with the playing surface, such as golf greens, should they be removed **(Figure 5–5)**.

Clippings collected from golf greens should be disposed of properly to prevent undesirable odors near the playing area and to prevent fire hazards when clipping piles accumulate. Compost piles can be developed by alternating layers of clippings with a mixture of soil and nitrogen fertilizer. When composted, clippings can then be used as ground mulch in flower beds or inaccessible mowing areas. If not composted, clippings should be dispersed so piles are not allowed to form.

5.2 AERIFICATION

Turf on heavy use areas such as golf course greens, sports fields, and other high-traffic areas often deteriorates due to compacted soil, thatch development, and excessive use **(Figure 5–6)**. Unlike annual row crops that are periodically tilled to correct these problems, turf managers cannot provide such physical disturbances without destroying the playing surface. Soil-related problems are usually confined to the upper three inches (7.6 cm) of the turf profile. Once formed, they may not be completely corrected, especially where improper site preparation occurred prior to establishment. However, over the years, a number of mechanical devices that provide soil cultivation with minimum turf surface disturbance have been developed. Cultivation is accomplished by core aerification, vertical mowing, spiking, slicing, and topdressing.

Aerification or **"coring"** is the removal of small soil cores or plugs of soil with grass from the turf surface, leaving a hole in the sod **(Figure 5–7)**. Holes are normally 0.25 to 0.75 inch (6.4 to 19 mm) in diameter, with their depth and distance apart depending upon the type of machine used, forward speed, degree of soil compaction, and level of soil moisture present. Traditional aerifying machines penetrate the upper two to four inches (5 to 10 cm) of soil surface with cores spaced anywhere from two to six inches (5 to 15 cm) to the center. Recent innovations in aerification equipment provide options for creating holes to depths of greater than 10 inches (25 cm) and diameters ranging from one-eighth- to one inch (3.2 to 25 mm). Turf generally responds best when cores are close together and deep. This pattern removes more soil, exposes more surface area for water and nutrient intake, and alleviates compaction better than wider or shallower tine spacing and depth. In addition to the depth and diameter of the holes, options are now available on how to create the hole and core spacing. Advantages and disadvantages associated with coring include the following:

Figure 5-7. Routine aerification (coring) is a necessary, accepted industry maintenance practice to maintain healthy turf.

Figure 5-8. The only practical means with which golf courses can relieve soil compaction is aerification followed by cores being discarded.

Figure 5-9. Classic sign of insufficient soil oxygen when the healthiest turf is in previous aerification holes.

Benefits of Coring

1. Relieves surface and subsurface soil compaction. Compaction or soil bulk density is quantified as soil mass per soil volume. As it is impractical to increase soil volume, turf managers alleviate compaction by reducing soil mass through aerification and removing the plugs **(Figure 5–8)**.
2. Allows deeper, faster penetration of water, air, topdressing sand, fertilizer, lime, and pesticides into the rootzone.
3. Allows for penetration of oxygen into the soil for plant roots **(Figure 5–9)**.
4. Allows for atmospheric release of toxic gases (e.g., carbon dioxide, methane, carbon monoxide) from the rootzone, minimizing the occurrence of **"black layer" (Figure 5–10)**.
5. Improves surface drainage to help dry out saturated soils and prevent formation of puddles.
6. Improves penetration of water into dry or hydrophobic soils (e.g., relieves localized dry spots) **(Figure 5–11)**.
7. Penetrates through soil layers that develop from topdressing with dissimilar materials. These form stratified layers where water will not drain out of the finer layer until it is fully saturated. A one-eighth inch (3.2 mm) layer of fine soil is sufficient to prevent drainage in an otherwise perfect soil profile.
8. Aids in soil replacement when combined with topdressing.
9. Encourages organic matter/mat/thatch control by stimulating those environmental conditions that promote healthy soil microorganism activity that naturally decomposes the components attributing to thatch development.
10. Increases rooting by constructing a rootzone more conducive for active root growth.
11. Improves turf resiliency and soil cushioning.
12. Improves seedbed preparation for renovation, overseeding, and interseeding.

Figure 5-10. "Black layer" from deficient soil oxygen due to inadequate core aerification and excessive soil moisture.

Figure 5-11. Localized dry spots from inefficient irrigation water penetration due to insufficient aerification which then allowed excessive thatch accumulation.

Disadvantages of Coring

1. Temporary disruption or damage to the playing surfaces.
2. Increased surface desiccation as roots and soil surfaces are exposed.
3. Temporarily provides a better habitat in which cutworms, mole crickets, and other insects can reside.

Generally, the benefits of aerification far outweigh any detrimental effects. Turf managers must decide which option is best to solve the existing problem.

Frequency and Timing of Cultivation

The frequency of core cultivation should be based on the intensity of traffic to which the turf is exposed. Other factors include soil makeup, hardness of the soil surface, drainage capability, and degree of compaction. **Table 5-3** lists general recommendations for maintaining desirable turf on mature golf greens. If these ***minimum*** values are not retained, the frequency and intensity of core cultivations should be increased. Areas receiving intense, daily traffic such as golf greens, approaches, landing areas, aprons, and tees annually require a minimum of three core aerifications. Additional aerifications may be needed on exceptionally small greens where traffic is more concentrated, areas consisting of heavy soils high in silt and/or clay that do not drain well, areas with localized dry spots, or soils exposed to saline or effluent water use. Such areas may need aerification with smaller diameter tines (3/8 inch, 9.5 mm, or less) every four to six weeks during active growing months. Failure to maintain an aggressive aerification program in such situations will result in a gradual reduction in turf quality from poorly drained soils, thin grass stands, mat accumulation, and continued problems with algae and moss.

Less intense traffic areas should be aerified on an as-needed basis. Most warm-season grass fairways should be aerified twice yearly, with the first timed in mid-spring once the grass is actively growing and chances of a late freeze have passed. The second aerification should be in late summer. If the area is to be overseeded with ryegrass, then the second aerification should be timed approximately four to six weeks prior to seeding. Aerification is not recommended within six to eight weeks before the first expected frost to allow enough time for grass recuperation before cold weather ceases growth. The aerification of cool-season grass fairways is usually performed twice yearly, usually in fall and early spring, when temperatures are conducive for optimum growth.

Another means to determine how much to aerify each year is based on the amount of turf surface impacted by aerification. A 15 to 20 percent surface area being impacted on an annual basis is a reasonable goal for many well-established golf courses. A percentage basis is sometimes easier for non-agronomists to understand instead of trying to comprehend tine diameters and spacing. Neglected courses may need a more aggressive aerification program. As outlined in **Table 5–4**, using various tine sizes and hole spacings will determine the surface area of turf impacted **(Figure 5–13)**. For example, a fourfold increase in surface area impacted occurs when using a 0.5-inch (1.3-cm) tine instead of 0.25-inch (0.6-cm) tines. An approximately 50 percent increase in surface area impacted occurs when using 5/8-inch (1.6-cm) tines instead of a 0.5-inch (1.3-cm) tine. Another example involves changing tine spacing; for example, changing tine spacing from two × two inch (5 × 5

Table 5-3. Target ranges for various soil physical and organic properties of established golf greens depending on their description.*.

	GREEN DESCRIPTION			
	NATIVE SOIL	MODIFIED SOIL	WELL-DRAINED	
CHARACTERISTIC			0- to 4-in	4- to 12-in
Infiltration rate (in hr^{-1}, cm hr^{-1})	>2 (5)	>4 (10)	>6 (15)	>10 (25)
Non-capillary porosity (%)	>12	>14	~20	>20
Capillary porosity (%)	15 to 30	<30	15 to 25	<20
Bulk Density (g cm-3)	1.35 to 1.45	1.35 to 1.45	1.35 to 1.45	1.40 to 1.50
Water retention (%)	10 to 25%	<25	10 to 20	10 to 20
Organic content at various depths (%):				
-0.25- to 1-in (0.6 to 2.5 cm)	1.5 to 2.5	1.5 to 3.0	1.5 to 2.5	0.1 to 1.0
-1- to 2-in (2.5 to 5 cm)	1.0 to 2.0	1.0 to 2.0	1.0 to 2.0	0.1 to 1.0
-2- to 3-in (5 to 7.6 cm)	0.5 to 2.0	0.5 to 2.0	0.5 to 2.0	0.1 to 1.0
-3- to 4-in (7.6 to 10 cm)	0.5 to 2.0	0.5 to 2.0	0.5 to 1.5	0.1 to 1.0

*Target ranges from ISTRC reports (http://www.istrc.com).

Figure 5-13. A wide variety of aerification cores are commercially available.

cm) to one × two inch (2.5 to 5 cm) (with 3/8-inch diameter tines, 1 cm) increases the surface area impacted by 100 percent.

Spiking and Slicing

Two other cultural practices available to help relieve surface compaction, promote better water penetration and aeration, stimulate new shoot-and-root development, sever stolons and rhizomes, and help incorporate topdressing are **spiking** and **slicing**. These generally are pull-type, non-powered units consisting of a series of blades mounted on a horizontal shaft. A slicer has thin, V-shaped knives bolted at intervals to the perimeter of metal wheels that cut into the soil. Turf is sliced with narrow slits about one-fourth inch (6.4 mm) wide and two to four inches (5 to 10 cm) deep **(Figure 5–14)**. Slicing can be performed much

Table 5-4. Aerification tine size diameter and hole spacing effects on the turf surface area displacement.*

TINE DIAMETER	TINE HOLE SPACING	HOLES PER SQUARE FEET	SURFACE AREA IMPACTED PER TINE	SURFACE AREA DISPLACEMENT	AERIFICATIONS NEEDED TO IMPACT 20% SURFACE AREA
inch	inch	number	in2	%	number
1/4 (0.25)	1 × 1	144	0.049	4.9	4
	1.25 × 1.25	92		3.1	6.5
	1 × 2	72		2.5	8
	2 × 2	36		1.2	16.7
	2.5 × 2.5	23		0.8	25
3/8 (0.375)	1 × 1	144	0.110	11	1.8
	1.25 × 1.25	92		7.1	2.8
	1 × 2	72		5.5	3.6
	2 × 2	36		2.76	7
1/2 (0.5)	1 × 1	144	0.196	19.6	1
	1 × 2	72		9.8	2
	1 x 1.5	64		8.7	2.3
	1.5 x 2	48		6.5	3.1
	2 × 2	36		4.9	4
	2.5 × 2.5	23		3.1	6.5
5/8 (0.625)	1 × 1	144	0.307	30.7	0.7
	1 × 2	72		15.3	1.3
	1 x 1.5	64		13.6	1.5
	2 × 2	36		7.7	2.6
	2.5 × 2.5	23		4.9	4
	5 × 5	5.8		1.2	0.8
3/4 (0.75)	2.5 × 2.5	23	0.44	7.1	2.8
	5 × 5	5.8		1.8	11
1 (1.0)	5 × 5	5.8	0.79	3.16	6.5

*Multiply inches by 25.4 to obtain millimeters (mm) or 2.54 to obtain centimeters (cm), multiply square inch by 6.45 to obtain square centimeters.

Figure 5-14. Narrow slits in turf from slicing and spiking.

Figure 5-15. Turf following vertical mowing to remove thatch and correct grain development.

faster than coring and does not interfere with the turf surface since soil cores are not removed; thus, no clean up is necessary after the operation. Slicing is also performed on fairways and other large, high-traffic areas during midsummer stress periods when coring may be too injurious or disruptive. Slicing is an excellent tool to prevent surface crusting and algae development and can be used during periods of heavy rainfall when other aerification techniques cannot. Weekly use is recommended, especially during stressful growing conditions. Slicing, however, is less effective than coring and is most effective when used in conjunction with coring. As with coring, slicing is best accomplished on moist soils to facilitate penetration.

A spiker has solid tines mounted on a horizontal shaft. It provides an effect similar to a slicer, but the penetration is limited to approximately one inch (2.5 cm). The distance between perforations along the turf's surface is also shorter. Because of these reasons and since spiking causes less surface disruption than coring, this is primarily practiced on greens and tees. Both a slicer and spiker help (1) break up soil surface crusting, (2) break up algae layers, and (3) improve water penetration and aeration. Solid tines are associated with a spiker, and holes are punched by forcing soil downward and laterally. This causes some compaction at the bottom and along the sides of the holes. Since only minor disruptions of soil surfaces occur, spiking and slicing can be performed more often (e.g., every 7 to 14 days) than with core aerification (e.g., every 4 to 8 weeks). A number of additional devices are available which help provide healthier turf with less surface disruption.

5.3 VERTICAL MOWING

A vertical mower is a powered unit with a series of knives vertically mounted on a horizontal shaft. The shaft rotates at high speeds and the blades slice into the turf and rip out thatch and other debris **(Figure 5–15)**. Depending on the task, the shaft can be raised or lowered to cut shallowly or more deeply into the turf. Vertical blade thickness varies between 1/32 and 1/4 inch (0.8 to 6.4 mm), according to use. Golf greens require thinner blades to prevent excessive surface damage while fairways require heavier, thicker blades to obtain desired results.

Depth

Different objectives can be met with vertical mowing depending on the depth of penetration and blade spacing. Grain is reduced when knives are set shallow enough to just nick the surface of the turf. Shallow vertical mowing also is used to break up cores following aerification, thereby providing a topdressing effect. Deeper penetration of knives stimulates new growth of creeping species when stolons and rhizomes are severed and also removes accumulated thatch. Seedbed preparation prior to overseeding also is accomplished by deep vertical mowing.

When dethatching is the objective, thatch depth will determine the depth of blades. The bottom of the thatch layer should be reached by vertical mowing, and the soil surface beneath the thatch layer should preferably be sliced. However, there is a limit to the depth blades should be set or excessive removal of turf roots, rhizomes, stolons, and leaf surface may occur. For example, blades should be set at a depth to just cut stolons and no deeper if new growth stimulation is the objective. Vertical blade spacing for thatch removal should be between one and two inches (2.5 to 5 cm). This range provides maximum thatch removal with minimal turf damage.

Deep vertical mower penetration requires the use of a heavy-duty machine that can penetrate two to three inches (5 to 7.6 cm). Deep vertical mowing grooves the turf surface, so topdressing is often required to smooth the surface and cover exposed stolons. Shallow-rooted or immature turf can be severely damaged or torn out by deep vertical mowing. Preliminary testing at the site to be verticut should be done by hand pulling to measure if favorable rooting of the grass exists. Irrigation and topdressing should follow such deep vertical mowing to prevent quick desiccation of exposed roots, rhizomes, and stolons, as well as to help smooth the turf surface and encourage turf recovery.

Frequency

The rate of thatch accumulation dictates the frequency of vertical mowing **(Figure 5–16)**. Vertical mowing should begin once the thatch layer on golf greens exceeds 0.25 to 0.5 inch, 6.4 to 13 millimeters. This layer can be periodically checked when cups are changed or at any time by using a knife to slice a plug from the green. Areas prone to thatch accumulation may require heavy vertical mowing several times per year. For bermudagrass, the first is during mid- to late-spring when the grass is actively growing. This removes thatch and encourages turf spread by slicing stolons and by warming the soil surface quicker than if the thatch is allowed to remain. The second vertical mowing should be timed two to four weeks before the anticipated fall overseeding. This discourages late-season bermudagrass growth that can compete with the overseeded grasses, and exposes the soil surface so grass seed can reach the soil better and have optimum germination. However, fall vertical mowing will result in a degree of surface damage that may not heal until the overseeding has time to become established. Bentgrass greens are vertically mowed in fall and again in spring when temperatures are mild and the grass is actively growing. However, newer cultivars tend to form a tighter stand surface than older ones; thus, may require more frequent vertical mowing.

Figure 5-16. Excessive thatch accumulation due to insufficient aerification, topdressing, grooming and vertical mowing.

Soil and thatch should be dry when deep vertical mowing is performed or turfgrass injury will be more extensive since moist conditions encourage excessive plant material to be removed. Following verticutting, debris should be disposed of and the area immediately irrigated. Approximately five to seven days following heavy vertical mowing, nitrogen should be applied to encourage rapid recovery. With warm-season grasses, the last heavy vertical mowing of the season should be timed at least four weeks before the first anticipated frost. With cool-season grasses, the last verticutting should occur at least one month prior to the onset of unfavorable growing conditions, such as the high heat of summer or cold winter temperatures.

If the thatch layer has become excessive (>2 inches, 5 cm), it may become unmanageable by vertical mowing. In such extreme conditions, the grass and thatch layer need to be removed with a sod cutter. Soil must be added to level the area and then reestablished. This problem can be best avoided by verticutting and topdressing frequently enough (e.g., every four weeks during the growing season) to keep the thatch under control. Additionally, judicious use of fertilizer nitrogen and pesticides will sometimes slow rapid and extreme thatch accumulations.

Interchangeable vertical mower units are now available for many of today's greensmowers. This equipment allows for frequent vertical mowing and simultaneous debris collection. The vertical blades on greensmowers should be set to only nick the surface of the turf so the surface is not impaired. By conducting frequent, light vertical mowing, the severe vertical mowing needed for renovation may be avoided **(Table 5–5)**. Large turf areas such as fairways are vertical mowed by using units that operate off a tractor's power take off (PTO). Such units have heavily reinforced construction and large, thick (approximately 1/4-inch, 6.4-mm) blades that are able to penetrate the soil surface.

Grooming and Conditioning

The grooming mower (also called turf conditioner) is a recent advancement in vertical mowing. Grooming keeps greens smooth and quick by reducing grain and removing excessive top growth **(Figure 5–17)**. In front of the reel-cutting unit is an attached miniature vertical mower (often referred to as **vertical grooming**) with typical blade spacing of <1/4 inch (6.4 mm) set 0.0625 to 0.125-inch (1.6 to 3.2 mm) below the height of cut that rotates through slots in the front roller. In front of the vertical groomer, a roller is mounted to increase turf penetration in dense turfgrasses and to improve the height of cut. A solid or full roller minimally penetrates, and performs best on stiffer turfgrasses that quickly rebound after the roller goes over them. A swage roller has thickened outer edges where the center of the roller does not touch the grass. It, therefore, penetrates the grass surface very little. Grooved rollers provide maximum turf penetration due to the many grooves or slits in them.

Table 5-5. Turf surface area impacted by vertical mowing blade widths.

VERTICAL MOWER BLADE WIDTH	SPACING	SURFACE AREA IMPACTED	VERTICAL MOWINGS NEEDED TO IMPACT 25% SURFACE AREA
inch	inch	%	number
5/64	0.5	15.6	1.6
	1	7.8	3.2
9/64	0.5	28	0.9
	1	14.1	1.8

Figure 5-17. Typical grooming device and grooved rollers used on golf courses.

Each time turf is mowed with this unit, the turf is lightly vertically mowed (or groomed or conditioned). This unit improves the playing surface by standing up leaf blades before mowing, thereby removing much of the surface grain. New shoot development is also stimulated by slicing stolons and removing thatch near the surface. Weekly grooming, along with timely topdressing and aerification, helps eliminate the need for traditionally performed turf renovation by severe vertical mowing.

Other groomers use a rotary brush that operates in the opposite direction of the mower blade. The brush stands the grass up prior to mowing, reducing grain and providing a smooth surface. Combs are also mounted behind the front roller to lift up (or comb) the grass to reduce grain and improve cutting.

5.4 TOPDRESSING

Topdressing adds a thin layer of soil to the turf surface, which is then incorporated into the turf by dragging or brushing it in (**Figure 5–18**). The benefits of a proper topdressing program include:

1. Increasing thatch decomposition
2. Truing and smoothing the playing surface
3. Reducing grain
4. Enhancing turf recovery from injury
5. Encouraging a denser and finer-textured turf
6. Enhancing overseeding
7. Modifying existing soil

On newly vegetatively established turf, topdressing partially covers and stabilizes the newly planted material, smooths gaps from sodding, and minimizes turfgrass desiccation. Topdressing is performed on established turf to smooth the playing surface, control thatch and grain, promote recovery from injury, and possibly change the physical characteristics of the underlying soil. Unfortunately, in recent years, many superintendents have reduced the number of coring and topdressing procedures due to member complaints about disrupted play. These procedures, however, are sound, fundamental agronomic practices necessary to maintain an optimal putting surface; if eliminated, putting green quality will diminish over time. An effective topdressing program requires: (1) selecting an appropriate topdressing material, (2) using the appropriate frequency and rate, and (3) adjusting the schedule to best suit a particular site or situation.

Topdressing Materials

Deciding on the material to use for topdressing is one of the superintendent's most important long-term agronomic decisions. Using undesirable materials can be disastrous

Figure 5-18. Hand applying a light layer of sand topdressing to smooth the playing surface and help prevent thatch accumulation.

Figure 5-19. Layering from using different topdressing materials over time. This disrupts normal water and soil oxygen exchange throughout the rootzone.

and ruin the integrity of many initially well-built facilities. This usually occurs when a topdressing material is finer in particle size than that from which the green is constructed. Therefore, locating a topdressing source that meets your needs is the first step.

When the underlying soil of the playing surface is unsatisfactory, a decision will be needed on whether to rebuild the facility or try to slowly change its composition through aggressive coring and topdressing. If the soil problem is considered severe, then the superintendent's green committee will probably be disappointed with the coring and topdressing approach and should consider reconstruction.

If the golf green soil profile is satisfactory, then the topdressing material used should match the initial construction sand. When new greens are constructed, stockpiling enough rootzone mix to cover two to five years of routine topdressing is highly recommended to prevent the introduction of dissimilar soil into the green. The only difference in the stockpiled material and regular soil mix used in construction may be the absence of organic matter in this topdressing material. Enough organic matter is usually produced by normal plant growth for future needs.

One of the most commonly observed problems with improper topdressing is the formation of various alternating layers of soil (stratification) that arise from using different topdressing materials over time **(Figure 5–19)**. Differences in textural characteristics between sands and organic matter layers result in poor root growth caused by physical barriers, lack of oxygen, entrapment of toxic gases, micro-perched water tables, and dry zones. Even a one-eighth-inch (3.2 mm) layer of different soil textures may disrupt normal soil water and gas movement. Once these layers are allowed to form, aggressive vertical mowing and coring are required to correct the problem, short of reconstruction. Aerification holes should extend at least one inch (2.5 cm) below the depth of the deepest layer. The use of one of the new deep-tine or deep-drill aerifiers often is required to reach these greater depths. Shallow spiking or coring above the layering is of very little benefit.

Dry topdressing material penetrates core aerification holes better than damp or wet topdressing material. Topdressing should then be matted in by dragging a steel mat, brush, or piece of carpet over the areas in several directions to evenly distribute the material. This area should then be watered immediately to reduce soil drying and to provide further settling of newly topdressed soil. With the introduction of deep core aerifiers, changing the underlying soil characteristics may be expanded. Deep coring once per year, followed by heavy topdressing with a desirable sand, should be practiced to improve poorly draining greens. Between these corings, conventional aerification and topdressing should still be performed. Over several years, progress can be made in improving the soil characteristics of the playing area by this technique, assuming drain lines are installed beneath the surface. Excess topdressing

Table 5-6. Approximate soil volumes needed to topdress golf greens to various depths.

RELATIVE RATE	DEPTH		SOIL VOLUME		
	inch	mm	ft^3/1,000 ft^2	yd^3/5,000 ft^2	m^3/100 m^2
Light	1/167 (0.006)	0.15	1/2	0.09	0.015
	1/83 (0.012)	0.30	1	0.19	0.030
Medium	1/42 (0.024)	0.61	2	0.37	0.061
	1/28 (0.036)	0.91	3	0.56	0.091
	1/20 (0.048)	1.22	4	0.74	0.122
Heavy	1/10 (0.10)	2.54	8	1.5	0.244
	1/8 (0.12)	3.05	10	1.9	0.30
	1/6 (0.17)	4.23	14.2	2.3	0.38
Extremely heavy	1/4 (0.25)	6.35	21	3.9	0.64
	1/2 (0.50)	12.7	42	7.7	1.28

material should be properly stored to keep it dry and uncontaminated. Covered soil bins, elevated sand "silos," or polyethylene covers provide good storage conditions until their use.

Topdressing Frequency and Amounts

Rates. The frequency and rate of topdressing depend on the objective. Following coring and heavy verticutting, moderate to heavy topdressing is used to help smooth the surface, fill coring holes, and cover exposed roots resulting from these two processes. Irregular playing surfaces or soil profile renovation will require frequent and relatively heavy topdressing. A suggested yearly total amount ranges from 25 to 45 cubic feet of sand per 1,000 square feet (0.75 to 1.3 $m^3/100\ m^2$). This, along with aerifying, grooming, and vertical mowing, helps prevent organic matter content from exceeding 3 percent (by weight). The topdressing is generally applied as light (e.g., 1/2 to 1 ft^3/1,000 sq.ft., 0.015 to 0.03 $m^3/100\ m^2$), frequent (e.g., every 1 to 3 weeks) events to minimize sand layer development and to prevent smothering **(Table 5-6)**.

Specific soil volumes needed for a given desired depth can be determined by the following. It is normally easier to convert the desired depth in inches to feet.

Example

To topdress a 6,000 square foot green with one-eighth inch depth topdressing, the following calculations are needed:

Step 1. One-eighth-inch topdressing depth is converted to feet by dividing by 12 since there are 12 inches per foot.

1/8 inch ÷ 12 inches per foot = 0.011 foot depth of topdressing desired

inch × 25.4 = millimeters (mm)

inch per 1,000 square feet × 83.3 = cubic feet per 1,000 square feet

cubic feet per 1,000 square feet × 27 = cubic yards per 1,000 square feet

cubic feet per 1,000 square feet × 0.185 = cubic yards per 5,000 square feet

cubic feet per 1,000 square feet × 0.030463 = cubic meters per 100 square meters

cubic yards per 1,000 square feet × 0.822 = cubic meters per 100 square meters

Step 2. Next, find the total volume, in cubic feet (cu. ft.), of the area to be topdressed.

green size (6,000 sq.ft.) × topdressing depth (0.011 ft.) = 66 cubic feet

Step 3. Finally, convert the 66 cubic feet to cubic yards (cu. yd.) by dividing with 27 cubic feet per cubic yard.

66 ft^3 ÷ 27 yd^3 = 2.4 yd^3 of soil volume is needed to topdress the 6,000 square feet green to a depth of one-eighth inch

Aerified Green. The topdressing needs of an aerified green are greater than those for greens not aerified due to the filling of aeration holes. It generally is easier to first determine total volume of cored holes for one square foot and then convert this to the total surface area of the green being topdressed.

Example

Step 1: Determine the total volume of all core holes for one square foot. A 0.5-inch (1.3-cm) diameter core is extracted to a depth of three inches (7.6 cm) on two-inch (5-cm) centers, producing:

$$\frac{144 \text{ inches}}{\text{sq.ft.}} \times \frac{\text{cores}}{2 \times 2 \text{ inches}} = \frac{36 \text{ cores}}{\text{sq.ft.}}$$

The volume of a core is [3.14 × (radius)^2] × height = [3.14 × (0.25 in.)^2] × 3 inches = 0.59 in.^{3} per core.

Step 2: Determine the volume of cores per square foot:

$$\frac{0.59 \text{ in.}^3}{\text{core}} \times \frac{36 \text{ cores}}{\text{sq.ft.}} = \frac{21.2 \text{ in.}^3}{\text{sq.ft.}}$$

Step 3: Determine the total amount of topdress material by multiplying the amount per square foot by the area of the green. If a green is 6,000 square feet in area, then:

$$\frac{21.2 \text{ in.}^3}{\text{ft}^2} \times \frac{6{,}000 \text{ ft}^2}{\text{green}} = \frac{127{,}200 \text{ in.3 topdressing}}{\text{green}}$$

Since 1,728 cubic inches are in each cubic foot, this can be converted by:

$$\frac{127{,}200 \text{ in}^3}{\text{green}} \times \frac{\text{ft}^3}{1{,}728 \text{ in}^3} = \frac{73.6 \text{ ft3 topdressing}}{\text{green}}$$

Since 27 cubic feet are in each cubic yard, this can be converted by:

$$\frac{73.6 \text{ ft}^3 \text{ topdressing}}{\text{green}} \times \frac{\text{yd}^3}{27 \text{ ft}^3} = 2.73 \text{ yd3 topdressing material}$$

Therefore, 2.73 cubic yards of topdressing material is needed per 6,000 square feet of green to fill 0.5-inch diameter holes three inches deep on two-inch spacing.

Frequency. If the objective of topdressing is to change the characteristics of the underlying soil, then a heavier topdressing program following numerous core removal operations is required. But, even following a rigorous coring and topdressing program, adequate modification of underlying soil may require several years to accomplish.

If thatch control is the main objective of topdressing, the amount and frequency are governed by the rate of thatch accumulation. Thatch layering between 0.25 and 0.5 inch

(0.64 and 1.3 cm) on golf greens is desirable. This relatively thin thatch layer cushions (holds) the approaching golf shot better and also provides a certain amount of protection for grass crowns from traffic. However, once this thickness is exceeded, frequent topdressing along with possible coring and verticutting are necessary. A suggested amount of topdressing when thatch is not excessive (1/4 to 1/2 inch) is approximately one cubic foot per 1,000 square feet (0.03 m^3/100 m^2). If this relatively light rate does not adequately enhance the decomposition of the thatch layer, then the frequency of application and topdressing rate should be increased.

If the objective of topdressing is just to provide routine smoothing of the playing surface, then light, frequent topdressings are suggested. Matting or brushing the green following topdressing results in the material being dragged into low spots. Surface irregularities of the green are reduced and the area is somewhat leveled. Topdressing with 0.25 to 0.5 cubic yard per 5,000 square feet (0.04 to 0.08 m3/100 m2) of green surface every two to four weeks provides a smoother, truer playing surface. Light topdressing is also performed approximately 10 to 14 days prior to major club tournaments to increase the speed of greens and provide a smoother putting surface. Frequent, light topdressing should also be applied on new bermudagrass greens to cover stolons and to smooth the surface. This should be performed every two to four weeks until complete coverage or the desired smoothness is achieved.

Fairways. Topdressing fairways is becoming more popular. This practice helps provide firmer fairways for better ball roll and overall playability, drier fairways from increased thatch decomposition, and less traffic restrictions, especially after rain events. Fairways are typically topdressed monthly during the grass's growing season. Topdressing rates range from four to six tons per acre (13,440 to 17,920 kg/ha). Heavier, less frequent topdressing may lead to layering. Greens grade quality topdressing sands for fairways are not normally necessary. Often a locally available mason's sand is sufficient if rocks do not contaminate it.

Thatch/Organic Matter Content Control

Most practices covered in this chapter are geared toward reducing soil compaction and minimizing thatch/mat or organic matter levels. Greens predominantly built with sand are designed to provide adequate internal drainage and to minimize soil compaction. However, organic matter can accumulate excessively over time and the benefits of sand greens gradually diminish. An upper limit of 3.5 to 4.5 % (by weight) of organic matter in the surface 2-inches (5 cm) of soil has been suggested to maintain desirable hydraulic conductivity **(Table 5-3)**. Cultural practices such as vertical mowing, grooming, aerifying, and topdressing are necessary to keep the organic matter buildup in check.

5.5 MANAGING PUTTING SPEEDS

Today's golf course superintendent is in the middle of a hot debate concerning golf green putting speeds (or distances). On one hand, club members see professional golfers playing every weekend on the best-maintained golf courses in the world, where not a blade of grass is missing or out-of-place. Even drainage ditches and creek banks are completely covered with lush, dark-green turf. The greens putt like glass and the pros actually complain they are too fast. Everything seems to be perfect and the members have trouble understanding why their home course cannot be maintained in a similar condition. Interestingly, the average handicap for American golfers is 16.1 for men and 29.2 for women.

On the other hand, the superintendent knows what is required in terms of money, time, labor, and resources to obtain "tournament" playing conditions. These courses can spend up to five years preparing for one tournament and spare no expense in achieving the best possible playing surface. Members do not realize the greens have been pampered for months leading up to the tournament, often not allowing membership play during this time. The finest equipment and supplies have been purchased or leased and used on the greens. The greens are built with the latest technology which allows perfect soil water content control.

As with most things in life, a reasonable compromise must be struck to keep the majority of golf course members happy without being too expensive. Before using putting speed as the sole criteria for judging the quality of a green, other components influencing putting speed need to be discussed. A high-quality green should be uniform in terms of density and coverage, deeply rooted, and free of disruptions from insects, diseases, or weeds. The individual leaves and tillers of the green should be oriented vertically to eliminate grain. The green does not necessarily need to be dark-green in color and lush in growth. **A diminishing-quality putting surface can be expected if putting speed is emphasized long term over other components of a good golf green such as smoothness, density, and health.** Other potential negative effects of emphasizing greens speed over healthy grass include:

- Fewer useable pin placements,
- Flatter greens with less interesting contouring,
- More putts, thus, slower rounds,
- Slower recovery of ball marks and old hole plugs due to less carbohydrates from less fertilizer inputs and less rooting depth,
- Increased turf stress from weaker (but faster) greens.

Golf course officials should first decide on the desired speed for both normal play and for tournament play. This decision should be based on the desires of the course members, as well as the amount of normal play received by the course, the superintendent's knowledge and experience, the course's budget and equipment, and other resources the club can make available to maintain the greens. Before unrealistic speeds are outlined by the club, reasonable expectations of the resources available to the superintendent should be discussed.

The Stimpmeter

Edward Stimpson, an avid golfer and 1935 Massachusetts Amateur Champion, designed the Stimpmeter in the 1930s. It is an extruded 36-inch (0.9 m) aluminum bar with a V-shaped groove along its entire length. A golf ball is placed in a notch 30-inches (76 cm) from the end that rests on the ground and the bar is raised to an angle of approximately 20 degrees until the ball is released **(Figure 5–20)**. The distance the ball rolls is then measured and recorded.

The USGA suggests rolling 3 golf balls one at a time down the Stimpmeter bar, record the distances, and then re-roll the balls in the opposite direction. The greens speed is then calculated from the average of the 3 ball rolls of the two directions.

Grooming putting surfaces to maximize green speed and quality involves the following **(Table 5-7)**.

1. Grass selection
2. Mowing practices
3. Fertilization
4. Aerification
5. Topdressing
6. Brushing/combing/grooming
7. Plant growth regulators
8. Water management
9. Rolling.

Suggested Sequence of Events

The following sequence of agronomic events is suggested to provide acceptable putting surfaces in terms of uniformity, density, and speed for a tournament (modified from Throssell, 1985). If all of these are incorporated into a total

Figure 5-20. Using a stimpmeter to gauge a green's ball roll distance.

Figure 5-21. Use of a roller to help smooth the playing surface and to increase ball roll distance.

Table 5-7. Cultural practices influencing putting speeds (or distances).

PRACTICE	COMMENT
Grass Selection	Ultradwarf cultivars, due to their lower mowing height tolerance, denser shoot counts and narrower leaves, generally provide best (furtherest) putting speeds.
Mowing height	Generally, a ⅛-inch (3.2 mm) decrease in height increases putting speeds 8 to 12 inches (20 to 30 cm).
Mower type	Drum-type walk-behind mowers increase putting speeds 0.5 to 1 foot (15 to 30 cm). Floating heads also increase speeds about 6-inches (15 cm).
Double cutting	Double cutting starting two days prior to and continuing during a tournament increases speeds ~6-inches (15 cm).
Grooming	Walk behind mowers with groomers increase speeds ~2-inches (5 cm).
Fertilization	For each pound of excessive nitrogen applied annually per 1,000 sq.ft. (4.9 g/m2), ~ 4-inch (10 cm) decreases in speeds occur.
Aerification	Aerification not followed by topdressing decreases speeds ~5-inches (13 cm) for up to 28 days.
	Aerification followed by topdressing increases speeds 6 to 15 inches (15 to 38 cm) up to 29 days, depending on rate. The increases, however, are not normally seen until day 8 following topdressing.
Rolling	One pass increases speeds ~1 foot (0.3 m) that day and ~6-inches (15 cm) the next day **(Figure 5–21)**.

Table 5-8. Putting green speeds as determined by the stimpmeter (USGA).

	BALL ROLL DISTANCE*			
PUTTING CHARACTERISTIC	NORMAL CONDITIONS		TOURNAMENT CONDITIONS	
	feet	meters	feet	meters
Slow	<7.5	<2.3	<8.5	<2.59
Medium	7.5 to 9.0	2.3 to 2.7	8.5 to 10	2.6 to 3.1
Fast	>9.0	>2.7	>10	>3.1

*Based on an average of ball roll distance up and down a green's slope.

management practice package, putting characteristics should be acceptable for the majority of participants. **Table 5–8** lists guidelines for ball speeds based on the stimpmeter.

Three Months Prior to the Tournament. Begin a PGR program to help regulate growth throughout the day. It requires several applications of PGRs to "condition" the grass so as not to have any phytotoxicity. These are usually spaced one to three weeks apart depending on use rate.

Six Weeks Prior to the Tournament. Fertilize with a 3-1-2 ratio fertilizer at the rate of one pound actual nitrogen per 1,000 square feet (4.9 kg N/100 m2). This fertilization will strengthen the grass for the upcoming aerification and aid recuperation.

One Month Prior to the Tournament. Core aerify with relatively small (e.g.,< 3/8 inch, 9.5 mm) tines when the green has adequate moisture to minimize damage to the putting surface. Aerification is needed when greens are considered excessively hard and do not hold approaching shots well, if the greens are not properly draining, or if localized dry spots are developing. If these problems are not present, then core aerification can be skipped. However, one month may be needed for the grass to recover and fill-in holes left from coring. Individual cores should be removed following aerification. The exception to this is when a desirable soil mixture is currently present. The cores in this case should be incorporated back into the profile by lightly verticutting or dragging with a brush or piece of carpet or steel drag mat.

Following aerification, the greens should be topdressed with a medium rate of desirable, clean soil. One to three cubic feet of material per 1,000 square feet (0.03 to 0.09 m3/100 m^2) should provide a medium topdressing rate. This should be immediately incorporated by dragging. Care must be taken during this process to prevent excessive desiccation or turf damage. Irrigate heavily following aerification to help prevent exposed roots from drying.

One week following aerification, greens should receive the equivalent of one pound actual nitrogen per 1,000 square feet (4.9 g N/m^2) as a quick-release nitrogen source (e.g., ammonium sulfate or ammonium nitrate). Rapid-release nitrogen will aid in recovery of aerification holes and be timed in advance of the tournament so excessive growth will have subsided.

Two Weeks Prior to the Tournament. All nitrogen fertilization should be completed by this time. If not, the grass will be growing too aggressively by tournament time, and consequently, the putting speed will be disappointingly reduced.

The greens should also be lightly vertical mowed in two directions at this time. Vertical mowing blades should just barely touch the plant crowns. This will remove some of the surface debris left over from aerifying and will reduce grain. Greens should be groomed daily at this time by using grooved rollers, brushing, and/or combing.

Between 10 and 14 days prior to the tournament, the greens should receive a light application of top-dressing. One to two cubic yards per 5,000 square feet (0.03 to 0.06 $m^3/100\ m^2$) should be ample to provide the final touches in smoothing the putting surface. The topdressing material should be immediately incorporated by dragging it in several directions.

Five Days Prior to the Tournament. If the greens start to lose some color due to lack of nitrogen fertilization, application of liquid iron sources should be considered. Two ounces of iron sulfate or a chelated iron source in several gallons of water should be applied per 1,000 square feet (6.4 L/ha). To prevent burn, this should not be applied during the heat of the day.

The mowing height can be reduced at this time from 3/16 inch (4.8 mm) to 5/32 or 1/8 inch (4 or 3 mm). This height, combined with the other management practices already outlined, should provide satisfactory putting conditions for the tournament.

Three Days Prior to the Tournament. Begin double cutting the greens at the intended tournament height three days prior to the tournament so the maximum benefits from this practice are experienced. The clean-up mowing lap should be performed only once daily to prevent excessive tearing of the grass or soil compaction.

Water management during the weeks leading up to the tournament is critical. Excessive soil moisture should not be used as a method to soften the greens. Water should be applied to wet the rootzone and soil should be allowed to dry before reapplying it. Firm greens are often desired to challenge golfers for precise approach shots. However, with the added stresses of a lower mowing height and double cutting, constant inspection for wilting should occur and afternoon syringing should be considered.

Tournament Day (Optional). If green speed is totally unacceptable, then the use of a roller(s) is available. The greens should be allowed to drain (not be wet) before this is attempted and should follow routine mowing. One pass is recommended per day.

Once the tournament is completed, the mowing height should be raised. Greens should then be fertilized and adequately watered to aid in recovery from the concentrated tournament play.

5.6 BUNKER MAINTENANCE

Bunkers have, in a relatively short period, become the main focus of golfer complaints **(Figure 5–22)**. Greens traditionally were the lightning rod for criticism on a golf course. However, superintendents have done amazing jobs with greens, so the focus is currently on bunkers.

Common bunker complaints from golfers are the depth or inconsistent depth of sand in them, "fried-egg" lies (sand too soft), lack of consistency between bunkers, and varying moisture levels in the same bunker and between bunkers **(Figure 5–23)**. Many of these complaints stem from improper initial bunker design and construction. With complaints so rampant concerning bunkers, golf courses should pay justifiable time and resources to them. Legitimate questions during the construction phase include: how many bunkers does the course really need to make it a challenging layout and not become a maintenance night-mare? Are steep-faced bunkers needed which easily and constantly wash following rainfall or even normal irrigation? Do we need islands or fingers of green grass extending into the bunkers? These look interesting, but rarely come into play and significantly increase installation and maintenance costs. Or, Can we afford the drainage systems and daily maintenance necessary for high quality bunkers?

Routine practices associate with maintaining acceptable bunkers include:

– Raking,
– Edging,
– Mowing and blowing,
– Firming sand faces,
– Checking sand depth and replacing lost sand,
– Pumping standing water.

Bunker raking usually involves either a complete raking or just a touch-up. With the increased use of bunker liners to reduce washing, many courses now rely on hand-raking bunkers when in the past, they used powered equipment. Hand raking helps firm sand loosened by washing and helps reduce snagging liners.

Edging preserves the sharp, well-defined perimeters of bunkers often seen on television. Weekly line trimming is performed during periods of active turfgrass growth while edging with a sidewalk-type edger is typically once or twice monthly. Trimming debris then must be removed.

Mowing involves trimming grass-faced bunkers on a routine basis to keep a manicured appearance. Walk-behind mowers are used on gentler-sloped bunkers facings while floating mowers are used on steeper-sloped facings. These are performed weekly, following by blowing clippings out of the bunker. Additional blowing is needed to remove tree leaves, additional grass clippings, and other debris from bunkers. Frequency varies according to season with daily blowing needed during major leaf drop events (fall, following rain events, etc.) and less common during slower growth periods.

Checking, replacing, and packing sand in bunkers have become major considerations for routine bunker maintenance. Bunker sand depths are checked weekly

Figure 5-22. Excellent bunker maintenance on a golf hole.

Figure 5-23. Poor bunker maintenance.

Figure 5-24. Bunker washing, standing water, and organic matter accumulation following a rain event.

with a goal of 1 to 2 inches (2.5 to 5 cm) minimum sand depth to prevent exposure or snagging of liners during play or routine maintenance. Hand shovelling is used on smaller, routine depth corrections associated with normal rain events. Following shovelling, sand facings should be packed with hand tampers to prevent the "fried-egg" deep settling of incoming shots. This is performed once or twice monthly.

However, over time, additional sand is lost from play, wind, and routine maintenance practices. Also, often following a major rain event, a thin layer of silt and clay and organic debris accumulates at the bottom of the bunker **(Figure 5–24).** This layer should be removed to retain desirable bunker drainage. Ideally, smaller amounts of sand should be added frequently to replenish bunkers compared to less frequent, larger amounts. The smaller amount helps prevent softer sand and packs better than deeper layers.

An undesirable sight is seeing a bunker become more of a water hazard than a sand hazard. As bunkers age, their drainage slows due to compaction, introduction of silt, clay and organic matter, and use of different sand-sized particles. Crews then use hand or powered pumps and shovels to remove silt and clay, new sand added, and then hand raked.

5.7 ORGANIC GOLF COURSE MANAGEMENT

An emerging trend in many areas is towards more "organically" maintained golf courses. The fact is golf has an almost 500-year history and for 400 of those years, courses were maintained "organically," which is to say, with little artificial inputs. However, as with most industries through the 20th century, golf began to take advantage of science and technology to deliver a product more appealing to its customer base as facilities sought to keep pace in a highly competitive market. Often this meant making use of chemicals to counter problems often exacerbated by practices necessary to satisfy player expectations. More recently though increased government regulation and growing public concern about chemical impacts in general have prompted some to look for alternatives. The Great Recession in the first decade of this century also forced many facilities to re-examine spending and search for maintenance practices that maximized sustainability, both economically and environmentally. To date, "organic" maintenance generally struggles to produce playing conditions equal to traditional maintenance, particularly under the most stressful conditions. However, as more and more trials and research is conducted, that gap is narrowing.

Definition

"Organic" has many definitions. Chemists consider carbon-containing compounds as organic. Another is "of relating to, or derived from living organisms," while the original meaning was "of or pertaining to an organ or its function." A contemporary strict definition would be "no added synthetic pesticides or fertilizers." A more realistic definition could be "derived from plant materials, biological organisms, or mined from natural deposits." The United States Department of Agriculture (USDA) has a very detailed protocol to raise food crops and labels it "organic." For additional information, refer to http://www.nal.usda.gov/afsic/pubs/ofp/ofp.shtml. However, a uniform definition or standards of managing golf courses "organically" currently does not exist.

Management considerations

The most consistent problems when golf courses go organic are disease infestations, followed by insects and weeds. This is severely compounded when proper construction criteria are not provided, improper grass selection occurs, improper or inadequate turf cultural practices are implemented, and, golfers demand as high a quality of turf when grown organically compared with conventional maintenance.

Construction considerations. Everything possible must be done prior to going organic to minimize conditions which favor pests and weaken turf at the expense of healthy turf. Agronomically, this includes minimizing shade by adequately removing trees, providing excellent golf green and course drainage by building sand-based rootzones, installing extensive fairway and rough tile drainage, and contouring the course for surface drainage. For cool-season grass greens grown in heat-stress environments, surface fans are required on all poor air circulation greens. Sub-surface fans (pumps) for greens can remove excessive moisture and incorporate soil oxygen. Grasses must be selected primarily on their ability to resist pest invasion and secondarily on their playing characteristics. Wells for monitoring along the perimeter of the course are needed to monitor ground water quality. Documenting water quality helps counter allegations that the course is contaminating ground water. Water entering and exiting the site, such as streams, need to be periodically monitored, again, to document that water quality is maintained on the property. Irrigation systems will require injection capability as many biological-control agents require daily exposure due to their short-term life expectancies. The latest and most complete cultural equipment and supplies need to be provided by grow-in. Extra trained personnel or "scouts" should be hired by grow-in to monitor and implement IPM or non-chemical golf course management, regardless if major tournaments or other events are scheduled.

Membership considerations. Critical to any successful "organic" maintenance program is a successful outreach effort to members and golfers. This outreach should explain the reasons behind the shift in maintenance practices and detail potential outcomes which likely will include increased weed presence and potentially slower corrections of other problems when they do occur. The outreach should also explain the extent to which the new maintenance program will be organic. Most facilities pursuing organic maintenance still use traditional inputs to some degree when circumstances demand. Generally speaking, these facilities must find the balance between what members will tolerate to achieve the benefits – economic and environmental - of reduced use of traditional inputs including water.

6 INTEGRATED PEST MANAGEMENT

6 INTEGRATED PEST MANAGEMENT STRATEGIES

One of the most appealing aspects of golf is the beauty of the course. To maintain acceptable playing conditions, the superintendent must minimize pest problems such as weeds, insects, nematodes, and diseases. One method to meet these objectives is the incorporation of a commonsense approach or way of thinking to protect the turf, which is accomplished by gathering information, analyzing the information, and making a knowledgeable decision. **Integrated pest management (IPM)** combines proper plant selection, correct cultural practices, monitoring of pests and environmental conditions, use of biological control, and the judicious use of pesticides. Like the pieces of a puzzle, all are critical to complete the entire picture of turfgrass management. The principles and practices of IPM also are typically included in **best management practices (BMP)**, **turfgrass management practices (TMP)**, **best turfgrass management practices (BTMP)**, and sustainable agriculture.

Unfortunately, player pressure to maintain tournament-like conditions year-round have often forced superintendents to abandon some sound agronomic practices. Players commonly request less than one-eighth inch (3.2 mm) mowing heights along with "soft" greens that putt with unreasonable speed and have no scars or disruptions in consistency. Often, this requires grasses to be grown outside their natural range of adaptability. As a result, superintendents have been forced to increase their fertilizer, water, and pesticide usage to maintain the grass at the players' satisfaction level.

Public concerns about chemical use has been increasing while restrictions on the availability of traditionally used resources has also become an issue. Superintendents must consider incorporating and informing the public about programs like IPM that reduce these inputs for maintaining golf courses. However, until golfers themselves modify their expectations for playing conditions, they will continue to pressure superintendents, resulting in practices that are not necessarily best for the grass or the environment.

Figure 6–1. Ascertaining the current site conditions of a golf course.

6.1 STRATEGIES OF INTEGRATED PEST MANAGEMENT

Developing IPM strategies requires superintendents to have reliable information about the following:

1. Obtain information concerning the current site conditions regarding a golf course **(Figure 6-1)**. This involves the total ecological situation involved with the particular turfgrass and pest. Identify the pest and know its biology and life cycles, as well as management practices that disrupt or influence these to reduce pest numbers. Understanding the strengths and weaknesses of the pest increases the chances of success. This allows one to know:
   a. When to expect the pest problem or when, in its life cycle, it is most susceptible for control.
   b. Where to expect their occurrence. Mapping and record keeping can help spot the "when" and "where" of infestation patterns.

   Site assessment also involves documenting current growing conditions such as **(Figure 6-2)**:

   – soil type,
   – hydraulic conductivity of greens,
   – soil and irrigation water pH,
   – soil nutrient and CEC levels,
   – soil pests such as nematodes and noted diseases,
   – surface air movement of each green.

Figure 6–2. Inspecting the soil condition of a golf green.

Figure 6–3. Research indicating the non-preferential of mole crickets to a particular turf variety.

2. Developing IPM strategies include correcting any major agronomic or environmental problems in growing as healthy a turf as possible. Develop this in conjunction with club officials and submit to the general membership when completed.
3. Implement the plan including using a detailed monitoring system to carefully follow pest trends, which determines if a pesticide will be necessary, and if so, when and where it would be most effectively applied.
4. Maintain careful records to measure IPM effectiveness.
5. Periodically, evaluate the program, adjusting weaknesses as needed. Also inform membership and the general public that these IPM practices are being implemented to demonstrate that golf course managers are at least as environmentally aware and sensitive as players are.

IPM control strategies can be subdivided into **chemical** and **nonchemical strategies**. Both are equally important in implementing a successful program.

Non-chemical Strategies

The following contribute to the integration of non-chemical strategies for pest management: host-plant resistance, pest-free propagation (or sanitation), site preparation, cultural practices, and biological control.

Host-Plant Resistance. One of the oldest means of pest control is through careful selection and breeding of pest-resistant or pest-tolerant plants. People have traditionally selected those plants that grew best or had the highest yields, and then used them in subsequent years. Many turfgrass varieties are the result of this type of selection process, where a patch of turf grew better, was denser, or had better color than the surrounding grass. Genetic work has revealed certain genes for pest resistance and/or better turfgrass characteristics **(Figure 6-3)**. This genetic resistance can be incorporated into a cultivated plant to provide more effective pest control. For example, "Floratam" St. Augustinegrass was the first commercially available variety resistant to chinch bugs (*Blissus* spp.). However, some plants are less resistant to certain pests and their use must be weighed against other desirable characteristics. For example, L-93 creeping bentgrass has good resistance to dollar spot while Crenshaw bentgrass does not.

Pest-Free Propagation. One of the easiest, yet often overlooked, means of preventing pest establishment in turf is by using pest-free planting materials. Each state established a seed certification program, one of the first regulatory measures designed to provide pest-free propagation. Each bag of seed, in order to meet certification, must provide information on purity and germination percentages **(Figure 6-4)**. In addition, a weed seed listing must be provided. No noxious weed seeds are allowed in the seed bags.

Turf managers should take this process one step further and ensure all planting materials introduced contain few, if any, pests. For example, with the limited nematode control options currently available, a sod and sprig purchaser should make every effort to assure their purchase does not bring a serious nematode problem with it. A nematode assay of the material before delivery can help

Figure 6–4. Blue seed tag indicating the turf cultivar and noxious weed content.

Figure 6–5. Insufficient drainage continues to plague the golf industry, weakening the turf to the point it is more prone to pest attack.

by showing the kinds of nematodes present and if any are at excessive levels. It is not realistic to expect turf planting material to be entirely free of nematodes but it is reasonable to seek material that contains few serious types and none in high numbers. The buyer can determine if root pests have been severe in the production field by visually examining root systems at the time of purchase, thereby preventing a high risk of damage once the material is planted. The turf also should be inspected for other pests such as weeds and fire ants. The old saying "an ounce of prevention is worth a pound of cure" has never been more true than when deciding which planting material to use.

Exclusion is another non-chemical IPM strategy related to pest-free propagation. It involves keeping pests out of the region or country. However, exclusion usually involves legally enforced stoppage of plant pests at ports of entry, which is accomplished by the inspection, interception, destruction, and quarantine of the plants. Some of today's worst turf pests have been accidentally or intentionally introduced. For example, many turf weeds initially were introduced into the United States as experimental pasture materials, for soil stabilization, or as ornamental plantings. Hopefully, with more stringent quarantine laws today, additional foreign pests will remain excluded.

Site Preparation. Properly preparing the planting site is an important, yet often unrecognized, IPM step. This involves planning and constructing highly utilized areas, such as putting greens or tees, with precise water management capabilities. Precise water management is the major key to successful turf maintenance under intense playing conditions **(Figure 6-5)**. Disease and soil compaction can occur if soil saturation is allowed during intense play. Adequate surface and subsurface drainage must be provided so play can quickly resume after a heavy rain without soil compaction. However, golf greens must be able to retain adequate levels of moisture and nutrients to avoid their continuous reapplication.

Other considerations for site preparation and construction include: (1) provision of proper sunlight and ventilation around golf greens, (2) adequate sizing of greens for even distribution of traffic, (3) proper drainage in fairways, and (4) provision of adequate quantity and quality of irrigation. All too often, these preconstruction criteria are neglected, causing even the most intense IPM programs to fail, leaving members dissatisfied with the services rendered.

Figure 6–6. Planting the correct turf cultivar and then providing best management strategies to keep it healthy are the first line of defense against pest invasion.

Cultural Practices. Probably the best defense against pest invasion is providing a dense, healthy, competitive turf. This is achieved by providing cultural practices that favor turf growth over pest proliferation, which disrupts the normal relationship between the pest and its host plant, making the pest less likely to grow, survive, or reproduce **(Figure 6-6)**. These practices include proper irrigation, fertilization, mowing, aerification, and topdressing. Prolonged use of incorrect cultural practices weakens the turf, promotes pest invasion and its spread, and often encourages excessive thatch development. Thatch not only harbors many insects and disease pathogens, but it also limits pesticide effectiveness while reducing the efficiency of a watering program.

Biological Control. Biological pest control uses natural enemies, such as pathogens, predators, and parasites, to reduce pest populations to aesthetically acceptable levels **(Figure 6-7)**. Criteria for a successful biological control agent include: (1) the absence of non-target effects on desirable plants or other organisms, (2) its ability to reproduce quickly to prevent the pest from attaining damage thresholds, (3) its persistence in the environment, even at non-damaging pest levels, and (4) its adaptability to the environment of the host. The biological control agent also should be free of its own predators, parasites, and pathogens.

Pests in their native habitats are regulated through Mother Nature's system of checks and balances. Predators and parasites help keep pest populations at a relatively constant level. Problems occur when pests are introduced into those areas lacking these natural regulatory means. As a result, foreign pests often become epidemic since the ecosystem is defenseless. For example, mole crickets in their native South American habitat are not considered a major problem. Other insects, nematodes, and fungi that attack mole crickets in South America tend to minimize their effects. However, when mole crickets are accidentally introduced in the United States without the presence of these organisms that control them, they soon reach epidemic levels. If it were not for these natural biological control agents, the world would be overrun by only a few organisms. Scientists currently are exploring the numerous naturally occurring organisms in the pests' native habitats that can be successfully transferred to other areas. Various successes have occurred using biological control agents such as parasites, predators, or diseases to control pest organisms.

Figure 6–7. Using a parasitic nematode to naturally control mole crickets.

A few examples of biological control measures currently are being used in commercial turf production. Bacillus popilliae and *B. thurengensis*, bacteria commonly known to cause the milky spore disease, have been used to control Japanese beetle grubs. More effective strains are currently being developed. The white amur carp, a fish native to southeast Asia, provides submerged aquatic weed control in golf course ponds. Extracts from various wood decaying fungi are being reformulated as commercial fungicides. Other potential agents for biological control of turf pests include endophytic fungi for insect control, bacteria such as *Xanthomonas* species for annual bluegrass control, various rust (*Puccinia* spp.) fungi for nutsedge control, and several parasitic bacteria, nematodes, and fungi for the control of mole crickets and damaging nematodes in turf.

Biological control systems are complex; they are not totally effective, nor always predictable. The concept of biological control has been so widely publicized that the general public views it as a viable and readily available alternative for all pesticides. Although this is not yet the case, it is an area currently receiving much attention and hopefully will provide additional control strategies in the future.

It is important to remember that not all biological control is successful and when it fails it can have long lasting consequences. The Cane Toad was introduced to Australia to control beetles feeding on sugar cane. While it was largely unsuccessful in this control, it has thrived in Australia and is now a major pest which itself requires control.

If chemical control is used inappropriately, its effectiveness often weakens over time due to resistance buildup or enhanced microbial biodegradation. If biological control is used inappropriately, it can strengthen the pest's population over time as these or other naturally occurring control mechanisms may be eliminated.

One underlying requirement of the use of biological control agents is the public's willingness to accept a certain level of pest damage. Some pests must remain in order for the biological control agent to retain its primary food source otherwise it could die off and the cycle could easily swing back in favor of the pest.

Thus, total pest elimination is not feasible when integrating biological control measures. There also is a time lag between the use of a biological agent and actual control. Club members must be educated to these facts and be willing to accept minor levels of pest pressure and time delay for long-term success.

Chemical Pest Control

Not all pest problems can be solved by host-plant resistance, manipulating cultural practices in the plant environment, or by the use of biological control agents. In these cases, pesticides become the second line of defense. In the IPM scheme, pesticide use is not eliminated. However, indiscriminate spraying is eliminated and only practical pesticide use is employed so there is minimal damage to the natural biological control agents of the pest, as well as minimal damage to the environment. This requires extensive knowledge of the ecology and interrelation of the pest, the pesticide, the host plant, and the beneficial natural biological control agent. Several considerations for strategic pesticide use involve making management decisions concerning the following:

1. Locate and identify the pest using reliable monitoring techniques and establish an aesthetic threshold. Pest identification is a fundamental requirement when developing an IPM program. The task of identifying pests can be both frustrating and time-consuming. Pest diagnosis often can be assisted by training and by having well-illustrated pest literature on site.

   Once pests have been identified and their infestation levels recorded, a control action must be initiated at a predetermined pest threshold level. These threshold levels are known as economic, damage, or action thresholds in other IPM programs. For turf managers, economic and related threshold-level terms mean little since crop yield is not the ultimate goal, but rather an aesthetic level of turf quality. An aesthetic threshold deals with the amount of visual damage a particular turf area can with-stand before action is required. Highly maintained areas such as golf greens have a lower aesthetic threshold level than less-maintained areas such as roughs, which can withstand a higher degree of pest damage before action is required. These thresholds also vary with the expectations for a particular golf course, the availability of financial resources, and available alternative control measures.
2. Attack a pest during the most susceptible point in its life-cycle, which usually is during the early stages of development. For example, the most effective time for mole cricket control is during its first instars, which normally occur during the month of June. However, prior scouting and mapping of mole cricket infested areas have proven most beneficial when pinpointing sites of future pesticide use. The same philosophy of attacking the most susceptible point in its life-cycle also is also true for most weeds. Young, actively growing weeds are usually the easiest to control. Once weeds begin to mature, they become more difficult and expensive to control.
3. If a pesticide is necessary, use the one that is most effective but the least toxic to non-target organisms and the environment. Read the label and use the recommended rate, and spot treat, if possible, instead of applying "blanket" or "wall-to-wall" treatments. Obviously this relies on effective scouting techniques and proper recording or mapping of pest outbreaks.

6.2 IMPLEMENTING AN IPM PROGRAM

Developing and implementing an IPM program involves certain steps. However, each golfing facility differs and will require an IPM program tailored to its interest, level of expectation, and available budget. Pest problems are going to occur on any golf course; even the best management program cannot guarantee problems will not occur. The very nature of managing a golf course predisposes it to stress since the turf is maintained at its very edge of survival. For example, golf greens are generally mowed below one-eighth inch (3.2 mm), which is much lower than the natural adaptation of these grasses. This results in a precarious balance between the needs for grass maintenance and those for grass survival. The following steps have proven successful in developing an IPM program or mindset and should provide a good starting point for golf course superintendents.

1. Define the role and responsibility of everyone involved in the pest management program. This includes establishing communication between club officials, players, and crew members, who must be aware of the new approach the superintendent is trying and that it is an ongoing experiment **(Figure 6-8)**. They need to expect some successes and some setbacks. Assurance and understanding will be needed by all participants during the initial stages of development to prevent misunderstanding and provide ample time for desirable results to occur.

Figure 6–8. Demonstrating to players and local community leaders how the golf course incorporates all possible means of managing pests in the most environmentally friendly manner.

2. Determine management objectives for specific areas of the course and correct all practices that favor pest development or place undue stress on the turf. Obviously, highly maintained areas such as greens and tees receive a priority for pest control. Lower-maintained grass such as the driving range or roughs are a lower priority. A thorough inspection should be conducted of each site on the course before implementing the IPM program. This will provide the groundwork from which all management decisions can be based and also will provide a record justifying the correction of problems made during course construction or from subsequent management. A field history form similar to **Table 6–1** should be used to record data, including the current turf species, its area, mowing schedule, soil analysis, soil drainage, fertilizer programs, irrigation scheduling, and shade and traffic patterns. Be prepared to improve existing problems that weaken the turf, or the potential success of the IPM program will be greatly reduced. Solicit funds for these improvements, as they will save money in the long run. Again, this requires open communication between club officials and the superintendent.

A weather monitoring system should also be installed, which will provide detailed, localized data on important variables such as rainfall patterns, soil temperature and moisture, wind movement, humidity, and sunlight indices. These climatic conditions usually play the most important role in specific turf growth patterns. Being able to track or pinpoint them enables the superintendent to modify cultural practices to supplement or offset its effects.

3. Set aesthetic or action thresholds and begin monitoring and recording pest levels. An aesthetic or action threshold is the point when pest populations or environmental conditions indicate some action must be taken to prevent intolerable damage. These thresholds will vary according to the location of the course, the specific pest being scouted, the level of use of the turf area, the expectations of club members, and budget constraints.

   The pest in question will partially determine its aesthetic threshold. For example, the number of mole crickets tolerated on an area basis is less than the number of sod webworms. Related to this threshold level is the site in which the pest is found. Golf greens have a much lower aesthetic threshold for mole crickets than a rough or out-of-play area. Unfortunately, exact threshold numbers have not been developed for every pest encountered in turf. However, **Table 6–2** provides a starting point for several common turf insects.

Table 6–1. Field history report form for golf courses.

CLUB				SUPERINTENDENT			PHONE	
HOLE NUMBER				SCOUT			PHONE	
DATE								
SITE	TURF SPECIES	AREA (SQ. FT.)	MOWING SCHEDULE	SOIL ANALYSIS	SOIL DRAINAGE	FERTILIZATION AMOUNT (N/1,000 SQ. FT.)	FRE-QUENCY	IRRIGATION SCHEDULING
				pH P K		Spring Summer Fall Winter		
Green								
Tee								
Fairway								
Rough								
Driving range								
Nursery green								
Practice green								

Comments on specific topics such as shade, overseeding blend, nitrogen carrier, topdressing mix, weather, irrigation salinity levels, and so forth:

Table 6–2. Aesthetic or action levels for several common turf insects

INSECT	AESTHETIC OR ACTION THRESHOLD LEVELS (PER SQUARE FOOT)*	INSPECTION METHOD
Annual bluegrass weevil	30 to 80 grubs (spring)	Visual inspection of clipping (adult); soap flush (adult); soil core (grub)
	20 to 40 grubs (summer)	
	5 to 10 grubs (preventive)	
Armyworms	1 to 2 caterpillars	Visual and soap flush
Bermudagrass mite	4 to 8 tufts	Visual
Billbugs	10 to 14 grubs	Visual (adult); pitfall (adult); soil core (grub)
Black turfgrass ataenius	50 grubs	Soil core (grub)
Cutworms	1 caterpillar	Pheromone trap (adult); visual and soap flush (caterpillar)
European crane fly (leatherjacket)	15 to 50 larvae	Visual and soil core
Green June beetle	5 to 7 grubs	Visual and soil core
Hairy chinch bug	15 to 20 bugs	Water float
Japanese beetle	6 to 10 grubs	Pheromone trap (adult); soil core (grub)
May beetles	4 to 5 grubs	Light trap (adult); soil core (grub)
Masked chafers	8 to 20 grubs	Light trap (adult); soil core (grub)
Oriental beetle	8 to 10 grubs	Pheromone trap (adult) and soil core (grub)
Temperate sod webworms	2 to 6 caterpillars	Visual and soap flush
Tropical sod webworm	0.5 to 1 caterpillar	Visual and soap flush

*Smaller numbers represent threshold levels for highly maintained areas such as golf greens and tees. Larger numbers are for less intensively maintained areas such as fairways, roughs, athletic fields, and lawns. Multiply values by 11 to obtain numbers per square meter.

Tools required for scouting vary with pest problems, scout training, and golf course budget. A good set of eyes and an inquisitive mind are essential, supported by a standard 10X hand or pocket lens, soil probe, soil profile probe, spade, cup cutter, pocket knife, tweezers, scalpel, collection vials and paper bags, digital camera, access to e-mail and the World Wide Web, and field identification guides. Soap and water also are necessary for insect monitoring.

More expensive but precise instruments may be used in a room designated as a diagnostic laboratory, including stereo- and compound-microscopes, soil sieves, pH meter, conductivity meter, and elementary soil analysis kits. These need to be supplemented by ongoing scout training at short courses, formal classes, appropriate diagnostic guides, and opportunities to visit similar setups to exchange ideas.

Monitoring intensively maintained golf courses includes scouting greens, tees, fairways, roughs, ornamental plantings, and trees. Greens and tees generally require the greatest amount of attention and are monitored daily or every other day. Remaining areas are monitored less frequently, usually weekly. Monitoring frequency may require adjustment depending on climatic conditions and reports of nearby pest problems.

Recording pest levels should be done on a form similar to the one in **Table 6–3**. This will allow the scout and superintendent to monitor pest trends and determine if these levels reach or exceed aesthetic thresholds. Maps developed for each golf hole should accompany these forms. Maps can easily be drawn on a computer using one of the popular "draw" or "paint"-type programs. Maps enable the scout to pinpoint pest problem areas, thereby allowing spot versus traditional blanket pesticide treatment. Over time, these maps can indicate where pest problems annually occur and possibly allow superintendents to correct management or environmental variables influencing them. For example, mole cricket egg laying activity (tunneling) during April and May should be mapped and these areas treated in June, as mole crickets tend to deposit eggs in the same areas each year. Chemical control is not effective with early spring applications when most mole crickets are adults that are not susceptible to most insecticides. Certain insecticides also work best on young insects, and are selectively ineffective against adults. Scouting and mapping, therefore, are essential for optimizing such materials. Maps also provide area information for the superintendent and allow new crew members a visual aid in treating problem areas. Aerial photographs and digital cameras are valuable in identifying, tracking, and mapping problem areas.

4. Use pesticides correctly and only when threshold limits are reached. One of the goals of IPM is intelligent and prudent pesticide use. Once these thresholds are reached, the pesticide used should be the safest one available; spot treatments should be practiced, if possible; and all safety precautions should be followed. Pests should also be treated during the most vulnerable stage of their life cycle. In addition:
    - Use natural biological controls when possible.
    - Spray only when necessary and strictly control the location of pesticide application.
    - Select pesticides that are least toxic, less mobile, and have a short half-life.
    - Identify areas that may be particularly susceptible to ground/surface water contamination.
5. Evaluate the results of the habitat modification and pesticide treatments by periodically monitoring the site environment and pest populations. Keep written records of site pest management objectives, monitoring methods, and data collected. Also record the actions taken and the results obtained by the pest management methods. This will provide additional information for club members who do not understand the program but would understand results. This will also demonstrate that golf course superintendents are striving to reduce the chemical inputs in maintaining the course and obtain an ecological balance between man and nature.

6.3 ADDITIONAL CONSIDERATIONS

Pest management strategies for turf production are in their infancy but are nonetheless being developed and used. Strategies necessary for a successful IPM program have been outlined and should provide a starting point for golf course superintendents. No one recipe, however, will work uniformly across all golf courses. Individual programs will most likely evolve for each particular course depending on their demands, needs, acceptance of pest damage, and budgets. Golf course members should realize that it will take time to implement and measure the success of IPM methods. Open communication between all crew members, club officials, players, and the superintendent are necessary for programs to be understood and to succeed **(Figure 6-9)**. Read and study information on pests associated with

Figure 6–9. Attending a research and demonstration field day to learn of the latest trends and techniques of pest management.

Table 6–3. Field infestation report form used for golf courses.

<table>
<tr><td>CLUB</td><td colspan="2"></td><td>SUPERINTENDENT</td><td></td><td>PHONE NUMBER</td><td></td></tr>
<tr><td>HO.E NUMBER</td><td colspan="2"></td><td>SCOUT</td><td></td><td>PHONE NUMBER</td><td></td></tr>
<tr><td>DATE</td><td colspan="2"></td><td></td><td></td><td></td><td></td></tr>
<tr><td>SITE
(TURF SPECIES)</td><td>MOWING HEIGHT</td><td>SOIL MOISTURE</td><td>WEEDS
SPECIES NO. OR PERCENT</td><td>DISEASES
SPECIES NO. OR PERCENT</td><td>INSECTS
SPECIES NO.</td><td>NEMATODES
SPECIES NO.</td></tr>
<tr><td>Green</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Tee</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Fairway</td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="7">Notes:</td></tr>
<tr><td colspan="2">1. Goosegrass
2. Crabgrass
3. Thin paspalum/Dallisgrass
4. Broadleaves
5. Quackgrass
6. Nutsedge (Yellow, Globe, Purple, Annual, Kyllinga)
7. Nutsedge (Purple)
8. Poa annua
9. Broadleaves
10. Other</td><td colspan="2">1. Dollar spot
2. Leaf spot
3. Pythium blight
4. Pythium root rot
5. Fairy ring
6. Brown patch (R. solani)
7. Rhizoctonia leaf and sheath blight (R. zeae)
8. Bermudagrass decline
9. Algae/Moss
10. Other</td><td colspan="2">1. Mole crickets
2. Sod webworms
3. Armyworms
4. Cutworms
5. White grubs
6. Fire ants
7. Mites
8. Grass scales
9. Billbugs
10. Other</td><td>1. Sting
2. Lance
3. Stubby-root
4. Root-knot
5. Cyst
6. Ring
7. Spiral
8. Sheath
9. Other</td></tr>
</table>

golf courses in your state, their life-cycles, the ecology surrounding their occurrence, and the pest management strategies to successfully suppress their numbers below threshold levels. More importantly, follow those management guidelines that encourage competitive turf growth and discourage pest establishment.

IPM represents a case of redirecting resources invested in turf maintenance, in which professional knowledge and judgment is partially substituted for chemicals. It may or may not be cheaper in upfront costs, but does provide an excellent means of reducing unwelcome environmental and personnel risks without sacrificing turf health. IPM reduces pesticide use or "softens" the kinds of pesticides needed, as well as our potential liability for unforeseeable clean-ups or other corrective actions for specific pesticide use or handling sites. IPM thus improves the performance and the perception of the golf industry as good stewards of modern urban society.

6.4 ANIMAL PESTS

A number of animals can become problematic on fine turf installations. These can include alligators, armadillos, bears, beavers, deer, geese, hogs/pigs, moles, rabbits, raccoons, gophers, groundhogs/woodchucks, skunks, snakes, and more. Rarely do these animals feed directly on the turf but rather, either destroy it searching for food or through breeding and excretions, cause undesirable turf or playing conditions.

Sightings of wildlife, especially birds and mammals on turfgrass, give most people a rewarding sense of being close to nature. With increasing urbanization, it is nearly impossible to live in most areas without seeing or hearing wildlife on a daily basis. Many of these experiences are enjoyable; others are confrontational. Unpleasant encounters with animal pests can result in injury, or fear of injury, property damage, or minor nuisances. Some of our frustrations with wildlife can be alleviated by simply learning why wildlife appear to be causing a problem. Others require more action oriented prevention and control techniques.

Canada Geese

Of the animal pests on golf courses, Canada geese (*Branta canadensis maxima*) are among the most annoying and widespread **(Figure 6-10)**. Resident Canada geese become aggressive during brood season, produce extensive fecal droppings, foul water quality, and feather shed during molt. Geese also may represent a potential serious environmental threat or risk to human health and safety. Urban Canada geese may also fly to surrounding agricultural lands to feed on crops such as corn, soybeans, rice, winter wheat, and other grains.

Besides the direct impact of Canada geese residing in urban areas, they can act as decoys for migratory geese, causing periodic increases in urban goose populations. Geese in urban areas are very aggressive around their nests or goslings and may attack or threaten pets, children, and adults.

Geese also trample grass in medium-heavy soils, which creates a surface "hard pan" that prevents vegetative growth. This leads to erosion and loss of habitat for other species. Geese in high concentrations or even a smaller flock that remains in the same place for an extended period of time may overgraze the grass, creating large, dead spots of turf.

Figure 6–10. One of the most annoying and widespread animal pests on golf courses are Canadian geese. Their droppings are unsanitary and aggressive behavior is unsafe for participants.

High concentrations of geese increase the likelihood that avian diseases will be transmitted, creating the potential for massive die-offs. Disease organisms originating from a single species of waterfowl can also spread to other species. Canada geese are suspected of transmitting salmonella to cattle. Transmission of disease or parasites from geese to humans has not been well documented, but the potential exists.

Breeding, Nesting, and Feeding. Canada geese usually begin nesting at three years of age. Pairs usually stay together for life unless one dies; in that case the remaining goose usually finds another mate, generally within the same breeding season.

Canada geese usually nest within 150 feet (46 m) of water, and most nests are surrounded by or are very close to water. Water provides access to food, a place to drink, aids in preening and bathing, and is an avenue of escape from predators. A typical Canada goose nest is bowl-shaped, approximately 1.5 feet (46 cm) in diameter, and made from the surrounding vegetation lined with goose down plucked from the female's breast.

A good view of the surrounding area is always important in nest site selection. Nesting females tend to use the same immediate area year after year. Both males and females defend the nest site territory before incubation. Egg laying is initiated shortly after nest construction starts.

After the eggs are laid, the male does not incubate but will stand guard and defend the incubating female by striking at opponents with its wings or nipping with its beak. Average clutch size is slightly more than 5 eggs per nest; nests may contain 1 to 15 eggs. The average incubation period is 26 to 28 days. Incubation does not begin until all eggs are laid, so that all goslings usually hatch the same day. If the nest is destroyed or the eggs are eaten or removed by predators, Canada geese may renest, usually in or near the first nest. Renesting is more common when nest failure occurs early in the egg-laying period.

Parents often move their broods to areas chosen for the presence of suitable food, visibility, and proximity to water. Canada geese are grazers and they prefer tender, well fertilized lawn grass in urban areas. As mentioned, they tend to choose open areas with few obstructions to give them views of potential predators.

Molting. Adult Canada geese undergo a complete replacement of flight feathers each summer, which takes about a month for most individuals. Nuisance goose management is very important during this period because all birds present are flightless and thus vulnerable to capture. Mown lawns, parks, and golf courses suit their habitat requirements. Adults with young will molt at the brood rearing area 10 to 20 days after the non-breeding geese initiate their molt.

Migration. Canada geese nesting in the continental United States and southern Canadian provinces usually migrate only short distances, generally staying within their state of birth or flying to neighboring states. Although only a small portion of migratory geese use urban areas, they may have a startling impact on the environment when, within the span of a few days - a pond that previously had only a few geese on it suddenly supports a flock of several thousand. Migratory birds are usually much more wary of human activities than resident geese.

Regulations Covering Canada Geese Management Strategies. Canada geese are protected by the Migratory Bird Treaty Act of 1918 (16 USC 703-711). This act made it illegal to harvest waterfowl or other migratory birds except during the hunting season or by permit. It prevented the unrestricted egg harvesting and commercial hunting for meat and feathers that was commonplace in the United States in the late 1800s and early 1900s. This treaty gave the United States and Canadian governments (U.S. Fish and Wildlife Service and Canadian Wildlife Service, respectively) the authority to set limits, make regulations, and issue permits to harvest or take waterfowl. In addition to federal permits, most states require permits anytime one intends to destroy eggs or nests, capture, translocate, disturb, or harvest Canada geese. Local laws or regulations may also affect the use of control techniques such as firearms, chemicals, and auditory and visual scaring devices.

Controlling Canada Geese. The following suggestions for controlling Canada geese populations have delivered success in many instances. Complete control, however, rarely follows only one avenue; thus, an integrated management approach is necessary which implements several means of control or deterrent.

1. **Do not feed geese** - Feeding Canada geese or other wild fowl promotes a dependency on humans and creates problems for them. Appropriate signage that explains why feeding is discouraged should be part of a campaign to encourage people to stop feeding and domesticating Canada geese and other animal pests.
2. **Habitat modification** - Modifying the habitat in which geese live, feed, and reproduce helps discourage them from becoming resident geese. Numerous ways and means of providing this are available. Some of the more popular include:

   Vegetative barriers. Planting shrubs, hedges, or prairie plants around the water (heights >30 inches, 76 cm, and widths at least 20 to 30 feet, 6 to 9 m), are most effective. These physically impede the movements of geese to and from the water, make less new shoots available to feed on, and block their line of sight, making it more difficult for geese to see potential predators. Barrier plantings require protection from geese during establishment. Letting the grass grow longer and reducing fertilizer use will also help greatly. Geese love the tender shoots of grass, especially Kentucky bluegrass, bromegrass, Canarygrass, Colonial bentgrass, perennial ryegrass, quackgrass, and red fescue. They tend not to prefer mature tall fescue, periwinkle, myrtle, pachysandra, English ivy, hosta or plantain lily, ground juniper, or switchgrass.

Rock barriers. Large boulders (>2-ft., 0.6 m, diameter) placed along the shoreline may discourage goose use and access to grazing sites by making it difficult for them to exit the water. Their effectiveness is improved when used in conjunction with vegetative barriers.

Fence barriers. Fences can prevent geese from walking into an area. Fences should be at least 30 inches (76 cm) tall, and have openings no larger than 3 inches (7.6 cm) in diameter. Woven wire, chicken wire, picket fencing, erosion control fencing, plastic snow fencing, and construction fencing are examples of effective materials. The effectiveness of fence barriers may be enhanced when used in conjunction with landscaping modifications (vegetative barriers, rock barriers, etc.).

A popular fence that seems to be effective, especially for private areas, is a triple-strand electric fence. The wire should be strung 5, 10 and 15 inches (13, 25, and 38 cm) above the ground. The amperage required to exclude Canada geese is minimal and will not harm them. Two-strand portable electric fencing is also effective and economical in small areas. The lower strand is set up eight inches (20 cm) off the ground and the upper strand at about 18 inches (46 cm). Low impedance energizers powered by batteries or plug-in outlets deliver short electrical bursts once a second that geese learn to avoid.

Note: To avoid accidentally shocking pedestrians, electric fences should be well marked with signs and not used in public-use areas.

Tall trees. Establishing tall trees around small ponds (<1/2 acre, 0.2 ha) may prevent geese from landing since geese are large birds that require a relatively large open space to land and take off. However, shade provided by trees can also be attractive to geese.

Steepen banks. Canada geese prefer a gentle, grassy perimeter slope that enables them to easily walk into and out of the water to feed or rest. If access to the water is poor, adult geese may leave to raise their young elsewhere.

To steepen the shoreline, build a vertical seawall 3 feet (0.9 m) above the surface of the water or create a 63 degree angle from the water's edge. Allowing vegetation to grow tall along this slope will help protect it from erosion and keep the geese from walking up. Rip-rap, while ineffective on gentle slopes, is often effective on steeper ones.

Allow water to freeze. Aerating ponds is one of the reasons Canada geese have become year round residents in colder climates. Allowing a pond to freeze over forces geese to seek alternative water sources and may encourage them to migrate. Concentrations of geese will maintain open water even in below freezing temperatures. Harassment may be necessary to force the birds to leave long enough for ice to form.

Swan decoys. The premise is aggressive swans will defend their territory, especially during the breeding season, and will exclude other waterfowl from the area. Place the swan decoys out when the migratory season for geese has begun. Domestic waterfowl, including mute swans, act as decoys for Canada geese when they are flying over an area. Since native swans are difficult to acquire, non-native mute swans are commonly used instead. However, mute swans are much more tolerant of other waterfowl and may only defend the immediate area around their nests. It is not uncommon to find situations where mute swans and Canada geese peacefully share a site, adding to any fecal concerns that may already exist.

Flagging. Some have had success putting up plastic flags around four feet (1.2 m) off the ground. The 3 mm black plastic flags should be at least a 2 x 3 foot (0.6 x 0.9 m) wide sheet. These sheets blow in the wind, disturbing the geese. A "V" shaped notch should be placed on the end of the flag to aid its being rustled by the wind.

Overhead grid systems. One of the most effective methods of exclusion is the installation of a grid system over the water surface. Grids work on a simple principle: Canada geese are large birds, requiring a long glideslope to land, much like an airplane. A grid system above the water surface will be seen by the geese as a barrier between them and the water.

Grids work best on bodies of water less than 150 feet (46 m) across, but can be used on larger bodies up to 300 feet (91 m) across. Nearly any type of cord can be used to construct the grid, from cotton kite string to plasticcoated Kevlar cord. Anchor points for the grid lines can be trees, wooden stakes or "U" channel fence posts.

Grid system specifications are variable, but spacing the grid lines 20 feet (6 m) apart and suspending them at least 3 feet (0.9 m) above the water's surface should be sufficient to exclude geese, while allowing ducks, gulls or other smaller birds access to the water.

Modifications can be made if water levels change or if geese penetrate the system. For example, geese may land on the shore and walk into the water under the grid. The solution would be to place a barrier around the water to keep them from entering under the grid. For example, place two strands of cord 6 inches (15 cm) and 12 inches (30 cm) above the ground running the length of the shore and attached to the anchor points. For a more permanent solution, plant a hedge row or install a fence.

3. **Scarecrows** - This method can be done easily and without reservation. Scare techniques are mainly effective early in spring as adult geese are seeking secure, secluded places to nest. Noisemakers like sirens and natural gas exploders can haze geese, but the loud sounds are equally displeasing to people. Moreover, goose flocks can eventually get used to loud noises that are not accompanied by a real threat. One should be careful to have some limb of the scarecrow move, as European experience has shown that some motion is necessary to deter Canada geese.

   Mylar helium balloons painted with eye spots can be tethered in fields. They scare geese because they look like large predators. Half-inch strips of flashing mylar tape or ribbon can also persuade geese to move onto other nearby mown grass. Both the rattling sound and the light flashes frighten geese. Such tape is available through garden centers, feed co-ops and mail-order catalogs.

   Reflective tape. Mylar tape is a visual barrier used in conjunction with other exclusion methods. Mylar tape is 1/2 inch (13 mm) wide, red on one side and shiny on the other. To use as a fence, string one or two strands between two posts and twist the tape two or three times. When the wind blows, the tape rotates, creating a flash between the red and shiny sides. This unfamiliar flash acts as a visual barrier and makes the geese shy away from the area. It works best on bright days with breezes and before animal habituation begins.

4. **Chemical repellants** – Several chemical repellants are available with varying levels of success (**Table 6-4**). Application of Dimethyl (DMA) and Methyl Anthranilate (MA) to areas surrounding ponds have decreased the number of geese and weight of fecal deposits.

   Methyl Anthranilate. Products using the active ingredient methyl anthranilate (artificial grape flavoring), help change the birds' behavior. When applied to grass where geese feed, methyl anthranilate makes the grass unpalatable. Geese may still frequent the treated area, but they will not feed there. Methyl anthranilate does not readily wash off after a rain if allowed to dry first, but must be reapplied after mowing.

   Anthraquinone. Anthraquinone, repels geese in two ways. First, geese experience a harmless "gut reaction" after eating the grass. Secondly, the grass appears unnatural and uninviting because the anthraquinone brings out the ultraviolet spectrum when applied to turf. Combining the strange look of the grass with the intestinal reaction they experience, geese often look elsewhere to nest and feed. Anthraquinone does not readily wash off after a rain, but needs to be reapplied after mowing. Adding a growth regulator can keep the grass from growing as rapidly. This product is considered to be environmentally safe and does not produce long-term physical effects on the birds that ingest it.

5. **Dogs** - Using dogs to harass geese from an area has become one of the most popular and successful methods. While highly trained border collies are popular, just about any athletic, medium-large dog capable of obeying commands can be used. Control of the dog is vital because dogs used in this manner are legally considered an extension of your hand and must not be allowed to catch, injure or kill a Canada goose.

   Dogs are most effective in the autumn during migration by harassing the Canada geese and thereby discouraging geese from settling in for the winter. In spring, dogs are used to prevent Canada geese from developing nesting sites. Typically, a handler and a dog enter an area occupied by unwanted geese. On command, the dog is allowed to chase after the geese. Geese will likely seek refuge from the dog in a nearby body of water. If this is the case, the dog can be allowed to enter the water. To make this method more effective, use a boat or pyro-

Table 6–4. Repellents for various vertebrate pests.*

COMMON NAME OF INGREDIENT(S)	TRADE NAME(S)
Geese	
Methyl Anthranilate	Rejex-It Ag-36, Fog Force, Goose-B-Gone, GooseChase
Pepper (capsaicin)	Bobbex-G, Amorex
Anthraquinone	Flight Control
Rodents (squirrels, rabbits, moles, gophers, chipmunks)	
Castor Oil	Rejex-It Mole and Gopher Chaser, Scoot Mole, Mole Repellent, Get Away Mole Repellent, Mole Med
Pepper (capsaicin)	Hot Pepper Wax Animal Repellent, Scoot Squirrel, Bobbex-R
Ammonium salts of fatty acids	Professional Deer & Rabbit Repellent
Urine	Predator urine
Strychnine bait	Gopher Getter
Blood meal	Plantskydd repellent

* Products listed are not endorsed or guaranteed to work nor is criticism implied of those excluded.

technics to further harass the geese. Harassment should continue and be repeated until the geese leave the area permanently.

6. **Egg substitution and oral contraception** - There are at least five methods of intervening in the Canada goose reproductive cycle: egg addling, egg oiling, shaking, puncturing or freezing, or egg substitution (using wooden eggs). These methods should only be undertaken by a professional under contracted service, as approaching Canada geese is not without risk.

   Oral contraception is the newest option and remains untested but shows promise for the future. Nicarbazin (the active ingredient) is consumed by the birds which are then unable to lay fertile eggs. This product may help minimize the growth of goose populations before their numbers become intolerable.

   Egg Addling. Also known as shaking the eggs. This method requires eggs be shaken but not broken. Shaking the eggs kills the embryo, but breaking the eggs may just cause the mother goose to lay more. A dog or another person can help keep the geese away from the nest so the eggs can be addled quickly and safely. Careful record keeping is important so you will know when to remove the eggs from the nest. If you don't, the goose may remain on the nest too long, deplete her food reserves and suffer needlessly. Obviously, this technique doesn't help resolve a present problem but it will help reduce geese populations next year.

   Egg Coating. As in addling, this method helps control geese damage by reducing future population growth. Coating the eggs with mineral oil starves the embryonic goose of air, resulting in death. A permit is needed to disturb Canada Geese nests in any way.

7. **Hazing/Harassment** - Noisemaking devices (cracker shells, propane cannons, whistles, or audible distress calls of different bird species as well as howls from coyotes and dogs, etc.) can help deter geese from an area when used in conjunction with habitat modification. If used alone, geese will become habituated to hazing. Many noisemaking devices often require a permit or license, especially within city limits. Projectiles are illegal to fire in some areas. Canada geese seek areas where they can go about their daily activities with minimum disturbance. If someone or something bothers them enough, they usually will find another area where they will not be disturbed. However, they often get used to some harassment techniques when they learn they won't be harmed.

   Harassment techniques usually will not stop damage once it has started. They are, however, useful in preventing damage before it begins. If Canada geese were raised on an area or have become accustomed to using it for feeding, they will be more difficult to move.

   Dead Geese Effigies. Nobody likes a dead goose, especially live geese. A lifelike goose decoy placed in an "agony" position convinces live geese there are predators in the vicinity. Geese effigies can be used on land and water (water applications must be anchored so they won't float away). A minimum of two decoys must be used for flocking geese to believe predators will return to inflict more damage. Coyote and fox decoys have also been used with some success.

   Laser Harassment. In certain situations, lasers have been used to quietly haze Canada Geese. This technique is quiet and relatively easy to apply and appears to work on geese. As issues of safety, health, and property damage associated with wildlife populations increase, so too does public demand for non-lethal, non-injurious, and environmentally benign solutions to such problems. Relatively low-power, long wave-length lasers (630-650nm "red" beam) provide an effective means of dispersing some problem bird species under low-light conditions, while presenting no threat to the animal or environment. Do not look into the beam.

   Pyrotechnics. Although not all geese react to pyrotechnics, most do. Pyrotechnics are specially designed Class C fireworks that are used to frighten wildlife. The types of pyrotechnics in this class include:

   - Screamers and bangers - large bottle rocket-type devices fired from a 15-mm starter's pistol that whistle loudly or explode
   - Shellcrackers - firecrackers fired from a 12-gauge shotgun.

   The distance a particular pyrotechnic device will travel varies from 50 to several hundred yards (>46 m) depending on manufacturer and type. Check with the manufacturer to be sure a particular device fits your needs. They can be very effective when used as soon as the flock begins to use the pond or property. But if they become established, their effectiveness is lessened or may be only temporary. Individuals using pyrotechnics should be trained in their use, and should wear eye and ear protection. Be cautious when using them in populated areas. *Note: Check with local authorities for possible ordinances restricting the use of pyrotechnics before purchasing these devices.*

   Propane Cannons. Propane cannons are popular tools in use at hundreds of airports around the country. Many farmers also have used them with some success. They operate from the gas in a standard propane tank. On a timed basis, a small amount of propane is ignited, producing a loud report that can be heard more than a mile (1.6 km) away.

   The simplest models explode every 30 seconds to 30 minutes, based on the setting. More sophisticated models use computer chips to control the detonation more randomly, on a particular schedule or by remote control. Canada geese, like many other animals, have the ability to quickly adapt to propane cannons and sometimes quit responding without additional aversive conditioning. Propane cannons may not be suitable for large communities because the devices are loud and may be more of a nuisance than the geese.

Chasing. Chasing geese on foot or in a golf cart is labor intensive; but in conjunction with other harassment methods, it can be successful if people are persistent. The idea is to chase geese long enough to cause them to go elsewhere, where they can live without being chased.

Other techniques used to harass Canada geese include:

- high pressure water sprayers,
- air horns,
- beating pots and pans together,
- toy water craft, model airplanes, drones, and helicopters,
- paint ball and similar devices.

When coupled with techniques mentioned, they encourage Canada geese to relocate. The key is to be more persistent than the geese and to use at least two means of deterrent. As long as the geese are not physically harmed, these harassment techniques are legal.

8. **Capture and Relocation** - Geese, like all waterfowl, molt all of their primary wing feathers at once and become flightless for a short period in late summer. You can "round-up" the geese at this time and relocate them. This is a costly and time-consuming process best used when all other efforts have failed. Capturing and relocating geese requires federal and state permits. It is best to use preventative techniques before geese get established in an area. Once geese are established, it becomes very difficult to deter them from a given area, particularly after nesting has begun.

   Capture and relocation of adult geese is not viable as the birds imprint the area where they learn to fly and most will return to the capture site or a similar setting. Since giant Canada geese already occupy virtually all suitable habitat, there is limited opportunity to relocate juvenile geese without creating similar problems at release sites. Relocation can be effective for young juveniles because they imprint on the release area where they learn to fly rather than returning to the area where they were captured. In some instances, localized populations may be captured during the molting season and processed for human consumption through charitable organizations. This step may be taken only when other techniques have not been successful.

9. **Shooting** - Where allowed, hunting is an important tool for managing problems caused by Canada geese. Hunting helps to reduce the number of birds in an area, provides a repellent effect for geese not taken and reinforces the use of non-lethal techniques, such as pyrotechnics. Early goose hunting opportunities are designed to harvest local giant Canada geese before the migrants arrive. Many areas with resident Canada geese prohibit the use of firearms. Check federal, state and local regulations before hunting.

10. **Others**

   Toxicants. There are no toxicants registered with the Environmental Protection Agency for controlling Canada geese in the United States.

7 TURFGRASS DISEASES

7 TURFGRASS DISEASES

Plant diseases are among the most feared, yet least understood, phenomena turf managers face. Although some types of diseases are present at almost any given time, they may or may not develop into epidemics that result in unacceptable damage. Many interacting factors determine the severity of disease development over time.

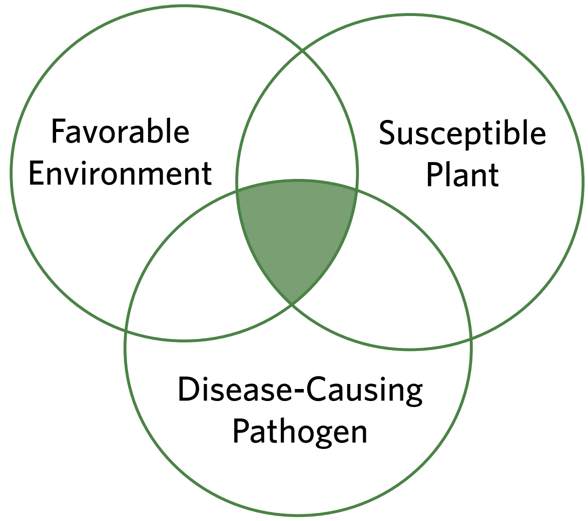
This chapter will discuss turf diseases in the context of their importance, diagnosis, prediction, risk of damage, and recuperative ability.

7.1 WHAT IS A DISEASE?

A **disease** is defined as a detrimental condition developing from a continuous interaction between a causal agent and a host plant. Diseases interfere with the normal function of some part of the plant, resulting in lower yields or reduced quality.

Infectious diseases in turfgrasses, as in other plants, originate from an interaction between a susceptible plant, a plant pathogen (usually a fungus), and an environment favorable for the disease-causing organism to attack. Often the environment is unfavorable for ideal growth and development of the host plant. Diseases do not occur until all three parameters overlap **(Figure 7–1)**. Thus, diseases produce an abnormality that injure the plant or reduce its value. Information on all three factors should be gathered to obtain information for diagnosis of the problem. Turf managers should try to alter any or all of these three factors to combat the disease.

Figure 7–1. Disease occurrence requires the simultaneous presence of a susceptible plant, a disease-causing pathogen, and a favorable environment.



Fungi

Fungi are small, threadlike organisms composed of tiny filaments (hyphae) that cannot manufacture their own food. Although many fungi resemble plants without chlorophyll, they are not plants and are classified in their own Kingdom, the Fungi. Similar to fungi are the Stramenopiles. These fungus-like organisms include many algae but also Pythium, the downy mildews and the Labyrinthulomycota among the turf pathogens. Fungi and the Straminopiles are either parasitic or saprophytic **(Table 7–1)**. **Parasites** obtain their nutrition from another living organism, and **saprophytes** obtain their nutrition from non-living organic

Table 7–1. Parasitic habits of turfgrass fungi and Straminopiles.

PARASITIC HABIT	TURF PATHOGEN	PRIMARY INFECTION SITES
Facultative parasites—Parasitic fungi that can survive as saprophytes until conditions are favorable for infecting living plants, after which they become parasitic.	• *Colletotrichum, Curvularia, Xanthomonas*	• Mostly shoots
	• *Pythium, Typhula*	• Mostly roots
Facultative saprophytes—Fungi that function primarily as parasites, but can temporarily subsist as saprophytes on dead organic matter.	• *Gaeumannonyces, Leptosphaeria, Magnaporthe,*	• Roots
	• *Pyricularia, Rhizoctonia, Sclerotinia, Microdochium (Fusarium)*	• Shoots
	• *Drechslera, Bipolaris*	• Shoots and roots
Obligate parasites—Fungi that live only in association with a living host, feeding on them.	• *Erysiphe, Puccinia, Urocystis, Ustilago, Panicum mosaic virus (SADV)*	• Shoots
	• *Parasitic nematodes*	• Roots
Obligate saprophytes—Fungi that only live with dead organic residues, such as thatch and mat, and do not infect living plants.	• *Fuligo, Mucilago, Physarum*	• Shoots
	• *Agaricus, Lepiota, Lycoperdon, Tricholoma*	• Roots

materials. Some fungi are **facultative parasites**, meaning they are normally saprophytic, but can sometimes infect living plants. An example is *Sclerotium rolfsii,* which causes southern blight. Most fungi that are pathogens of turfgrass are **facultative saprophytes**, which are normally parasitic, but can survive in the absence of the host on dead organic matter (usually crop debris). Examples include *Rhizoctonia solani*, which causes brown patch, and *Sclerotinia homoeocarpa*, which causes dollar spot. Fungi occurring in turf systems as saprophytes may nevertheless be mistaken as parasites, such as the harmless slime mold fungi. Fairy ring fungi, although saprophytic, do cause detrimental chronic disorders in turf. Some fungi, such as rust and downy mildew fungi, are **obligate parasites**; these organisms must parasitize living plants in order to grow and reproduce. They utilize a specialized hypha within the infected plant cells called a **haustorium** that is used to extract nutrients from the living host. **Obligate saprophytes** live only in association with dead organic residues, such as thatch; thus, they do not infect living plants. Examples include the true slime molds, *Mucilago* and *Physarum*.

Most fungi produce **spores** (seedlike bodies), consisting of single or multiple cells, that are spread by wind, water, mechanical means such as mowers, or by infected plant materials such as grass clippings. Under moist conditions, spores germinate and grow by producing threadlike filaments, or **hyphae**. Collectively, a mass of hyphae is known as a **mycelium** (or **mycelia** for plural). Mycelia may function by absorbing nutrients from plant cells and also can become dormant, thereby providing some fungi a means to survive periods of inactive growth. Some fungi produce hardened, aggregated mycelial structures called **sclerotia**, which may aid in resisting unfavorable environmental conditions. Fungi need water to grow and are highly dependent on temperature to grow and cause disease. Fungi also are ubiquitous, meaning they are found everywhere and many are primarily responsible for degrading dead organic matter, such as thatch.

Fungi produce spores either through sexual reproduction, by asexual means, or as a combination of both. The portion of a fungi's life-cycle involving sexual reproduction is termed the **perfect stage**. The **imperfect stage** is the life-cycle phase involving asexual reproduction. In some fungi, spores produced asexually in vast numbers may quickly colonize susceptible plants and produce epidemics.

When a fungal pathogen is not actively attacking the plant, it has not disappeared from the turfgrass area but is simply surviving in a dormant state or as a saprophyte living off organic materials in the thatch and soil layers in the environment. Fungicides generally do not eliminate turfgrass pathogens, but simply suppress the pathogen's activity on the plant while the environment is conducive for disease. Generally, they should be thought of as plant pharmaceuticals acting as plant protectants and/or chemotherapeutic agents.

Bacteria

Bacteria are microscopic single-celled organisms with rigid cell walls but no organized nucleus (termed **prokaryotes**). Fungi and Stramenopiles are **eukaryotes**, meaning they have organized nuclei within their cells. Bacteria reproduce by fission (or simple cell division), and can rapidly reproduce. Bacteria lack chlorophyll, although bacterial pathogens can be obligate or facultative parasites, and other bacteria can be beneficial as saprophytes as well. They overwinter, like fungi, in and on thatch, plants, seed, soil, and sometimes in insects. Bacterial pathogens enter plants only through wounds (which may be made by living organisms, such as insects) or natural openings, such as lenticels, hydathodes, or stomata. Although some bacteria are able to swim, splashing water, wind-blown water, insects, infected tools, or plant cuttings are the normal means of dispersal. Once inside the host, bacteria cause damage by producing toxins or they block vascular tissue. This blocking retards water movement and infected plants wilt. Practically all plant-infecting bacteria are rod-shaped.

More than 80 bacteria species have been reported to cause plant diseases. Fortunately for turf managers, only a few damage finely maintained turf. The only major known economically significant bacterial turf disease is **bacterial wilt** caused by specific forms of the pathogen, Burkholderia *(Xanthomonas) campestris (= Xanthomonas translucens* pv. *poae)*. These forms attack a number of grass species but are found most often on annual bluegrass and the vegetative propagated creeping bentgrass cultivars Toronto C-15, Nimisilla, and Cohansey. More recently, Acidovorax avenae has been shown to be pathogenic on creeping bentgrass under certain conditions of environmental stress. The term **'bacterial decline'** has been used to describe the symptoms and to differentiate the disease from the better known and studied 'bacterial wilt' described above **(Figure 7–2)**.

Figure 7–2. Example of the requirement of a susceptible plant (bentgrass), a disease-causing pathogen (Pythium spp.) and a favorable environment (hot, humid, wet conditions).

Nematodes

Nematodes are small eel-like worms that lack eyes. Those capable of causing disease in plants are mostly microscopic, with the largest approaching only 1/16 inch (1.6 mm) in length. Nematodes cause disease by infecting plant roots; however, some species infect leaves, stems, buds, and even replace embryos in the seeds of some plants. They possess a specialized feeding apparatus, a needlelike stylet, in their heads, which is utilized to tear and stab plant cells and extract their contents for nutrition. Some, like root-knot and cyst nematodes, set up specialized feeding sites within plant roots, inducing giant cells and cell proliferation in root tissues, leading to gall formation in the case of root-knot nematodes. Nematodes as turfgrass pathogens are discussed in an accompanying chapter.

Phytoplasmas

Phytoplasmas (previously known as mycoplasma-like organisms) are also prokaryotes, but do not have rigid cell walls. They are also believed to be obligate parasites, and are vectored by insects (many are leafhopper-transmitted). Some diseases, called yellow diseases, once thought to be caused by viruses have since been shown to be caused by phytoplasmas. Although diseases of turf in other parts of the world have reportedly been caused by phytoplasmas, such as yellow dwarf of bentgrass in Japan, none have been reported in the United States.

Viruses

Viruses are much smaller than bacteria, and can only be viewed with the aid of electron microscopes. Viruses are extremely small obligate parasites composed of nucleic acid (DNA or RNA) and a protective protein coat. Viruses are really complex molecules, but are infectious in nature. Viruses infect plants through wounds or by introduction into cells by means of a vector (insect, fungus, nematode), depending on the virus. For example, barley yellow dwarf virus is vectored by aphids, tomato spotted wilt virus is vectored by thrips, and wheat soilborne mosaic is vectored by a soil-borne fungus. Once inside the cell, a virus utilizes the host plant to produce more viral particles. Being produced inside the plant, viruses cause systemic infections. They seldom kill their host plants, but do severely affect their quality and health.

The diseases **St. Augustinegrass decline (SAD)** and **centipede mosaic** are the most common economically significant virus-induced diseases in turfgrasses. These are caused by various strains of **panicum mosaic virus** which is easily mechanically transmitted, most often by mowers and possibly by insects. St. Augustinegrass decline occurs most often in Texas and the southeastern United States. Symptoms first appear as a mild chlorotic mottling, blotching, and a speckling or stippling of the leaf blades for the first several years. Initially, symptoms resemble iron or zinc deficiency, mite damage, or yellow tuft (downy mildew) disease. Virus symptoms on infected leaf blades have a mosaic pattern with yellow streaking. Leaf nutrient deficiency symptoms, however, include continuous yellow stripes parallel to the veins. Symptoms intensify over time and infected plants may eventually die, leaving voids for weeds to fill. St. Augustinegrass grown under low nitrogen or drought conditions appears most susceptible. Chemical controls are not available. Planting a resistant variety such as "Floratam," "Raleigh," "Floralawn," or "Seville" St. Augustinegrass is the only known means of controlling this disease, but cultivar selection is important because of differences in low-temperature and shade tolerance as well as chinch bug susceptibility. Maintenance of good turf vigor and density by using proper fertilization, mowing, and fertility practices helps mask the symptoms.

In Florida, sugarcane mosaic virus (SCMV) has been found to cause a serious disease of St. Augustinegrass distinct from SAD, which has not been reported in Florida. Mosaic disease of St. Augustinegrass was first reported in the 1960s in sugarcane producing areas of Florida. The disease was named for the distinct symptom it produced. Differences in susceptibility among St. Augustinegrass cultivars were noted, and resistance was used to minimize the impact of the disease over the last 50 years. In recent years, SCMV has recurred in a few sites in Florida on lawns and landscapes of St. Augustinegrass and have been severely affected. To date, SCMV has not been identified in the Carolinas, although strains of Panicum Mosaic Virus, causing 'centipede mosaic' have been found in centipedegrass.

Parasitic Higher Plants

Parasitic plants, like mistletoe and dodder, and protozoa are also known to cause infectious diseases in some plants, but none are known to cause turfgrass diseases.

7.2 DISEASE CONTROL STRATEGIES

Correct Diagnosis

Turfgrass disease diagnosis involves a process of elimination. For accurate diagnosis, a number of steps are taken, the first being careful observation of **symptoms**. **Leaf spots** occur with various sizes and colors, most commonly with round or oval lesions on leaves with a distinct marginal border to the lesion. Gray leaf spot is an example of leaf spots. **Foliar lesions** are large, irregular areas on leaves with a distinct border such as is typical with brown patch. **Stem lesions** may occur with large irregular areas on leaf sheaths with a distinct border: symptoms typically seen with large patch. **Foliar blight** or **dieback** involves necrosis of leaves or entire tillers such as with Pythium blight. **Crown rot** symptoms involve the necrosis of crowns, rhizomes, or stolons as occurs with summer patch. **Root rot** involves the necrosis of roots, typical of 'patch' diseases such as spring dead spot.

Table 7–2. Major turfgrass diseases and their location.

FOLIAR DISEASES	STEM AND CROWN DISEASES	ROOT DISEASES
Bipolaris and *Drechslera* leaf spots, Brown patch, Copper spot, Dollar spot, Gray leaf spot, Pink patch, Pink snow mold, Powdery mildew, Pythium blight, Red thread, Rusts, Southern blight, Stripe Smut, Yellow tuft	Algae, Anthracnose basal rot, Dead spot, Large patch, Melting out, White Patch	Bermudagrass decline, Necrotic ring spot, Pythium root rot, Spring dead spot, Summer patch, Take-all patch

Directly observing the fungi associated with turf diseases is usually difficult due to their microscopic size. However, certain observable parts of the pathogen (called **signs**) may be visible with a hand lens. Common signs include spores such as yellow masses associated with various rusts, and mycelium, which may be visible in early morning with dollar spot or Pythium blight. Other signs are **sporophores** or spore producing structure, **sclerotia** which are small, round survival structures, and **mushrooms**. Patterns of symptomatic turf are key observations for diagnosis in the field. Are discrete patches formed? What is the size and aggregation of patches? Do leaves have identifiable lesions? Do these lesions and thinning stands occur throughout the turf or only in patches? Are symptomatic plants associated with unique environmental or microclimatic factors of importance?

Three main types of plant diseases occur on turf. Foliar diseases are generally easy to detect and diagnosed and can be controlled curatively **(Table 7-2)**. Stem and crown disease are more difficult to detect and diagnose and control curatively. Root diseases can cause significant damage to root systems even before symptoms appear. Most root diseases cannot be controlled curatively.

As mentioned, most pathogens (fungi) causing turfgrass diseases are microscopic; therefore, individual spores cannot be seen by the naked eye. However, with some diseases, spores collect to sufficient levels that they become visible as threads, powders, or masses. When the causal fungus is visible, its appearance often becomes the most important clue for diagnosis.

True **pathogenicity** (ability to cause disease) can be proved only by reliable scientific methods, usually requiring a laboratory and greenhouse or growth chamber. Three disease factors (grass, pathogen, and environment) provide the sources of diagnostic information. Thus, the next step in identification is an examination of the environment during the onset of disease occurrence. For example, what were the temperature, light intensity, and moisture conditions prior to and during disease development? The nature of the disease site also is important. Air and water drainage, soil conditions, sun and shade, slope, and nearness of other plantings or buildings all may be important in the development of turfgrass diseases. Knowledge of prior chemical applications to the site, including pesticides and fertilizers and even fungicides, may be important to make a correct diagnosis. Heavy thatch accumulation and poor mowing practices stressing the turf may trigger or amplify certain disease problems.

Finally, the submission of affected turf samples to a reputable laboratory or pathologist can assist in receiving a correct diagnosis and advice on corrective measures to take. This should be supplemented with close-up and head-high digital images of the affected turf, any noticeable symptoms or signs, and any unusual patterns.

In the Carolinas, commercial turf diagnosis is available at:

Clemson University
Plant Problem Clinic and Nematode Assay Lab - Commercial Turfgrass Clinic
511 Westinghouse Rd., Pendleton, SC 29670
Phone: 864-646-2133 Fax: 864-646-2178
http://www.clemson.edu/public/regulatory/plant_industry/pest_nursery_programs/plant_prob_clinic/pdf/commturf_form.

North Carolina State University
Plant Disease and Insect Clinic
Campus Box 7211
1227 Gardner Hall
100 Derieux Place
Raleigh, NC 27695-7211
http://turfpathology.plantpath.ncsu.edu/files/2014/03/2015-Turf-Form.pdf

Since it is usually not practical to eliminate the turfgrass host, disease control recommendations are aimed at: (1) using disease-resistant grasses, (2) suppressing the pathogen, and (3) altering the environment so it is less favorable for disease development. Thus, an integrated management program including cultural and chemical methods is the key to preventing and controlling turfgrass diseases. This method uses all available tools to manage diseases below an economic or aesthetic threshold.

Cultural Control

Similar to the human immune system, plants have a complex system for protection from disease. When stressed or energy is depleted, this defense system does not work properly. Cultural practices should promote healthy, vigorous plant growth to create an environment not conducive for pathogen infection and disease development and to better fight off an attack. This may be achieved by planting disease-resistant cultivars, if they are available; following sound principles of site preparation during turfgrass establishment; and managing an established turf through proper mowing, fertilization, irrigation, and cultivation practices.

For all fine turf areas, cultural control should encompass landscape design to promote drying conditions, sunlight penetration, good drainage, and so forth. Since living organisms are involved (turfgrass plants as well as the pathogens affecting them), a goal should be selecting appropriate plants for the particular site. If this is performed, disease potential should be minimized (but will never be eliminated). If a disease should affect the turfgrass, other cultural practices should be implemented first or, at the very least, implemented at the same time fungicides are applied. If a particular putting green, tee, or fair-way has a history of developing a particular disease at a particular time of year, then one should implement cultural practices to prevent this yearly reoccurrence. If changing a practice will prevent problems later, then it may be reasonable to change the practice. The following cultural practices are all designed to alter the turfgrass environment to prevent diseases or at least lessen their severity.

Disease-Resistant Grasses. When establishing a new turf area or when renovating disease-damaged turf, it is important to select grasses known to be resistant to pests commonly occurring in the area **(Table 7–3)**. Resistant cultivars can produce chemical toxins to the fungus, have morphological or chemical characteristics that prevent fungi entrance, or lack a nutrient the fungus needs. For example, certain Kentucky bluegrass varieties are resistant to melting out, stripe smut diseases, and spring leaf spot, diseases that devastate many bluegrass varieties. Crenshaw bentgrass, meanwhile, is highly susceptible to dollar spot

Table 7–3. Relative disease proneness of turfgrass species.

SUSCEPTIBILITY RANKING	TURFGRASS SPECIES
Very high	Annual bluegrass
	"Colonial" bentgrass
	Creeping bentgrass
	Velvet bentgrass
	Roughstalk bluegrass
High	Kentucky bluegrass
	Perennial ryegrass
	Fine fescues
	Tall fescue
Moderate	Bermudagrass
	Seashore paspalum
	St. Augustinegrass
	Zoysiagrass
Low	Bahiagrass
	Carpetgrass
	Centipedegrass
	Buffalograss
	Kikuyugrass

Figure 7–3. Research continues to explore plant resistance to pests. Shown is the resistance and susceptibility of various creeping bentgrass cultivars to dollar spot disease.

disease. Blends of various varieties or even turf species often provide a wider spectrum of pest resistance than planting a monoculture of one specific variety (Figure 7–3). If one cultivar loses its disease resistance, the entire turf stand is not ruined since other resistant cultivars are present. For example, blending Crenshaw and L-93 bentgrasses reduced dollar spot disease occurrence compared to Crenshaw-only stands. It is generally not a good idea to replant the same grass previously killed by the same disease, if another option exists.

In several cases, grasses naturally turn a different color or form patches that are often confused with disease symptoms. For example, Penncross and some other cultivars of creeping bentgrass often begin to segregate over time to distinct patches in terms of color, density, and disease resistance. This segregation is often confused with disease symptoms, causing major concern to players and management. Bermudagrass also often turns a purple color in fall when days are bright and nights are cool and can also form distinct patches of grass with a different texture, color, and density, causing similar concern as with bentgrass when a disease is active. These are non-disease-related situations where fungicides provide little, if any, relief.

Proper Turfgrass Establishment. Disease problems can often be avoided by implementing proper site preparation prior to planting. Buried debris, soil layering, and failure to incorporate amendments or construct drainage facilities where necessary can provide unfavorable turfgrass growing conditions. The turf may then become weakened from stresses associated with site construction, causing the turf to become more susceptible to disease.

Soil should be of uniform texture and well-structured in order to provide sufficient moisture, aeration, and nutrients for optimal turfgrass growth. A minimum of six inches (15 cm) of good topsoil is recommended. The site should also be well-drained. Surface drainage should be implemented to remove excess water following heavy rainfall or irrigation. Internal drainage should be provided by using soil mixes or amendments that allow adequate infiltration and percolation rates. Drain tiles installed below the surface can aid in reducing excessive surface moisture that can weaken turf roots over time.

Golf greens need special provisions for ensuring adequate drainage. Specially amended topsoil composed primarily of sand with some organic amendment and perhaps a small percentage of soil should be used along with subsurface drainage tiles. This is critical when trying to grow grasses outside their naturally adapted areas, such as growing bentgrass in the hot, humid areas.

Surface and Subsurface Moisture. Moisture is critical for many fungal spores to germinate and develop. While irrigation is essential to prevent drought damage, the amount of water and the timing of its application can prevent or contribute to disease development. Dew (more importantly, the length of the dew or leaf wetness period), a critical factor for disease development, is dependent on temperature and humidity. Extending the length of the dew (free water) period by irrigating in the evening before dew forms or in the morning after the dew evaporates extends the leaf wetness period. Therefore, irrigate when dew is already present, usually in the pre-dawn hours. This will also dilute or remove the guttation fluid accumulating at the cut leaf tip, which may provide a food source for some pathogens. For many golf courses, eight hours or more may be needed to irrigate the entire course. Since the putting greens are most susceptible to diseases, irrigate them during the predawn hours, so they will dry quicker. As more and more courses implement new computer-driven irrigation systems, this is often easier to accomplish. Mowing, whipping, and dragging, tree/shrub pruning and removal, and fan installation also help reduce leaf wetness duration.

If localized dry spots have developed, supplemental hand watering will be required on these areas in addition to the normal irrigation cycle. Spiking these areas before watering is also useful, as is the addition of materials that increase water absorption. As a general guideline, deep, infrequent irrigation discourages most diseases and encourages plant rooting. Shallow, frequent (e.g., daily) irrigation encourages many pathogens and reduces plant rooting, thereby reducing its vigor to resist diseases. Soil acts as a reservoir for water; thus, managers do not have to frequently irrigate. Rooting depths should be routinely monitored, and irrigation cycles appropriately adjusted to supply adequate moisture to the entire rootzone, encouraging plants to "search" for water held in reserve. When initial signs of impending stress are noted (or ideally, just before this stage), adequate irrigation should again be supplied to wet the rootzone.

Proper soil moisture also influences certain diseases. Adequate surface and subsurface drainage are two extremely important considerations prior to turf establishment which often dictate the level of turf health. Diseases encouraged by excessive soil moisture and low soil aeration include brown patch, Pythium blight and root rot, anthracnose basal rot, summer patch and take-all patch, spring dead spot, algae, and black layer.

Nutritional and Soil pH Status. Many diseases are also influenced by the nutritional status of the grass, especially concerning nitrogen. Achieving a perfect balance to maintain green, healthy, and growing plants should be the goal because both excessively high and low nitrogen fertility contributes to turfgrass diseases and recovery. Excessive nitrogen applications, for example, encourage *Rhizoctonia, Pythium*, snow molds, powdery mildew, and stripe smut. Low nitrogen levels, meanwhile, encourage dollar spot, anthracnose, rust diseases, and red thread. When a foliar disease is active, select a fertilizer blend with a high percentage of the slow-release component and a lower percentage of the rapid-release component. Adequate nutrition should be available to plants for continued growth, but the goal is to minimize luxuriant growth that induces greater susceptibility to pathogens. With bentgrass/Poa, for example, summer fertility typically involves weekly to biweekly applications of soluble fertilizers at 0.1 to 0.2 lbs actual nitrogen per 1,000 square feet (49 to 98 g N/100 m^2) per application. Micronutrients, such as iron, also are added.

Potassium is an important component in disease prevention as it reduces plant stress. Again, a nonstressed plant is not as susceptible to diseases. This has probably best been documented with *"Helminthosporium"* leaf spot diseases. An N:K ratio of at least 1:1 is best, although a ratio of 1:2 may be necessary in certain circumstances. It is important to remember potassium is not held tightly in sandy soils. While many superintendents are using slow-release nitrogen components, quick-release, highly soluble potassium sources are often used. If fertilizer is not frequently applied, a nitrogen/potassium imbalance may occur, creating a stress situation for the turf. Soil and leaf tissue testing should be performed periodically to indicate plant availability of nutrients.

Today, most new or reconstructed putting greens are composed of at least 80 percent sand by volume, with the remainder composed of an organic material such as peat moss. These high sand content greens are not composed of constituents such as clays that help to hold potentially leachable nutrients, such as potassium, in the rootzone. These rootzone mixes initially have a very low cation exchange capacity (CEC). Two to three years will be required before a rootzone with desirable CEC characteristics develops. Thus, during the first few years, plant nutrition should be carefully monitored.

High soil pH (>6.5) also appears to aggravate certain ectotrophic root infecting disease (ETRI) such as spring dead spot, necrotic ring spot, summer patch, bermudagrass decline, and take-all patch.

Table 7–4. Turfgrass disease occurrence as influenced by nutrient levels.

DISEASES FAVORED BY EXCESSIVE NUTRIENT LEVELS	DISEASES FAVORED BY INADEQUATE NUTRIENT LEVELS
Nitrogen	
Copper spot	Anthracnose
Gray leaf spot	Dollar spot
Gray snow mold (*Typhula* blight)	Leaf spots
Pink snow mold (*Fusarium* or *Microdochium* patch)	Melting out
Pythium diseases	Necrotic ring spot/summer patch
Rhizoctonia diseases	Red thread
Spring dead spot	Rust
Stripe smut	'Mini Ring'
Take-all patch	
Phosphorus	
	Pink snow mold
	Pythium diseases
	Take-all patch
Potassium	
Pink snow mold	Dollar spot
Rhizoctonia diseases	Leaf spots
	Red thread
	Spring dead spot
	Take-all patch
Calcium	
	Pythium blight
	Red thread
Sulfur	
	Pink snow mold
	Take-all patch
Iron	
	Pink snow mold
Manganese	
	Take-all patch and other ETRI diseases
High pH (>~6.5)	
Bermudagrass decline	
Necrotic ring spot	
Pink snow mold	
Spring dead spot	
Summer patch	
Take-all patch	

7.3 CHEMICAL CONTROL PRACTICES

A primary misconception many turf managers have concerning fungicides is that these materials kill fungi. Fungicides do not eliminate pathogens from the turfgrass area, and should never be utilized with this strategy in mind. When a fungal pathogen is not actively attacking the plant, it has not disappeared from the turfgrass area but is simply surviving in the environment in a dormant state or as a saprophyte living off dead organic matter in the thatch and soil layers. Most fungicides act as **fungistatic** compounds, meaning they primarily suppress fungal growth to prevent plant infection during environmental conditions conducive for disease development. Fungicides are applied either prior to anticipated disease outbreaks (**preventive**) or following the appearance of disease symptoms (**curative** or **eradicants**). Thus, fungicides should be considered as prophylactic plant pharmaceuticals. Those with some eradicant activity still work as plant protectants, but may also behave as chemical therapeutic plant pharmaceuticals.

Preventive fungicides are needed when chronically damaging diseases occur. This is especially true on golf greens that have seasonal problems with certain diseases such as Pythium blight, anthracnose, gray leaf spot, summer decline, brown patch, and snow molds **(Figure 7–4)**. Preventive use of fungicides often allows substantially lower rates than those required for curative treatment. Knowledge of the site, the grass being cultured, and the probability of certain diseases occurring during particular environmental conditions is crucial information for proper deployment of chemical and cultural control strategies. Newly overseeded areas also are prime candidates for preventive fungicide use until the overseeded grass becomes fully established. It is perfectly acceptable to use fungicides on a preventive basis as long as one understands what diseases/pathogens one is protecting the grass from at any given time of the year.

To be effective, a curative fungicide use strategy should be used at the onset of disease symptoms. Obviously, correct disease diagnosis is crucial for this strategy. Once significant turf damage has occurred, it is generally useless to curatively apply fungicides. Many fungicides, such as mancozeb, ethazole, and others, act as contacts (non-plant penetrants). They are more economical to use and less likely to have pathogens develop disease resistance; however, they generally only provide short duration (7 to 14 day) control under high disease pressure.

Figure 7–4. An example of a successful fungicide program for pest management (right) compared to a poor one (left).

Only use fungicides when absolutely necessary as overuse has the potential to increase or shift the disease spectrum on turfgrasses, lead to development of fungicide-resistant strains of pathogens, and increase thatch development.

Fungicides

Fungicides can be classified in various ways, and managers should become familiar with all of the different classifications for knowledge on their mode of action, as well as strategies for minimizing undesirable effects and maximizing disease management effectiveness. Fungicides may be classified based on how they behave on or within turfgrass plants. Basically, there are two categories of their topical modes of action: they penetrate the plant or they do not.

1. Contact fungicides—these are mostly curative
2. Systemic (penetrant) fungicides—these are curative and preventive

a. Local systemics (or penetrants)
    1. Xylem mobile
    2. Xylem limited

b. Mobile systemic (or penetrants)
    1. Acropetal—upward movement from roots
    2. Basipetal—downward movement from shoots

Phosphonates (Phosphorous acid salts). Phosphonate-containing products have recently been linked with disease control and possible fertilizer benefits. Phosphonate is a compound containing a carbon-to-phosphorus bond. Salts of phosphorous acid are phosphates (PO_4^{-3}) and phosphate products often contain a mixture of phosphorous acid and potassium hydroxide (KOH). From a fungicidal view, products made up of the salt and esters of phosphorous acid ($HPO(OH)_2$), typically provide the desired control. Phosphorous acid is a readily available solid substance, that when mixed with water, forms a strong acid referred to as phosphonic acid. In its pure from, phosphonic acid is so strong it causes excessive plant injury, thus, it is combined or diluted with other chemicals. This is often performed by mixing with an alkali salt such as potassium hydroxide (KOH) to form potassium phosphorous acid or potassium phosphite (KPO_3^{-2}) and is the active ingredient in Alude, Appear, Magellan, Biophos, Resyst, Vital and others plus is the main ingredient in several phosphonate fertilizers such as K-Phite (0-29-26), Ele-Max Foliar Phosphite (0-28-26) and Nutri Phite P + K (0-28-26).

Other fungicides are produced by reacting phos-

Table 7–5. Examples of resistance of turfgrass pathogens to fungicides.

DISEASE	PATHOGEN	FUNGICIDE
Dollar spot	*Sclerotinia homoeocarpa*	benzimidazoles, dicarboximides, DMIs
Powdery mildew	*Erysiphe graminis*	DMIs
Pythium blight	*Pythium aphanidermatum*	metalaxyl
Gray leaf spot	*Pyricularia grisea*	QoIs, benzimidazoles
Anthracnose	*Colletotrichum graminicola*	QoIs, benzimidozoles, DMIs

phonic acid with ethanol to form ethylphosphonate with aluminum added to neutralize the ethyl-phosphonate ions and produce fosetyl-Al (also called aluminum tris (oethyl phosphonate)). Fosetyl-Al is found in Aliette WDG, Prodigy, and the Chipco Signature fungicides.

Although similar in structure, phosphonate derived fungicides act differently in plants, soil, and plant pathogens than the traditional phosphorus-containing fertilizer, phosphate. In plants, phosphonate is transformed to phosphorous acid ($H_2PO_3^-$) which does not appear to be involved in any phosphorus metabolism in plants and only very inefficiently in soils.

Phosphonate fungicides are unique in plants as they move both in the xylem and phloem, thus, these are true systemics. Due to this mobility, especially to roots, phosphonate fungicides provide good control for root diseases caused by various *Pythium* spp., especially when applied preventively. When combined with mancozeb or a patented blue pigment, phosphonate-containing fungicides also significantly improved turf quality and control or at least reduced the severity of bentgrass "summer decline" or bentgrass "summer stress complex." This blue inert pigment in mancozeb, copper phthalocyanine, is an insoluble organic pigment (#15) added to make the naturally yellow colored mancozeb, have a green hue. Chipco Signature is a combination of fosetyl-Al plus a similar pigment, chlorinated phthalocyanine. 'StressGard' technology contains this pigment technology and is thought to add to turf health in addition to pathogen control.

The exact mode-of-action of phosphonate fungicide is not known but is suspected to either stimulate a plant's natural chemical and physical defenses against disease, improve the plant's photosynthesis capability, interfere with phosphate metabolism in fungal cells (the mechanism with most evidence for Pythium control) or inhibit several key enzymes necessary for fungal growth and development. This is assumed to be why these fungicides work best when applied preventively.

Fungicide Resistance. Fungicide resistance by turf pathogens is an increasing problem, especially with systemic fungicides since the physiological processes these materials inhibit are genetically controlled by only one or a few genes. Being so specific in their mode of action, fungi may exist in nature at low frequencies that circumvent this, reducing the efficacy of the fungicide. Resistant fungi are then able to multiply as the susceptible fungi in the population are reduced by the fungicide. With repeat applications, resistant fungi multiply until the population is mostly fungicide-resistant and disease control is severely reduced or completely lost. Usually, strains of fungi resistant to a fungicide will be resistant to all fungicides in the same chemical class (called **"cross-resistance"**). Examples of diseases where resistance has been documented include anthracnose, dollar spot, powdery mildew, necrotic ring spot, and summer patch to members of the fungicide family benzimidazoles (thiophanate-methyl); Pythium blight to metalaxyl (or Subdue); dollar spot and pink snow mold to iprodione (26GT); dollar spot to DMI, benzimidazole and dicarboxamide fungicides; and gray leaf spot and anthracnose resistance to the strobilurin fungicides **(Table 7–5)**.

Much research and promotion have been associated with a relatively new class of fungicides, the strobilurins. The original discovery was a natural fungicide, strobilurin A, produced by the pine cone fungus, *Strobilurus tenacellus*, a mushroom-producing fungi. The initial form of strobilurin A is light sensitive. Today's synthetic analogs were developed to decrease light sensitivity. Their mode of action is to block electron transport through the mitochondrial system; thus, treated fungi cannot produce energy.

The first strobilurin fungicide labeled on turf was azoxystrobin (Heritage) in 1997. It is a synthetic strobilurin fungicide which is acropetal systemic. It has upward mobility from the roots and is especially effective for control of several soil-borne diseases. Trifloxystrobin (Compass) was the next strobilurin fungicide registered in 1998. It embeds itself in the waxy cuticle of plants, and is not xylemmobile. However, it can move in waxes through leaves and in the vapor phase within and around treated leaf tissue. It provides broad spectrum control of many diseases and is very rainfast. The third registered strobilurin fungicide was pyraclostrobin (Insignia), registered in 2003, which is also a local systemic, and has excellent rainfast properties. A fourth active, fluoxastrobin (DisArm or Fame) is also on the market and is similar to azoxystrobin in that it is xylem mobile. One noted disease most strobilurin fungicides do not consistently control is dollar spot. Since the history of resistance development in dollar spot fungal populations is high, the use of strobilurin fungicides for dollar spot suppression needs to be carefully monitored and all strategies for delay of fungicide resistance need to be employed.

Mixing Fungicides. Fungicides are often mixed to increase the spectrum of disease control, to avoid resistance, and to improve turf quality. The most likely mixture contains a contact and a systemic fungicide. The contact fungicide provides a protective coating while the systemic fungicide protects root and crown pathogens and extends control of foliar pathogens. Common tank-mixtures include a contact product such as chlorothalonil or mancozeb with a more systemic product such as azoxystrobin, fludioxonil, flutolanil, fosetyl-Al, iprodione, mefenoxam, myclobutanil, propamocarb, propiconazole, thiophanate-methyl, triadimefon, or trifloxystrobin. As previously mentioned, these mixtures are a common technique to delay or reduce the risk of resistant forms of pathogens from increasing and to provide curative and residual control from a single application. Use the low rate of each and apply on a 14 to 21 day interval.

Commercially available mixtures of fungicides are on the market. Their components can be mixed separately by the applicator if each product is legally labeled for the turfgrass site, and they are a compatible tank-mix. The applicator, however, should be aware if one of the materials needs to be watered-in while the other one does not.

A special consideration should be given to applications of fosetyl-aluminum (Signature). Due to the acidic and reactive nature of this chemical, care should be exercised in mixing Signature with certain other chemicals. Do not mix Aliette with either soluble fertilizers or flowable chlorothalonil or mancozeb formulations. In addition, do not add acidifying products to alkaline spray water when using Aliette. In a neutral spray water (pH=7.0), Aliette will acidify the spray water to a pH of about 4.5. Similar precautions should be observed with other phosphonate fungicides.

Spray Volumes. Application spray volumes for disease control are generally higher than for other pests such as weeds. Delivery rates for most fungicides are in the 45 to 135 gallons per acre range (1 to 3 gallons per 1,000 sq.ft.), specifically 1 to 2 gallons per 1,000 square feet (4 to 8 L/100 m^2) for diseases attacking foliage and crowns, and 2 to 3 gallons per 1,000 square feet (8 to 12 L/100 m^2) for fungicides aimed at crown and root pathogens. For fairways, about 50 gallons per acre (935 L/ha) is standard for dollar spot but higher volumes should be utilized for root diseases such as summer patch. This high volume should be applied by regulating (slowing) sprayer speed and changing nozzle types instead of using higher spray pressures.

A broadcast boom fitted with flat fan or air-induction nozzles and delivering 30 to 60 psi (20 to 414 kPa) has provided very good results. Flooding nozzles have not been as effective for diseases of foliage or crowns. As pressure increases, droplet size decreases, spray volume and drift potential increase and nozzles may wear quicker. A general rule-of-thumb is that spray pressure must be quadrupled to double sprayer output.

Chemical Groups

Fungicides are also divided into groups based on their chemical properties **(Table 7–6)**. To prevent fungicide resistance from developing in a pathogen population, it is important to know which fungicides belong to the same chemical group or have the same biochemical mode of action. Biochemical mode of action refers to the way the fungicide inhibits fungi, whether at sites controlled genetically by one or a few genes or through multiple genetic control mechanisms. Fungicides should be periodically alternated or rotated, or used in mixtures with fungicides belonging to different chemical groups to prevent fungicide resistance. For example, alternating between propiconazole (Banner Maxx) and tebuconazole (Torque or Mirage) is not alternating between chemical groups as both fungicides belong to the same chemical group, the demethylation inhibitors (DMI). The occurrence of resistance has been problematic with plant-penetrant fungicides since their modes of action in controlling fungi are more genetically specific and the probability of resistant strains becoming selected is higher. In **Table 7–6**, fungicides are listed based on their chemical group.

Read Labels

You would not think of giving a family member any medication without reading the instructions first. Turfgrass fungicides deserve the same amount of respect. After all, they are plant pharmaceuticals. In addition to rates and intervals for application, labels provide information concerning the use or non-use of surfactants with the material, compatibility between other pesticides or fertilizers, amount of water to use in the application process, posting or reentry restrictions, and so forth. Keep up-to-date with the labels. Take the time to read them completely at least once each year. Remember, labels are the law.

Table 7–6. Turfgrass fungicides classified by chemical activity

CHEMICAL GROUP (ACTIVITY)	MODE OF ACTION	COMMON NAME	DISEASES CONTROLLED
Contact (Nonsystemic or nonplant penetrants)			
Aromatic hydrocarbons (also called **substituted aromatics** or **substituted benzenes**) (protective)	Interferes with DNA synthesis, as well as enzyme, membrane, or chitin production needed for growth and reproduction.	Chloroneb Ethazol (Etridiazole) PCNB (Quintozene)	*Pythium* spp. (chloroneb, ethazol, mancozeb, & maneb); brown patch (chloroneb, PCNB, thiram, mancozeb, & maneb); dollar spot (PCNB, mancozeb, & maneb); snow mold; "Helminthosporium" diseases (PCNB, mancozeb, & maneb); rust (mancozeb & maneb); melting out (PCNB, mancozeb); preventive blue-green algae (mancozeb). Little turf phytotoxicity or undesirable growth regulatory effects. Chloroneb and ethazol are short-lived (7 to 10 day) contacts. All have low resistance risk.
Dithiocarbamates or **carbamates** (protective)	Interferes with fungi cell respiration, enzyme activity, and cell membrane fluidity.	Mancozeb Maneb Thiram	
Arylaminopyridine	Dual mode of action, with uncoupling oxidative phosphorylation in mitochondria plus reactivity with thiols	Fluzazinam	Dollar spot, brown patch, "Helminthosporium" leaf spots, red thread, pink patch, anthracnose, pink and gray snow molds, algae. 2ee label for rapid blight. Low resistance risk.
Benzonitriles (also called **nitriles**) (protective)	Interferes with DNA synthesis and nuclear division.	Chlorothalonil	Dollar spot; copper spot; "Helminthosporium" diseases; brown patch; preventive anthracnose; gray leaf spot; snow mold; red thread; stem rust; preventive blue-green algae. Little turf phytotoxicity or undesirable growth regulatory effects. Often combined with propiconazole for dollar spot control. Low resistance risk.
Pyrollnitrin (or **Phenylpyroles**) (protective). Anti-fungal compound derived from the bacterium *Pseudomonas pyrocinia.*	Interferes with fungal membrane transport.	Fludioxonil	Brown patch; "Helminthosporium" leaf spot diseases, dead spot. Low resistance risk. Narrow control spectrum, short residual.
Oxidants	Oxidation of cell membrane proteins and enzymes of microbial organisms.	Sodium Carbonate Peroxyhydrate Hydrogen Dioxide	Predominantly algae. Low resistance risk.
Local-systemic (or local-penetrant)			
Dicarboximides (protective)	Inhibits DNA synthesis in cell division of spores, disrupts membranes, and blocks certain respiratory enzymes.	Iprodione Vinclozolin	Dollar spot; "Leaf spot" diseases; brown patch; copper spot; snow mold; melting out; red thread; Curvularia blight. Also combined with propiconazole for dollar spot control. Moderate resistance risk. Low root disease activity.
SDHI (also called carboxamides, benzamides, or anilides))(curative and protective)	Inhibits the respiratory enzyme succinate dehydrogenase which is needed in the mitochondrial transport chain, specifically the Complex II of the mitochondria.	Flutolanil	Brown patch; large patch; red thread; southern blight; and basidiomycete (*Lycoperdon* spp.) fungi which cause fairy rings. No control of non-basidiomycete fungi such as dollar spot and anthracnose. Moderate resistance risk.
		Boscalid	Dollar spot. Narrow spectrum of control.
		Fluxapyroxad, Penthiopyrad	Dollar spot; brown patch; large patch; fairy ring; spring dead spot; "Leaf spot" diseases. Moderate resistance risk.

CHEMICAL GROUP (ACTIVITY)	MODE OF ACTION	COMMON NAME	DISEASES CONTROLLED
Local-systemic (or local-penetrant) cont.			
Carbamates (curative and protective)	Inhibits membrane function and sporulation through altering fatty acid composition.	Propamocarb hydrochloride	Pythium blight and damping-off; less clear on Pythium root rot control. Also combined with mancozeb and fosetyl-Al for Pythium blight control. Low resistance risk.
Qi1 (protective)	Inhibits fungal spore germination by inhibiting the Qi site of Cytochrome bc1 in complex III of the fungal mitochondrial membrane.	Cyazofamid	Pythium blight, damping-off, and Pythium root dysfunction. Moderate resistance risk. Narrow spectrum of control.
Mobile plant penetrants (systemics)			
DeMethylation inhibitors or **DMIs** including triazole, pyrimidine groups (curative and protective). Also often referred to as **ergosterol biosynthesis inhibitors** (or **SBIs**).	Inhibits ergosterol synthesis, which are components of fungi cell membranes.	Fenarimol Myclobutanil Propiconazole Tebuconazole Triadimefon Triticonazole	Curative against dollar spot; anthracnose; rust (cyproconazole, propiconazole, & triadimefon); snow mold; "Helminthosporium" diseases (propiconazole); copper spot (cyproconazole, triadimefon); powdery mildew; red thread; southern blight (cyproconazole, triadimefon); and gray leaf spot (cyproconazole, propiconazole). Protective against brown patch, especially if tank-mixed; Summer patch; zoysia large patch; stripe smut. Undesirable turf growth regulatory effects may occur if used during stress (e.g., summer) periods. Moderate resistance risk. Excellent root disease control.
Benzimidazoles (curative and protective)	Inhibits DNA synthesis, mitosis, and development of the fungal skeleton. Upon wetting, these materials transform to methyl-2-benzimidazole carbamate (MBC).	Thiophanate-methyl	Dollar spot; brown patch; anthracnose; copper spot; snow molds; stripe smut; Microdochium patch, bermudagrass decline. High resistance risk. Root disease control is moderate to poor.
Acetanilides (also called **phenylamides**) (curative and protective)	Blocks RNA synthesis of mycelia and spore production. Does not inhibit spore germination or zoospore release.	Metalaxyl Mefanoxam Oxadixyl	Pythium blight and damping-off; not always effective against Pythium root rot. Yellow tuft; downy mildew. Often combined with mancozeb for Pythium blight control. High resistance risk.

CHEMICAL GROUP (ACTIVITY)	MODE OF ACTION	COMMON NAME	DISEASES CONTROLLED
Mobile plant penetrants (systemics) cont.			
Phosphonates (curative and protective)	Increases plant resistance and blocks mycelial development and spore germination.	Fosetyl-Aluminum (Al) Phosphite salts Potassium salts of phosphorous acid Sodium, potassium and ammonium phosphites	*Pythium* spp.; better as a preventative rather than a curative. Yellow tuft. Often combined with metalaxyl, propamocarb, mancozeb, or chlorothalonil. Low resistance risk.
Strobilurin (or QoIs) (curative and protective). Anti-fungal compounds derived from various wood-decaying fungi such as *Strobilurus* and *Oudemansin* spp.	Inhibits spore germination and mycelial growth by blocking electron transport in the cytochrome bc complex, disrupting mitochondrial respiration, and ATP production.	Azoxystrobin Pyraclostrobin Trifloxystrobin Fluoxastrobin	Brown patch; Pythium blight; summer patch; snow mold; anthracnose; red thread; "Helminthosporium" leaf spot; grey leaf spot; rust; take-all patch. Suppression of fairy ring caused by *Lycoperdon* spp. Minimum activity on dollar spot (Pyraclostrobin). Little turf phytotoxicity or undesirable growth regulatory effects. Broad spectrum of control. Long residual. Good root disease activity. Poor overall dollar spot activity. High resistance risk.
Antibiotics (or Polyoxins). Antifungal compounds derived from *Streptomycin* (protective and curative)	Inhibits chitin, a substance in fungal (and insect) cell walls. It also inhibits spore germination and mycelium growth.	Polyoxin D zinc salt	Best for brown patch and gray leaf spot. Suppresses gray snow mold, *Rhizoctonia* damping-off, large patch, pink snow mold, leaf spot/melting out, snow mold, red thread, and yellow patch. Recently labeled for preventive anthracnose. Moderate resistance risk.
Biofungicides	Either: (1) antibiotic biosynthesis; (2) resource competition; or (3) hyperparasitism.	*Bacillus licheniformis* SB3086 *Bacillus subtilis* GB03 *Bacillus spp.* *Burkholderia cepacia* *Gliocladium catenulatum* J1446 *Pseudomonas aureofaciens Tx-1* *Streptomyces cacaoi* var. *asoensis* *Streptomyces griseoveridis* (K61) *Streptomyces lydicus* WYEC 108 *Trichoderma harzianum 1295-22* Rosemary oil, clove oil, thyme oil, wintergreen oil, butyl lactate, plus lecithin	

7.7 DIAGNOSTIC FEATURES AND MANAGEMENT OF SPECIFIC TURFGRASS DISEASES

This section will discuss the primary diseases that occur on turfgrasses. The exact time when a disease will occur is dependent on the environment. Some of these diseases are rare or their duration is so limited that they are relatively unimportant. Chemical control treatments are listed as the common name only.

Anthracnose Leaf Blight

The causal agent of anthracnose leaf blight is *Colletotrichum cereale* Manns.

Occurrence. Several manifestations of anthracnose diseases exist in turfgrasses. Anthracnose diseases occur on many cool-season grasses as anthracnose leaf blight and occasionally as anthracnose basal rot. Bermudagrass and centipedegrass also may develop anthracnose leaf blight. On bermudagrass, the disease occurs in the fall as the growth of the grass slows. On centipedegrass, leaf blight may occur under conditions of unusually wet and humid weather in the late spring, summertime, or fall. Anthracnose leaf blight occurs by itself and in combination with *Bipolaris sorokiniana* (or leaf spot) to severely thin annual bluegrass, fine-leaf fescue, perennial ryegrass, creeping bentgrass, and certain cultivars of Kentucky bluegrass. Anthracnose infection is associated with plant stress. It is favored during environmental periods of limited grass growth such as warm (80 to 90°F, 27 to 32°C) summer weather when the soil is dry, leaves are wet, and high atmospheric humidity occurs with cool-season grasses. Anthracnose leaf blight often selectively infects annual bluegrass in bentgrass/annual bluegrass stands in late spring **(Figure 7–5)**. Although common, anthracnose leaf blight is usually of minor significance except on greens dependent on annual bluegrass as a component of the putting surface.

Figure 7–5. Anthracnose damage to Poa annua compared to the healthy creeping bentgrass.

Symptoms/Signs. This pathogen attacks grass shoots, stems, and roots. Initial symptoms are small (size of a dime) yellowing of the annual bluegrass turf which turns bronze in color if warm weather persists. Commonly, this occurs after flowering of annual bluegrass during heat stress. Lower leaves of plants initially show symptoms as elongated reddish-brown lesions that may enlarge and eventually encompass the entire leaf blade. The disease occurs as irregular-shaped patches. A water-soaked black rot of crown tissue may be evident if sheath tissue is removed (anthracnose basal rot). One-celled, crescent-shaped conidia are produced. The black fruiting bodies of the fungus (**acervuli**) can be seen growing in rows on infected leaves during hot weather. These acervuli have black spines called **setae** protruding from leaf tissue. Affected turf areas may thin and have a yellow-to-orange or reddish-brown cast to the overall area. The fungus overwinters as a saprophyte in dead plant tissue in the thatch and on stems beneath the leaf sheath of live plants.

Cultural Controls. Utilize cultural practices that minimize stress to cool-season grasses such as reducing soil compaction, heavy traffic, and provide adequate nitrogen fertility. Most damage occurs on annual bluegrass under heat stress. Begin a solid-tine aerification or slicing program in late May or early June, just prior to traditional heat-stress periods. Failure to aerify at this time may enhance anthracnose in July and August. Raise the mowing height and water to prevent wilt. Adequate nitrogen fertility will help reduce the severity of anthracnose leaf blight in some areas during cool periods. Fungicides will be needed in addition to light nitrogen applications during summer to prevent turf stand loss.

Chemical Controls. Apply systemics preventively on 21-day intervals. For best curative control, tank-mix a systemic fungicide with a contact and reapply in 14 to 21 days.

Anthracnose Basal Rot

The causal agent of anthracnose basal rot is *Colletotrichum cereale* Manns.

Occurrence. Increasingly, anthracnose basal rot is occurring in stands of creeping bentgrass, especially 'Penncross,' 'Pennlinks,' and 'Dominant,' and/or annual bluegrass. Generally, anthracnose basal rot of annual bluegrass and bentgrass appears in summer, although cases have been noted in spring under conditions normally associated with good bentgrass growth. Presumably, the early appearance is from residual infected plant material from the preceding season. Usually, some stress factor is associated with the development of anthracnose basal rot. Stressful weather (heat, drought or excessive rain) alone can spark the disease but is increasingly associated with putting greens under high management, which implies various combinations of traffic, low cutting heights, grooming, rolling, soil compaction, poor soil drainage, and low fertility. Mower cleanup laps often are the first areas to show disease symptoms. Mechanical damage from these practices typically intensify the disease. In some cases, anthracnose basal rot has developed in bentgrass after it has been affected with localized dry spots. In addition to a stressed host, surface moisture film is needed for infection. Annual bluegrass is especially susceptible following seedhead production, leaving the plant deficient in carbohydrates.

Symptoms/Signs. The disease organism persists in turf as a saprophyte in thatch or infected plant material. The disease is initiated when a fungal spore penetrates a healthy grass plant, presumably in late-spring into early-summer. Hyphae then grow between plant cells at the crown region without symptom development as the fungus becomes semi-dormant until the plant is under stress. When stressed, the pathogen invades plant cells, starts killing them, triggering symptoms. At this time, initial symptoms are small (size of a dime) and chlorotic or even dark-blue to purple. At it progresses, annual bluegrass turns yellowish with patches 1 to 2 inches (2.5 to 5 cm) in diameter. Bentgrass turf turns reddish-orange or bronze to copper in color if warm weather persists. Crowns are affected, and leaf lesions are usually absent. Leaves die back from their tips, beginning with older leaves, turning orange or yellow. Healthy appearing, but infected plants, can easily be pulled up and their base or crown region will be black and rotted, exhibiting a rotted, water-soaked appearance if the plants are only initially infected. It may occur in diffuse patches or in no particular pattern. As the disease worsens, the darkening (rotting) progresses up the stem. Usually dark, black masses of **setae** (black, hair-like projections seen with a 10X lens) and abundant sporulation in fruiting bodies called **acervuli** are noted. The spores from these acervuli spread the disease to neighboring plants. Eventually, irregularly-shaped yellow to brown patches develop, ranging in size from 0.5 to 6-inches (1.3 to 21 cm) in diameter in annual bluegrass or up to 18-inches (46 cm) in creeping bentgrass. Healthy neighboring plants fill in bare areas, causing an uneven, unsightly appearance that disrupts ball roll. Basal rot infection inevitably leads to plant death.

Cultural Controls. A major challenge of managing anthracnose basal rot is that infection occurs well before symptoms become apparent. Once the pathogen enters the plant, it remains in a semi-dormant state until the plant is stressed, when it then begins to kill plant cells. By the time symptoms develop, control of infected plants becomes extremely difficult. Therefore, using proper cultural practices to reduce stressful growing conditions to plants and minimizing excessive leaf moisture limits the time the pathogen attacks plants. Maintaining year-round tournament-like playing conditions is believed to be a major contributing factor to anthracnose basal rot outbreaks.

When the disease is active, avoid extremely low cutting heights and extremely low fertility, use floating head mowers and solid rollers, not grooved ones, skip daily mowing clean-up laps. Research suggests sand topdressing in spring and summer reduces anthracnose, presumably by providing support to the susceptible crowns of annual bluegrass. Summer mowing heights should be raised to 0.125 inches (3.2 mm) or higher and sufficient yearly nitrogen provided (4 to 6 lbs N/1,000 sq.ft., 18 to 27 g N/m^2), and proper use of plant growth regulators are needed to produce a healthier, less disease-prone plant. Utilize cultural practices that minimize stress to cool-season grasses such as reducing soil compaction, heavy traffic, and moisture stress. To promote some growth and plant recovery, moderate applications of soluble ammonium sulfate or urea at 0.1 to 0.125 lbs N/1,000 ft^2 (49 to 61 kg N/100 m^2) is suggested every 7 to 14 days as a tank-mixture with fungicides. Irrigation should be provided to prevent wilt or development of localized dry spots. Some surfactants for prevention of localized dry spots may be beneficial. Do not mow when greens are excessively wet and change cups frequently to direct traffic from weakened areas. Syringe to prevent wilt and mow infected greens last to reduce disease spread. Also, avoid major club tournaments during peak disease period.

Chemical Controls. Currently, using preventive and curative fungicide programs plus scouting for symptoms to catch the disease as early as possible appear best for management. Scouting indicates where the disease started and spread for developing future management strategies plus this allows early curative fungicide use to help stop the spread of disease. Keep records on the specific environmental conditions in which the disease occurs, then use this information as an application timing guide for following years. Following first-year disease occurrence, areas infected the previous year can be targeted for preventive control. In areas of the Carolinas with high heat stress in summertime, preventive summer fungicide programs are needed for anthracnose as well as other summer diseases. With anthracnose basal rot, affected plants generally die and recovery depends on surrounding, unaffected plants.

Apply effective fungicide products preventively, typically from late spring through summer in areas of high disease potential. Under traditional heavy pressure sites, preventive control should begin in spring prior to Poa seedhead formation. For best curative control, tank-mix a systemic fungicide with a contact such as chlorothalonil, and reapply in 14 to 21 days. Other effective fungicides include polyoxin-D, tebuconazole, metconazole, and propiconazole. Resistance is common to thiophanate methyl and the strobilurin fungicides. To delay resistance, avoid using fungicides from the same chemical class in succession and also be aware of the possible negative growth regulation from sterolinhibiting (DMI) fungicides. Due to potential turf damage or excessive growth regulation, avoid summer applications of propiconazole unless it is needed in a mixture with chlorothalonil for curative control.

Bacterial Wilt

The causal agent of bacterial wilt is *Burkholderia (Xanthomonas) campestris (= Xanthomonas translucens* pv. *poae).*

Occurrence. These forms attack a number of grass species but are found most often on annual bluegrass and the vegetative propagated creeping bentgrass cultivars Toronto C-15, Nimisilla, and Cohansey. The switch in the 1980s to sand topdressing programs was associated with several outbreaks of bacterial wilt in vegetative propagated bentgrasses. The sand was thought to cause excessive wounds, allowing infection, or possibly the number of beneficial organisms in pure sand topdressing were too low to compete with the pathogen. Recently, bacterial wilt in annual bluegrass has been increasing in occurrence. Like anthracnose, plants severely stressed by low mowing heights, soil compaction, under-fertilization, and excessive wear are more susceptible to bacterial wilt. The disease is enhanced by extensive rainfall, followed by warm weather that induces wilting. Although not known why, bacterial wilt is often seen in spring following severe winter damage. Following a spring flush of disease, infected plants tend to recover until mid-summer when temperatures then increase plant stress as well as become optimum for disease occurrence. As temperatures decline in fall, plants recover and the disease usually declines unless fall days are warm, causing disease resurgence.

Symptoms/Signs. Bacterial wilt symptoms initially appear as tiny red- to copper-colored spots resembling dollar spot except for the unusual color. The disease grows best at about 86 F (30 C) but can be observed from mid-Spring until early-Fall. Often etiolation (tissue yellowing or bleaching from the lack of photosynthesis) occurs, especially if plants are left un-mowed for 2 or 3 days **(Figure 7–6)**. It can be active whenever infected plants are growing. As the disease progresses, the spots become larger and portions of the green wilt as the bacteria clog the xylem tissue of the plants. When cut and observed microscopically (≥100X), infected leaves ooze out streaming bacteria cells. Infected tillers of plants eventually die.

Cultural Controls. Control of the disease in bentgrass involves switching from vegetative planted turfgrass or annual bluegrass to seeded varieties with a wider genetic base for resistance. Avoiding plant injury through sand topdressing where the disease is present also helps as well as relieving other management stresses to the turf.

Chemical Controls. Being bacterial in nature, fungicides have little effect on this disease. The antibiotic oxytetracycline may provide temporary (four- to six-week) control. However, since bacteria enter plants by mower wounds, repeat treatments are necessary, which soon become cost prohibitive. In addition, the antibiotic can be very phytotoxic in warm weather and may cause more harm than good. Copper hydroxide, hydrogen dioxide, and mancozeb can reduce bacterial populations on leaves. However, since these products do not penetrate plants, only surface bacteria will be affected. These also need reapplication following mowing.

Bermudagrass Decline

The causal agent of bermudagrass decline is *Gaeumannomyces graminis* (Sacc.) Arx & D. Olivier var. *graminis*. This disease causal organism occurs on many turfgrasses including bermudagrass, St. Augustinegrass, kikuyugrass, bluegrass, bentgrass, and Seashore paspalum.

Occurrence. Primarily observed during summer and early fall months when temperatures are above 75 to 80°F, 24 to 27°C (including night) with high humidity, cloudy skies, and frequent rainfall. This disease is mostly limited to putting greens due to the stress imposed by very low cutting heights combined with reduced sunlight from extensive cloudy weather, shorter days of late summer, cooler nights, thus, slower bermudagrass growth, and extensive rainy pe-

Figure 7–6. Turf shoot extension and bleaching (called etiolation) from bacterial wilt infection.

Figure 7–7. Bermudagrass decline.

riods. Tees may also be affected if mowed excessively low. As a general rule, the outer margins of a golf green exhibit the disease symptoms first, presumably due to added pressure from turning mowers, but can spread slowly across an entire green (**Figure 7–7**). It occurs on all types of putting greens—old, new, poorly-drained, and well-drained. At this time all plant material is assumed to be infected since the causal fungus is ubiquitously found with all bermudagrass plants. Tifdwarf bermudagrass often declines with continual mowing heights at 0.125-in (3.2 mm) combined with the above mentioned stress factors. The disease tends to be less severe with the ultradwarf bermudagrasses unless the mowing heights are below 0.125-in for extended periods with the environmental stresses noted previously.

Symptoms/Signs. This is a root rot disease; therefore, the plant is easily stressed for water and nutrients. By the time aboveground symptoms appear, pathogens have been active on roots for at least a few weeks and possibly months. Initial symptoms are irregular, off-color patches ranging in diameter from a few inches to a few feet. Lower leaves will exhibit the aboveground symptoms first by becoming yellow and then brown (dead). Roots with initial symptoms will usually be thin and off-white in color with isolated black lesions. Eventually, roots will turn black and rot. Stolons and rhizomes may also have black lesions. Black strands of fungi (runner hyphae) will be present on the outside of roots, as well as distinctive multi-lobed hyphopodia (specialized hyphae visible microscopically on root surfaces). Entire plants may die, resulting in an irregular thinning of grass, and if not controlled, bare patches may develop. This disease should not be confused with Pythium root rot, which causes a general decline across the entire green or limited portions of the green. Pythium root rot does not usually result in plant death.

Cultural Controls. Bermudagrass decline is very difficult to control once it is established. Therefore, preventive measures that alleviate stress are the best methods for completely controlling the disease or at least decreasing the potential damage.

1. Raise the mowing height, especially during stressful growth periods during summer and early fall months. **This is the most important preventive measure.**
2. Aerify greens frequently to avoid compaction problems. Remove the cores.
3. Topdress after aerification with a topsoil mix containing at least 70 percent sand. More frequent topdressing may be necessary on putting greens where the disease has been previously observed. Topdressing also covers dying lower leaves, leaving the "appearance" of a healthy, green playing surface.
4. Balance nitrogen applications with equal amounts of potassium. On new sand greens, monitor other nutrients as well—especially phosphorus and micronutrients. Fertilize to encourage recovery. Remember, deeper roots are damaged; thus, shallower ones have to "work" for nutrients in the top few inches of soil. Nitrogen should be applied with potassium in a 1:1 or 1:2 ratio. Apply micronutrients, especially iron and manganese, if they are in low supply or unavailable to the plant due to a high soil pH. Two to 8 lbs Mn per acre (2.21 to 9.0 kg/ha) typically helps reduce the symptoms of this disease causal agent. A readily available source of phosphorus may be useful. Foliar feeding of nutrients may be useful if the root system is severely damaged.
5. Do not raise soil pH by adding dolomitic lime to greens. If it is necessary to add magnesium, use magnesium sulfate (Epsom salts) or, if calcium is needed, then consider calcium sulfate (gypsum). The disease is typically more severe in sites with neutral to alkaline soil pH, so the addition of lime may increase their activity as the pH increases.

Chemical Controls. Best control is achieved when fungicides are used preventively, prior to symptom development. Do not use these excessively as they may have negative growth-regulating effects on bermudagrass. Treat in spring prior to infestations when daytime temperatures are <80°F (27°C). Apply in 2 gallons of water/1,000 sq.ft. (8 L/100 m^2) and incorporate further with irrigation. Cultural control methods, especially raising the cutting height, should also be implemented in mid-late summer before decline begins. Control seems to be best when fungicides are watered into the rootzone (but not below it) immediately after application. These fungicides penetrate the plant, but are xylemmobile (see fungicide section). The use of a contact fungicide such as mancozeb or chlorothalonil on the leaf tissue may also be useful to prevent secondary leaf infections from occurring and to prevent algae formation in thin areas of the green (see algae section). Propiconazole and other DMI fungicides should not be used during the warm summer months. If *Rhizoctonia zeae* is also present, do not use thiophanate methyl products, since it is not sensitive to this chemistry. Tank mixing fosetyl-Al plus mancozeb also has shown some suppression when used preventively. This tank mixture is not watered-in.

Brown Patch and Large Patch

The causal agent of brown patch is *Rhizoctonia solani* Kuhn.

Occurrence. Brown patch is the most widespread turfgrass disease. It affects all turfgrass species and is observed most often on creeping bentgrass, tall fescue, perennial ryegrass, and annual bluegrass during warm (above 85°F, 29°C) weather when night temperatures are above 68°F (20°C) and foliage remains wet for extended (>10 hours) periods for several consecutive days. In cool-season grasses, infection is triggered by a rapid rise in air temperature combined with either rainfall or extended periods of high humidity, resulting in the leaf canopy being continuously wet for 48 hours or more. *Rhizoctonia* species are found in all soils and survive unfavorable environments as dormant, thick-walled mycelia or as compact masses of thick-walled cells (**bulbils**) resembling sclerotia in plant debris. There is some evidence inferred that infected but asymptomatic plants, may become blighted when weather favors symptom expression and serves as primary inoculum for initiating new disease cycles. Strains of R. solani which cause brown patch in cool-season grasses are typically the subspecies groups AG-1 or AG 2-2 IIIB.

On warm-season grasses, large patch occurs in bermudagrass, zoysiagrass, seashore paspalum, St. Augustinegrass, and centipedegrass. The strain of R. *solani* (AG-2-2 subgroup 'LP') is most active as a pathogen in the spring or fall months when the temperatures are relatively cool and the turf surface stays continuously wet for several days due to extended rainfall or over-irrigation. This disease in zoysia may be referred to as "zoysia patch."

Symptoms/Signs. Symptoms of brown patch differ in cool-season grasses, depending on the height of cut. On putting greens, the disease begins as small circular light-green to dark-purplish patches that eventually turn yellow and then brown or straw-colored **(Figure 7–8)**. Patches may expand to several feet in diameter, and may or may not have green, relatively healthy appearing turf in the center of the patches. On lower heights of cut, a dark gray, purplish or dark-brown "smoke ring" may be visible, particularly under conditions of high relative humidity or when dew is on the green. This ring is composed of mycelium and freshly wilted, infected grass. These symptoms may change as the day progresses so, by late morning, the patch appears more uniformly light-brown, yellow-orange, or straw-colored. On higher heights of cut, typical of roughs, leaf lesions are more apparent and a smoke ring symptom may not be visible, although mycelium may still be visible upon careful examination of affected leaves low in the turfgrass canopy. The turf may also appear "sunken." The later symptoms are typical in tall fescue. Brown patch is distinguished from summer patch in annual bluegrass by the characteristic leaf lesions on individual blades associated with brown patch. Lesions are irregularly shaped grayish-colored leaf spots with a dark-brown margin.

Figure 7–8. Brown patch of a creeping bentgrass golf green.

Figure 7–9. Large patch of a warm-season golf course fairway.

Large patch symptoms in warm-season grasses differ significantly from those observed in cool-season grasses. In warm-season grasses, discrete leaf lesions are not usually formed; rather, a soft, dark rot will occur on the lower portion of the leaf sheath. Whole leaf fascicles pull up easily due to this basal leaf sheath rot. Eventually, entire shoots will easily pull off the stolons. When disease is active, margins of patches exhibit yellowed shoots, whose basal leaf sheaths are recently infected and rotted. So, a yellow- to light-brown band of more recently affected shoots surround the more-brown patch of affected turf. Roots are not normally affected by this pathogen or those causing disease in cool-season turfgrasses. Roots may decline, however, as foliage is destroyed. Patches up to 20 feet (6 m) in diameter may develop on bermudagrass, zoysiagrass, seashore paspalum, St. Augustinegrass, or centipedegrass during cool, wet weather and shoot green-up in the spring **(Figure 7–9)**. Leaf sheaths of plants at the perimeter of these patches are dark brown or black. As temperatures warm, turf vigor increases and eventually grows over diseased areas, but cultivars or species with lower turf recuperative potential (like Meyer zoysia, or centipede) may still exhibit symptoms into the summertime, and weeds typically invade these weak areas of turf. These large patches are perennial in nature, and may reappear in the same location in following years, expanding in size.

Cultural Controls. For cool-season grasses, avoid excess nitrogen, especially readily available forms such as soluble liquids or quick-release nitrogen sources just prior to hot, humid weather. For bentgrass greens, use very low rates and adopt a "spoon feeding" approach to avoid stimulating succulent foliage, but still maintain the ability of bentgrass turf to recover from disease. Complete elimination of nitrogen fertility, even in the summertime for bentgrass greens, is not advised as new root-and-shoot growth is needed for plants to recover from disease and (hopefully) transient highly stressful high temperatures. Maintain adequate levels of phosphorus and potassium. Avoid excessive irrigation, and irrigate greens when dew is already present so leaves do not stay continuously wet. Dragging a hose across the turfgrass or whipping greens with a bamboo or fiberglass pole will also remove morning moisture. Increase air circulation by removing adjacent underbrush and consider tree removal to improve morning sunlight penetration to the green. The use of fans for bentgrass greens promotes healthier grass and reduces disease pressure. Remove clippings on infected areas or when conditions favor disease development. Use sharp mower blades to reduce turf stress and excessive wounding. Regularly core aerify to increase soil drainage, improve soil oxygen status, and reduce thatch buildup. Increasing mowing height also encourages turf recovery.

For brown patch management in warm-season grasses, avoid early fall applications of excess nitrogen. Also, avoid early spring nitrogen applications until sustained spring turf growth occurs. Improve drainage, as it has been observed large patch chronically appears in poorly drained areas. On golf course roughs where centipedegrass has been utilized, large patch may become severe as superintendents water to establish fall overseedings of ryegrass in fairways. This may be an argument against using centipedegrass for this purpose. Managing thatch accumulations will help to improve recuperative potential as well.

Chemical Controls. Preventive control (such as fall application for warm-season grasses) in chronic disease areas helps prevent spring disease symptoms. For creeping bentgrass in summertime, preventive applications are necessary to allow conservation of healthy foliage for maintenance of root systems and hence the turf stand. During other times of the year (spring, winter, and fall), when favorable weather for epidemics is likely to be of short duration, curative approaches are successful. Apply on the appropriate schedule during hot, humid weather when night temperatures exceed 68°F (20°C). Waiting for symptoms to develop before chemical control, however, may result in dead or thinned areas of turf that are unable to recover until favorable turf-growing conditions resume in fall. In summer, algae development becomes problematic under these conditions.

Rhizoctonia Leaf and Sheath Spot (also called 'Mini Ring' in bermudagrass)

The causal agents of Rhizoctonia leaf and sheath spot are *Rhizoctonia zeae* Voorhees and *R. oryzae* Ryker & Gooch. Mini ring of bermudagrass is also thought to be caused by *Rhizoctonia zeae.*

Occurrence. Rhizoctonia leaf and sheath spot occurs primarily during the warm late spring, summer, and early fall months, especially when nighttime temperatures exceed 77°F (25°C) and humidity is high. However, it has also been observed in winter months after a sustained, high-temperature period (>80°F, 27°C) with high humidity. Another environmental factor associated with secondary infection is a dry rootzone as found with localized dry spots. The *Rhizoctonia* species infect by mycelial growth arising from infested plant debris or from sclerotia or thick-walled cells that survive in thatch or soil. These fungi rarely form spores, and therefore spread primarily by mycelial growth or movement through mechanical means.

Symptoms/Signs. Lesions may be present on leaves and leaf sheaths. Normally, the disease appears as a total blight of leaf tissue, resulting in a reddish-yellow coloration of leaves. On creeping bentgrass greens, symptoms can include yellow rings similar to those of yellow patch disease, but also can resemble brown patch symptoms, including the formation of a faint smoke ring symptom in high humidity; sometimes a creamy visible foliar mycelium occurs as well. Individual infected leaves have gray or tan irregular lesions with tan or brown borders. Warm-season grasses rarely exhibit lesions on upper leaf blades as do cool-season grasses but lower leaves are blighted. Roots are not normally affected by these pathogens. Two types of overall "patch" symptoms have been observed. One is large areas of chlorotic (yellow) turf which never turn brown. The symptoms most often observed are necrotic (brown) rings of all sizes (6 inches to 6 feet diameter, 0.2 to 1.8 m)—ranging from full circles to semi-circles to quarter-circles. Rings often appear sunken, are never dark green as with true fairy rings, and they do not normally expand in size, only in number. On bentgrass greens, symptoms may resemble those of yellow patch except yellow rings or arcs are present in summertime.

On bermudagrass, mini ring consists of frog-eye (centers still green) circular patches 4 to 18 inches (10 to 46 cm) roughly in diameter that typically develop during hot, humid days of late summer and early fall when bermudagrass growth has slowed **(Figure 7–10)**. Centers of patches often have more intense green color than the perimeters. Disease patches often are on higher, drier parts of greens.

Cultural Controls. Control information is quite limited. As with all turfgrass diseases, maintain an adequate and balanced fertility regime, such as slow-release nitrogen sources. This is especially important for prevention and recovery

Figure 7–10. Mini-ring of a ultradwarf bermudagrass golf green.

of the mini ring symptoms in bermudagrass. In fact, if fertility is kept low, experience has shown that fungicides are largely ineffective once symptoms occur. Irrigate only when dew is already present on the turf and irrigate the entire rootzone. Do not allow the turf to become drought stressed, especially putting greens. In other words, avoid having a dry root system when the leaf canopy is wet due to high humidity.

Chemical Controls. Consistent disease control has been somewhat less successful with the fungicides currently registered for *R. solani* (brown patch/Rhizoctonia blight). Best control to date has been with strobilurin fungicides and SDHI fungicides, especially flutolanil. Polyoxin-D has been shown to have some efficacy although residual control is short. Some DMI fungicides have good activity, such as tebuconazole but on bermudagrass, use only low rates and long intervals of application due to growth regulating tendencies. Do not use fungicides containing benomyl or thiophanate methyl as *R. zeae* and *R. oryzae* are not sensitive to this group of fungicides.

Dollar Spot

The causal agent of dollar spot is *Sclerotinia homoeocarpa* F. T. Bennett.

Occurrence. This disease is favored by low soil nitrogen levels, close mowing, micronutrient deficiency, dry soil, heavy dews, soil compaction, and excessive thatch accumulation — characteristics of most modern golf greens. It occurs during periods of warm, humid weather when heavy dews occur. All turfgrasses are susceptible, with creeping bentgrass, ryegrass, Kentucky bluegrass, annual bluegrass, and roughstalk bluegrass (*Poa trivialis*) being most susceptible among cool-season grasses and bermudagrass and zoysiagrass most susceptible among warm-season grasses. Activity begins at 60°F (16°C) and is optimum between 70 and 80°F (21 and 27°C), especially when free moisture is present for 10 hours or more. Although a very persistent disease, dollar spot does not normally cause quick, total kill of a turf area.

Symptoms/Signs. Small (2 inches, 5 cm, diameter), bleached patches of dead grass on low-cut turf such as golf greens will develop first **(Figure 7–11)**. Irregular, light-tan lesions with distinct brown borders will be present on individual leaf tissue at the outside edge of the patch. Leaves may be girdled and collapse at the lesion even though leaf tips remain green. In contrast, lesions caused by *Pythium* fungi generally are water-soaked in appearance, feel greasy to the touch, and do not have distinct borders around the bleached diseased leaf tissue. In taller turfgrass, four- to six-inch (10- to 15-cm) patches of mottled, straw-colored turf often occur. Lesions on taller-mowed grass often die-back from the tip and have straw-colored or bleached lesions shaped like an hourglass. White, cottony mycelium may be observed in early morning hours when dew is present and can easily be confused with early stages of Pythium blight or the web of spiders. Spider webs, however, are flat, have a web pattern, and do not cause leaf lesions while mycelium from dollar spot or Pythium blight is three-dimensional.

Figure 7–11. Dollar spot of untreated creeping bentgrass (left) compared to fungicide treated turf (right).

Dollar spot fungi do not form spores; rather, the disease spreads from mycelial growth and movement of infected plant parts, infested equipment, or traffic. Dollar spot fungi survive as dormant mycelium in plant parts and as thin flakes of fungal tissue on foliage or in soil. Disease often develops earlier in spring where it was not adequately controlled the previous fall. Spots in sod-forming grasses, such as bermudagrass and bentgrass, usually disappear once disease is controlled; however, spots in bunch-type grasses, such as ryegrass, often remain due to their inability to fill-in damaged areas. Severity usually peaks in late spring and again in late summer on cool-season grasses when night temperatures are cool enough to allow heavy early morning dew formation and high humidity in the turf canopy. Dry soils also favor dollar spot. Leaf wetness periods of 10 or more hours are conducive for severe dollar spot outbreaks on putting greens cultured to cool-season grasses. On warm-season grasses, dollar spot occurs all season long on under-fertilized turf.

Cultural Controls. Plant resistant cultivars, blends, and mixtures of various grasses whenever possible. Bentgrass cultivars Crenshaw and SR1020 are highly susceptible while Penncross, L-93, A-1, A-2, and 007, are more resistant. Avoid extreme nitrogen or soil moisture deficiencies. If the disease develops, apply a quick-release source of nitrogen such as ammonium sulfate; symptoms will subside, although control is not sustained as long as with some fungicides. Do not use this approach with creeping bentgrass in heat-stress environments as quick-release fertilizers may cause excessive, succulent growth, promoting heat- and moisture-stress problems. Organic fertilizers may help delay dollar spot in early season, but do not adequately reduce its severity when disease pressure is high. Maintain adequate phosphorus, potassium, micronutrients, and lime. Irrigate during early morning hours to limit periods of high humidity and remove leaf moisture (dragging a hose over the area or using a whipping pole to remove moisture may enhance spread). Avoid thatch buildup by aerifying, topdressing, and verticutting.

Prevent disease spread by removing clippings from infected areas, washing equipment before entering a non-infected area, and by encouraging golfers to clean their shoes between rounds. Raising the mowing height also reduces disease severity on golf greens.

Chemical Controls. Most fungicides labeled for control do a good job. Contact fungicides provide 10- to 14-day preventive control while effective systemics provide 14- to 28-day control. Use higher rates only for curative control situations. Resistance has been problematic for the benzimidazole class of fungicides (including thiophanate methyl) and the sterol biosynthesis inhibitors (fenarimol, propiconazole, triadimefon, cyproconazole, myclobutanil). Once induced, resistance to these fungicides appears to be long lasting. Resistance has also developed in response to overuse of dicarboxamides which include iprodione, or vinclozolin, but the pathogen populations become sensitive to these fungicides if they are not used for several years before being used again. Rotating and tank-mixing fungicides are necessary for managing disease resistance. For resistant-prone fungicides, do not apply products from the same chemical class (or family) two or more consecutive times. Tank-mixing a low resistant-prone contact fungicide with a systemic (or penetrant) as previously discussed also reduces the chances of resistance. Another way of reducing the risk of resistance is rotating different single site inhibitors with the multisite fungicide with each treatment. The single site inhibition products cannot have the same mode–of–action or resistance may eventually build up. Strains of the fungus *Trichoderma* and several formulations of antagonistic bacteria appear promising as biocontrol agents when disease pressure is low.

Preventive control treatments should start in spring when nightly low temperatures are between 50 and 70°F (10 and 21°C). Repeat applications on 14- to 21-day intervals, depending on the products and rates selected. In addition, flat fan nozzles work best due to their even coverage. Spray application volume should also be 1.5 to 2.0 gallons of water per 1,000 square feet (6 to 8.2 liters per 100 m2).

Fairy Ring

The causal agents of fairy ring include *Chlorophyllum, Marasmius, Lepiota, Agaricus, Amanita, Lycoperdon, Calvatia, Vascellum,* and over 50 other basidiomycetes (mushroom-, toadstool-, or puffball-producing fungi). The name fairy ring is from English folklore where the rings were believed to be where fairies had danced. There are records of fairy rings in Europe over 100 years old and up to several hundred feet in diameter. These fungi do not infect turfgrass plants, but change the soil properties which affect the growth and/or appearance of the turf, making these very noticeable.

Occurrence. Fairy rings are most common in soils with high organic matter, often where old tree stumps, lumber, and other organic debris were buried during construction, or they may occur in soils of very poor fertility. Newly constructed putting greens, in which the rootzone mix consists of sand and an organic amendment (such as peat), may develop severe infestations after only a few years or even months. The fungi live by decomposing organic litter such as thatch and plant debris. Fairy rings caused by *Lycoperdon* (a common puffball) may develop on 100 percent sand-based greens as well. Fairy rings are most frequently observed during late spring through summer months, presumably due to warm, wet weather, which favor fungal growth. In some instances, organic acids associated with certain species of fairy ring may cause/promote hydrophobic localized dry spot (LDS). However, fairy ring can occur under any soil condition supporting turfgrass growth.

Usually growth stimulation of the turfgrass occurs in the form of darker-green rings or arcs. Grass stimulation associated with fairy rings is due to the increased availability of nitrogen, from decomposition of organic complexes in soil by the fungi or from decomposition of the fungi themselves as the rings expand outward. Grass inside a fairy ring is usually in a state of decline and frequently infested with weeds or algae. This decline is thought to be from depletion of nutrients; lack of soil moisture due to an impervious mat of fungal tissue at or near the soil surface; a toxic agent, such as cyanide-containing compounds produced by the fungus; or a combination of two or more of these. Fairy rings caused by *Marasmius oreades* rarely cross each other as the fungi produce compounds that inhibit the growth of other fairy ring fungi.

Symptoms/Signs. Fairy rings have been classified in several ways, depending on the symptoms and conditions induced. One classification describes them as belonging to two basic types: **edaphic** or **lectophilic**. Edaphic fairy rings are those induced by soil-inhabiting fungi. Edaphic fairy rings occur as rings or arcs of green stimulated turf which may or may not be accompanied by adjacent areas of dead or declining grass. A mat of white to cream-colored fungal mycelium may be present at or just below the soil line. This mat becomes very evident when a plug of grass is incubated in a sealed bag for two or three days. Soil beneath rings may become very dry and difficult to wet during summer and autumn. Edaphic fairy rings are more common in lawns and pastures. Three types of symptom expression are described for edaphic fairy rings. It should be noted that the same fairy ring fungi can cause any of these symptoms at certain times of the season or under varying environmental conditions.

Figure 7–12. Type I fairy ring where a ring of dead grass is adjacent to darker green turf.

Type I rings—These have a zone of dead grass just inside a zone of dark-green grass **(Figure 7–12)**. These are more prevalent on new greens than on established ones. The dead grass may form from mushroom mycelia accumulating below the soil surface and cause soil to become hydrophobic (water repelling). Type I rings generally cause the most damage due to this soil drying which prevents water from reaching plant roots, killing the turf or severely stunting its growth.

Type II rings—These have only a circular band of dark-green, rapidly growing turf, with or without mushrooms present in the band **(Figure 7–13)**. On frequently mowed areas (greens and tees), mature mushrooms may never be observed but the "button" stage may be present at ground level. Turf is normally not killed.

Type III rings—These do not exhibit a dead zone or a stimulated dark-green zone, but simply have a ring of mushrooms present. Mushrooms or puffballs often develop after rains or heavy irrigation during mild weather. Rings normally expand each year. The size and completeness (circular, semi-circular, quarter-circular) of the bands vary considerably (e.g., 1 to 100 feet, 0.3 to 30 m).

Figure 7–13. Type II fairy ring with just patches of darker green turf.

Type II and III fairy rings are more prevalent during cool, wet springs whereas Type I fairy ring is more common in hot, dry summers. Lectophilic fairy rings (sometimes called "superficial" fairy rings) are those inhabiting thatch and upper soil surfaces. Lectophilic fairy rings tend to be less problematic although, on putting greens, they can be unsightly and may still induce hydrophobic conditions that require treatment.

Cultural Controls. Remove Type III mushrooms as some (e.g., *Amanita, Chlorophyllum*) are poisonous, but these pose little threat to the turf and their mushrooms are easily removed by mowing, However, other edaphic fairy rings are very difficult to control. If necessary for aesthetic purposes, mask the dark-green ring symptoms with nitrogen fertilizers (especially for Type II rings). However, do not over fertilize cool-season grasses in summer as this may stimulate other, more severe problems. Fumigation may be used where sod in affected areas is removed, and the top six inches (15 cm) of soil are then mixed with a fumigant such as metam sodium or dazomet. Once the fumigant has dissipated, the area is resodded. Affected areas may also be excavated by digging up all infested soil in the ring area and two feet (0.6 m) beyond. Soil in the affected area is then removed to a 12-inch (30-cm) depth. Uncontaminated soil is then replaced and the area reseeded or sodded.

Although it is possible to excavate and fumigate fairy ring sites, it is quite likely rings will return if the food source is still present underground. In some situations on putting greens, Type I fairy rings are also associated with localized dry spots in which the fungi have produced humic and fulvic acids that coat sand particles. In those situations, it may be useful to spike the area and use wetting agents to increase water absorption. Also, aerify and remove soil cores to allow better nutrient and water penetration. Infected areas should be heavily hand watered, being careful not to overwater adjacent, unaffected areas that could result in other diseases and problems. Do not bury and plant over organic debris such as tree stumps, large roots, and lumber left over during the construction and establishment phases of turf areas.

Chemical Controls. Removing afflicted sod, followed by soil fumigation, tilling, and replanting, helps reduce fairy ring occurrence. Best results occur when fungicides are applied following aerification and irrigation to move them into the zone of fungus infestation. Also, the use of a wetting agent program to combat hydrophobic soil conditions is helpful. However, wetting agents alone will not control fairy ring fungi. By inhibiting the fungi with fungicides and providing better water infiltration and soil movement with wetting agents, symptoms can sometimes be suppressed for months. Pressure water injection of the fungicides and wetting agent combined is also helpful.

Microdochium Patch (Fusarium Patch or Pink Snow Mold)

The causal agent of Microdochium patch is *Microdochium nivale* (Fr.) Samuels and Hallett (formerly, *Fusarium nivale* Ces. ex Berl. & Voglino).

Occurrence. Microdochium patch is probably the most significant disease in the Pacific Northwest, although it is also important in northern areas of the United States, Canada, and Europe. It is referred to as Microdochium patch in the absence of snow cover and pink snow mold with snow cover. It occurs during periods of cool (32 to 60°F, 0 to 16°C), wet spring and fall weather with or without snow cover. Alternating thawing and snow cover, repeated frosts, cold fogs, and light rain are particularly favorable for leaf-to-leaf spread of the fungus. Creeping bentgrass, annual bluegrass, Kentucky bluegrass, ryegrass, and fine leaf fescue are all susceptible, with annual bluegrass and bentgrass being most susceptible and Kentucky bluegrass, tall fescue, and red fescue least susceptible. Although sometimes susceptible, Microdochium patch on warm-season grasses is uncommon, but may occur on bermudagrass at or near full dormancy.

Symptoms/Signs. When Microdochium patch occurs without snow cover, the spots are one to eight inches (2.5 to 20 cm) in diameter and reddish-brown in color **(Figure 7–14)**. At this stage, the disease can be easily confused with Pythium blight or copper spot. When the disease occurs under snow, spots are usually from two to three inches (5 to 7.6 cm) up to two feet (0.6 m) in diameter, and range in color from tan to whitish-gray or reddish-brown. Immediately after the snow melts, spots will initially appear water-soaked and may have pinkish, salmon-colored mycelium present in the margins (hence, the common name), later turning to light tan in color. In the center of patches, grass collapses and is frequently matted and water-soaked. If severe, spots may coalesce to form large areas of diseased turf. Grass on the outer edge of patches generally appears water-soaked, with profuse gray- or pink-colored mycelium of the fungus present. The disease may spread by mycelial growth or movement of spores that are produced in enormous amounts on diseased tissue in fruiting bodies called **sporodochia**. The white- or salmon-pink-colored sporodochia are very small and, with the aid of a hand lens, appear as flecks on dead plant tissue. These cannot be readily seen after the plant tissue dries. Spores are easily transported by water, machinery, animals, and foot traffic, and tracking patterns on greens are not uncommon. Conidia usually occur in orange-colored spore masses. It probably survives the summer months as resistant hyphae (mycelia) and spores in turfgrass debris. On dormant bermudagrass, under periods of high moisture, a grayish-colored patch can form. Permanent bermudagrass damage has not been seen. Unlike gray snow mold (*Typhula* spp.), pink snow mold does not produce sporocarps or sclerotia.

Figure 7–14. Microdochium patch.

Cultural Controls. Avoid late summer and early fall fertility that may lead to lush growth during cool, wet weather or under snow cover. Avoid excess spring nitrogen when *Microdochium* patch is a problem. Acidifying fertilizers such as ammonium nitrate and ammonium sulfate may aid in reducing soil pH and disease occurrence. Soil pH should be maintained below 7.0. Increase soil potassium in late fall to increase turf cold hardiness and to suppress the disease. Poor drainage and long leaf blades that mat down produce high humidity that favors disease development. Reduce shade and improve soil aeration and drainage. Remove tree leaves as the disease often develops underneath when they remain on the turf for long periods during cold, wet weather. Use snow fences or plant landscape plants adjacent to golf greens to prevent excess snow accumulation. Avoid compaction during winter by preventing skiers and snowmobiles from being on greens and tees. If covers are used on greens for insulation, treat with a fungicide prior to installation of the covers.

Chemical Controls. Contact fungicides generally provide the best control and should be applied before the first seasonal snow storm. Other combination tank mixes with good suppression should be applied in late September to early October as a tank-mix of a systemic fungicide and a strobilurin fungicide. This helps control *Microdochium* patch, dollar spot, anthracnose, and brown patch. Sequential treatments should be used in disease-prone areas during mid-winter thaws. In warmer climates, a curative approach is generally successful due to the probability of more favorable weather for turf recovery in winter.

Table 7–8. Common names, causal pathogens, and primary turfgrass hosts of various "Helminthosporium" diseases.

DISEASE	PATHOGEN	PRIMARY TURFGRASS HOSTS
Melting out	*Drechslera poae* (Baudys) Shoemaker	Kentucky bluegrass, rough bluegrass, ryegrass, buffalograss
Helminthosporium leaf spot	*Bipolaris sorokiniana* (Sacc.) Shoemaker	Kentucky bluegrass, bentgrasses, annual bluegrass, tall fescue, ryegrasses, bermudagrass, buffalograss
Red leaf spot	*Drechslera erythrospila* Paul and Parberry	Bentgrasses
Helminthosporium blight (Net blotch)	*Drechslera dictyoides* (Drechs.) Shoemaker	Fescues, ryegrasses, Kentucky bluegrass
Zonate eyespot	*Drechslera gigantea* (Heald and Wolf) Ito	Bermudagrasses, but also bentgrasses and Kentucky bluegrass
Stem and crown necrosis	*Bipolaris specifera* Nicot	Bermudagrasses, zoysiagrasses
Leaf blotch	*Bipolaris cynodontis* Marignoni	Bermudagrasses

"Helminthosporium" Diseases—Leaf Spot and Melting Out

The causal agents of "Helminthosporium" diseases and primarily *Bipolaris* and *Drechslera* spp. (previously known as species of *Helminthosporium*). *Bipolaris* species tend to be more problematic on warm-season grasses while *Drechslera* species tend to occur on cool-season grasses.

Occurrence. Leaf spot fungi previously belonged to the genus *Helminthosporium*, and they are still often referred to as "Helminthosporium" diseases. These fungi induce a variety of symptoms in many warm- and cool-season turfgrasses and attack all plant parts of turfgrasses. Thus, leaf spots, crown rots, and root, crown, rhizome, and stolon rots may occur, depending on the specific disease. **Table 7–8** lists several common Helminthosporium diseases.

In general, leaf tissue as well as crowns, rhizomes, and roots may be affected. These diseases become severe under moderate temperatures in spring, fall, and summer under wet, humid conditions. Conidia (spores) of these fungi are abundantly produced in lesions and are dispersed by wind, water, and through dispersal of infested tissue removed by mowing. Crown and root rotting becomes more apparent in late spring and summer when stressful conditions eliminate severely infected plants, causing a "melting out" symptom common with *Drechslera poae* in Kentucky bluegrass. These fungi survive as dormant mycelia in thatch and leaf litter, on colonized plants, and as conidia.

Symptoms/Signs. Drechslera species cause leaf spots during cool, humid conditions, especially following cloudy weather, with crown and root rot phases occurring during warm, dry weather or during wet periods following dry periods. Symptoms vary on different cool-season turfgrasses. Leaf lesions are generally distinct and begin when temperatures are between 70 and 85°F (21 and 27°C), and are tiny water-soaked areas that become dark-brown to purplish-black (**Figure 7–15**). Lesions are usually surrounded by a yellow area of varying width that fades to the normal green of the leaf tissue. Older lesions may have a white or bleached area in their centers. Severely affected cool season grasses may become almost entirely yellow in appearance. Leaf spots, crown rotting, and root rotting occurs. On leaves, small water-soaked lesions occur initially, are brown in color, or are a purplish color (**Figure 7–16**). Lesions on leaf sheaths similarly occur, but may encircle leaf sheaths and girdle leaf fascicles. When temperatures are above 85°F (27°C), lesions mature, the centers may turn tan or white in color and yellow, and chlorotic tissue may surround the actual lesions. Microscopically, abundant, dark, multicellular spores borne on simple modified hyphae are associated with the lesion's necrotic tissue. Gradual browning and thinning occurs over a period of weeks to months. As diseases progress, large irregular areas turn yellow, then brown, and then thin out. Lesions on stolons, stems, crowns, rhizomes, and roots are dark-purple to black. Crown/root rots will also occur at this time and infected plants lack vigor, often wilting even when adequate soil moisture is present.

Figure 7–15. "Helminthosporium" leaf spot.

Figure 7–16. Close-up of “Helminthosporium” leaf spot of bermudagrass.

On closely mowed bentgrass, leaves from red leafspot turn reddish-brown or dark gray in irregularly shaped areas, causing a smoky blue appearance resembling drought stress. Lower (older) leaves tend to show symptoms earlier, presumably due to their slowed growth.

On bermudagrass, leaf spot is most pronounced in fall and early spring months when the grass is green but not actively growing due to cool temperatures. Leaf spot rarely causes permanent damage to bermudagrass but can cause streaking, browning, light-brown blotches, and stand thinning under severe infestations. Turf normally fully recovers when good grass growing temperatures return.

Cultural Controls. Use resistant cultivars, blends, and mixtures of cool-season grasses whenever possible to alter the genetics of the host and prevent devastating epidemics. Balance nitrogen levels with potassium and increase nitrogen rates to promote turf growth. Avoid drought stress and reduce leaf-surface moisture by deeply but infrequently watering. Avoid late afternoon and evening watering and encourage good soil drainage. Encourage air movement and light penetration by removing shade sources and unneeded adjacent vegetation. Avoid thatch accumulation greater than one-half inch (1.3 cm). Raise mowing height between 1.5 and 2 inches (3.8 and 5 cm) for bluegrass to improve the survival of affected plants, but note this practice may be dependent on the particular cultivars being used. Overuse of phenoxy herbicides (MCPP, 2,4-D, and dicamba) for broadleaf weed control may enhance disease development on cool-season grasses or if used when bermudagrass is not actively growing. Avoid using these pesticides or treat preventatively for “Helminthosporium” disease control prior to their use.

Chemical Controls. Chronic problems with these diseases may be site specific, and preventive or curative control approaches should be used accordingly. Some disease enhancement has been noted with some of the sterol biosynthesis inhibitor fungicides and thiophanate-methyl. Preventive control is best. For cool season grasses, begin applications in early spring after new growth is apparent and repeat at 7- to 21-day intervals until warm weather occurs. Curative control of the warm weather group such as leaf blight and melting out are often ineffective when symptoms are obvious since the fungus is well-established and inaccessible in infected plant crowns, roots, rhizomes, and stolons. Fungicide applications in early to mid-fall are generally successful for managing leaf spot in bermudagrass putting greens.

Necrotic Ring Spot

The causal agent of necrotic ring spot is *Ophiosphaerella* (=*Leptosphaeria*) *korrae* J. C. Walker & A. M. Smith.

Occurrence. A major disease of Kentucky bluegrass and annual bluegrass, along with summer patch, necrotic ring spot has a similar pattern of occurrence to yellow patch and summer patch. Undoubtedly, all of these distinct diseases have been confused due to the similarity of occurrence and symptoms in Kentucky bluegrass. Necrotic ring spot has been recorded on lawns and sports turf of Kentucky bluegrass, roughstalk bluegrass, annual bluegrass, and fine-leaf fescue. To date, necrotic ring spot occurs mostly in the northeastern, north central, mountainous western states, and Pacific northwestern United States.

Symptoms/Signs. This is a root and crown rot, caused by *Ophiosphaerella korrae*, one of the “ectotrophic” root-infecting fungi that destroys the plant’s ability to absorb water, causing it to wilt and die more rapidly than healthy grass. This fungus colonizes roots and crown tissues, growing slowly and initially infecting cortical tissues, and eventually entire roots. Initial symptoms are thin, wilting circular yellow to light-green patches of turf that range in size from a few inches up to a foot or more in diameter. Eventually, patches can expand up to 3 feet (1 m) in diameter, gradually turning brown or straw-color and die **(Figure 7–17)**. Sunken, crater-like patches of this disease appear in spring or late summer in cool, wet weather.

Figure 7–17. Necrotic ring spot disease of Kentucky bluegrass.

Patches may develop a “frog eye” appearance in which diseased turf occurs in circles or arcs, with surviving plants or weeds in the center. Individual plants exhibit brown to black, rotted roots and crowns, with varying degrees of chlorosis, necrosis, and tip die-back of shoots. Necrotic ring spot patches tend to be large (>1 foot, 0.3 m, in diameter), often with the frog eye symptoms, and mostly occur in spring and early fall. Summer patch tends to be smaller (<1 foot, 0.3 m) in diameter and occurs most often during summer-stress periods.

Distinctive leaf lesions are not associated with this disease, but leaves often die from the tip back. Plants at the edge of patches often have a bronze or copper color, while affected greens often have a spotted effect as infected annual bluegrass plants die-out and adjacent bentgrass is unaffected. A dark-brown to black discoloration of lower shoots, stems, and roots is often associated with advanced stages of the disease and affected plants easily pull from soil.

These fungi survive as saprophytic mycelium and sclerotia in soil and as conidia. Sometimes, the sexual stage of the fungus forms, a small black flask-shaped **pseudothecium**. They initiate in moist soil, thrive when temperatures are up to 80 F (27 C) and become more severe in higher temperatures and drought conditions. They are especially found in newly planted turf sites that were recently cleared woodlands. They are also found in compacted soils and areas high in nitrogen during spring and summer. Disease spreads by transporting affected roots, stems, crowns, and soil by maintenance equipment.

Cultural Controls. As with most root diseases, control requires an integrated strategy involving cultural, genetic, and fungicidal use. Utilize watering practices to minimize drought stress and encourage deeper rooting. When disease has severely damaged the root system, it requires light and frequent (e.g., 0.1 inch/day, 25 mm) irrigation, most often during afternoon stress. Reduce soil compaction by aerifying and using lightweight maintenance equipment but do not aerify when the disease is active. Cutting heights can be raised to increase carbohydrate production and improve the chances of turf recovery. Utilize fertility practices to maintain a moderate soil pH of about 5.5 and utilize slow-release nitrogen sources. Using slow-release nitrogen forms consistently reduces disease symptoms in research trials. Differences also occur in susceptibility among Kentucky bluegrass cultivars. Check with your local turf specialist for a recent listing of these. Plant a 75 to 85 percent blend of these and other resistant cultivars with 15 to 25 percent (by weight) of turf-type perennial ryegrass. Avoid herbicide use during hot weather.

Chemical Controls. Preventive applications have shown efficacy if applied before symptoms develop (preventive) and repeated at 21- to 30-day intervals during the summer. A single mid-spring (e.g., April/May) application of one of the DMI fungicides has shown good control through late summer/early autumn. Adequate nitrogen and soil moisture are necessary or these fungicides are less effective.

Pink Patch and Cream Leaf Blight

The causal agent of pink patch and cream leaf blight is *Limonomyces roseipellis* Stalpers & Loerakker.

Occurrence. Pink patch and cream leaf blight cause disease in cool and warm season grasses, being documented in creeping bentgrass, fescues, ryegrasses, bluegrasses and bermudagrass. Infections occur under nearly identical environmental conditions as red thread, and sometimes can occur concurrently with red thread. Pink patch and cream leaf blight occurrence in bermudagrass putting greens occurs in fall, winter and early spring and infections appear to be largely superficial. The disease occurs, like red thread, under relatively cool wet conditions on turf that is slowly growing or semi-dormant. However, abundant mycelium can develop on the lower leaves and cause unsightly pink to gray-white patches. The causal organism is a basidiomycete fungus, and close microscopic examination reveals clamp connections (pink patch); however those isolates associated with cream leaf blight symptoms lack clamp connections. Mycelium of the fungus usually occurs in ‘rhizomorph-like’ aggregates of hyphae, giving a loose ropy appearance when observed microscopically.

Symptoms and Signs. Small roughly circular patches appear in lower foliage of affected grasses **(Figure 7–18)**. Patch coloration can be a reddish to tan color. The disease is slow-moving; rapid spread of the disease upon observation of initial symptoms is rarely observed. Infected leaves appear chlorotic, tan in cool season grasses. In bermudagrass lower leaves are covered in mycelium and the turf may appear a darker green than surrounding unaffected turf. When bermduagrass goes dormant in transition zone environments, the patches have a distinct pink coloration.

Figure 7–18. Cream leaf blight.

Cultural Controls. Fertilize turf adequately to promote even, normal growth. Maintain soil pH in the slightly acid range (pH 6 to 6.5). Prevent drought stress by supplemental irrigation when needed.

Chemical Controls. Fungicides with good activity against basidiomycete fungi are recommended for pink patch control. Many fungicides labeled for red thread will also be labeled for pink patch. Because the infestations are in the turf canopy, spray as you would for any foliar disease and do not incorporate the treatments with irrigation.

Pythium Blight (Cottony Blight, Greasy Spot, Damping-Off, Seedling Blight)

The causal agents of Pythium blight are *Pythium aphanidermatum* (Edson) Fitzpatrick and other *Pythium* species such as *P. myriotylum* Drechs., *P. graminicola* Subrum., P. arrhenomanes Drechs., and *P. ultimum* Trow.

Occurrence. All turfgrasses are susceptible, with the cool season grasses—creeping bentgrass, annual bluegrass, Kentucky bluegrass, and perennial ryegrass—being the most susceptible. Although this disease is frequently observed on bermudagrass putting greens, the disease is less severe when compared with Pythium blight on cool-season turfgrasses. With all cool season grasses, disease can be especially severe on newly established stands **(Figure 7–19)**. In cool season grasses, it is most likely to occur when day and night temperatures exceed 85 and 68°F (29 and 20°C), respectively, when the relative humidity is high, and foliage wetness occurs for more than 10 hours daily for several consecutive days. Pythium blight can be a highly destructive disease. Disease occurrence on bermudagrass greens occurs most commonly in fall, winter and spring and occurs when temperatures are relatively cool but when excessive moisture provides conditions favorable for outbreaks **(Figure 7–20)**.

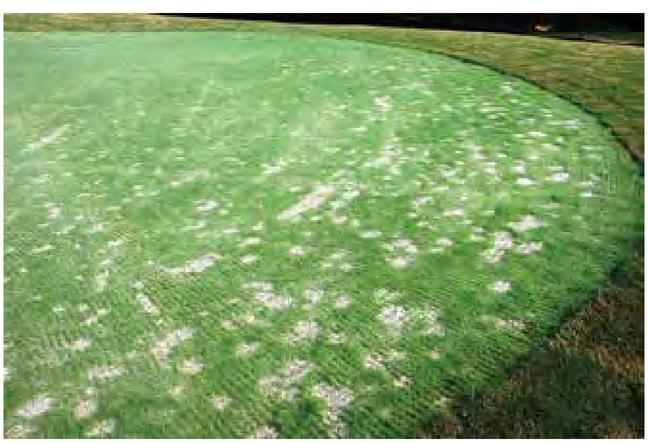


Figure 7–19. Pythium blight of a newly seeded creeping bentgrass green.

Figure 7–20. Pythium blight streaking of bermudagrass.

Pythium species are not true fungi but fungus-like water molds classified in the Stramenopiles; thus, they require sufficient surface moisture for development. All soils contain *Pythium* species unless the soil has recently been fumigated. *Pythium* species causing Pythium blight are facultative parasites, meaning they are saprophytes in thatch or soil and quickly become pathogenic when favorable conditions develop. The organisms produce thick-walled sexual spores that survive for long periods in the soil. The germination and "grow-in" period of newly established bentgrass greens or overseeded cool season grasses are ideal for disease development since fall temperatures can still be quite warm and the turf is being irrigated more frequently than normal. Extended periods of warm, foggy mornings also favor this disease, potentially destroying large areas in a short period of time on cool season grass hosts. On creeping bentgrass, conditions may be favorable for relatively long periods of time during summer, depending on location. Greens situated in low, protected areas with poor sunlight penetration and air movement are most at risk. Bentgrass is more susceptible when saline soil conditions (and presumably high-soluble salts from fertilizers) exist.

Symptoms/Signs. Small, distinct reddish-brown patches of grass, usually about one to six inches (2.5 to 15 cm) in diameter, first appear dark and water-soaked (slimy), but later shrivel and turn straw-colored as humidity and/or temperature decrease. In some cases, after heavy rains and prolonged high relative humidity, the first sign of disease is a white, cottony mycelial growth. Turf grown in shaded, low lying areas adjacent to water where air circulation is poor and humidity highest is likely to become diseased first. Water-soaked, blackened leaves often feel greasy or slimy. If conditions become less humid during the day, bleached lesions can be observed on partially damaged leaves, especially on bermudagrass and tall fescue, but these lesions have no distinct border, which easily distinguishes them from dollar spot. Pythium blight can initially be confused with both copper spot and Microdochium patch on creeping bentgrass in the fall. Patches may spread

Figure 7–21. Typical streaking of Pythium blight of overseeded ryegrass.

quickly in a "streak" pattern, usually following water drainage movement (**Figure 7–21**). White cottony mycelium may be observed in early morning when dew is present, but this disease sign is not always apparent. Pythium fungi is spread by direct mycelial growth as well as through a spore or spore-containing sack called **sporangia** and small swimming spores released from sporangia called **zoospores.** These fungi also produce thick-walled resting spores called **oospore**s that may survive in soil and thatch for extended periods. Disease may spread rapidly when sporangia, zoospores, oospores, or infected plant parts are moved by water along drainage patterns, or by mowers or traffic. Often, two or more *Pythium* species may simultaneously occur, requiring growing the fungus on special laboratory media and microscopically examining the sporangia and oospores for specific identification. Being water molds, *Pythium* spores can survive in ponds used for irrigation, which makes control difficult as the turf is re-inoculated with each watering. Although less common on bermudagrass, lower mowing heights and ultradwarf cultivars have seemingly led to an increase of Pythium on bermudagrass golf greens.

Cultural Controls. Improve drainage, air circulation, and light penetration by removing shrubs, trees, and limbs and possibly add fans in pockets of poor air movement. Reduce soil and leaf moisture, as moisture control is a key to *Pythium* management; therefore, early morning removal of dew and guttation water by poling or dragging a hose and utilization of early morning irrigation is beneficial. Plant fungicide-treated seed at the recommended amount, avoiding very high seeding rates. Avoid excessive use of nitrogen prior to warm weather. Minimize equipment or foot traffic across wet infected turf. Wash equipment before entering unaffected areas and encourage golfers to clean their shoes between rounds. Delay overseeding in late summer/early fall until the weather turns cool and dry. Alleviate soil compaction as this reduces turfgrass rooting, which then requires turf managers to irrigate lightly and frequently. Maintain a slightly acidic soil pH, using properly balanced fertilization and avoiding calcium deficiency. If growing in bermudagrass greens from sprigs, strive to complete the establishment during warm summer months, as Pythium can infect in fall if managers are still fertilizing and irrigating to 'push' the sprigs to cover.

Chemical Controls. Preventive, short-term (e.g., 5 to 10 days) control is provided by several contact fungicides. Apply during hot (>80°F, 27°C), humid (≥85 percent) weather when night temperatures exceed 65°F (18°C). Be careful using chloroneb and ethazole, as these are potentially phytotoxic to the turf. Preventive control is provided by systemic fungicides, and tends to provide longer residual (14- to 21-day) control. Whenever possible, plant fungicide treated seed. Otherwise, apply a fungicide immediately after planting, and reapply approximately 7 to 14 days later (after the seed has germinated). Alternate between compounds to avoid development of fungicide-resistant strains of *Pythium*.

Due to the potential for rapid development of this disease and loss of large areas, turf managers growing cool season grasses should consider a preventive fungicide program when hot, humid (e.g., foggy) weather is forecasted. Alternating between contact and preventive fungicides should also help reduce the risk of resistance problems. Use curative rates only when absolutely necessary to prevent resistance build up.

Pythium Root Rot/Pythium Root Dysfunction

The causal agents of *Pythium* root rot are Pythium spp. including *P. aristosporum* Vanterpool, *P. aphanidermatum* (Edson) Fitzpatrick, *P. arrhenomanes* Drechs., *P. graminicola* Subrum., *P. irregulare*, *P. myriotylum* Drechs., and *P. vanterpooli* Kouyeas & Kouyeas. In addition to these Pythium species, Root dysfunction also involves *P. hyphae, P. volutum* Vanterpool & Truscott, and *P. torulosum* Coker & F. Patterson with *P. volutum* appearing most often for root dysfunction.

Occurrence. These *Pythium* species are capable of infecting roots and crowns of cool-season grasses such as bentgrass and annual bluegrass year-round, causing stunting and yellowing **(Figure 7–21)**. The newer ultradwarf bermudagrasses also are susceptible. *Pythium* root rot is still poorly understood for the different turfgrasses and different Pythium species. Symptoms may appear at any time of the year, but they will usually be associated with wet conditions—either from too much precipitation or too much irrigation. Poor drainage and soil compaction conditions will compound this problem and encourage algae development in areas where disease has weakened or killed the grass. Root damage from nematodes or *Gaeumannomyces spp*. also may contribute to this disease. It is thought most of the plant damage from the *Pythium spp*. is in the fall or spring when soil temperatures are between 50 and 75 F (10 and 24 C), yet symptoms are not expressed until the heat and drought stress of summer.

Symptoms/Signs. Symptoms are typically non-specific declines in turf quality. However, circular patches in rings, arcs, or solid patches of a few inches up to about three-feet (0.9 m) most often occur in summer under heat and drought stress on creeping bentgrass. However, drought stricken greens can also show symptoms in fall and spring. Symptoms also are more prevalent on low nitrogen fed (annually at <4 lbs N/1,000 sq.ft., <20 g N/m^2) greens, especially sand-based rootzones. Small or large turf areas will become a general yellow, orange, or brown color and gradually begin to thin, often resembling drought stress. However, the areas do not normally thin to bare soil. Symptoms may disappear following fertilization or irrigation, but often reappear when these again become limited. Commonly, turf in aerification holes remains healthiest, indicating adequate soil oxygen is necessary to minimize the disease.

Pythium root dysfunction describes root tissue that does not function properly but has no apparent rotting. Roots appear thin with few root hairs and have a general tan discoloration, but are not black and rotted as they are with other root rotting diseases such as necrotic ring spot or bermudagrass decline. Infected roots also lack or have a loose cortical structure and have bulbous (swollen) root tips. Infected roots evidently have limited water and nutrient uptake capability, thus, causing drought- or nutrient-stressed symptoms leading to eventual collapsing of the plant. Foliar mycelium is absent, often causing confusion with melting out disease, take-all patch, or, possibly, anthracnose. This disease cannot be diagnosed from field symptoms alone. Microscopic examination of affected roots and crowns is required to determine if *Pythium* spp. oospores and hyphae are associated with the symptoms. If affected turf is left untreated, death may occur in 2 to 3 weeks. Interestingly, symptoms often appear on higher elevations first, presumably due to the root dysfunction, which limits plant water uptake, whereas, root rot develops in very wet or shady areas and often appears in more irregular patterns rather than distinct circles.

Figure 7–22. Pythium root rot of creeping bentgrass.

Cultural Controls. The first line of defense against any Pythium disease is reducing management stress on the grass as any stress on the grass tends to encourage the disease. Improve drainage, provide sufficient nitrogen, aerate, and reduce irrigation as *Pythium* spp. require very wet situations for disease development. Aerify in spring to improve surface drying, provide soil oxygen, and to promote rooting. When symptoms are present, irrigate only as needed to prevent permanent wilt and compensate for the damaged root system by hand watering. To prevent the disease, avoid frequent shallow irrigations that constantly keep the turf wet. Reduce nematode populations, if justified by a nematode assay. Increase mowing height to ¼-inch (6.4 mm) or higher to reduce stress and promote root growth. Mow affected greens with walking mowers, skipping clean-up laps and possibly mowing on an alternate-day basis. Wash mowers when used between infected and uninfected turf areas to minimize the spread of disease spores. Aerify and topdress to stimulate new root growth. Check for soluble salt levels in the upper soil and thatch, especially in the first year of turf establishment when excessive fertilizer is used for grow-in.

Chemical Controls. Currently, a rotational treatment program appears to work best. Initially, apply pyraclostrobin or cyazofamid and water-in with 0.125-inch (0.3 cm) of irrigation or applied in 5 to 10 gallons of water per 1,000 square feet (20 to 40 L/100 m^2) which suppresses the disease for approximately 28 days. At least two applications will probably be required. Treat preventively in fall and spring when soil temperatures are between 50 and 75 F (10 and 24°C) and continue at three-week intervals. Also, aerify in conjunction with fungicide use to increase soil oxygen while reducing soil moisture. If applied curatively, application intervals should be 14 to 28 days. This is due to inconsistent disease control. Alternate between compounds to avoid development of fungicide-resistant strains of Pythium. Note that, except for pyraclostrobin, these fungicides are specific for *Pythium* spp. only. Treat preventively as trying to "cure" bentgrass of this disease during summer heat and obtaining turf recovery requires weeks or even months.

Red Thread

The causal agent of red thread is *Laetisaria fuciformis* (McAlphine) Burdsall (formerly, *Corticium fuciformis*).

Occurrence. Red thread can be a destructive disease on slow-growing turf. Perennial ryegrasses and fine leaf fescues are notably susceptible, especially in nitrogen-deficient turf. The disease is primarily a problem during winter or early spring months in cooler (60 to 70°F, 16 to 21°C), humid environments. The disease is fairly common in humid winter months in the upper elevation or northern United States regions.

Symptoms/Signs. Red thread appears as irregular-shaped patches about four to six inches (10 to 15 cm) in diameter that are bleached-tan to reddish in color (resembling dollar spot). From a distance the disease often appears similar to dollar spot and the turf often develops a ragged straw-brown appearance as if it had been mowed with a dull mower blade or may be suffering from drought stress **(Figure 7–23)**. Decline of leaves is rapid in affected areas. Bright coral-pink to red antler-like "threads" or sclerotia of the fungi are easily seen with the naked eye protruding from dying leaf tips that may have a split, torn appearance. Threads are gelatinous in the early morning dew, but later dry and become thin and brittle. Threads occur most often during the cool, drizzly days of spring but can also occur throughout summer in higher elevations. The fungi overseasons on leaves and thatch as pink or red, gelatinous crusts of fungal threads or sclerotia. Red thread, like dollar spot, may increase with the current trend of using lower nitrogen rates.

Cultural Controls. Increase nitrogen fertility in the spring and fall when possible. This increases plant vigor which allows the plant to outgrow disease damage. Collect and destroy clippings to minimize spread of sclerotia. Potassium should also be applied with nitrogen. Water deeply but infrequently to prevent prolonged leaf wetness. Avoid watering in late afternoon and evening. Improve air circulation and reduce humidity by pruning trees and removing underbrush. Collect and dispose of clippings from infected areas and wash equipment before entering unaffected areas. Encourage golfers to clean their shoes between rounds.

Figure 7–23. Red thread disease of fine fescue.

Chemical Controls. Fall and winter treatments help prevent spring disease development.

Spring Dead Spot

The causal agents of spring dead spot are *Ophiosphaerella* (=*Leptosphaeria*) *korrae* J. Walker & A. M. Sm.; *Ophiosphaerella* (=*Leptosphaeria*) *narmari* J. Walker & A. M. Sm.; and/or *Ophiosphaerella herpotricha* (Fr.:Fr.) J. Walker.

Occurrence. Spring dead spot is the most serious disease of bermudagrass in the United States, where it undergoes complete dormancy in winter. It also occurs sporadically in zoysiagrass. The highest-maintained turf is generally most susceptible. Hybrid bermudagrasses that tend to produce excessive thatch are most prone to disease attack while cold hardy cultivars such as "Midiron," "Midfield," "Midlawn," "Patriot," and "Vamont" are more resistant. Resistant seeded varieties include "Yukon," "Guymon," and "Riviera." Late-summer nitrogen applications, abundant fall moisture, and low winter temperatures also predispose bermudagrass to spring dead spot development. Spots generally begin to appear after the turf is at least three to five years old however outbreaks have occurred on ultradwarf bermudagrasses within a year of establishment. Infected areas recover slowly and weeds frequently invade these areas during summer. Presumably, fungi causing spring dead spot infect in late summer and fall, and weaken the turf without visible symptoms. Parameters affecting winter hardiness and spring green-up also influence spring dead spot symptom development and turf recovery. All of the reported causal agents are slow-growing root ectotrophic fungi, similar to organisms causing take-all patch, necrotic ringspot, and summer patch in bluegrass and bentgrass. In fact, *Ophiosphaerella korrae* is known to cause both necrotic ringspot and spring dead spot. The dark-brown, black mycelium from ectotrophic-growing fungi directly penetrate roots, stolons, and rhizomes, filling vascular tissue with a brown substrate and dark, spindle-shaped sclerotia. *Gaeumannomyces graminis* var. *graminis* has been associated with spring dead spot symptoms as well, however more recent research with molecular tools and results of successful field inoculations suggest *Ophiosphaerella korrae, O. herpotricha*, and *O. narmari* are the agents demonstrated to cause SDS symptoms in the field.

Figure 7–24. Spring dead spot disease of bermudagrass.

Symptoms/Signs. Dead, straw-colored spots two to three feet (0.3 to 0.6 m) in diameter appear in spring as affected bermudagrass begins to "green-up" and is often confused with winter kill **(Figure 7–24)**. Spring dead spot patches are sunken, generally well-defined, and circular, in contrast to more diffuse dead areas caused by direct low-temperature injury. Roots and stolons of affected bermudagrass are severely rotted. Patches may enlarge over three to four years, develop into rings, and then disappear. Affected spots may also remain greener in late fall going into winter. Patches in overseeded affected bermudagrass may resemble brown patch in spring. Patches are usually perennial in nature, often recurring in the same location over several years. After a year or two from their first occurrence, patches develop into doughnut or frog eye patterns with relatively non-symptomatic bermudagrass in the centers. After several years, spring dead spot may entirely disappear from a site although this phenomenon is not predictable.

Rhizomes and stolons from adjacent bermudagrass slowly fill-in dead spots. This slow process allows summer annual weeds such as crabgrass to easily become established. Use of certain pre-emergence herbicides for summer annual grassy weed control may affect recovery from spring dead spot. Herbicides that inhibit cell division (the dinitroanaline group, as well as dithiopyr and indaziflam) may inhibit new stolons from colonizing patches and slow recovery. Oxadiazon, however, does not inhibit rooting and might be a better choice of a pre-emergence herbicide in SDS areas. Managers may also opt to use post-emergence techniques for weed control in areas prone to severe spring dead spot.

Cultural Controls. Spring dead spot is a disease of intensively managed mature bermudagrass. Use acidifying fertilizers such as ammonium nitrate and ammonium sulfate to help speed recovery and reduce disease severity. However, avoid excessive nitrogen fertilization and do not apply nitrogen in the fall. Raise the mowing height and ensure adequate potassium levels in the fall. Reduce thatch by aerifying and pulverizing soil cores. Bermudagrass cultivars with varying resistance to SDS include Ashmore, Midiron, Midlawn, Patriot, Riviera, TifSport, Yukon, and U-3. Those with less SDS resistance include Arizona common, Mohawk, NuMex Sahara, Panama, Princess-77, Southern Star, and Transcontinental.

Chemical Controls. Some newer fungicides, including tebuconazole, fluxapyroxad + pyraclostrobin, penthiopyrad, difenoconazole + azoxystrobin, and propiconazole + azoxystrobin have provided good control of SDS in recent trials. Further research is needed but results have been encouraging since fenarimol has been withdrawn from the market, and had been the most efficacious fungicide for SDS control. Applications should be made generally in early to mid-September and a second application about a month later. Sprays can be applied in 2 gal/1000 ft^2 but should be immediately incorporated with additional irrigation to move the fungicides to the rootzone. These fungicides can also be applied as drenches (5 gallons water/1,000 ft^2, 0.2 L/m^2) or at lower water volumes and incorporated with 0.25-inch (0.64 cm). Several years of consecutive use may be required on fairway height bermudagrass for complete control as the patches are typically reduced in size following each yearly fungicide use.

Summer Patch

The causal agent of summer patch is *Magnaporthe poae* Landschoot and Jackson.

Occurrence. Summer patch is primarily a soil-borne disease of bluegrass caused by a slow-growing ectotrophic root-infecting fungus which spreads to adjacent plants by growing along roots. Being a soil-borne fungus, early disease diagnosis can be difficult and often goes undetected until plants begin to stress. It is easily confused with necrotic ring spot *(Ophiosphaerella korrae)*, as their hosts and symptoms are very similar. It is a major disease of annual bluegrass, but also affects Kentucky bluegrass, fine fescues, and creeping bentgrass. Parameters increasing stress to these grasses also influence the development of summer patch. Summer patch primarily occurs in the northeastern and mid-western United States, and also in California and the Pacific Northwest. Colonization of new turfgrass roots, crowns, and rhizomes begin in spring when soil temperatures reach 65 to 70 F (18 to 21° C). Initially, plant damage is not noticeable as new root growth replaces diseased roots. However, as temperatures rise to 82 to 86 F (28 to 30°C), cool-season root growth slows while the pathogen's growth increases. Outbreaks occur from mid-June through September during high temperature stress, especially when nighttime temperatures remain above 70°F (21°C) and during heavy rainfall. Disease severity is directly related to infection severity and turfgrass vigor. Sunny areas and those adjacent to heat-stress areas such as sidewalks are most susceptible. Interestingly, mature turf is infected more than young immature stands. It can overwinter in infected host tissue, causing annual outbreak of disease.

Figure 7–25. Summer patch disease of Kentucky bluegrass.

Symptoms/Signs. Patches of affected turf are circular, semicircular, or serpentine in shape ranging in size from a few inches up to about a foot (0.3 m) in diameter. ***(Figure 7–25)***. Patches are generally smaller than those caused by necrotic ring spot. Initially, plants are wilted, gray-green in color, and may develop heat-stress banding (white bands across individual leaf blades). These affected plants wilt, die, and become matted, tan, or brown, leaving patterns of patches, rings, and arcs of symptomatic turf. Tufts of green grass or weeds may remain in the center, leaving a frog eye pattern. On golf greens with high populations of annual bluegrass, patches are initially small 2 to 3 inch (5 to 6.6 cm) reddish-brown patches. As stress increases, patches may coalesce. Leaf lesions are not found with summer patch. On turf roots, dark runner hyphae is visible and may infect crowns and rhizomes. Roots and crowns are rotted and are brown to black in color, similar to necrotic ring spot. Due to the lack of leaf lesions, laboratory identification is necessary as summer patch resembles symptoms of many other diseases.

Cultural Controls. Management of cultural practices which reduce plant stress is necessary in any summer patch control program. Once summer patch is established, it often reappears in the same area in successive years since it is a root disease. Utilize cultural practices to improve root systems, such as core aerification, proper watering (adequate moisture, avoiding even transient drought stress), and thatch management to eliminate plant stress. Core aerify prior to infection periods but not during an active disease outbreak. Avoid heavy spring and summer nitrogen fertilization. Maintain a soil pH of 6.3 or less, thus, avoid indiscriminant lime application. Use ammonium sulfate or sulfur-coated urea to help keep soil pH acidic which tends to help retard the disease. Raising cutting heights prior to and during anticipated periods of heat stress can be beneficial. Consider conversion of *Poa annua*-dependent greens to bentgrass, and other areas to perennial ryegrass or tall fescue which are highly resistant.

Chemical Controls. Preventive fungicide applications have been effective. Apply fungicides with adequate water to move the active ingredients to the rootzone, which should have moderate moisture in the soil when the fungicides are applied. A key preventive control strategy is to treat before the pathogen colonizes and suppresses root growth. Since infections occur well in advance of symptom expression, apply preventively in spring when soil temperatures at a depth of two inches (5 cm) reach 62°F (16.7°C), before symptoms develop, and repeat two to three times on a 21- to 28-day interval during summer.

Take-All Patch (or Ophiobolus Patch)

The causal agent of take-all patch is *Gaeumannomyces graminis* (Sacc.) Arx & Olivier var. *avenae* (E. M. Turner) Dennis.

Occurrence. Take-all patch is a root disease of bentgrass, and to a lesser extent annual bluegrass, ryegrass, and fescue. The disease occurs most frequently in cooler (40 to 70°F, 4.4 to 21°C) climates and in soils of high pH and excessive moisture. It appears mostly from late spring through summer months and survives as a saprophyte in grass debris and living plants. It may also occur in late fall and winter. Take-all patch is a problem in the northeastern, north central, and northwestern states of the United States, Europe, Japan, and Australia. It has also been a problem in the mid-Atlantic states and the mountains of North Carolina. Its occurrence elsewhere has not been officially confirmed or reported, although the disease is suspected to occur at times under special conditions, such as new (<8 years old) golf courses or recently fumigated courses with moderate (pH>6.5) soil pH levels, recently limed sandy soils with low organic matter and low fertility, and conditions of soil compaction and high moisture during infection periods. As soil organisms recover from the fumigation process, disease severity declines, presumably due to the antagonistic effects of these soil organisms. During this time, turf rarely is killed but takes on a yellow, thin appearance. Plants grown in soils with low levels of plant-available manganese are especially susceptible to infection. Nitrate fertilizers also encourage the disease by raising soil pH.

Symptoms/Signs. Roots, crowns, and stems are affected with no distinctive leaf spots or sheath lesions. Dead, yellow or reddish-brown to orange-tan, sunken circular patches ranging from several inches initially up to three or four feet (0.9 to 1.2 m) in diameter develop in late spring when soils tend to be cool and wet and may increase in size slowly over the summer months **(Figure 7–26)**. Symptoms may fade with warmer soil temperatures and adequate moisture but reappear during drought during summer and fall. These may persist several years and increase in size each year. The fungus is active around the margins

Figure 7–26. Take-all patch disease of bentgrass.

of patches and causes dark-brown to gray to black rotted tissue of affected roots and crowns. Dying bentgrass at advancing margins has a purplish tinge, and freshly infected plants may become bronze in color. Black strands of mycelium are visible under the base of leaf sheaths or on the surface of roots, rhizomes, and stolons. Black flask-shaped **perithecia** (fruiting bodies) may be visible with a hand lens on dead tissue. These contain septate, elongated ascospores. Weeds such as annual bluegrass, fescue, crabgrass, and various broadleaf weeds commonly invade the centers of patches. The fungus overseasons as mycelium in plant debris, thatch, and on perennial plant parts.

Cultural Controls. Since take-all patch is favored by alkaline soils, fertilize with acidifying fertilizers such as ammonium nitrate and ammonium sulfate or use other acidifying compounds such as elemental sulfur at three to five pounds per 1,000 square feet (15 to 25 g/m^2). Split the total yearly amount of acidifying compound into several applications so as to maintain a soil pH of around 5.5. Minor elements such as manganese, magnesium, and zinc should also be tested and soil applied if deficient. Soil (granular) applications of these nutrients are typically more effective than foliar sprays for take-all suppression. Either spring or fall applications of two pounds of manganese per acre (5 kg/100 m^2) in heavy soils and six to eight pounds per acre (30 to 40 kg/100 m^2) in sandy soils have proven beneficial. Patch suppression has followed use of manganese sulfate, ammonium chloride, and ammonium sulfate. Annual applications are usually needed. Acidic soils favor more manganese availability, thus, better disease suppression. Control thatch accumulation and promote rooting by aerifying, topdressing, and verticutting and deep, infrequent irrigation. In situations with chronic infections, replant affected areas with less-susceptible grasses, blends, or mixtures of non-host grasses.

Chemical Controls. Preventive control is best and has been effective when applied in late fall or early winter. If take-all patch was prevalent the previous year, mid-spring applications when soil temperatures are between 40 and 60 F (4.4 and 15 C) may be beneficial but generally are best when applied in fall. Some curative control may be provided by azoxystrobin or thiophanatemethyl. At least 2 gallons per 1,000 sq.ft. (8 L/100 m^2) carrier volume should be used to help fungicides reach root tissue with 4 to 5 gallons 16 to 20 L/100 m^2) being more effective. Applications should be followed by 0.25-inch (6.4 cm) irrigation.

Algae

The causal agents of algal infestations are the cyanobacteria *Nostoc* and *Oscillatoria*, but also include the green and brown algae genera *Chlamydomonas, Hantzschia* spp., and others. Algae contain complex cells with nuclei, mitochondria, chloroplasts, an endoplasmic reticulum, and other organelles. Algae are considered plants since they contain chlorophyll. However, they are primitive plants since they lack roots, stems, and leaves; thus, must be in aquatic or near aquatic environments to thrive.

In addition to true green algae, primitive bacteria called **cyanobacteria**, also called the blue-green algae, infest turf stands with dark, slimy colonies. Cyanobacteria (*Oscillatoria, Phormidium*, *Lynbya, Nostoc*, and *Anacystis* spp.) contain none of the complex eukaryotic cells as algae and are more closely related to other bacteria such as E. coli and *Xanthomonas. Oscillatoria* is a small, primitive, photosynthetic microbe that produces dark crusts and slime layers on putting green soils and foliage. It produces energy by photosynthesis at low light intensities; thus, it invades closely mowed, shaded greens. Cyanobacteria can grow rapidly in water or wet soils with sufficient light, nutrients, and temperature and can move by sliding on their own produced mucilaginous (slimy) materials. Cyanobacteria are filamentous, producing **trichomes**, which are long chains of cells making up the black slime coating often seen on greens. They typically move to plants from thatch at night or on shade greens and retract back to cooler thatch during hot temperatures. They also produce toxins that enter plants through mowing injury. Cyanobacteria are known to be the most ancient organism with photosynthetic capability and have the ability to synthesize and secrete large quantities of polysaccharides from cells. The polysaccharides provide a protective coating allowing the cyanobacteria to withstand moisture and heat stresses. Some cyanobacteria can survive deserts, hot springs, arctic conditions, and other environmental extremes. In addition, an antibiotic produced by *Oscillatoria* attacks photosystem II in plant cells. Due to lack of oxygen and drainage under cyanobacteria crusts, the plant may yellow and thin.

Occurrence. Algae are most noticeable on close-cut, poorly drained, low lying, and shaded areas on tees and putting greens. Soil layering, poor surface drainage, compaction, poor disease control, and other stresses can predispose greens and other highly managed sites to algae infestations. As turf thins from stress, algae typically invades. Although erroneously thought to cause algae on golf courses, algae species found in irrigation ponds, lakes, and streams are different and do not appear to contribute to this problem.

Figure 7–27. Algae infestation in weakened creeping bentgrass.

Symptoms/Signs. Symptoms begin slowly, often at the edges of greens. Turf areas in partially shaded, damp locations become weak and begin to thin, usually starting in early summer. Algae begin to predominate in these areas. These algae are commonly green or brown in color and can be sheet-like, leaf-like, or cushion-like in appearance. Initially, these spots may be difficult to see, but as they enlarge, the turf begins to yellow and thin due to a lack of oxygen and drainage under the crust. Algae will develop on turf areas where grass is less dense than normal and surface soil moisture is high resulting in a dark-color "scum" or "mat" forming on the soil surface **(Figure 7–27)**. Frequently, on bentgrass greens affected by brown patch disease, algae invade the thinned areas. If left untreated, these areas will continue to "thin-out" and expand in size until a large mat of algae forms, preventing turfgrass growth and penetration of irrigation water. Black algal scum development often occurs in summer following periods of rainy, overcast, warm days. Turf thinning from summer DMI fungicide use also may trigger algae invasion. Commonly in bentgrass greens cultured in heat stress summer environments, a 'yellow spot' symptom occurs in mid to late summer. Presumably this symptom is a result of algal toxins, and can be alleviated with the fungicides mancozeb or chlorothalonil. Other fungicides (DMIs and strobilurins) may increase the yellow spot symptoms although turf is rarely thinned.

Cultural Controls. Due to their rapid development, preventive management is the best approach. Prevention begins by correcting those conditions that predispose the turf to algal growth. This involves reducing surface moisture by improving air circulation and light exposure by removing adjacent underbrush and selectively removing trees. Improve drainage and reduce irrigation frequency and amount. Reduce freely available nitrogen and phosphorus. Avoid organic-based products if excessive phosphorus is present in them. Reduce irrigation and improve the growth of the turfgrass where algae is present so the turf can form a dense area. If the area occupied by algae is large, spiking, verticutting, and topdressing will help break-up and dry the mat. Applying ground limestone or hydrated lime will help desiccate algae. Diluted bleach, copper sulfate, and chloride also may help reduce algae growth. However, these should not be used during hot temperatures, as they may cause varying levels of turf discoloration. Be judicious in the use of copper-containing fungicides to avoid a build-up of copper and potential copper toxicity in soils. This would be more of a risk in sandy putting green mixes with low organic matter. Increase the mowing height, as low mowing aggravates the problem.

Chemical Controls. Some fungicides help to prevent development of algae and prevent its spread when a mat has already formed. They need periodic applications (e.g., every 7 to 14 days) and should be used **prior** to algae formation and continually as long as conditions remain favorable for occurrence. Control diseases, such as brown patch, to prevent thinning of the turf canopy. Some curative control is provided by hydrated lime or mancozeb + copper hydroxide. Being a desiccant, hydrated lime typically works quickly while the mancozeb + copper hydroxide takes several days. Once the algae is controlled, switch to a preventive program. In areas with high disease pressure and low turf recuperative potential, such as the transition zone of the United States, preventive disease control approaches are necessary in the summertime.

Moss

The causal agents of moss include *Selagimella, Byrum, Amblystegium, Brachythecium, Ceratodon, Hypnum, Polytrichum* spp., plus others. *Amblystegium trichopodium* and *Brachythecium* spp. are usually found in higher-cut turf and are often referred to as "yard moss." *Bryum argetum*, referred to as silver thread moss, has a silvery appearance and is found more frequently on greens **(Figure 7–28)**. Unlike most mosses, silver thread moss grows well in both wet, shady environments and hot, dry sites in full sun.

Figure 7–28. Silver thread moss on a golf green.

Moss are threadlike, branched, primitive (400 million years old) plant forms encompassing many species. They spread by spores disseminated by wind and water movement. Most moss species are **bryophytes**, meaning they do not form true roots, but form rhizoids which are filamentous structures and do not provide anchoring. Consequently, they can survive on rocks, concrete, and masonry walls. Bryophytes also are nonvascular plants requiring constant contact with water to prevent drying. Others are able to absorb water through their rhizoids. Mosses are able to photosynthesize and fix nitrogen. Moss are nonparasitic to the turf and spread by plant fragments (mainly) and less so as spores. They can also survive long periods of desiccation.

Occurrence. Moss is most noticeable on close-cut areas such as tees and putting greens that drain poorly (thus remaining wet) and are heavily shaded. However, moss can rapidly fill a void if thin turf develops, whether grown in full sun or shade. Moss can survive weather extremes in a dormant state or by living symbiotically with blue-green algae. Algae, therefore, can be a precursor to moss encroachment and should be discouraged to prevent moss colonization. Silver thread moss occurs first in weak turf areas such as ridges and mounds where grass is thin from scalping, drought or nematode infestations. It is favored by acidic, infertile soils with thatch. It typically forms in summer following periods of rain or overcast, warm days. It is encouraged by (1) extremely low mowing heights, (2) minimal nitrogen fertilization, (3) increased use of sand growth medium, (4) intense topdressing with finer-textured sands that slow drainage, and (5) loss of mercury-based fungicides. Moss appears sensitive to metal-contaminated soils, with the heavy metals, especially mercury, being most toxic. These metals participate in the destruction of chlorophyll molecules in moss, which is why many copper-based products are currently being used against it.

Symptoms/Signs. Turf areas in partially shaded, damp locations become weak and begin to thin. Moss begins to predominate in these areas. Moss forms a tangled, thick, green mat occurring in patches over the soil surface. Moss will develop on turf areas where grass is less dense than normal and surface soil moisture is high. Acidic, infertile soils with excessive thatch also favor moss development. If left untreated, these areas will continue to "thin-out" and expand in size until a large mat forms preventing growth of the grass and penetration of irrigation water. Moss mats typically develop in summer following periods of rainy, overcast, warm days.

Cultural Controls. Control involves a long-term, persistent program combining cultural and chemical control methods given the fact that healthy turf is the only means to prevent and cure moss. Control begins by correcting those conditions that predispose turf to moss growth. This involves reducing surface moisture by improving air circulation and light exposure by removing adjacent underbrush and selectively removing trees. Improve surface and subsurface drainage and reduce irrigation frequency and amount. Reduce freely available nitrogen at the site. Reduce irrigation and improve turfgrass growth where moss is present so the turf can form a dense area. If the area occupied by moss is large, spiking, verticutting, and topdressing will help to break up and dry the mat. Moss turning orange-brown or golden brown in color indicates positive desiccation is occurring. However, mosses are adapted to survive periods of desiccation, so simple drying of the moss will not cause it to die.

Several trends in fertility and moss development have been noted. For example, calcium-rich soil may encourage certain moss species while moss tends to be discouraged in potassium-adequate soils. Spike or rake the dehydrated moss layer to remove any remaining impervious layer. Products controlling moss that can be phytotoxic to turf include hydrogen peroxide, copper sulfate, copper soaps, and zinc sulfate. Baking soda applied lightly at six ounces per gallon of water (40 g/L) also helps desiccate moss.

Chemical Controls. Chemical control is erratic and often unsuccessful, especially if agronomic practices are not corrected that favor moss growth and development. Ammonium sulfate at 1/10 to 1/8 pounds nitrogen per 1,000 square feet (0.5 to 6.1 g N/100 m^2) applied weekly is thought to help desiccate moss and encourage competitive turf growth. Applying ground limestone (75 to 100 lbs/1,000 sq.ft., 368 to 491 kg/100 m^2) or hydrated lime (2 to 3 lbs/1,000 sq.ft. in 3 gallons of water, 9.8 to 15 kg/100 m^2 in 1,220 liters) will help desiccate the moss and raise the soil pH level that favors competitive turf growth. Diluted bleach and dishwashing detergent at four ounces per gallon of water (31 ml/L) applied as a drench; ferrous sulfate at four to seven ounces per 1,000 square feet (13 to 22 L/ha); granular iron sulfate at up to three pounds per 1,000 square feet (15 kg/100 m^2); or ferrous ammonium sulfate at 10 ounces per 1,000 square feet (31 kg/100 m^2) also may help reduce moss growth. Five to seven treatments applied at two-week intervals are often necessary. However, these should not be used on greens during hot temperatures, as they may cause varying levels of turf discoloration. Applications should be performed on sunny days when temperatures are between 55 and 80°F (13 and 27°C). Iron-containing products should be used if a copper-containing product is also used.

Chlorothalonil applied for three consecutive weeks also has suppressed moss. This works best when air temperatures at the time of application are >80°F (27°C), preferably >85°F (29°C). In cooler weather, copper hydroxide alone (e.g., Kocide 2000) or copper hydroxide combined with mancozeb (e.g., Junction) at 0.1 to 0.15 pounds copper per 1,000 square feet (0.1 to 0.17 kg Cu/ha) can be used every two weeks for a total of five to seven applications. Due to the potential of copper buildup, limit applications to a total of one pound copper per 1,000 square feet (1.1 kg Cu/ha) yearly. Iron chlorosis may occur with copper use;

therefore, apply iron at 0.05 pounds iron per 1,000 square feet (0.06 kg Fe/ha). Products containing potassium salts of fatty acids (e.g., DeMoss, HO_2) applied weekly at two to three ounces per 1,000 square feet (6.4 to 9.5 L/ha), or No-Mas (22 percent fatty acid) at 0.8 gallons per 1,000 square feet (3.2 L/100 m^2) may be used to control moss in turfgrasses. These should be applied in high rates of water, ≥ 6 gallons of water per 1,000 square feet (24 L/100 m^2). Two applications, two weeks apart, are typically needed. They control moss through a contact mode of action but should be carefully used. All label information should be closely followed. Again, if iron chlorosis (turf yellowing) occurs, alternate the fatty acid applications with 0.05 pounds iron per 1,000 square feet (0.06 kg Fe/ha). Tank-mixing iron with fatty acids often has iron precipitation, clogging spray nozzles. High soil or spray water pH may reduce control.

Most recently, QuickSilver 1.9L (carfentrazone) has been used to help desiccate silvery thread moss. On greens, use 0.098 lb ai/A (~6.6 oz/A) to control silvery thread moss and apply as often as every 2 weeks when temperatures are ≤ 85°F. Annual bluegrass can be damaged at rates greater than 2.0 oz/A. Use NIS at 0.25% (v/v). Do not apply if bensulide has been applied within the previous 75 days.

Localized Dry Spots

At least one causal agent of localized dry spots are Basidiomycete fungi, probably *Lycoperdon* spp. There may be other reasons for development of localized dry spots not due to fungi such as coating of sand particles by humic substances, initial poor mixing of the greens mix, buried rocks and other debris, and tree roots near the soil surface.

Occurrence. Localized dry spots are most noticeable on close-cut areas such as tees and putting greens, usually during warmer months where this water-repellent soil develops in the top two inches (5 cm) of the soil profile. Localized dry spots caused by fungi have been primarily observed on greens less than three to four years old, especially those aggressively topdressed with sand.

Figure 7–29. Localized dry spots on a golf green.

Symptoms/Signs. Dry spots are several inches to several feet across and often irregularly or serpentine shaped **(Figure 7–29)**. An affected area will appear drought stressed, despite daily irrigations or rainfall. "Puffball" mushrooms may be present throughout the dry area, but these signs are not always apparent. The fungus has colonized (covered) the sand particles in the rootzone mix. Due to this fungal covering, the sand is now hydrophobic and repels water, despite heavy rainfall or watering. Soil hydrophobicity primarily occurs in the upper two inches (5 cm) of the soil profile. It is thought as fungi mycelium decomposes, organic substances are released that coat and bind the coarse sand particles so tightly together they prevent water penetration. This organic matter decomposition is a natural process and cannot be stopped. Also, it has been recently observed that anthracnose basal rot of creeping bentgrass may be initiated by development of stress from localized dry spots. Localized dry spots can also be a symptom of nematode infestations in sand-based root zones.

To determine the water repellency tendencies of a soil, the water drop test can be used. A soil core one inch (2.5 cm) in diameter and at least six inches (15 cm) in depth is extracted. Drops of water are placed on the soil at increments of one-half to one inch (1.3 to 2.5 cm), starting at the soil surface. If droplets remain intact on the surface for more than five seconds, the soil is hydrophobic. The longer droplets remain, the more water-repellent the soil.

Cultural Controls. Since hydrophobic soils tend to be in the upper two inches (5 cm) of soil, management practices to encourage rooting beyond the two-inch (5-cm) depth should be implemented. Hydrophobic sand must be broken up and wetted, which can be accomplished by spiking the dry patch every five to seven days or core aerifying. For a small area, a pitchfork or similar tool will accomplish this task. Irrigate dry patches by hand several times a day, in addition to any normal irrigation or rainfall.

The addition of a wetting agent to the water is also useful and should be watered-in. Some programs of prevention by utilizing several applications of certain wetting agents have been successful. Ideally, it is best to treat the entire green with the specified wetting agent and then, if needed, go back and spot treat areas continuing to show localized dry spots. Wetting agents can last up to five months but are affected by organic matter content, cultural practices, and the degree of hydrophobicity. When excessive thatch, mat, or compacted soil is present in conjunction with localized dry spots, core cultivate prior to wetting agent application. Soil treated with wetting agents will not hold more water than its normal field capacity after treatment. However, the soil surface of sands may drain and dry out quicker following wetting agent use. If excessive organic matter (thatch or mat) is present, moisture may be retained longer when treated with a wetting agent. Using high pressure water injection cultivation in combination with a wetting agent also helps to alleviate symptoms.

Chemical Controls. No chemical controls are currently registered as localized dry spot is from organic coating of sand particles and not directly from fungi; thus, fungicides rarely work. If chronic infestations of fairy ring fungi such as *Lycoperdon* spp. are present, then control with flutolanil, azoxystrobin, or pyraclostrobin may be beneficial.

Additional Diseases

Many additional diseases can invade various turfgrasses while many are present in the turfgrass environment but are not active. Most of these diseases are local in nature, often influenced by local micro-environments and agronomic growing conditions. Consult local turf specialists for proper identification and control options. Refer to the reference section of this text for further information on additional diseases.

Much more information about other diseases and updates on the ever-changing best management practic-es and plant protection products can be found at:

http://www.clemson.edu/extension/horticulture/turf/pest_guidelines/

http://www.turffiles.ncsu.edu/

8 TURFGRASS NEMATODES

8 TURFGRASS NEMATODES

Plant parasitic nematodes can cause serious damage to turfgrass stands compromising root systems reducing a plant's nutritional uptake and exacerbating drought stress. In subtropical and warm regions, parasitic nematodes are among the most troublesome turfgrass pests. Symptoms of nematode damage to turfgrasses can be easily confused with the effects of nutritional deficiencies, water or heat stress, or other diseases. A good knowledge of nematode sampling, biology, and turfgrass management strategies for different environmental conditions is a prerequisite for successful management of turfgrass nematodes without heavy reliance on nematicides.

8.1 NEMATODE DESCRIPTION

Nematodes (sometimes called eelworms) are probably the most abundant multicellular animals known. Fortunately, the overwhelming majority are nonparasitic (free-living). They are microscopic (tiny) non-segmented roundworms measuring 0.1 to 3 millimeters (1/250 to 1/8 inch) in length. With the unaided eye, adults are barely visible. When viewed under magnification, they appear almost transparent but with definite body outlines. Most nematodes are slender (eel-like) throughout their life stages, but a few become swollen as they mature. Although flowers, stems, leaves, and roots of some plants are attacked by certain plant parasitic nematodes, most nematode pests in turfgrasses are root parasites. **Figure 8–1** shows a schematic diagram of a nematode.

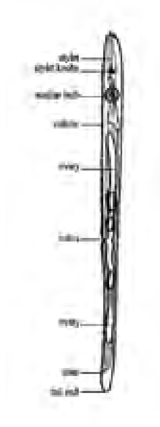


Figure 8–1. An illustration of a typical nematode.

Most nematode parasites of turfgrasses remain entirely outside of roots with only their stylet (hollow protrusible spear) thrust inside the root (these are termed **ectoparasites**). A few are **endoparasites**, where they spend part of their life-cycle completely inside the roots. Endoparasitic nematode feeding often causes root swelling or galls, or rotting and lack of root-hair development. Some endoparasitic nematodes move freely within and out of the root for all developmental stages (termed **migratory endoparasites**) while other species remain in a permanent feeding position within the root tissue for most of their life-cycle (termed **sedentary endoparasites**). Sting, ring, and stubby-root nematodes are examples of ectoparasites; lance and lesion nematodes are migratory endoparasites, while root-knot nematodes are sedentary endoparasites **(Table 8–1)**.

Plant nematodes are aquatic animals living in the soil water film or in plant fluids. They are very well-adapted plant parasites. Females produce a few dozen to over 500 eggs each breeding season. When a host plant is unavailable, eggs of some species survive for years but hatch quickly when stimulated by exudates from plants. Their activity, growth, and reproduction increase as soil temperature rises from about 50°F to about 90°F (10 to 32°C). Generation time is between three and six weeks for many nematodes.

8.2 TURFGRASS NEMATODES

Several different kinds of nematodes can affect turf, with the most damaging described in the following pages. Table 8–1 also lists the numbers of each kind of nematode expected to cause similar levels of damage.

Sting Nematode (commonly *Belonolaimus longicaudatus*, also *B. gracilis*, and other species)

Sting nematodes are the largest of the turf parasites in the southeastern United States, with adults reaching lengths of nearly one-eighth inch (3.2 mm). They occur naturally in dune sands and the sandy soils of sandhill regions. Sand-based rootzones in constructed putting greens are ideal habitats for sting nematodes as well as other species. The following combination of characteristics describe the genus *Belonolaimus*: possession of a very long stylet with knobs at the base, a median bulb (valvulated "pump"), vermiform (eel-like) adult, two ovaries, and a round tail end. Sting nematodes use their very long stylets to siphon plant sap from turfgrass roots. These nematodes are ectoparasitic; thus, they remain outside of roots while feeding, with only their long stylets penetrated deep into the vascular tissue. Although lesions are evident throughout the root system, the most active feeding occurs at root tips. In sufficient

Figure 8–2. Typical erratic turf damage from sting nematodes.

numbers (usually ≥20/100 cubic centimeters [cc] soil), sting nematodes retard overall root development, making plants more sensitive to moisture stress. Turfgrass top growth is stunted, appears yellow, and thins out **(Figure 8–2)**. Sting nematodes are generally found only in very sandy (>80 percent sand) soils. They feed on all grasses grown for turfgrasses, but damage is most severe on bermudagrass, St. Augustinegrass, zoysiagrass, bentgrass, and ryegrasses. Many other grasses are hosts to sting nematodes including oats, centipedegrass, barley, and ryegrass. Centipedegrass in sandy soils can be severely damaged by sting nematodes. Weedy plants such as prostrate spurge, Florida pusley, knotweed, or bahiagrass may invade sting- and also ring-nematode-infested areas.

Ring Nematodes (*Criconemella, Mesocriconemella spp.*)

Ring nematodes are characterized by a body with prominent rings, one ovary, vermiform adults, blunt tail, and a knobbed stylet. Ring nematodes feed ectoparasitically (from the outside of the roots). Brown lesions appear along the roots and tips, and roots become stunted. When high numbers of ring nematodes are present, severe root rotting may occur. Ring nematodes are widely distributed on many turfgrasses (namely Kentucky bluegrass, annual bluegrass, St. Augustinegrass, zoysiagrass, bermudagrass, and creeping bentgrass), but are considered to be a major pest on centipedegrass, especially in sandy soils.

Lance Nematodes (*Hoplolaimus spp.*)

Lance is the most widely occurring nematode in the world. The stylet knobs of lance nematodes resemble a tulip, their tail length is <1.5 times the anal body diameter, they have a median bulb, two ovaries are present, and mature females are vermiform (bulb-shaped). These nematodes feed mostly ectoparasitically but can enter and move through the root cortex, making them very difficult to control even with chemical nematicides (termed: migratory endoparasites). For this reason, lance nematodes frequently occur in high numbers more in older turfgrass areas, such as older putting greens where other nematodes were controlled over the years with various nematicides. In zones of heavy feeding, roots exhibit slight tissue swelling followed by necrosis and sloughing off of cortical tissues. Lance nematodes have a wide host range and attack all commonly grown turfgrasses (St. Augustinegrass, bahiagrass, creeping

Table 8-1. Nematodes affecting turfgrasses and damage threshold levels typically used to justify nematicide application.

Common name (Scientific name)	Most susceptible grasses	Threshold* (No./100 cc soil)
	Endoparasitic	
Root-knot (*Meloidogyne spp.*)	St. Augustinegrass	80
	Bentgrass	80 to 100
	Bermudagrass	80
	Zoysiagrass	80
Lesion (*Pratylenchus spp.*)	All	150
Cyst (*Heterodera spp.*)	St. Augustinegrass	na
Ectoparasitic	Ectoparasitic	Ectoparasitic
Sting (*Belonolaimus longicaudatus*)	St. Augustinegrass	10 to 20
	Bermudagrass	10 to 20
	Zoysiagrass	10 to 20
Lance (*Hoplolaimus spp.*)	St. Augustinegrass	50
	Bentgrass	40 to 60
	Bermudagrass	80
Ring (*Criconemella spp.*)	Centipedegrass	150 to 300
Stubby-root (*Nanidorus minor*)	All	100
Sheath (*Hemicycliophora spp.*)	All	80 to 200
Spiral (*Helicotylenchus spp.*)	All	200 to 600
Awl (*Dolichodorus heterocephalus*)	Turfgrass (especially bermudagrass) in wet locations	80
Dagger (*Xiphinema spp.*)	Rarely a turf pest	150 to 300
Stunt (*Tylenchorhynchus spp.*)	Rarely a turf pest	100 to 400
Root-Gall (*Subanguina radicicola*)	Poa annua	na

*Threshold level ranges commonly used in research by universities. Numbers are not absolute as the health of the turf and environmental conditions substantially influence these. na = data not available.

bentgrasses, bermudagrass, annual and Kentucky bluegrasses, annual ryegrass, and zoysiagrasses). It is the most important nematode pest of St. Augustinegrass and the hardest nematode to control/manage.

Root-Knot Nematodes (*Meloidogyne spp.*)

These nematodes enter and feed inside roots and are classified as sedentary endoparasites. The female enlarges into a pear-shaped mature form that remains embedded within the root. It possesses a knobbed stylet and median bulb. Second-stage larvae enter root cells with the aid of their stylet and migrate through the root cortex toward the vascular tissue, where they become stationary. Saliva secretion during feeding by the nematodes induces enlargement and accelerated division of root cells at certain points inside roots. Mature female nematodes enlarge, appear pearly white, and produce eggs in a gelatinous sac matrix that usually protrudes on the outside of the root surface. Symptoms on both fibrous and lateral roots appear as distinctively small, spherical, or elongated swellings having the same color as the adjacent root surface. Root swellings may be difficult to see without a hand lens. Although damage is typically seen when root-knot nematodes are present, exact economic thresholds in turfgrasses are largely unknown. In turfgrasses, they occur mostly in thatch and upper soil profiles. Root-knot nematodes have a very wide host range. Root-knot nematodes can colonize all common turfgrasses, but they are most commonly found on zoysiagrass, St. Augustinegrass, bermudagrass, and bentgrasses. Similar to lance nematodes, it has been observed that root-knot nematodes occur in large numbers in older greens. Their numbers may increase relative to ectoparasites, which may be differentially susceptible to certain nematicides.

Stubby-Root Nematodes (*Paratrichodorus* and T*richodorus spp.*)

These ectoparasites are characterized by the possession of a distinctive short, curved, spear without basal knobs and the absence of a median bulb. They mostly feed at growing root tips, which stop elongating, may become slightly swollen and discolored (or both), and often become very short and "stubby." Root symptoms resemble those induced by sting nematodes. Lesions are large, brownish, irregular in shape, and often extend deep into the root tissue. Aboveground symptoms appear as a pronounced chlorosis with reduced growth rates. Most warm-season grasses are hosts of stubby-root nematodes. Kentucky bluegrass, tall and red fescues, St. Augustinegrass, bermudagrass, centipedegrass, and zoysiagrasses are common hosts. Numbers can fluctuate in assays of bentgrass putting greens, and their importance as pathogens of bentgrass is not well understood. Knowledge to date has shown that Trichodorus obtusus is more pathogenic to bermudagrass, zoysiagrass and St. Augustinegrass than is Nanidorus (Paratrichodorus) minor.

Spiral Nematodes (*Helicotylenchus spp.*)

Spiral nematodes are ectoparasites and are among the most frequently found nematodes on all common turfgrasses. They possess a median bulb, knobbed stylet, two ovaries, ventrally located tail tip, and take on a characteristic spiral shape when relaxed. Spiral nematodes are rarely serious pests of turfgrasses when they are the dominant species encountered. However, they cannot be dismissed entirely as pathogens when they occur in high numbers or at lower populations in combination with other plant parasitic species. In high numbers, roots are poorly developed and discolored brown with premature sloughing of cortical tissues. Aboveground, the turfgrass stand becomes sparse and difficult to maintain because of reduced plant vigor. Leaf blades become narrower and appear pale to chlorotic. Symptoms are not evident during vigorous root-and-shoot growth in the moist months of spring and early summer even in the presence of very high numbers of spiral nematodes. The nematode populations peak in the advent of both higher temperatures and decreased availability of soil moisture in the top few inches of soil (which also coincides with plant decline). Nematode numbers decline during dormancy periods, but increase again in the cooler weeks of early fall when plant growth resumes. Both warm- and cool-season grasses are good hosts for spiral nematodes.

Awl Nematodes (commonly *Dolichodorus heterocephalus*)

Awl nematodes are ectoparasites possessing a median bulb, long knobbed stylet, two ovaries, and female tail ending in a short terminal "awl-like" point. Awl nematodes are very damaging to turfgrasses in wet locations such as the low land areas near lakes, ponds, and canals. Turfgrass hosts include bentgrasses, centipedegrass, tall fescue, St. Augustinegrass, and especially bermudagrass.

Lesion Nematodes (*Pratylenchus spp.*)

Lesion nematodes are occasional turfgrass pests. They are endoparasites possessing a median bulb, a single ovary, and a short but very robust knobbed stylet (stylet length ÷ body diameter at stylet base is <1.5). Root lesions are initially minute and brown. They progressively enlarge and promote secondary fungal invasion, and may eventually girdle the root. With high populations of lesion nematodes, the root system may appear severely pruned. Both larvae and adults can penetrate and move through and between root cells. There is a preference for feeding in the more mature cortical areas behind the root tips. Two common species, *P. brachyurus* and *P. penetrans*, favor soil temperatures of 80 to 90°F (27 to 32°C) and 70°F (21°C), respectively, and can complete their life-cycles (egg to egg) in six to nine weeks under optimal conditions. Both warm- and cool-season grasses can be colonized by root lesion nematodes.

Stunt Nematodes (*Tylenchorhynchus spp.*)

Stunt nematodes possess two ovaries, a median bulb, a round tail end, but a short stylet with round (not tulip-shaped) knobs. The tail is somewhat cylindrical; the tail end is round. They are an occasional turfgrass pest, but may reach very high populations on bentgrass and *Poa annua* in cooler regions in sand-based rootzones. Brown lesions may be evident on the roots, but definite lesions are not usually present (as a rule). Roots appear shriveled and severely shortened. *Tylenchorhynchus dubius* on bentgrasses feeds primarily on root hairs and areas immediately behind root tips with only the stylet penetrating the epidermal cell. Other species browse more and may group into clusters on epidermal cells that cause a mechanical breakdown of epidermal, cortical, and vascular tissue. Stunt nematodes can survive in the presence of adequate soil moisture for several months without a host. Both warm- and cool-season grasses are suitable hosts.

Dagger Nematodes (*Xiphinema spp.*)

Dagger nematodes are long, slender, and shaped like a "dagger." The stylet is very long with basal flanges (not knobs). The guiding ring for the stylet is nearer to the base than it is to the apex of the stylet. A median bulb is absent. Dagger nematodes feed ectoparasitically and induce reddish-brown to black, slightly sunken root lesions. In very high numbers, extensive feeding reduces root growth. Warm-season grasses (especially zoysiagrasses) and perennial ryegrass are suitable hosts. Other hosts include bentgrasses and Kentucky bluegrass.

Other Nematodes

Other nematodes may damage turf, especially when numerous other pests, pathogens, or environmental conditions stress the turfgrass. Occasional turf pests include spiral, stunt, and dagger nematodes (previously mentioned); sheath (*Hemicycliophora* spp.) and sheathoid (*Hemicriconemoides* spp.) nematodes; cyst nematodes (*Heterodera* spp.); and, root-gall (*Subanguina radicicola* and *Anguina pacificae*). All, except the cyst and root-gall, feed ectoparasitically. *Hemicycliophora* is identified by the presence of a loose sheath around the body of the nematode. *Hemicriconemoides* do not have a loose sheath, but do have fairly pronounced annulations in the cuticle and a tail end that is more pointed than Mesocriconemella (ring nematode). The bodies of female cyst nematodes enlarge into lemon shapes that eventually become completely filled with eggs. Egg-filled cysts can be observed still attached to affected roots; St. Augustinegrass is especially susceptible to cyst nematodes. An endoparasitic seed and gall nematode (*Anguina pacificae* and *Subanguina radicicola*) can be found on *Poa annua* and bentgrass in coastal regions of Northern California. It has the ability to feed on crown tissue, causing gall formation, not just roots like most turf parasitic nematodes.

Figure 8–3. Root damage from sting nematodes (left) vs. healthy turf (right).

8.3 DIAGNOSIS OF NEMATODE PROBLEMS

Although diagnosing nematode problems is often difficult, there are several clues that are used during the investigative process. These include the type of symptoms, pattern and timing of damage, previous history, nematode species present, and the results of nematode counts.

Root symptoms

Root symptoms include lesions; galls; stubby, swollen root tips; lateral root proliferation; and/or stunted shallow root systems with few feeder roots **(Figure 8–3)**. Common symptoms associated with certain nematodes were previously described. The penetration and movement of endoparasitic nematodes within roots leave openings that allow root invasion by secondary microorganisms in the soil such as fungi. The result is accelerated rotting (blackening) of roots and proneness of plants to wilting. The physiological and biochemical responses of the turfgrass to the invasion by the nematodes and microorganisms weaken the host further and may even break general host tolerance. Heavily affected root systems have much less soil clinging to them when a plug is pulled from the turf compared to unaffected turfgrass stands. The root symptoms, however, are not unique to nematodes and should always be considered in conjunction with other observations when diagnosing nematode problems.

Aboveground symptoms

Aboveground symptoms include wilting, thinning, or gradual decline; or the yellowing of leaves without lesions or deformities **(Figure 8–4)**. Again, these symptoms are not unique to nematodes and can be caused by heat or drought stresses, nutrient deficiency, fungal diseases, insect feeding, soil compaction, prolonged saturation of soil with water, or chemical contamination. The turfgrass is weakened by the nematode damage and is unable to outcompete invading weeds (such as sedges, knotweed, Florida pusley,

Figure 8–4. Typical above-ground symptoms of nematode damage including wilting, thinning and yellowing of turfgrass leaves without lesions.

Figure 8–5. Certain plants often invade nematode infested sites such as prostrate spurge (shown) and Florida Pusley.

and spurges). Nematode-affected areas may appear more weedy than other turf areas.

Pattern of damage

Nematodes do not cause uniform damage to an expanse of turfgrass (as occurs, for example, in rust diseases). Rust fungi produce millions of dry spores that are easily dispersed over long distances in open air by the wind. Nematodes, however, produce a mere 50 to 500 eggs (per female). These eggs are in the soil environment and are not immediately and easily dispersed from the source by an active agent (such as the wind). Nematodes do not migrate more than one meter in one growing season and must depend on movement in surface water run-off, irrigation water, and soil clinging to equipment, sod, or plugs for long-range movement. Nematodes, therefore, show an irregular (somewhat patchy) horizontal and vertical distribution in the soil. Symptoms above ground also follow this irregular distribution, but nematode-affected areas usually do not show distinct sharp boundaries. However, these symptoms resemble early stages of many fungal turfgrass diseases and could be misdiagnosed as nematode-related.

Timing of damage

Plant parasitic nematodes are obligate parasites and feed most when the turfgrass roots are actively growing. They are therefore most numerous during mild weather, in late spring (May to June) and early fall (October to November) on warm-season grasses, and early summer (June/July) and again in fall (November/December) on cool-season grasses. The turf usually shows no aboveground symptoms of nematode damage until unfavorable environmental conditions prevail (for example, during hot, dry periods when soils are dry).

Soil sampling

Nematode counts are the surest way to determine whether a problem in the turf is indeed caused by parasitic nematodes. It is good practice to take soil and root samples monthly so changes in the populations of plant parasitic nematodes in the turfgrass stand can be monitored and kept below acceptable damage threshold levels. Given the irregular distribution of nematodes in the soil, it is imperative that adequate soil/root sampling be conducted in order to confirm the nematode problem with some degree of certainty. Golf course superintendents could be wasting precious time and thousands of dollars on fungicide applications if a problem is not correctly diagnosed as nematode-related. The same waste of resources would occur if the problem is suspected to be caused by nematodes when the real cause is another stress.

To sample nematodes, composite sample of 10 to 20 soil cores are taken from suspected areas. Soil cores should be at least one-half inch (1.3 cm) in diameter to four-inches (10-cm) deep, placed into a clean plastic bag, and sealed. Typically, a 10 to 20 core composite is required to achieve sufficient soil volume for an adequate sample. The laboratory will take a 100-cc (about a cup) sub-sample for assay. If several areas show symptoms of nematode damage, separate the samples from each area and store these out of direct sunlight and at room temperature. Sample from the edge of an affected area, avoiding spots where the grass is already dead. If samples cannot be shipped to a lab within two days, place them in a refrigerator, but do not freeze them. Another common mistake is to place samples in a vehicle where they quickly heat to lethal temperatures. Also sampling from an adjacent "good" turf site may help provide better insight into the nature of the problem.

Both private and university laboratories provide good nematode assay services and should be consulted about the services they offer, as well as instructions for taking and submitting samples. It is usually best to stick to one lab since assay methods and results differ between laboratories. The decision to use a nematicide should be based on the quality of turfgrass required and budget allowances. It should not always be predicated on some fixed threshold level of nematodes set by a laboratory. The level of damage tolerated by one golf course may be completely unacceptable on another. The most important management principle to go by is the fact that the health and vigor of turfgrasses directly affect their relative susceptibility to a given level of parasitic nematodes. In fact, the majority of nematode-induced damage is culturally managed, without nematicides. Nematicides only become necessary if populations reach unmanageable levels and/or if particularly virulent species, such as *Belonolaimus* spp. (sting), are present.

Figure 8–6. Visible slits in the turf from injecting a commercial nematicide.

8.4 NEMATODE MANAGEMENT

Although no turfgrass cultivars are currently available that are resistant to all nematode species, significant differences exist among turfgrass varieties in terms of the numbers and species of nematodes feeding on them and their proneness to damage caused by feeding activities. Visual symptoms and even adequate soil/root sampling may sometimes not be enough to confirm a nematode problem. A positive growth response to an effective nematicide may sometimes be required for confirmation.

Turfgrasses tolerate some feeding by most nematodes; therefore, the most practical strategy for nematode control is often the promotion of vigorous root growth (using recommended cultural practices and timely nematicide applications).

1. *Cultural practices* - Certain cultural practices help minimize stresses that make the turfgrass more susceptible to nematodes. To facilitate deeper penetration of the soil by roots, irrigate deeply (but less frequently) instead of using shallow, daily watering. Also, raising mowing heights can improve nematode tolerance by increasing plant rooting. To achieve proper infiltration and adequate oxygen levels in soil, coring with narrow, hollow tines or spiking should be performed (in late spring and early summer). Cultivation should be performed at times of the year when the best turf recovery occurs (e.g., in late spring for warm-season turfgrasses and in mid-spring or early fall for cool-season turfgrasses).

   Excessive fertilization with water-soluble nitrogen must be avoided since nematode numbers increase rapidly on succulent roots and, during periods of environmental stress (for example, in summer), the roots are placed under an additional strain. Organic forms of nitrogen have been shown to be associated with lower nematode numbers than inorganic forms. However, judicious use of a balanced fertilizer is always advocated.

   Plant diseases, nutrient deficiencies, shade, and soil compaction (traffic) should be managed or minimized in order to decrease the impact of nematode diseases on turfgrass stands. Avoid mowing low to prevent additional stress to the nematode-infested turfgrass stand that is forced to survive with reduced shoot biomass.

   Certain soil amendments to turf grown in sandy soils are known to improve soil composition and reduce the impact of plant parasitic nematodes. Preplant incorporation of colloidal phosphate and/or composted municipal sludge, or long-term use of the latter as a top-dressing, have been shown to reduce nematode damage to turfgrass stands.

2. *Use of tolerant grasses* - Whenever possible, avoid planting species or cultivars that are the most susceptible to the nematode species deemed problematic in a given locality. **Table 8–1** lists parasitic nematodes and the most susceptible grasses. By establishing turf initially with a tolerant variety, the impact of certain nematodes and the cost of nematode management will be reduced overall. Information on the relative tolerance of the hundreds of varieties of different turfgrasses is scarce. The bermudagrass variety "Tifdwarf," however, appears to be more tolerant of stunt and ring nematodes than "Tufcote," "Tiffine," "Continental," or "U-3." "Tifway" is fairly tolerant of the sting nematode while "Tifdwarf," "Tufcote," "Tifgreen I," "Tifgreen II," and "Midiron" are susceptible. Polyploid St. Augustinegrass varieties are typically more tolerant of sting nematodes compared to diploid varieties.

3. *Chemical control* - Because crop rotation, varietal resistance, biological control, and several other disease-management strategies are not always practical or effective for turfgrass nematode control, the use of chemical nematicides is currently the most reliable approach to reducing parasitic nematode levels in turfgrass stands. Chemical nematicides can be applied as preplant fumigants and as post-plant nonfumigant contact chemicals. Fumigants are toxic to plants and are labeled for use only before establishment of the turfgrass stand. In established turfgrass stands, contact

nematicides are available as granular or spray formulations and are always watered-in immediately after application. They also have some insecticidal activity. No single product is effective against all nematodes on a given turfgrass species.

Soil Fumigation Before Planting

Soil fumigants are chemicals applied as gases or liquids that readily vaporize. They are toxic to the turfgrass but may be used to treat soil prior to seeding or planting to reduce plant parasitic nematodes, weeds, fungal pathogens, and other soil-borne microorganisms. Turfgrasses established in fumigated soil show more uniform and vigorous growth. The fumigants used in turf are the gas methyl bromide, and the liquids 1,3-Dichloropropene (Telone II), 1,3-Dichloropropene-chloropicrin (Telone C-17), and metam-sodium (labeled as Vapam, Sectagon, or Busan 1020). All three fumigants are "restricted use" pesticides requiring special equipment and application only by licensed professionals, especially when large areas are to be treated.

1. Methyl bromide is a very effective broad-spectrum biocide which has "served" the turf industry well. It is standard practice on new greens, tees, and areas being replanted to fumigate with methyl bromide. Custom applicators often have their own name brand of methyl bromide, such as Terr-O-Gas. The commercial production of methyl bromide is scheduled to cease in 2017, since it has been found to be ozone-depleting and a potentially serious environmental pollutant. Methyl bromide will therefore not be available for nematode control after the phase-out period.
2. Telone C-17 is not without problems. It contains tear gas and is now under special review. Residues have been detected in the air near schools and residential areas.
3. Metam-sodium (Vapam) is a useful option, although not as effective as methyl bromide. It can be applied as a drench in water or by injection. After application, metam releases gases, especially methyl isothiocyanate, which provide control. Metam products do not, however, penetrate tough tubers, stolons, and rhizomes, as well as methyl bromide, and are more sensitive to soil temperature and moisture levels. Also, the fumes from metam-sodium escape slowly from the soil, especially when the soil is cool, wet, or high in organic matter or clay content; thus, it should be used several weeks prior to an anticipated planting. Busan, Sectagon, and Vapam are examples of commercial formulations of metam-sodium.
4. Dazomet (trade name Basamid) is a granular product that is applied preplant, and can be incorporated with irrigation. The granules dissolve in water and release methyl isothiocyanate similar to metam-sodium products. Treated areas can be tarped to improve efficacy.

When using fumigants, best results are usually obtained when the old sod is first stripped from the area to be treated, followed by thorough tilling of the soil at least two weeks prior to the application of the fumigant to allow adequate decomposition of old roots. Tilling loosens the soil and permits more rapid and uniform diffusion of the fumigant. At the time of application, the soil should be moist (not water-saturated). Too much fumigant escapes in dry soil and too little diffuses when pores are filled with water. The temperature of the soil should be about 50 to 80°F (10 to 27°C) (at a depth of 4 inches, 10 cm). Too much fumigant evaporates from hot soil, whereas diffusion is too slow in cold soil. For maximum effectiveness, the treated area should be sealed immediately with plastic tarp for several days. It is extremely important the fumigated area is not re-contaminated by accidental introduction of nematodes in soil clinging to tools, equipment, footwear, run-off water, or infested soil. Pests introduced into partially sterilized soil usually reproduce rapidly because of the lack of competition from microorganisms.

Nematicides for Established Commercial Turf

Currently, the only synthetic fumigant nematicide available in the United States is 1,3-Dichloropropene (trade name, Curfew). It can only be used on commercial turf (including golf courses and sod farms) where the risks of exposure can be minimized. Depending on use rate, 1,3-Dichloropropene has nematicidal, fungicidal, insecticidal, and herbicidal properties **(Table 8–2)**. This material is injected five to six inches deep (13 to 15 cm) through chisels spaced 12 inches (30 cm) apart with a coulter, knife, and roller assembly. In the soil, the product turns from a liquid to a gas, killing nematodes as it disperses through the soil. The coulter slices the turf open at least five-inches (13-cm) deep, with a six-inch (15-cm) knife, and an attached tube injects the material at a rate of five gallons of product per acre (9.4 liters per hectare), followed by rolling to seal the slit. With adequate fertility and irrigation, slits typically heal within two to three weeks. A half-inch (1.3-cm) irrigation should follow injection to help "cap" the treatment. The fumigant then diffuses throughout soil pores, killing nematodes on contact with 98 percent dissipation within

Table 8-2. Relative effectiveness of non-fumigant nematicides used in turfgrass nematode control.

Nematode	1,3-Dichloropropene (Curfew)
Sting	Good
Awl	na
Spiral	Good
Ring	Good
Stubby-root	Good
Sheath, Sheathoid	Good
Lance	Good
Root-knot	Good

24 hours after treatment. Nematicide applications should be made in autumn or spring (before nematode populations peak) during periods when soil temperatures are above 60°F (15.6°C), according to the product label. In transition zones where warm season grasses go dormant or semi-dormant, Curfew should be applied in spring or early summer so that slits will have time to heal. Early fall applications would be acceptable on cool season turfgrasses where healing of slits would occur relatively quickly. Since Curfew can only be used once in a season in states with 24C (special local need) labels, spring or early summer may still be the best timing for optimal results.

The reentry period of turf following injection is 24 hours unless full personal protective equipment (including suit, gloves, boots, and respirator) are worn. Injections cannot occur within 100 feet (30 meters) of an occupied structure such as a residence or place of business. Obviously, being a soil injection, buried obstacles such as irrigation heads and drains must be flagged and avoided.

Following treatment, turfgrass roots typically respond dramatically with greater root depths and mass. However, since the soil is not sterilized by 1,3-Dichloropropene, nematode populations usually rebound over time; however, with improved rooting, higher nematode populations may be tolerated. The product is also effective on soil insects such as mole crickets.

Several additional nematicides have state or local registrations or are anticipated to receive their registrations in the near future. Abamectin (Avid 0.15EC) currently has a special local need label (24C) for the Carolinas for nematode control on golf course greens only. Apply in 2 gallons water per 1000 sq.ft. with spray nozzles to deliver coarse droplets; spray onto wet turf and immediately incorporate with at least 0.1 inch irrigation per acre as abamectin is easily bound by soil organic matter. Addition of a soil wetting agent may improve performance. Avid 0.15EC is currently labeled for sting (*Belonolaimus* spp.) and ring (*Criconemella* and related genera) nematodes only. Use 3 to 4 consecutive applications on a 14- to 21-day interval. Combinations of Avid 0.15EC and Heritage fungicides are recommended to reduce fungal infections and promote healthier turf.

Furfural (Multiguard Protect 90EC (8.68 lb/gal furfural) is for use on golf course greens, tees, practice greens and sod farms only. Its use requires appropriate personal protective equipment (PPE) and buffer zones. Golf courses must be closed during application, with a 2 hour reentry interval to treated zones. See label for details. Apply at 1:9 dilution with water at a rate of 8 gallons per acre initially, followed by 5.5 to 8 gallons per acre in subsequent treatments. Due to its relative water insolubility, incorporate with irrigation (¼ to ½ acre inch water) within 15 minutes of application in sandy soils. Immediate incorporation is suggested as Multiguard Protect 90EC can be phytotoxic. Fufural has a contact mode of action and tends to be more effective on sting, less so on lance, and rootknot nematodes.

Two experimental products are anticipated to receive registrations soon for turf nematode control. One is fluensulfone, with the trade name 'Nimitz' and the other is a fungicide with nematicidal activity, fluopyram, with the anticipated trade name 'Indemnify.' Data generated to date is limited but both of these products have demonstrated efficacy to sting nematode and other genera. As nematicides, their mamalian toxicity is very low, which is a huge benefit to the industry. Safe and effective nematicides are among the most-needed pesticides for turf nematode pest management. Both fluensulfone and fluopyram are xylem-mobile, leading to the higher probability of effectiveness for endoparasitic nematodes such as root knot, lance and lesion as well as the ectoparasitic species. Optimizing practices such as pre- and post-application irrigation for incorporation still needs research, but we do know that incorporation with irrigation is necessary for best results with both products. In this regard, they are similar to Avid 0.15EC.

Maximizing the Effectiveness of Nematicides

Neither fumigant or non-fumigant nematicides completely eradicate plant parasitic nematodes. Some nematodes in deeper layers of soil and root tissue may escape exposure to lethal concentrations of the nematicide. Others are only temporarily paralyzed or disoriented by sublethal levels of the nematicide and will resume feeding when the chemical dissipates through diffusion, dilution, degradation, or leaching. Avoid the introduction of nematodes from other sources (for example, contaminated soil or sod). It is important to monitor the population levels of nematodes to know when nematicide treatments are needed.

Nematicides mainly affect nematodes; they do not stimulate plant growth directly. Nematicide-treated turfgrass therefore needs time to grow new roots in order to support new foliage and recover from nematode-induced stresses. Factors limiting root growth must be taken care of immediately after nematicide applications in order to achieve complete recovery of turf affected by nematode parasites. Ensure good drainage, adequate irrigation and aerification, balanced soil fertility, control of other pests and diseases, and reduced pedestrian traffic, if possible. Aboveground plant responses after a nematicide application are usually slow or delayed.

Timing of applications is important. In the southeastern United States, a very good response of bermudagrass to nematicide application in sting- and ring-infested soil is obtained by a mid-April application, normally several weeks after spring green-up. Presumably, nematode populations are suppressed and allow new stolon and root development at the time of year when growth is maximized. Fall applications of nematicides to suppress damaging nematodes in bermudagrass turf may also be made, but overseeding establishment of cool-season grasses can be adversely affected if seeding and nematicide application coincide or the interval is short. If a nematicide application is necessary in the fall, it should be done two to three weeks prior to the overseeding date.

Related to the timing of applications, the use of certain pre-emergence herbicides for crabgrass or goosegrass control, which act as inhibitors of cell division, may inhibit bermudagrass response to nematode suppression by nematicides. Although nematodes are suppressed by the nematicide application, turf may not respond because residual herbicides inhibit new stolons. Managers may opt to skip the pre-emergence herbicide application and use post-emergence strategies instead, or use a material (e.g., oxadiazon, or Ronstar) that does not inhibit "tacking" of new stolons into treated areas. This becomes a problem when damage to bermudagrass is substantial and managers rely on new stolon development for recovery (e.g., rhizomes are absent or weakened).

Avoid overuse of any nematicide because soil microorganisms that can degrade the nematicide will build up to high population levels, decrease the efficacy and longevity of the chemical in subsequent applications, and consequently shorten the period of nematode control. Prolonged frequent use of a given pesticide also allows the buildup of one or more parasitic nematode species against which the chemical is less effective.

Table 8-3. Examples of "biological" or "organic" product which tout nematode suppression.

Source	Contends or Mode-of-Action
Agroneem	Plant-based
Bioblitz	Plant-based
ClandoSan	Chitin + urea fertilizer
CMP	Mustard bran
Cyclewise Nema	Fungal
Dragonfire CPP	Plant-based
Floradox	Stimulates plants natural defenses
Keyplex 350DP	Stimulates plants natural defenses
Nemastop	Plant-based
Nematac S	Plant-based
Nematrol	Sesame extract
NeoTec S.O.	Plant-based
Neotrol	Sesame extract
Nortica	Biologically derived (Bacillus firmus)
O2YS	Chitosan
Safe-T Green	Biologically derived
Vector MC	Predacious nematodes

8.5 BIOLOGICAL CONTROL

There are several products on the market for management of plant parasitic nematodes using various natural products **(Table 8–3)**. Examples of earlier biological control products include a mixture of chitin from shells and urea to suppress root-knot nematodes when the material is incorporated into soil. Microbes increase to enzymatically break down chitin (chitinases) which may, concomitantly, degrade nematode eggs in soil. ClandoSan is one commercial formulation of this. Another product utilizes preparations of sesame, which has been shown to be toxic to nematodes under some circumstances. Nematrol, Neotrol, and others are commercial formulations. Also, various bacteria have been shown to suppress nematodes, and various commercial preparations of bacteria or bacterial products have come on the market. Incorporation of effective quantities of these materials into existing turf is problematic, as is the relatively high amounts of nitrogen as urea used to break down chitin.

Biological nematode control is also receiving much attention. Two insect-parasitic nematodes (*Steinernema riobravis* and *S. carpocapsae*, trade name Vector MC and others) have been used for mole cricket control. Their effectiveness, however, for certain plant-parasitic nematodes have been somewhat erratic.

Although many of these materials may suppress nematodes for short time intervals, none have given results in the field to date that compare with the efficacy of chemical nematicides. However, the need for safe and effective control of nematodes for turfgrasses has never been greater.

Products containing various *Bacillus* spp. are perhaps currently the mostly widely used of these products. Nortica (*Bacillus firmus*, strain I-1582) is termed a plant protectant as it doesn't directly control nematodes but produces various "biometabolites" which do. Scientists don't necessarily see large reductions in soil nematode populations following use, but the bacteria appears to "protect" roots against their feeding. Best results have been noted as preventative applications in the spring as bermudagrass turf resumes growth after winter dormancy.

9 TURFGRASS INSECTS AND RELATED ARTHROPODS

9 TURFGRASS INSECTS AND RELATED ARTHROPODS

Several insects and related arthropods are common pests on turf installations and can cause considerable damage if left unchecked **(Figure 9-1)**. Pests feeding on leaves and stems include sod webworms, armyworms, grass loopers, cutworms, chinch bugs, bermudagrass mites, and scale. Those feeding on roots include mole crickets, white grubs, billbugs, and ground pearls. Nuisance pests such as fire ants also are found.

An **integrated pest management (IPM)** program can manage insects and arthropod pests of turfgrass most effectively and economically, with minimal risks and impacts on people, pets and the environment. Instead of relying on only one pest management strategy (such as insecticides), IPM relies on a combination of prevention, cultural, biological and chemical management tactics to keep pest population and damage below a tolerable level (a.k.a. threshold). An IPM program includes the following components:

1. Setting a reasonable tolerance level for pest density and damage, and only initiating appropriate treatment when the **tolerance level or threshold** is exceeded.
2. Relying on the results of **monitoring or sampling** for pest management decision, instead of assuming that treatment is necessary or making treatment on a calendar basis.
3. **Identifying** the culprits and their life stages correctly in order to select the most appropriate treatment and treatment timing.
4. **Selecting treatments** that are less hazardous to people, non-target animals (including pests and beneficial organisms) and the environment.

Figure 9–1. Turf damage from insect feeding.

Early insect detection is vital to any pest management program. Therefore, turf should be inspected as often as practical. All employees should be trained to spot potential problems while performing their assigned duties. When pests are noticed, the employee should promptly notify the person responsible for pest management. If insecticides are used as part of a control program, be sure the formulation is labeled for the particular turfgrass area. Numerous restrictions are placed on several insecticides (e.g., soil type, number of applications, minimum distance from bodies of water, irrigation requirements, reentry, etc.), so read the label carefully before use.

9.1 INSECT BIOLOGY

Arthropod is a broad term that includes all insects, mites and other relatives. The following are the defining characteristics of an arthropod:

1. Multiple pairs of jointed and articulated legs and antennae.
2. The presence of a chitinous exoskeleton (body wall, or outer covering or shell). The exoskeleton provides arthropods with structural integrity, but it also limits their growth. To grow, arthropods have to shed this exoskeleton in a process called molting.
3. A segmented body. Insects are segmented in head, thorax and abdomen, whereas mites are segmented into prosoma (cephalothorax, equivalent to an insect's head and thorax) and opisthosoma (abdomen). The possession of wings is unique to insects.
4. A nervous system on the underside (ventral or belly) and a circulatory system on the upper side (dorsal or back).

Almost all arthropod pests of turfgrass are insects and mites, although other arthropod pests of turfgrass include spiders, fleas, ticks, centipedes, millipedes, sowbugs, and pillbugs.

The process by which insects and mites grow is called metamorphosis. During this process, the body of an insect grows, molts, and then becomes larger and more developed, and can sometimes appear different from the previous life stage. Insects undergo two types of metamorphosis:

1. Incomplete metamorphosis: Insects in this group are called hemimetabolous insects, and include species such as chinch bug, mole cricket, leafhopper and ground pearl. All mites are hemimetabolous. The juvenile form (called nymph) of these insects resembles

adult, but is smaller and lacks adult features such as wings and functional reproductive organs. The life cycle of a hemimetabolous insect or mite can be divided into three stages: egg, nymph, and adult. Within the nymphal stage, there may be several growth stages between molts (called instars). Many species of this group can damage turf as an adult and a nymph.

2. Complete metamorphosis: Insects in this group are called holometabolous insects, and include ants, armyworms, billbugs, white grubs and crane flies. The juvenile form (called larva) appears very different from the adult. Each group may have a specific name for their larvae: caterpillar (larva of a moth or butterfly), maggot (larva of a fly), or grub (larva of a beetle). The life cycle of a holometabolous insect can be divided into four stages: egg, larva, pupa, and adult. Several instars may also occur within the larval stage. Most holometabolous insects are damaging during their larval stage, but not during their adult stage.

Insect and mite pests of turfgrass can be broadly categorized as

1. Foliage and stem feeders, which include the caterpillar (black cutworm, fall armyworm and sod webworm), chinch bug, adult billbug, spittlebug, bermudagrass mite, Rhodegrass mealybug, greenbug and scale insects;
2. Root and rhizome feeders, which include mole crickets, white grubs, billbug grubs and ground pearls;
3. Nuisance pests, for example the fire ant, nuisance ant, ground-nesting bee & wasp, tick and millipede, can invade homes, disrupt turf quality or playability, or have medical significance due to their stings or bites.

Turf-damaging insects and mites either have **chewing** or **piercing** and **sucking** mouthparts. Chewing mouthparts are jawlike arrangements that insects use to tear, chew, and grind plant tissue. Piercing and sucking mouthparts are needlelike beaks that insects or mites insert into plant tissue to suck juices from them.

9.2 DETECTION AND IDENTIFICATION

The first step in formulating any pest management strategy is identifying the damage your turf is experiencing, especially before pest populations reach chronic levels. Insect pests attack grass plants either above or below ground, usually by either feeding directly on roots (below ground) or by sucking sap or chewing grass leaves (above ground). A few, such as Southern mole crickets and fire ants, do not normally feed directly on the plants, but in their search for food or nest building, disrupt the turfgrass surface. This is compounded by animals, such as moles, pigs, birds, skunks, armadillos, and raccoons, digging through the turf as they search for these turfgrass insects as a food source.

Figure 9–2. Rapid turf color loss from armyworms.

Surface (or aboveground)-feeding insects

These insects feed on the leaves and stems of turfgrass plants. Many of these hide in the thatch during the day, and then surface and feed on leaves and stems at night. Other surface-feeding insects remain on the leaf surface and feed. The larvae (caterpillars) of various moths have chewing mouthparts and eat entire leaves and stems. Adult beetles also have **chewing** mouthparts.

Indications of surface-feeding insects include:

1. Birds feeding on the turf surface.
2. Moths (mostly tan in color) flying zigzag patterns over the turf area, especially in late evenings.
3. Rapid turf color loss similar to fertilizer burn or drought stress even though irrigation is provided **(Figure 9-2)**.
4. Notched leaves or residue of chewed grass (frass) at or near the soil surface.
5. Fecal pellets, often green in color.

Other surface-feeding insects have **piercing and sucking mouthparts** that tend to discolor the grass, resembling drought stress. These insects include aphids, chinch bugs, spittlebugs, and mealybugs.

Subsurface (root or belowground)-feeding insects

These insects inhabit the thatch and rootzones, and can be very damaging due to their root and crown feeding. Due to their subterranean location, this group of insects is the most difficult to control. Pesticides must move through the leaf canopy, through the thatch layer, and into the soil. Thatch control, adequate incorporation through irrigation, and subsurface placement in the soil are means to increase the efficacy of control products. White grubs, billbug larvae, mole crickets, and ground pearls are the most damaging subsurface-feeding insects.

Figure 9–3. Poor turf rooting from insect grub feeding where the grass can be rolled up like carpet.

Indications of subsurface-feeding insects include:

1. Visible mounds of soil that are soft and cause excessive scalping injury or tunnels in soil or pulled up due to weak roots.
2. Poor turf rooting where the grass can be rolled up like carpet **(Figure 9-3)**.
3. Damage from insect-feeding animals such as moles, pigs, birds, raccoons, and armadillos.
4. Turf thinning.
5. Yellow, chlorotic turf appearance.

Detection techniques. Inspecting the turfgrass involves several common sampling techniques to identify the most common turfgrass insects. Early detection is important to head-off undesirable and unacceptable aesthetic damage.

1. **Visual Inspection**—Walking around the perimeter of the turfgrass area in question is the first step in detecting insect presence/damage. Pull up some grass stems and see if a particular feeding pattern is noticed. Certain insects and mites cause telltale feeding pattern/damage, for example, bermudagrass mites cause stunted terminals or "witches' brooms" deformation on bermudagrass, caterpillars often remove or chew holes in the leaf blade, and spittlebugs cause yellowish discoloration on centipedegrass. Kneel on your hands and knees and, with a 10X hand lens, see if tiny insects are detectable at the base of the turfgrass plant or on the soil surface. Physical disruption, such as tunneling from mole crickets, is relatively easy to detect when the insects are large nymphs or adults. However, remember the objective is to detect pest populations before major damage occurs. Surface-active insects feeding on aboveground plant portions are easiest to determine by visual inspection.

Figure 9–4. Checking for grubs in turf by severing three sides of a piece of turf and peeling back the grass.

2. **Soil/Thatch Inspection**—Manual inspection of the top two to three inches of soil or turfgrass thatch involves severing three sides of a piece of turf with a shovel and peeling back the grass to expose the thatch and soil **(Figure 9-4)**. White grubs, billbug grubs, and ground pearls are the principal insects found by this method. Several samples in an area should be taken to obtain a representative average.
3. **Soap Flush**—Soap flushing helps indicate insects hiding in the thatch or those moving too rapidly to be seen or caught **(Figure 9-5)**. Mix one to two fluid ounces (30 to 59 ml) of lemon-scented liquid dishwashing soap or one tablespoon (15 ml) of 1 percent pyrethrin in two to three gallons (7.6 to 11 L) of water and apply this to a two × two square foot (0.6 × 0.6 m) area of turf. The solution interferes with insect respiration and, if present, they will soon emerge in an attempt to breath. The area should be observed for at least two minutes to see if any insects emerge. Mole crickets, webworms, armyworms, cutworms, and beetles are detected by this method. Use of more than two fluid ounces (59 ml) of detergent may cause damage to the grass during hot and humid weather especially in cool season turfgrass.

Figure 9–5. Using a 'soap flush' to expose insects hiding in turf thatch.

4. **Water Flotation**— This method is especially effective in sampling for chinch bugs. Water flotation involves inserting a cylinder, such as an open-ended three-pound (1.4-kg) coffee can or a 4 inch PVC pipe, through the turf one to two inches (2.5 to 5 cm) deep and filling with water. Do not add detergent to the water. Stirring the turf may help dislodge insects. Those present should float to the top of the water level within two minutes.
5. **Traps**—Several traps are used to detect turfgrass insect pests. Traps are effective, but some can be costly and require frequent maintenance. Pheromone traps are very pest-specific, whereas other trap types may capture a large variety of pestiferous and non-target insects.
   a. **Pitfall Traps** – Pitfall traps are used to capture insects active on the soil surface and can be constructed of various materials. The simplest and cheapest variety is constructed by burying a plastic cup in the ground, with the rim of the cup flush with soil surface. The cup is then filled to one-third full with 70% ethanol or undiluted propylene glycol (act as killing liquid and preservative). A pitfall trap that captures insects in a larger area consists of 1 inch (2.5 cm) diameter PVC pipe with a portion removed from its side and placed face-up flush with the soil surface. A trap jar, one-third full of 70% ethanol or propylene glycol, is placed at one end of this pipe. As insects move across the soil surface, they fall in the open-sided PVC pipe, crawl down the pipe, and fall in the jar of killing liquid. To prevent dilution of the killing liquid by rainwater, a rain shelter constructed of a plastic plate can be installed over the pitfall traps. A turf manager or scout can pour the content of the plastic cup or trap jar into a large shallow container and examine the content for insect species of interest.
   b. **Pheromone traps** – Females of many insect species, such as Japanese beetle, Oriental beetle and various moth species (armyworms and cutworms), produce sex pheromones to attract males from a long distance. To avoid mistaken mate identification, sex pheromone is very species specific. Pheromone traps consist of a lure that emits a synthetic sex pheromone over a long time, and a collecting device that is either a sticky card, a jar filled with killing liquid, or an insecticide-impregnated kill strip. A scout and turf manager can examine the catch and change the lure and collection device periodically. Pheromone traps are good indicators of adult moth activity, but are not good predictors of potential damage. Pheromone traps are a good monitoring tool, but they are not effective in trapping and killing an entire insect population.
   c. **Light traps** – Night-flying insects are attracted to light, particularly ultraviolet (UV) or black light. Light traps use UV light to attract insects, which fall into a collection jar filled with a killing liquid. Light traps attract a wide variety of both pest and non-pest insect species. If large numbers of insects are captured, determination of population density of species of interest and species identification can be very time-consuming.

Scouts. A professional scout, who may be employed by several nearby courses, may be used to identify and quantify pest populations. Since these scouts visit several courses, pest trends are more easily recognized and useful information from one course can be used to assist others. A scout should typically hold a degree in agronomy, horticulture, entomology, or plant pathology with an emphasis in pest management.

Tools required for scouting vary with pest problems, scout training, and golf course budget. A good set of eyes and an inquisitive mind are essential. These are supported by a standard 10X hand or pocket lens, soil probe, soil profile probe, spade, cup cutter, pocket knife, tweezers, scalpel, collection vials, paper bags, and field identification guides. Soap and water also are necessary for insect monitoring.

More expensive, but precise, instruments may be used in a room designated as a diagnostic laboratory. Included are stereo- and compound-microscopes, soil sieves, pH meter, conductivity meter, and elementary soil analysis kits. These need to be supplemented by ongoing scout training at short courses, formal classes, appropriate diagnostic guides, and opportunities to visit similar facilities to exchange ideas.

Monitoring or sampling plan. The goals of a sampling plan are to estimate the pest population density or damage severity, and to inform turf manager of the potential of damage. Because of the uniqueness of each pest species, a sampling plan has to be developed for each pest species. However, few sampling plans for insect pests are available.

The most time-efficient sampling method focuses on specific locations on the golf course where insect pest problems are likely to occur or have frequently occur. Golf course superintendents (or their scouts) are on the course daily and often notice pest presence or damage. Historical records or experience of problem areas can be used to develop a “pest map” that identifies areas where sampling should be conducted regularly. For example, fall armyworm infestation often occurs first along tree line or erected structures, whereas cutworm or sod webworm problem occurs regularly on certain greens. These problem areas can be marked on a map, scouted regularly, and treated when necessary. This pest map will help reduce the need for wall-to-wall insecticide application. In order to minimize play disruptions and to better recognize specific pest damage such as disease symptoms and nocturnal insect feeding, early morning scouting is suggested.

The fact that most insecticides are most effective against specific life stage of a pest requires a golf course superintendent to have a good knowledge of the seasonal life cycle of pests. Monitoring or sampling plans should be initiated before the appearance of a target life stage. For example, because white grubs are most effectively managed with long-residual preventive insecticides that target egg hatch, the sampling plan for scarab beetles (i.e. adults of white grubs) should begin before the adult flight. Three methods aid in determining the timing of sampling plan initiation:

1. *Calendar date:* Insect pests often appear at approximately the same period each year; a golf course superintendent with prior experience can initiate sampling at about the same time each year. Although calendar-based sampling plans are the easiest to deploy, they are also the least accurate. Insect development depends on temperature and other environmental conditions, and may be accelerated or delayed for several weeks by favorable or adverse environmental condition. The inaccuracy in sampling may cause additional damage or costs.
2. *Plant phenological indicators:* Both insect and plant development are tied to temperature. Therefore, plant phenological events can be used as a signal or indicator of the progression of insect development and events. Annual bluegrass weevils begin laying eggs when flowering dogwood and eastern redbud are in full bloom (use preventive larvicides), whereas larvae begin to appear when Catawba rhododendron hybrid is in full bloom (use curative larvicides). Each insect pest species may have a unique plant phenological indicator; a list could be developed based on a superintendent's experience and research.
3. Degree-day models: Degree-day models measure the total number of heat-units (or degree-days) needed to achieve a particular life stage. Most models start accumulation of degree-days on January 1 and use a base temperature of 50°F. Most Cooperative Extension Services, as well as some online sources, can provide degree-day information for free. Each insect has a unique degree-day model. Adult bluegrass billbugs first appear when 280 to 352 degree-days have accumulated, whereas the first generation of larger sod webworm adults appear when 846 to 882 degree-days have accumulated.

Monitoring frequency may require adjustment depending on climatic conditions (particularly temperature), reports of nearby pest problems, and focus areas. Greens and tees generally require the greatest amount of attention and are monitored daily or every other day. Fairways, roughs, ornamental plantings and trees are monitored usually weekly.

Pest levels should be recorded on a form similar to the one in **Chapter 6**. This will allow the scout and superintendent to monitor pest trends and determine if these levels reach or exceed aesthetic or action thresholds. Pest maps should accompany these forms.

Identification. Correct identification of insects is the perhaps the most important step in developing an IPM program. Based on an incorrect identification or diagnosis of a pest or damage, a turf manager can make the wrong management decision, causing more damage, and wasting time, materials and labor.

Fortunately, only a small number of arthropod pests can cause damage to turf at any given time and on any given area. A turf manager can often narrow down the list of likely culprits by considering the damage caused, where among the turf profile the insect is found, and the time of year. The following sections on individual pest groups will describe characteristics that can aid in identification. A turf manager can also seek help from the Cooperative Extension Service (including county agents and extension specialist) or (public or private) plant problem diagnosis services. It is important to seek diagnosis assistance from reputable services staffed by trained and knowledgeable personnel.

If an insect sample is to be sent to the Extension Service or a diagnosis service for identification, the specimens should be prepared properly in order to retain many of the characteristics that are useful in identification. Most diagnosis services have specific guidelines on preparing and sending specimens; consult and adhere to these guidelines. Always use a crush-proof container, such as hard plastic vials. Large, hard-bodied insects, such as beetles, wasps and moths, should be wrapped in tissue paper and packaged in a container. Large, soft-bodied insects, such as grubs and caterpillars, should be dropped into gently boiling water for about 30 seconds, then wrapped in tissue paper and packaged in a container, or immersed in 70% ethyl alcohol or isopropanol. Soft-bodied or tiny insects should be put in vials filled with 70% ethyl alcohol or isopropanol. If insects are extremely small, ship a sample of the damaged turf. Always send several insect specimens and damaged turf so that a sufficient number of specimens and damage symptoms can be examined. When shipping plant material and alcohol, put the vials or containers in a tightly sealed plastic bag or ziplock bag to avoid the liquid or plant material from spilling. Put the sample and a piece of paper detailing the collection date, location and plant species (and cultivar if known) in a box, and ship to the diagnosis service overnight.

9.3 INSECT CONTROL STRATEGIES

Set Threshold Levels

Once the insect and its damage have been positively identified and its life-cycle understood, pest management involves setting threshold levels, recording pest levels, and possibly applying an appropriate control method. An aesthetic or action threshold is the point when pest populations or environmental conditions indicate some action must be taken to prevent intolerable damage. These thresholds will vary according to the location of the course, the specific pest being scouted, the turf area's level of use, club members' expectations, and budget constraints.

The pest in question will partially determine its aes-

Table 9-1. Aesthetic or action levels for several common turf insects.

INSECT	AESTHETIC OR ACTION THRESHOLD LEVELS (PER SQUARE FOOT)*	INSPECTION METHOD
Annual bluegrass weevil	30 to 80 grubs (spring)	Visual inspection of clipping (adult); soap flush (adult); soil core (grub)
	20 to 40 grubs (summer)	
	5 to 10 grubs (preventive)	
Armyworms	1 to 2 caterpillars	Visual and soap flush
Bermudagrass mite	4 to 8 tufts	Visual
Billbugs	10 to 14 grubs	Visual (adult); pitfall (adult); soil core (grub)
Black turfgrass ataenius	50 grubs	Soil core (grub)
Cutworms	1 caterpillar	Pheromone trap (adult); visual and soap flush (caterpillar)
European crane fly (leatherjacket)	15 to 50 larvae	Visual and soil core
Green June beetle	5 to 7 grubs	Visual and soil core
Hairy chinch bug	15 to 20 bugs	Water float
Japanese beetle	6 to 10 grubs	Pheromone trap (adult); soil core (grub)
May beetles	4 to 5 grubs	Light trap (adult); soil core (grub)
Masked chafers	8 to 20 grubs	Light trap (adult); soil core (grub)
Oriental beetle	8 to 10 grubs	Pheromone trap (adult) and soil core (grub)
Temperate sod webworms	2 to 6 caterpillars	Visual and soap flush
Tropical sod webworm	0.5 to 1 caterpillar	Visual and soap flush

*Smaller numbers represent threshold levels for highly maintained areas such as golf greens and tees. Larger numbers are for less intensively maintained areas such as fairways, roughs, athletic fields, and lawns. Multiply values by 11 to obtain numbers per square meter

thetic threshold. For example, the number of mole crickets tolerated on an area basis is less than the number of sod webworms. Related to this threshold level is the site in which the pest is found; golf greens have a much lower aesthetic threshold than a rough or out-of-play area. Unfortunately, exact threshold numbers have not been developed for every pest encountered in turf. However, **Table 9–1** provides a starting point for several common turf insects. Also, damage by birds and mammals feeding on pest insects may cause more acute damage than the insect.

Biological Control Strategies

Much research and talk has centered on "organic," "non-synthetic," "bio," or "biorational" pesticide control of pests. These bio pesticides have little, if any, adverse effect on beneficial organisms or to the environment. The best approach in pest control is to integrate all possible control and management strategies into a plan, since no single method of control is 100 percent reliable. These strategies include host-plant resistance, pest-free propagation (or sanitation), proper site preparation, cultural practices, and biological control. These are discussed in detail in **Chapter 6.**

Biorational pesticides are derived from a variety of sources, including endophytes, bacteria, nematodes, fungi, other insects, and insect-derived pheromones and growth regulators. Biorational pesticides tend to be short lived; thus, they may require multiple applications, are often life-stage-specific and insect-specific, requiring proper timing of application and positive insect identification.

Endophytes. A relatively new non-0chemical control method of certain insects involves naturally occurring fungi called **endophytes**. Endophytes (living within the plant, between cell walls) are fungi and other organisms that form symbiotic relationships with certain grasses but do not cause disease. Unlike most fungi, endophytes are not externally visible on plants. The endophyte fungus (*Acremonium coenophialum*) was initially discovered in forage production, as cattle and horses feeding on endophyte-containing tall fescue produced a syndrome referred to as "fescue toxicity." However, this fungus has been found to also produce ergot alkaloids (such as peramine, lolitrem B, ergovaline, paxilline, and others) that are toxic or incompatible to certain insects, and have since been transferred to certain turfgrasses. Other fungal endophytes include *Neotyphodium lolli* in perennial ryegrass and *Neotyphodium coenophialum* in tall fescue, while two endophytes, *Neotyphodium typhinum* and *Epichloe typhina*, occur in the fine fescues. In addition to providing resistance to various insects, secondary effects of certain endophytes include providing dollar spot control and increasing plant tolerance to drought and other stresses.

Infected plants appear the same as endophyte-free plants, and laboratory examination is the only way to detect its presence. Plants are not harmed by the fungus. In fact, the endophyte and the grass derive mutually positive benefits from their association. In addition to infested grass being more tolerant to insects, they also have more tolerance to nematodes and drought.

It appears the endophyte is spread only through infected seed. Therefore, cool-season grasses (fine fescue, perennial ryegrass, and tall fescue) currently have the most endophytes incorporated in them since most warm-season grasses are vegetatively established. Endophytes remain viable in storage as seed for only one or two years. Endophytes offer plant breeders and entomologists one of the most significant means for non-chemical control in years. However, market oversaturation, the fungi's fragility, and government regulations to define quantifiable levels have limited the commercial success of endophytes. Hopefully, further research will determine how to transfer these fungi to additional turfgrasses, stabilize their shelf life, increase their efficacy, and possibly offer tolerance to other pests such as nematodes.

Beneficial Bacteria. Several species of the soil bacterium, *Bacillus*, provide various levels of soil and forest insect control. The first, *Bacillus thuringiensis* (or Bt), was discovered in 1901 in Japan. Since then, over 30 subspecies and varieties of Bt have been identified **(Table 9–2)**. These bacterium produce protein crystals (endotoxins) that must be consumed by the insects. Other products produced by the bacteria also must be consumed to control certain insects. Once inside the insect's gut, the crystals dissolve if the proper acidity exists and binds to specific sites in the gut lining. Susceptible insect guts then become paralyzed and the insect stops feeding within a few hours and dies in several days.

Unlike many biological control agents, these bacteria generally are short-lived in the environment; they are readily degraded by direct sunlight, are slow to kill insects, do not reproduce in the insect host, are less effective on larger larvae, and are not spread from treated to non-treated sites. This has limited their acceptability in the commercial arena.

Bacillus thuringiensis varieties currently available include Bt *kurstake* and *aizawai* (best for caterpillars), Bt *israelensis* (for mosquitoes and European crane fly larvae), Bt *tenebrionis* and *san diego* (for potato beetle larvae), and most recently, Bt *buibui* and *gallereiae* (for Japanese beetle, Oriental beetle, masked chafer, and green June beetle grubs). The newer strains have less of these negative attributes and appear to be more efficacious.

Another Bacillus species (*Bacillus popilliae*) was the first microbial agent registered as an insecticide in the United States and has been used to control Japanese beetle grubs. It is often referred to as the milky disease since the bacteria causes the insect's body fluids to turn a milky white color prior to grub death. The use of this bacterium has been limited due to the extended period of time needed for populations to build to infectious levels and become lethal (three to five years). Milky disease also is relatively expensive and can be extremely variable in its control. It is harmless to earthworms, wildlife, humans, and beneficial insects.

Recently, another bacteria, *Serratia entomophila*, has shown promise for the control of grass grubs in New Zealand. A new class of insecticides, Spinosad, called naturalytes contain fermentation-derived products from the bacterium *Saccharopolyspora spinosa*. It is a gut poison; thus, it must be eaten by the insect. It is used at low rates and has relatively short residual activity. Research continues on the commercial development of these and other beneficial bacterium and their products.

Control with Bacillus. In order to be effective, Bt should be applied when the target pest is, or soon will be, actually feeding. Thorough application coverage is also necessary to reach insects feeding on the undersides of leaves and in concealed parts of the plant. Timing in relation to the age of the insect is also important. Young larvae are generally more susceptible than older ones. Scouting for early detection of a pest and timely applications are crucial for successful control with Bt. Since Bt is quickly degraded by sunlight, stickers applied with it may enhance its efficacy.

Genetic engineering has produced "BT genes" which can be artificially inserted into a plant's DNA and the plant then naturally produces the bacterium. As insects feed on these plants, they eventually die from ingesting the bacterium. This technology, though widely used in traditional agronomic crops, has yet to be approved for use in turfgrasses in the USA.

Beneficial nematodes. Research initiated at the University of Florida has led to the identification of several beneficial (or entomogenous) nematodes in the families Steinernematidae and Heterorhabditidae which attack a specific host, yet will not attack plants or vertebrates. These nematodes lack a stylet, or the piercing mouthpart, characteristic of plant-parasitic nematodes; therefore, they do not feed on plants. In addition, these nematodes are relatively easy to mass-produce, they can search out their target hosts, and can be applied with most standard pesticide application equipment assuming the tank is ultra clean, coarse nozzles are used with no filter, and at least 140 gallons per acre (1,200 L/ha) are used. The nematodes rapidly kill their host by entering the host's mouth or spiracles and move through the gut into the blood where a colony of bacteria is released. The bacteria then multiply and produce toxins that kill the infected insect. The nematode continues to feed inside the infected host and eventually reproduces, producing thousands of new nematodes that emerge and search for new hosts.

Since beneficial nematodes are considered parasites, and not microbial insecticides, they are exempt from registration by the USEPA. This greatly speeds up the reg-

Table 9-2. Insecticides for control of turfgrass insect and mite pests, listed by Insecticide Resistance Action Committee (IRAC) group number, mode of action, chemical class and active ingredient.

IRAC	MODE OF ACTION	CHEMICAL CLASSES	ACTIVE INGREDIENT	TRADE NAME EXAMPLES[1]
1A	Acetylcholine esterase inhibitors	Carbamates	carbaryl	Sevin
1B		Organophosphates	acephate	Orthene
			chlorpyrifos	Dursban
			trichlorfon	Dylox
2B	GABA-gated chloride channel antagonists	Fipronil	fipronil	TopChoice, Taurus
3	Sodium channel modulators	Pyrethroids	bifenthrin	Allectus[2], Aloft[2], Onyx, Talstar, Bifen, etc.
			cyfluthrin	Tempo
			cypermethrin	Demon, Triple Crown T&O
			deltamethrin	Deltagard
			lambda-cyhalothrin	Lambda, Battle, Demand, Scimitar, Tandem[2]
			permethrin	Astro
4A	Nicotinic acetylcholine receptor agonists/ antagonists	Neonicotinoids	clothianidin	Arena, Aloft[2]
			dinotefuran	Zylam
			imidacloprid	Allectus[2], Imidacloprid, Merit, Mallet, etc.
			thiamethoxam	Meridian, Tandem[2]
5	Nicotinic acetylcholine allosteric activator	Spinosyns	spinosad	Conserve
6	Chloride channel activators	Avermectins	abamectin	Avid, Award II fire ant bait
7A	Juvenile hormone mimics	Junevile hormone	s-methoprene	Firestrike[2], Extinguish, Extinguish Plus[2]
7C		Pyriproxyfen	pyriproxyfen	Distance Fire Ant Bait
11A	Microbial disruptors of insect midgut membranes	*Bacillus thuringiensis*	*B.t.* subsp. *aizawai*	Xentari
			B.t. subsp. *galleriae*	grubGONE! G
			B.t. subsp. *kurstaki*	Biobit, Crymax, Dipel, Juvelin, Lepinox
18A	Ecdysone agonists, molting disruptors	Diacylhydrazines	halofenozide	Mach 2
20	Mitochondrial complex III electron transport inhibitors	Hydramethylnon	hydramethylnon	Amdro Firestrike[2], Extinguish Plus[2], SiegePro
22	Voltage-dependent sodium channel blockers	Indoxacarb	indoxacarb	Advion fire ant bait, Provaunt
		Metaflumizone	metaflumizone	Siesta fire ant bait
28	Ryanodine receptor modulator	Diamides	chlorantraniliprole	Acelypryn
			cyantraniliprole	Ference
un	Unknown MOA	Azadirachtin Dicofol	azadirachtin	Azatin O, Azatrol, Molt-X, Ornazin
			dicofol	Dicofol 4E
uc	Unclassified: Pathogens	Bacteria	Bacillus popillae	Milky spore powder
			Chromobacterium subtsugae	Grandevo PTO
		Nematodes	Steinernema + Heterorhabditis spp.	Millenium, BioVector, NemaShield
		Fungi	Beauveria bassiana	Botanigard, Naturalis
			Metaehizium anisopliae	Met52, Tick-Ex

[1] Trade names are provided as examples only. No endorsement of products is intended, nor is criticism of unnamed products implied.
[2] Allectus = imidacloprid + bifenthrin; Aloft = clothianidin + bifenthrin; Tandem = thiamethoxam + lambda-cyhalothrin; Triple Crown T&O = zeta-cypermethrin + bifenthrin + imidacloprid; Amdro Firestrike and Extinguished Plus = s-methoprene + hydramethylnon.

istration process since these predators are exempt from long-term toxicological and environmental studies, which greatly increase the time and costs of bringing a new pesticide to the market.

Several beneficial nematodes are available, with more currently being screened as potential control agents. *Steinernema scapterisci* was the first isolated and commercialized nematode, followed by *S. riobravis*. These are used for mole cricket control. Additional beneficial nematodes include *S. glaseri* (white grubs), *S. scarabaei* (white grubs), *S. carpocapsae* (for billbugs and caterpillars such as cutworms, webworms, and armyworms), and *Heterorhabditis bacterophora* and *H. zealandica X1* (for white grubs).

Application rates in the field range from 1 to 6 billion nematodes per acre. These can be applied using most application equipment, with no screen or filter in the nozzle. Subsurface injection has been used but efficacy has not been consistently improved over surface application. Environmental conditions at the time of application are very important in the success of these nematodes. Most are extremely sensitive to ultraviolet light and will survive only briefly when exposed to direct sunlight. These nematodes also are very sensitive to moisture levels as they quickly desiccate. Only early morning or late afternoon applications should be made and irrigated-in immediately to provide high relative humidity, as well as a film of moisture on the leaf and soil surface for the nematodes to survive and move. Nematodes not immediately applied after purchase also must be properly stored to extend their life expectancy. Avoid spray tank temperatures above 77°F (25°C) and soil temperatures above 86°F (30°C) or below 59°F (15°C). Interestingly, biological nematodes may be most effective on mole crickets when applied during the fall adult activity period and tank mixing the nematodes with an insecticide may provide a quick knockdown plus long-term suppression.

Beneficial fungi. Various species of fungal pathogens have been discovered and screened as potential biological control agents. *Beauveria bassiana* and *Metarhizium anisopliae* are used against soil-dwelling and soft-bodied arthropods, such as chinch bugs, chiggers and ticks. Host infection is initiated when the spores of the fungus adhere to the insect body. These spores germinate under the correct environmental conditions and grow into the insect, eventually penetrating its circulatory system. The fungi then rapidly reproduce and produce toxins that kill the insect. Additional fungal spores are then produced that can spread through the environment, infecting other insects. Similar to beneficial bacteria and nematodes, fungal products can be applied with existing spray equipment, provided the tanks are clean of fungicides, fertilizer and other chemicals. Continued moisture and protection from ultraviolet light is required for the fungi to initiate infection, survive and kill.

Parasitic and predatory insects. Insect and mite pests are constantly under attack by their predators and parasites. Big-eyed bugs can be found feeding on southern chinch bugs in the southern United States, and fall armyworms often are preyed upon by paper wasps and ground beetles. Many wasps parasitize turf insect pests, for example, *Tiphia* wasp is a common parasitoid of white grubs and *Larra bicolor* has reduced mole cricket densities at some locations in Florida and Georgia by 90%. These predators and parasites are endemic to turfgrass systems and can help to maintain pest populations at a low level. However, their populations and activities can be severely hampered by modification of the environment (such as building a monoculture) and the application of detrimental insecticides (such as carbamates, organophosphates and pyrethroids).

The population and activities of predatory or parasitic insects on golf courses can be increased through:

1. Release of commercially produced and purchased predators and parasites. This method may not be practical because few predators and parasites are produced by commercial insectaries. Their release also requires detailed knowledge of their biology and ecology, appropriate release method, and careful management of the population and the environment.
2. Conservation or establishment of habitats. This is a more sensible approach to maintaining and attracting predators and parasites. Incorporation of flowering plants in the landscape can provide predators and parasites with food resources (such as alternative prey, plant sap, nectar and pollen) and habitats. Flowering plants that bloom at different times can increase survival of predators and parasites over the seasons. Some Florida golf courses plant *Spermacoce* in the roughs to attract *L. bicolor* wasps, which move into the golf courses to attack mole crickets after feeding on nectar on the flowering plants. It is important to understand, however, that the interactions between flowering plants, pests and predators/parasites are intricately linked and that detailed knowledge of these interactions will be needed to develop a successful habitat establishment program.
3. Judicious use of insecticides. Avoiding or reducing the use of carbamates, organophosphates and pyrethroids in turfgrass systems can help reduce the detrimental effects of these pesticides on predators and parasites. When using beneficial fungi, nematodes and bacteria, also avoid using pesticides that may kill these beneficial organisms.

Insect growth regulators (IGRs). Insect growth regulators are a class of artificial compounds currently being developed that mimic the action of the natural hormone, ecdysone. IGRs interfere with either the normal insect molting process, causing insect mortality, or by altering juvenile hormones, preventing insects from maturing. These also can inhibit the production of chitin, a polymer composite of the insect's exterior. The process is rate dependent and insect specific. Suboptimal application rates cause sub-lethal effects such as rapid maturation of insects to adult stages, and deformities of larvae. As mentioned, certain IGRs are more effective on specific insects; therefore, the turf manager must identify the insect present for maximum effectiveness.

IGRs generally require ingestion for optimum activity; therefore, the insect must be actively feeding when the IGR is applied. Young larval stages are most susceptible to IGRs that attack chitin synthesis. Armyworms, cutworms, sod webworms, fire ants, and white grubs are most susceptible to current IGRs. Typically, they are slower acting than many conventional synthetic insecticides.

Chemical Control

One of the goals of IPM is intelligent and prudent pesticide use. Once pest thresholds are reached, the pesticide used should be the safest one available; spot treatments should be practiced, if possible; and all safety precautions should be followed. Pests should also be treated during the most vulnerable stage of their life-cycle, such as mid- to late June for mole crickets. Refer to **Figures 9–6** and **9–7** for typical life cycles and control timings for the major turf insect pests.

Evaluate the results of the habitat modification and pesticide treatments by periodically monitoring the site environment and pest populations. Keep written records of site pest management objectives, monitoring methods and data collected. Also record the actions taken and the results obtained by the pest management methods. This will provide additional information for club members who do not understand the program but would understand results. This also will aid in demonstrating that golf course superintendents are striving to reduce the chemical inputs in maintaining the course and obtain an ecological balance between man and nature.

Historically, pesticides have been used extensively on golf courses. With an intensive and repeated use pattern, some pests have developed resistance to some of the most commonly used insecticides. A pest population is considered resistant to a particular chemical when a pesticide that was previously effective at controlling the pest has repeatedly failed to reduce the pest population. Pesticide resistance develops when the same chemical class or mode of action is used repeatedly against the same pest population. Some annual bluegrass weevil populations in the northeastern United States are resistant to pyrethroids, whereas some southern chinch bug populations in Florida are resistant to carbamates, organophosphates, cyclodiene organochlorines, pyrethroids and neonicotinoids. The most effective way in delaying or preventing the development of pesticide resistance is to use pesticides of different modes of action against each pest generation. To aid in the design of a pesticide rotation program the Insecticide Resistance Action Committee (IRAC) assigns each mode of action a unique group number. To avoid resistance development, pesticides of a mode of action or one IRAC group number should not follow another pesticide of the same mode of action or IRAC group number. For example, sensible pesticide rotation program against a known pyrethroid-resistant chinch bug population will include a rotation of acephate (IRAC group no. 1), clothianidin (4A) and carbaryl (3). **Table 9–2** lists current insecticides and their modes of action.

Chemical control is not the total answer but is a contributing method in insect pest management. **Table 9–2** lists current insecticides and their families used on turfgrasses. Influence of control is regulated by a number of inherent chemical properties and by environmental parameters interacting with these:

Thatch. This partially decomposed layer of turfgrass leaves and stems is located just below the shoot tissue and right above the soil layer. Excessive thatch (>½ inch, 1.3 cm) provides an ideal habitat (e.g., warmth and humidity) within which most insects can reside. Due to its high organic matter content, the thatch layer also tends to "tie-up" or

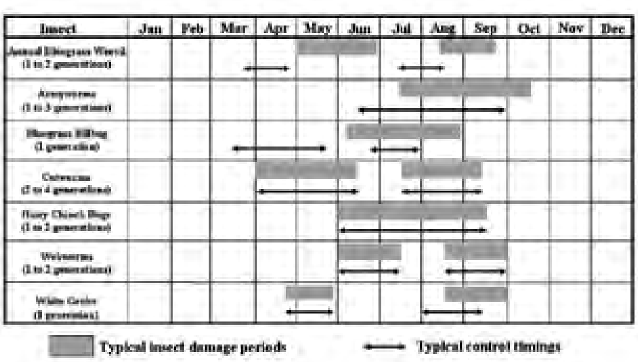


Figure 9–6. Typical damage periods, control timings, and generations per year for insects in the northern regions of the United States.

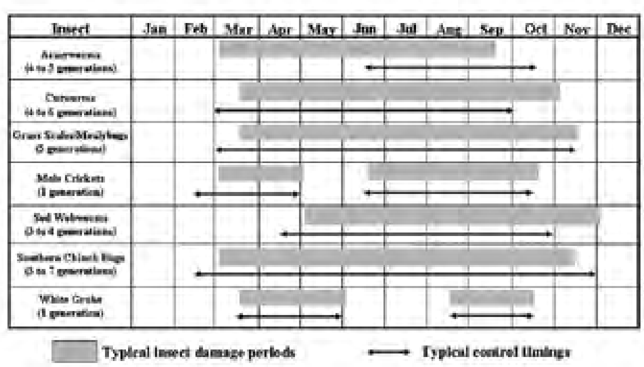


Figure 9–7. Typical damage periods, control timings, and generations per year for insects in the southern regions of the United States.

bind many applied pesticides. This lowers the effectiveness of these pesticides, especially when dealing with soil-inhabiting insects. Thatch control should be a routine practice for most golf courses, especially on greens and tees. One method of by-passing the thatch layer is application with a high-pressure injector or a slit granular applicator.

Irrigation. Irrigation water moves surface applied insecticides into and through the soil profile. For insecticides applied against soil- or thatch-dwelling insects, such as white grubs and mole crickets, materials should be watered in with irrigation or rainfall soon after the application to allow penetration of the chemicals to the soil layer where the insects are feeding. When applied against surface- or leaf-feeding insects, however, irrigation should be withheld or rainfall should be avoided for at least 24 hours to allow contact between insects and pesticide residue on the leaf surface. Read the label to determine if a specific product should be irrigated after application.

Ultraviolet Light (UV) Degradation. Exposure to sunlight often breaks chemical bonds that may make the compound inactive. Pyrethroids, insect growth regulators (IGRs), bio (microbial) pesticides, and botanical insecticides are often susceptible to UV degradation. Applying susceptible products late in the evening and/or watering them off the leaf surface are two means turf managers can use to reduce UV degradation.

Weather. Weather conditions, especially temperature, often influence the frequency of insect generations and severity of insect infestations and damage. A rapid temperature drop to subfreezing temperatures often kills significant numbers of overwintering insects. Drought conditions often delay development or reduce pest reproduction. Generally, as temperatures increase, insects reproduce and develop faster.

pH of Spray Tank and Soil. Most insecticides require a neutral (pH=7) or slightly acidic pH in the tank mixture. When the pH in a tank mixture exceeds 7.0, the product begins to disassociate through hydrolysis into inactive or ineffective byproducts. However, not all insecticides are sensitive to pH. After the tank-mix is made and agitated, the pH of the resulting solution should be taken. If a high pH is detected, a commercial buffering agent or acidifier should be added. Use the mixed pesticide solution immediately, never store overnight or leave the sprayer in open sunlight. Read the label and Materials Safety Data Sheet (MSDS) to determine if a particular pest control compound is sensitive to pH.

Enhanced Microbial Degradation. Microbes (usually bacteria and simple fungi) present in the soil often can use a portion of pesticides as a food source. During this process, complex compounds are broken down into those used for food. Certain continuously used pesticides can become victims to enhanced microbial degradation. Populations of aerobic microbes build up to levels that quickly break down pesticides within hours after being applied. Reduce the chance of enhanced microbial degradation by (1) rotating between classes of pesticides, (2) using one class of pesticides only once per year, and (3) applying only the recommended amounts of materials as excessive rates may favor microbial build up.

Longevity of Control. Modern synthetic insecticides belonging to the chemical classes organophosphates, carbamates, and pyrethroids are generally very effective against the target pest if application timing and methods are followed as recommended. One drawback to these materials, however, is their relatively short control. Three to 14 days, depending on the material, insect, and environmental conditions (as discussed earlier), is the general range of control for most of these materials. Improper application and subsequent watering practices reduce the control longevity of these materials as do excessive thatch layering, sunlight (UV) exposure, and improper spray tank pH levels.

Control also is rarely 100 percent effective, even if ideal application parameters and environmental conditions exist. However, populations should be lowered to below aesthetic levels. Slow repopulation from survivors and subsequent hatching of eggs and migration of adults from nearby untreated areas may require retreatment. Newer insecticides, such as imidacloprid and fipronil, show good soil longevity, and are extremely environmentally safe.

Food Quality Protection Act (FQPA). In 1996, the United States Congress passed the FQPA, which considered the potential exposure of infants and children to pesticides. Since it is believed children do not metabolize pesticides as efficiently as adults, traditional toxicology tests were believed not to provide an adequate margin of safety for them. The Environmental Protection Agency (EPA) modified toxicological studies to include "aggregate" and "cumulative" exposure.

All avenues of exposure now must be considered during the insecticide registration process, including minuscule amounts in water, meat and produce, drift, applications in schools or restaurants, and on lawns and gardens. Also, the EPA started reviewing all members of insecticides within the same family or class together. Studying "cumulative" exposure considered the tolerances of similar compounds on the same crop, and the total (cumulative) exposure must be considered when determining allowable residues for each compound. This led to the "risk cup" concept, which considered the total use of a class of products and set lower limits for this amount.

As a result of FQPA, companies were told by the EPA what production limits would be allowed for each class of insecticides; thus, companies started to decide which products and which markets were profitable enough to meet the lower production forecasts. Since people are sensitive to cholinesterase inhibitors, the organophosphates and carbamates were among the first group to be reviewed. Many home and ground labels were withdrawn or greatly revised to minimize exposures or to bring ingredients within the limits of this "risk cup."

Many widely used, broad spectrum products have disappeared or soon will, from the turf and ornamental markets. Dursban (chlorpyrifos), Turcam (bendiocarb), Oftanol (isofenphos), Crusade/Mainstay (fonofos), Mocap (ethoprop), and Triumph (isazophos) are some early casualties of FQPA. Fortunately, new products are being introduced to help replace some of the uses of cancelled ones. Newer products, however, only control specific pests, are more expensive, and are not as broad in their control as previous products. They, however, are deemed much more favorable in their toxicological properties but require more knowledge on insect life-cycles and movement patterns for optimum effectiveness.

9.4 SURFACE- OR LEAF-FEEDING INSECTS

Tropical Sod Webworm

Species. Tropical sod webworm, *Herpetogramma phaeopteralis* Guenée (order Lepidoptera: family Crambidae), feed on warm-season turfgrasses in the southeastern United States from Florida to Texas, Oklahoma, Tennessee and South Carolina. This species is also common in the Caribbean through Central America. The grass webworm [*Herpetogramma licarsisalis* (Walker)] is a turfgrass pest in Hawaii.

Description. Adults are dingy brown moths about 4/5 inch (20 mm) in length. Unlike the temperate sod webworms, adult tropical sod webworms hold their wings flat in a triangle shape and lack prominent snouts. Caterpillars have cream-colored bodies, yellowish brown heads, and brown spots along the length of the bodies. Pupae are often buried in thatch, reddish brown, 35/100 inch (9 mm) long, and 1/10 inch (2.5 mm) wide.

Biology. Adult moths prefer to rest in tall grass and shrubs during the day, and become active at dusk. Females live for 10 to 14 days and deposit several clusters of 10 to 35 eggs on the upper surface of grass blades. Eggs hatch in about 4 days, and the caterpillars develop through 6 larval instars in 21 to 47 days (depending on temperature) before reaching pupal and adult stages. Due to fatal cold temperatures, it is unlikely tropical sod webworms overwinter outside of Florida. Moths gradually migrate north in late spring and by early summer, become the sources of infestations in other states.

Damage Symptoms/Signs. Tropical sod webworms feed on all warm-season turfgrasses but prefer St Augustinegrass and bermudagrass. Caterpillars feed at night and hide in the thatch during the day; they prefer to feed in dry, hot turf areas. Young caterpillars feed on the upper leaf surface, creating 'windows' that can be easily overlooked. When mature caterpillars consume the entire leaf blade, a 'ragged' or thinned turf often results. Damaged areas may appear as patches of thinned turf and exposed thatch that become increasingly large. Roots, stolons and meristems of turfgrass are not affected by the infestation; therefore, with management and care, the turf can regrow and recover. In Florida, severe damage may occur in late fall when the moth population is the largest and the grass growth is slowest. Additional damage may be caused by birds and mammals digging for the caterpillars in the turf.

Sampling and Control. Early detection of infestation is crucial to the management of tropical sod webworm. "Hot spots" where annual infestations repeatedly appear should be monitored every 7 days through visual inspections and soap flush. Look for caterpillars and chewing damage in the periphery of thinned or poorly grown turf areas. Caterpillars are often found near the soil surface, and curl into a C-shape when touched. Also look for the silk trails left behind by the night-feeding caterpillars; the trails are easier to see when dew is present. Caterpillars usually climb up the grass blades within 5 minutes of soap flush. The activities of birds and other mammals, and flying moths between dawn and dusk, also help pinpoint areas with potential infestations.

The action threshold of tropical sod webworm is 5 to 10 caterpillars/m^2 (or about 1 caterpillar per ft^2) in high-maintenance turf in dry, sunny areas. Insecticide applications 10 to 12 days after observing the adult moths can provide effective control of young caterpillars. Irrigation should be withheld for 24 hours after the application of contact insecticides, whereas post-treatment irrigation is needed to move systemic insecticides to the root zones. Granular formulations of contact insecticides may not be effective because the concentration of active ingredients on leaf blades, where the caterpillars are feeding, may not be high enough.

Beneficial fungi (*Beauveria bassiana*) and nematodes (*Steinernema carpocapsae, Steinernema feltiae, Heterorhabditis bacteriophora* and *Heterorhabditis indica*) can be used against the tropical sod webworm. A study in Florida reported a reduction up to 93% in webworm population after *S. carpocapsae* application. A large number of predatory and parasitic insects feed on the tropical sod webworm. An egg parasitoid, *Trichogramma fuentesi* (Torre), parasitizes > 80% of eggs.

Avoid thatch build-up and stressful conditions by practicing fertilization, irrigation and mowing that are appropriate for the turfgrass species and location in question. Clipping removal may help reduce webworm population by removing eggs deposited on the grass blades. 'Common' and 'FB-119' bermudagrass is less preferred for larval development, whereas 'Amerishade', 'Floratine', 'FX-10', 'NUF-76', 'Winchester' St Augustinegrass, and 'Cavalier', 'DALZ8501' and 'JZ-1' zoysiagrass, are less preferred for oviposition and larval development.

Temperate Sod Webworms

Species. A large number of sod webworms (order Lepidoptera, family Crambidae) feed on warm- and cool-season turfgrass in the temperate regions of the United States. Some of the most common species are:

- Bluegrass sod webworm, *Parapediasis teterrellus* (Zincken), which is distributed in the eastern United States from Massachusetts to Connecticut and westward to Colorado and central Texas. This species is most prevalent in Kentucky and Tennessee where Kentucky bluegrass is dominant. Caterpillars also damage bentgrass greens, with symptoms similar to grub feeding.
- Striped sod webworm or changeable grass-veneer, *Fissicrambus mutabilis* (Clemens), which is found from Florida to New York and Ontario, and west to Illinois and Texas. This species is especially prevalent in Pennsylvania, Illinois, and Tennessee.
- Large sod webworm or greater sod webworm, *Pediasia trisecta* (Walker), which is distributed from North Carolina, Tennessee, Texas, New Mexico, and Colorado north to Washington state and southern Canada. This species is especially prevalent in Ohio and Iowa.
- Burrowing sod webworm, *Acrolophus popeanellus* (Clemens), which is sometimes a problem in the Midwest and southeastern United States.
- Silver-striped webworm, *Crambus praefectellus* (Zincken), which is found along the Pacific Coast and areas west of the Rocky Mountains in the United States.

These species have similar biology and management; therefore, they are discussed as a group in this section.

Description. Adult moths are small, dingy brown to almost white-colored, with a wingspan of ¾ inch (1.9 cm) and delicate fringes along the wing borders. Resting adult sod webworm moths have a very long, distinct, snout-like projection in front of their heads (giving this group a common name of 'snout moths'), and roll their wings in a tube (different from the flat, triangular-shaped wings of the tropical sod webworm). Temperate sod webworm adults are identified to species by varying wing color patterns and male genitalia, while larvae are extremely difficult to separate. Sod webworm caterpillars have a dark yellowish-brown head and greenish or beige, hairy body with numerous brown spots scattered over it. Mature larvae are ¾ inch (1.9 cm) long. Most sod webworm larvae curl into a ball when disturbed.

Biology. Temperate sod webworms overwinter as larvae tightly coiled in silk-lined tunnels or cases. In spring, the larvae pupate within these tunnels or cases and the adults emerge, mate, and lay eggs. During the day, moths rest in shrubbery adjacent to turf areas. At dusk they fly in a zigzag pattern over the turf, depositing clusters of 6 to 15 eggs on grass leaves. Eggs hatch in approximately 7 days when temperatures are at least 78°F (26°C) and larvae progress through 7 instars, requiring 25 days to complete their development. When temperatures are lower (72°F or 23°C), the caterpillars develop through 8 larval instars in 45 to 50 days. They pupate on the soil surface and emerge as adult moths in 7 days. Life-cycle from egg to adult requires 5 to 6 weeks at 78°F (26°C) and 12 weeks at 72°F (23°C).

In the southern United States, 3 to 4 generations may occur between late April and mid-October, with caterpillars overwintering from October to March. In the transition zone or middle region of the United States, 2 to 3 generations occur in May-September. In the northern United States, there may be 1 to 2 generations in May to September. Overwintering caterpillars can be found from October to April in central to northern United States.

Damage Symptoms/Signs. Adult sod webworms do not feed, but larvae damage grass by chewing blades or severing blades above the thatch and pulling this into their silk-lined tunnels. When first hatched, they only rasp the surface or skeletonize the blades. Damaged areas appear grayish and usually are only 2 to 3 feet in diameter. Often, damage is first noticed adjacent to shrubbery and flower beds where moths are resting. Moths are attracted to dark-green, healthy turf; therefore, golf greens provide a choice site for them. When larvae become larger, they notch the blades and grass becomes ragged in appearance. Injury initially appears as small, closely cropped grass patches as grass blades are clipped just above the crowns. Damaged areas then become larger and they often fuse. Continued feeding gives the turf a close-cropped yellowish, and then brownish, appearance from the exposed thatch. Webworms normally do not kill turf; therefore, turf normally can recover if the webworm is controlled and proper fertilization and watering practices are used. Birds often pull out the paper-like white silk sacs where the caterpillars hide, leaving them lying on the grass.

Sampling and Control. Approximately 2 to 6 caterpillars/ft^2 are required to cause economic damage. Irregular brown spots resembling dollar spot disease are early signs of damage. The presence of larvae can be confirmed by parting the grass and observing the soil surface in suspected areas for frass, pellets or curled-up resting larvae. They also can be flushed to the grass surface by using a soap solution. Flocks of birds frequently return to an infested turf area, especially in early morning. The presence of large numbers of moths flying over the turf area at dusk indicate the presence of sod webworms and egg-laying periods. The turf area should be monitored for webworms once a week when the moths are most active in an area. Damage is most evident in late summer when populations have increased and grass growth is slowed.

Insecticides may be applied after observing the adult moths or when the presence of caterpillars is confirmed by the sampling program. Irrigation should be withheld for 24 hours after the application of insecticides. Long residual control of sod webworm is difficult because moths are continually flying into the turf area and depositing eggs during the summer months. In addition, degradation of insecticide residues and constant growth of turfgrass also leave new grass unprotected, necessitating repeated applications during the peak activity of the sod webworms.

Control of early instar larvae is possible with various microbial insecticides containing *Bacillus thuringiensis* var *kurstaki*. Control is best on young larvae. Beneficial nematodes (*Steinernema carpocapsae* and *Heterorhabditis bacteriophora*) and fungi (*Beauveria bassiana*) are also available. Insecticides and microbial products should be applied late in the day to target caterpillars feeding at night. Endophyte-infested tall fescues and ryegrass may help reduce sod webworm damage. Several insect pathogenic nematodes are also being screened as possible control measures, as are some fungal endophytes and ichneumonid wasps.

Fall Armyworm

Species. The fall armyworm, *Spodoptera frugiperda* (Smith), is a perennial pest problem of all turfgrass species in areas east of the Rocky Mountains, particularly in the southeastern United States. Other armyworm species, such as the yellow-striped armyworm [*Spodoptera ornithogalli* (Guenée)], the true or common armyworm [*Pseudaletia unipuncta* (Haworth)] and the lawn armyworm [*Spodoptera mauritia* (Boisduval)] (all order Lepidoptera, family Noctuidae), are occasional turfgrass pests in various parts of the United States, and can destroy a turf area during outbreak. Armyworms were described by American colonists as a pest which devoured crops like an "army of worms."

Insect Description. Fall armyworm larvae are the injurious stage and are 1.5 inches (3.8 cm) long when mature. The caterpillars are greenish when small and dark-brown when fully grown. They have a light dorsal stripe, darker bands on each side running the length of the body, and four black spots on the end of the body. The caterpillars also have a distinct inverted yellow or white "Y" shape on their heads. Adult moths are brownish with light and dark markings and a distinct white blotch near the tip of each front wing. They have a wing span of about 1.5 inches (3.8 cm). Common armyworms do not have the light-colored Y-shaped mark but rather a brownish head with H-shaped darker brown lines.

Biology and Distribution. The life-cycle of the fall armyworm varies considerably according to the region. Armyworms continuously reside in Central and South America and the West Indies. They also survive mild winters in southern Florida and Texas. They spread each spring from these areas into the eastern United States and into southern New Mexico, Arizona, and California, reaching the northern states in fall; hence, their common name.

Female moths prefer to deposit eggs on light-colored, erected objects near turf, such as flags, poles, posts and fences. Each female is capable of producing 1,000 to 2,000 eggs over her lifetime of 7 to 21 days. Eggs are laid in clusters of 100 to 200, and are covered with grayish, fuzzy scales from the body of the female moth. Eggs hatch in about 3 days, and caterpillars develop through 6 instars in 14 to 30 days, depending on the temperature. Mature caterpillars burrow about 1 inch into the soil and pupate. A generation takes 5 to 6 weeks to complete. There may be 4 to 5 generations per year between May and November in the southeast. Except for those in southern Florida and Texas, all fall armyworm populations die each fall after freezing temperatures. The common armyworm is more cold tolerant and can survive as larvae or pupae further north.

Damage Symptoms/Signs. Despite its name, the fall armyworm is capable of causing damage to turfgrass in early summer, especially following cool, wet springs, which may reduce populations of natural parasites. However, most damage occurs during late summer and early fall after populations have increased during the season. Larval feeding is similar to webworm feeding except it usually does not occur in patches, but in more uniform and larger areas. Larvae feed day or night, but are most active early in the morning or late in the evening. Younger larvae feed on leaf margins, giving them a ragged look. Larger larvae eat all aboveground leaves and stems, resembling a "mowing." Bentgrass, bermudagrass, fescue, bluegrass, seashore paspalum, ryegrass, and grain crops (especially sweet corn) are most often attacked.

Inspection and Control. Moths typically lay eggs on structures such as buildings and fences and on plants such as shrubs and trees. Therefore the infestations almost always begin along the margins or edge of the turfgrass area. They migrate or "march" when the larvae are about 3 weeks old and can cause extensive damage at this time. Soap flushing can bring the larvae to the soil surface. Feeding birds and the presence of green fecal pellets also indicate an armyworm presence. Adult moths are often attracted to lights at night during flight periods. Management using insecticides and microbial products should target younger caterpillars; therefore, early detection is crucial to the management of fall armyworm.

Threshold levels vary on lower maintenance turf, but control may be justified if one armyworm is found per square foot on a green. Current strains of *Bacillus thuringiensis* offer inconsistent control. However, endophyte-containing grasses such as ryegrasses or fescues are quite resistant to armyworms. Stoloniferous grasses, such as bermudagrass, generally recover from armyworm feeding since the pests do not destroy plant crowns. Non-stoloniferous grasses, such as fescue, may not fully recover.

The spinosyn toxins and the parasite *Steinernema* nematodes provide biorational control. As new Bt strains are produced, they also may provide acceptable biorational control. Most synthetic pesticides such as the pyrethroids, organophosphates, carbamates, indoxycarb, IGRs, neonicotinoids, and spinosad also provide effective control. In addition to treating obviously damaged areas, treat one or two boom-widths outside the infested area to control the probable additional caterpillars feeding beyond.

Cutworms

Species. There are several cutworm species (order Lepidoptera, family Noctuidae):

- Black cutworm, *Agrostis ipsilon* (Hufnagel), is the most significant pest species on golf course turf throughout the United States, and the only cutworm species that requires regular management.
- Variegated cutworm, *Peridroma saucia* (Hubner), is an occasional pest of turfgrass.
- Granulate cutworm, *Feltia subterranea* (Fabricius), is found most often in the southern regions.
- Bronzed cutworm, *Nephelodes minians* (Guenée), is an occasional pest of turfgrass and prefers bluegrass.

Cutworm species vary slightly in habits and appearance from each other, but their life histories are generally similar. Because of its economic importance, the following description is based on the black cutworm.

Insect Description. Adult cutworm moths are generally stout-bodied, hairy, and have a wingspan of about 1.5 inches (3.8 cm). The forewings of adult moths are gray-black to dark brown, and mottled or streaked in color, whereas the hindwings are lightly colored and unmarked. Black cutworm adults have a distinctive black, dagger-shaped marking in the center of each forewing, which is lacking in other cutworm species. Resting cutworm moths hold their wings flat in a triangular position. Cutworm caterpillars are fat, hairless, dull gray or brown to nearly black-colored on the back, light gray in the bottom, with a pale stripe on the middle of the back, and measure about 1.75 inches (4.4 cm) when fully grown. If disturbed, the larvae usually curl into a C-shaped position.

Biology and Distribution. Cutworms are found throughout the United States. Adults and larvae are nocturnal and hide during the day, but may become active on cloudy days. Caterpillars often hide in silk-lined burrows, and may take advantage of existing coring holes. They overwinter in the soil either as pupae or mature larvae. In the spring, the hibernating larvae pupate and adults begin to appear in mid-March. Female moths deposit eggs singly or in clusters, and each female can lay as many as 1,200-1,600 eggs. Under optimum conditions, the eggs hatch in three to five days, and larvae develop in three to four weeks, passing through six instars. Pupae mature in two weeks during the summer but may require up to nine weeks in the fall. As many as four generations occur each year.

Figure 9–8. Typical feeding damage from surface-feeding insects such as cutworms.

Damage Symptoms/Signs. Cutworms are caterpillars that feed on the stems and leaves of young plants and often cut them off near the soil line; hence, their common name (Figure 9-8). Many prefer wilted plant material and may climb ornamental plants and feed on unopened buds. Bentgrass is a major target of cutworms and they often reside in and eat extensively around aerification holes. Damage to greens from insect-feeding birds can also be substantial. Damage appears as one- to two-inch (2.5- to 5-cm) dead spots resembling ball marks on closely cut turf with a pencil-sized hole in the middle.

Inspection and Control. Adult flight activities can be monitored with commercially available pheromone traps. Once adults are trapped, visual detection for feeding damage and soap flush for caterpillars can begin. Since cutworms are mostly nocturnal, late afternoon is best for their detection. Examine the turf for damage. Initial feeding symptoms often are mistaken for ball mark damage. Later symptoms often appear similar to dollar spot disease except a hole where the caterpillar resides can be found in the center of the damaged area. The soap or pyrethrum flush test will also aid in detection (use caution when using soap flush on bent greens in hot weather).

Threshold levels for golf greens are approximately one cutworm per square foot (11/m^2), while 5 to 10 larvae per square foot (54 to 108/m^2) are tolerable on fairways and lawns. Control is best when applied in late afternoon to early evening. Bt and *Steinernema* nematodes are effective on young (first to third instars) larvae. Many liquid insecticides provide good control. These should be applied late in the evening and **not** irrigated-in, as the insecticide should be left on the leaf surface for the insect to feed on. Granular insecticides may not be as effective. Because cutworms can move a long distance, a band 20 to 30 ft wide around golf greens should be treated to prevent the cutworms from moving into the greens. Repeated applications may be needed, especially for short-residual contact insecticides, because moths from overlapping generations are always present, eggs may be continuously produced, and cutworms might migrate from nearby turf areas.

Mowing removes 80 to 90% of cutworm eggs deposited on the tip of the grass blades. However, as the clippings fall onto other areas, these eggs can still hatch and initiate new infestation. Clippings should be removed and not moved onto greens with the mowing equipment. Cutworms do not seem to be greatly affected by the endophytic toxins in ryegrass and fescues.

Bermudagrass Mites

Species. The bermudagrass mite, *Eriophyes cynodoniensis* Sayed (order Acarina, family Eriophyidae), appears in all bermudagrass-growing states. It is also commonly referred to as the "bermudagrass stunt mite." Isolated cases of Eriophyid mites on zoysiagrass can also occur.

Insect Description. The mites are extremely small, only about 1/130-inch (0.2-mm) long, yellowish-white, and somewhat wormlike in shape with only two pairs of short legs. A microscope with at least 30X magnification is needed to see them.

Biology and Distribution. Bermudagrass mites are probably native to Australia but have spread to New Zealand, Africa, and America. They are found in all United States bermudagrass-growing regions. The biology of bermudagrass mites is poorly known. They multiply very rapidly, requiring only about seven days to complete their life-cycle. This short life-cycle allows for rapid build-up during late spring and summer. Each female is believed to produce 10 to 12 eggs in her lifetime. Eggs are deposited under the leaf sheath, and after hatching, mites molt twice before reaching adulthood. All stages are found under the leaf sheaths. Mites appear well-adapted to hot temperatures and become relatively inactive during cold temperatures. They spread through infected plants, clippings, machinery, mobile insects, and even by wind.

Damage Symptoms/Signs. Since the bermudagrass mite is so small, it remains hidden beneath the leaf sheath. Therefore, it can be identified more easily by symptoms of grass damage. The mites suck plant juices with their needle-like mouth parts that cause a characteristic type of damage. Grass blades turn light-green and abnormally curl. Typical vigorous spring growth is noticeably absent. Internodes shorten, tissues swell, and the grass becomes tufted so small clumps, often bushy in appearance, are observed. This is often called "witch's brooming" **(Figure 9-9)**. This characteristic growth is believed to be caused by a toxin injected into the developing grass node. The grass loses its vigor, thins out, and may die. Injury is more pronounced during dry weather and especially when grass is stressed due to poor maintenance. Since damage is often associated with drought stress, providing adequate moisture and nutrients helps the grass outgrow mite damage.

Inspection and Control. In most bermudagrass cultivars (such as Celebration), the witch's broom symptom is very easily detected and a reliable diagnostic characteristic for the infestation. In other cultivar (such as Tifway), however, the grass blades merely turn light green and the witch's broom symptom does not always appear. In this case, visual inspection of the light-green grass and the detection of the bermudagrass mite will be needed to confirm infestation. Inspection should focus on thinned turf, and symptoms may be most noticeable on taller-mowed grass, such as rough areas, around sand traps, and along canals and fence rows.

The following sampling plan and thresholds may be used. Construct a 3 x 4 ft rectangular frame with PVC pipes. Inside the frame, thread string through holes drilled through the PVC pipes at 1 ft intervals, creating a grid with 12 squares. Toss the frame onto an infested turf and count the total number of witch's brooms in 10 of the 12 squares. Once a month, take 1 sample every 50 ft on fairways and roughs, 4 frame samples from each greens approach, and 2 samples from each tee bank. Apply miticide if on average 4 or more witch's brooms are found in each sample. If less than 4 damaged stems are found, then a cultural control program may be sufficient. An alternative threshold for control is 4 to 8 witch's brooms per square foot. These sampling plans and thresholds have not been rigorously verified in the field.

There is currently no effective pesticide against the bermudagrass mite. Azadirachtin, bifenthrin, chlorpyrifos, cyfluthrin, deltamethrin, dicofol, and lambda-cyhalothrin are currently registered for general mite control in turfgrass; most have been ineffective against bermudagrass mite. The most effective insecticide is diazinon, which is no longer registered for use in turfgrass. Abamectin, dicofol and chlorpyrifos are alternatives to diazinon, but their

Figure 9–9. 'Witches brooming' damage of bermudagrass from stunt mite feeding.

efficacies are lower and will require repeated bi-weekly or monthly applications. The addition of a surfactant that helps pesticide solution to penetrate into the leaf layer will increase efficacy.

Lower mowing height may help remove many infested stems. Scalping and vacuuming clippings may be effective in removing the most severely infested grass. A higher fertilization and irrigation rate after scalping may allow recovery of infected turf. It is important to clean the mowing equipment thoroughly because infested clippings can initiate new infestations in other areas. Maintain good soil moisture, as dry conditions tend to favor mite damage.

Grass Scales or Mealybugs

Species. Over 37 species of mealybugs have been associated with grasses. Two major grass scales occur: (1) the rhodesgrass mealybug, also called rhodesgrass scale, *Antonia graminis* (Maskell); and (2) the bermudagrass scale, *Odonaspis ruthae* Kotinsky (order Homoptera, family Pseudococcidae and Diaspididae). These are not common pests but do occasionally occur in the United States from South Carolina to California, most often on bermudagrass and St. Augustinegrass, especially growing in shade. Rhodesgrass scale derives its name from feeding on its favorite host, rhodesgrass, a coarse-textured pasture grass. The buffalograss mealybug, *Tridiscus sporoboli* (Cockerell) and *Trionymus* sp., is often found on buffalograss but appears to cause little economic damage. Ground pearls also are scale insects and are discussed separately.

Insect Description. The rhodesgrass mealybug body is round and dark brown but is covered with a white cottony secretion that appears like tufts of cotton on the grass. Male mealybugs resemble tiny gnats with a single pair of wings and three pairs of red eyes. Adult males are not considered harmful to turfgrasses. The bermudagrass scale is oval shaped, white, wingless, and approximately 1/15 inch (1.7 mm) in diameter. They prefer the taller grass in rough areas, especially in heavily thatched and shaded areas. They also are found around sand traps, along fence rows, and in other similar areas. When the scales hatch into the crawler stage, they migrate beneath the leaf sheath, usually at the nodes. Only the youngest, immature stages are mobile. Adults settle on the leaf or stem, insert their needle-like mouthparts, become immobile, and eventually start excreting a white, cottony, waxy covering.

Biology and Distribution. The life-cycles of both insects range from 60 to 70 days, and there are up to five generations per year in the southern United States. Continuous generations occur from Orlando, Florida, south.

Damage Symptoms/Signs. As mentioned, bermudagrass and St. Augustinegrass are their favorite hosts. They infest the crown, nodes, or under leaf sheaths (not the leaves) and withdraw plant sap with their piercing/sucking mouthparts. Infested grass slowly loses vitality, discolors, and later appears to be suffering from drought. Stunting and thinning of the grass stand occurs under high infestation levels. Under heavy infestations, plants are often covered with tiny masses of white, waxy secretions. Injury is most severe during extended hot, dry (stressful) periods. The rhodesgrass mealybug produces considerable honeydew, and other insects such as ants or bees may be present on heavily infested turfgrass.

Inspection and Control. Plant leaves should be pulled away from the stem and sheaths examined for tiny, white cottony masses. Ants feeding on the honeydew also can indicate mealybugs. Since these insects produce more damage during dry weather, keep the turf well-irrigated and fertilized. Cultural control includes collecting grass clippings, which will contain some scales, and destroying them. Several insecticides provide control but are rarely needed. If needed, thorough spray coverage is necessary and a surfactant should be added.

Annual Bluegrass (or Hyperodes) Weevils

Species. *Listronotus maculicollis* (Dietz) (order Coleoptera, family Curculionidae); formerly *Hyperodes* sp. near *anthracinus* (Dietz), is the annual bluegrass weevil.

Insect Description. Larvae are C-shaped, legless, and from 1/32- to 3/16-inch (0.8- to 5-mm) long. Larvae are creamy-white in color with light brown to tan heads. They are difficult to distinguish from billbug grubs. Adults are small (1/8-inch, 3-mm, long) black to dark-gray weevils, about half the size of the Kentucky bluegrass billbug, and can be distinguished from the billbugs by the position of their antennae – the antennae of the annual bluegrass weevil emerges from the end of the snout; the antennae of billbugs emerge from snout closer to the head. The annual bluegrass weevil also has a broader snout than a billbug. Adults initially appear reddish in color when they first emerge from the pupal stage but turn black as their exoskeleton hardens.

Biology and Distribution. Annual bluegrass weevils are most often encountered in the northeastern United States including New York, southwestern Connecticut, northern New Jersey, Pennsylvania, Maryland, Delaware, and all of the New England states into Ontario and Quebec. It is a native insect to the United States and occurs in at least 40 states. The insect has two to three generations annually in the United States. Adults are in the overwintering stage and often hibernate in the leaf litter under trees of golf course roughs, and become active in early spring, often corresponding with early plant flowering. Eggs are deposited in early May in chewed-out stems. Larvae hatch in four to five days and burrow into the stems, eventually feeding on plant crowns, killing the plants. Sawdust-like frass is evident from this feeding and is apparent by late spring. Five instar stages occur, each lasting five to ten days, and resembling each other except becoming larger in size, appearing as a grain of rice with a brown head. Mature larvae pupate near the soil surface in mid-June. Pupae are somewhat diamond-shaped and creamy white. Young adults emerge in late June, lay eggs in mid-July, and the second generation of small larvae emerge in late July. Newly emerged adults are a rusty brown color, turning black in a few days. Most of these larvae pupate in late August. Since life-cycles overlap, all stages of development can be found from late June through early September. This becomes a challenge as small larvae, large larvae, pupae, and adults can occur at the same time, making it difficult to determine the dynamics of the population. If, for example, the population is primarily pupae, no current insecticides will work satisfactorily. It may be prudent to wait a week or so, until most of the pupae have emerged as adults. If most of the sample is in the adult stage, treat immediately to minimize egg laying. Currently, only annual bluegrass is the host of annual bluegrass weevils. It appears only in short-mowed (≤1/2 inch, 1.3 cm) annual bluegrass such as greens, tees, and fairways.

Damage Symptoms/Signs. Damage is generally most severe in early June and again in mid-summer (late July) when other turf stresses, such as water, fertility, and mowing, weaken the turf. Damage is from larvae feeding and begins as small yellow patches and brown spots that appear wilted or water-soaked and increase into larger areas **(Figure 9-10)**. Turf does not normally respond to watering. This is from larva severing stems from the plant. The edges of fairways, near woods, tees, or collars are often initial sites of damage. Feeding damage resembles anthracnose symptoms, causing easy misdiagnosis. Severe damage resembles a water-soaked appearance from the hollowed grass stems. Reducing *Poa annua* population reduces the presence of this insect as may the removal of fairway litter in late fall or early spring where adults reside.

Inspection and Control. Suspected infested areas should have a physical inspection in spring (April to early May).

Figure 9–10. Damage to Poa annua from annual bluegrass weevils.

A cup cutter (or similar device) should be used to collect cores. Break up the cores and place the loosened soil and plant parts in a pan filled with lukewarm water. This forces adults to crawl to the surface. A soapy flush can also be used in the field to indicate an adult presence. Another flush solution involves 0.75 cup (0.18L) of table salt (NaCl) in a quart (0.9L) of lukewarm water. If present, after about five minutes, all stages of weevils (except eggs) will float to the surface, although up to 45 minutes may be required.

Insecticides should be applied in spring just prior to adults beginning to lay eggs and can usually be timed when flowering shrubs and trees such as forsythia, wisteria, and dogwood bloom, typically from mid-April through early May. Where the second generation occurs, a follow-up insecticide application may be needed in early July. Treatments should be lightly watered-in. Threshold levels range from 30 per square feet (323/m^2) for golf greens and other areas in summer, and up to 50 per square foot (540/m^2) for well-maintained fairways and other areas in spring. Lower-maintained (non-irrigated) turf may have lower (e.g., 20 to 40 weevils per square foot, 215 to 430/m^2) threshold levels. Chlorpyrifos and synthetic pyrethroids (bifenthrin, cyfluthrin, lambda-cyhalothrin, deltamethrin) are used as periphery sprays for adults as are spinosad and a combination of bifenthrin and imidacloprid. A turf manager should rotate among insecticides of different modes of action because the annual bluegrass weevil has been reported to develop resistance to pyrethroids. All products typically require 2 to 5 annual applications with one or more of these as a fairway application.

The annual bluegrass weevil has few natural enemies. The beneficial nematode, *S. carpocapsae*, has been shown to reduce > 70% of larvae feeding in the soil. Since the annual bluegrass weevil only damages annual bluegrass, a turf manager may consider reducing annual bluegrass in the turf area or growing a different grass species. Removal of fairway litter (where adults reside) in late fall or early spring also reduces the number of overwintering adults. Healthy turf is the first step against damage.

9.5 SUBSURFACE- OR ROOT-FEEDING INSECTS

Mole Crickets

Species. Mole crickets (order Orthoptera, family Gryllotalpidae) are subterranean insects and are considered the most serious turfgrass pest in sandy, coastal plain areas from North Carolina to Texas. Isolated outbreaks have also occurred in southern California and Arizona, causing severe damage to bermudagrass, bahiagrass, and centipedegrass. Several species exist, including:

- The Southern mole cricket, *Scapteriscus borelli* Giglio-Tos, and
- The Tawny mole cricket, *Scapteriscus vicinus* Scudder (previously called the Changa or Puerto Rican mole

cricket), are the most damaging species on turfgrass.

- The Short-winged mole cricket, Scapteriscus abbreviatus Scudder, is found in isolated areas in the United States.
- The Northern mole cricket, *Gryllotalpa hexadactyla* Perty, is the only species native to the United States and causes least damage.

The following discussion focuses on the two most damaging species, the Tawny and Southern mole cricket.

Insect Description. Mole crickets are 1 to 1.5 inches (2.5 to 3.8 cm) long when mature and possess spade-like front legs that are well-adapted for tunneling through soil. Nymphs resemble adults but are smaller and wingless. The color patterns of Southern and Tawny mole cricket are distinct; the tawny mole cricket is a lighter creamy brown, while the Southern mole cricket is grayish to dark-brown and usually has four distinct light spots on its prothorax. The two species also can be distinguished by their dactyls (digging claws). The Southern mole cricket has a U-shaped space between its dactyls while the Tawny has a V-shaped space. A third species, the short-winged mole cricket, is abundant locally, especially along the southeast and southwest coasts in Florida. It is similar in appearance to the Tawny mole cricket, but has short wings and cannot fly; thus, it has limited distribution. The Southern, Tawny, and Short-winged species were introduced into the southeastern United States around 1900 as stowaways in sand used as the ballast material of South American ships. They are found throughout the Coastal Plain region of the southeast and northern Argentina, Uruguay, and Brazil. A fourth species, the Northern mole cricket, is native to the United States, but is not considered to be a major pest. It primarily inhabits moist soil adjacent to water.

Biology and Distribution. Mole crickets have a gradual metamorphosis life-cycle where adults appear similar to nymphs except for their underdeveloped wings. In most locations, the Tawny and Southern mole crickets have one generation per year. The process of this life-cycle begins in spring, when adults fly, mate, and lay eggs. In spring, starting in March and peaking in April, Tawny mole cricket adults are attracted to lights, with major flights during the full moon. Southern mole cricket flights begin in April and peak in mid- to late May. Flights may be delayed during cool, wet, windy weather conditions. The spring flight is the larger of the two flights. The second minor flight (the dispersal flight) is made in fall between August and December. This dispersal flight enables new generation adults to reach previously uninfested areas, locations previously protected from crickets, and areas already populated by these insects. The flights may be up to 6 miles (9.7 km) per night.

Mole crickets mate and disperse via flying in the spring. Adult males attract females by using a harp-shaped area located on the wing between the two forelegs. This "harp" resonates to produce a mating call. Males construct trumpet-shaped chambers at the soil surface during the mating period to increase the intensity of the mating calls. This also helps ensure females are attracted to areas with good soil moisture to lay eggs. The hollow tops of these chambers are often visible in early spring.

Inspection by soap flushing should be performed throughout this period and females constantly inspected for egg development. Most of the eggs are laid within the first 12 inches (0.3 m) of soil, but cool and/or dry weather may cause these chambers to be constructed at a greater depth. Females often lay eggs near where they mate as this usually is moist soil, increasing the chances of egg and nymph survival. Females usually lay about four clutches of eggs per year, and average 35 eggs per clutch. Adult males die after mating while adult females die after depositing their eggs.

In most of the southern United States, oviposition (egg laying) begins in late March with a peak in May. Eggs hatch in 20 to 25 days, and their emergence is complete by mid-June. Extended drought conditions may delay oviposition and egg hatch. The small nymphs are easiest to control, yet cause little visible damage; thus, are often ignored. Nymphs feed and mature throughout the summer, molting five to eight times, although their wing buds do not appear until the last two instars. As nymphs mature, it becomes more difficult to manage and control them. Adults begin to appear in the fall. Tawny mole crickets overwinter mostly as adults, while Southern mole crickets overwinter primarily as large nymphs. In most of the southeast, the Southern and Tawny mole crickets have only one distinct generation per year.

Tawny mole crickets tend to tunnel deeper into the soil than the Southern mole cricket which tends to dig and feed near the soil surface. This is important as the Tawny mole cricket may escape the lethal effects of some surface-applied insecticides. The Tawny mole cricket also tends to dig two V-shaped tunnels, presumably to provide

Figure 9–11. Extensive turf damage from mole crickets.

an alternative route for escaping enemies.

Damage Symptoms/Signs. Mole crickets damage turf in several ways. Tawny mole crickets are herbivorous and consume all parts of the grass plant. The Southern mole cricket is a predator and a scavenger, feeding on earthworms and insects, and is believed not to prefer plant material as food. Both species tunnel through the surface layer of the soil, causing considerable mechanical damage to the grass roots. The tunneling also loosens the soil so the grass is often uprooted, resulting in desiccation that can disrupt and break pre-emergence herbicide barriers, enabling weeds to germinate **(Figure 9-11)**. The majority of turf damage occurs in early spring when adults are active, and in late summer and fall when nymphs are reaching maturity. As one walks across infested turf, the ground often feels spongy because of burrowing and displacement of soil near the surface. Counts of up to 100 nymphs per square yard ($84/m^2$) can occur in heavily infested areas.

Most mole cricket tunneling occurs at night, with highest activity occurring a few hours after dusk and again just before dawn. They are especially active after rain showers or after irrigation in warm weather. Most activity within the top two inches (5 cm) of soil occurs when night temperatures are above 60°F (15.6°C). Both nymphs and adults tunnel in the top inch of soil and come to the surface to feed when soil is moist and may tunnel up to 20 feet (6 m) per night in moist soils. Their feeding and tunneling are greatly reduced during cold weather or when soil is dry.

Inspection and Control. The following critical steps are necessary for mole cricket control.

1. **Mapping.** Mole crickets tend to return to the same areas year after year. Mapping provides best indication where to scout later for nymphs to determine when the eggs are hatching. Mapping also pinpoints where spot treatment of insecticides is needed, eliminating wall-to-wall treatments. Map the infestation areas in spring, since adults usually lay eggs in the same area(s) where spring damage is seen. Mapping heavily infested areas in fall also indicates where damage is likely to occur in spring.
2. **Scouting.** Sample for the mole crickets with a soap flush. Sampling in the spring serves two purposes: 1) to determine the density and if the action threshold has been reached; and 2) to determine the life stage or size so that treatments can be applied when the nymphs are still small. When adults are collected, cut open the abdomen of a few females to determine if the eggs have matured and are ready to be deposited.
3. **Timing.** After the majority of egg hatch has occurred and before nymphs grow past ¼-inch (6.4 mm) long, apply the appropriate control product. This is typically from mid- to late June in the Carolinas. Irrigate prior to application and lightly afterwards (according to label instructions) for best results. Continue to monitor the treated area with the soap flush and be prepared to spot treat areas with unacceptable control.

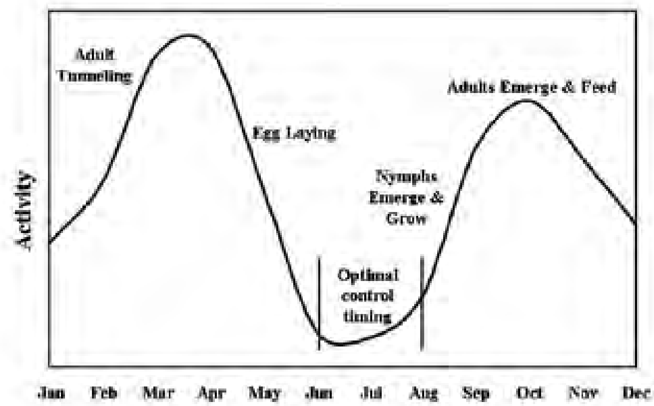


Figure 9–12. Mole cricket yearly activity graph indicating the optimum timing for control when the nymphs are young and actively growing.

In order to control mole crickets, a clear understanding of their life-cycle and behavioral patterns is essential, followed by proper mapping of damaged areas, scouting for egg hatch, and timing of insecticides of small newly hatched nymphs. A poor appreciation of what mole crickets are doing at any particular point in time is a recipe for failure **(Figure 9–12)**. Without this appreciation, successful control is unrealistic. Maps of each golf hole are useful in scouting and should be made in October or November indicating heavily infested areas. Additional mapping should be made in late winter through spring when overwintering mole crickets become active. Tawny mole crickets typically infest the same sites yearly. Mapping can pinpoint these preferred sites, enabling spot treatment of the heaviest infested areas. Spring mapping during periods of adult activity provides knowledge on where the majority of nymphs reside and where to apply your insecticide during early summer. If these areas are not mapped and treatments applied shortly after hatch when nymphs are small, insecticides become less effective by the time one sees activity in mid- to late summer.

To determine which species is prevalent in your particular area and the relative population level, use the following soap flush. Mix three tablespoons (44 ml) of lemon-scented liquid dishwashing detergent in two gallons (7.6 L) of water. Apply the soap mixture over a 2 × 2 foot (0.6 × 0.6 m) area of infested turf using a two-gallon (7.6 L) sprinkling can. Mole crickets present will surface in a few minutes. Flushing late in the afternoon or early in the morning, especially in moist soil, is best. This technique also may be used to verify the presence and developmental stage of nymphs. As crickets mature, the soap flush becomes less effective.

The majority of turf damage occurs in late summer and fall when the nymphs are reaching maturity. Tunneling damage also occurs in late winter and spring from overwintering adult crickets. Damage subsides in May after eggs are deposited and most adults have died. It usually is mid-July before nymphs reach sufficient size to again cause noticeable turf damage. Timing of the pesticide application is one of the most important aspects of successful mole cricket management. Mid- to late June usually is the optimum time to obtain maximum control with an insecticide application. Specifically, in the southeastern United States, treatment for Tawny mole crickets nymphs is typically late June while for Southern mole crickets, its early to mid-July as Tawny mole cricket eggs usually hatch about two weeks before those of the Southern mole cricket. Yearly environmental variations in temperature and soil moisture may affect the timing of hatch as warm and moist conditions can results in earlier hatch than normal while cool dry conditions may delay hatch.

As mentioned, mid- to late May through June, depending upon your location, is generally the best time to control mole crickets with insecticides, especially preventive (long-residual) ones. This is when nymphs are large enough to feed on or near the soil surface when insecticides are applied. Materials with the longest soil residual (three to six weeks) should be used to control the nymphs at or even before this time and include fipronil (Choice) and imidacloprid (Merit). It is crucial when using these materials to apply them right at, or soon after, egg hatch **(Table 9–3)**. Turf should be moist before insecticide treatments are made. Apply the pesticide as late in the day as possible, with dusk being the optimum time. Follow label directions explicitly regarding safety, dosage, application, and irrigation information. Later-hatching nymphs should also be treated with another long-residual material in mid-July. Commercial baits also are effective for this mid-July application as crickets are then big enough to ingest enough bait to make it effective. Moist soil and dry turf foliage at the time of application provide the best control with baits. Irrigation after bait application should not occur for several days as this may degrade the material.

By August, nymphs have grown considerably and become more difficult to control. Baits generally are still effective at this time, as are most curative insecticides including the pyrethroids and acephate (Orthene). Most commercial insecticides also are effective at this time. These should be applied when soils are moist to encourage cricket activity nearer the surface. Most insecticides (baits and Orthene are exceptions) need about a ½ inch (1.3 cm) irrigation following application to move the material into the soil and to encourage surface activity by the crickets. The residual activity of these products is relatively short; thus, it should be applied after the bulk of mole crickets have hatched. Late afternoon or evening applications provide the best control with all products.

By fall, numerous adults are present. At this time, they cause extensive damage and are difficult to control. Feeding continues throughout the fall until cold temperatures drive the crickets further down in the soil. Spot treatment generally is the best method of controlling adults. Timing for control is at dusk as feeding is optimum at this time.

In spring, feeding by adults declines as they prepare tunnels to lay eggs. Cutting open several fertilized females in spring helps better pinpoint when they will begin to lay eggs. Young eggs are white to almost clear in color, and turn tannish-brown just before being laid. When approximately 50 percent of the developing eggs inside the females become hard and BB-like, eggs will be laid in about one week and should begin to hatch in approximately one

Table 9-3. Comparison of insecticides for mole cricket control in turf.

ACTIVE INGREDIENT	TRADE NAME	RESIDUAL	COMMENT
Fipronil	Chipco Choice*	Very long	Slit applications only; caution use label.
Fipronil	Chipco TopChoice*	Long	Broadcast application; water-in; four months control.
Imidacloprid	Merit	Intermediate	Several formulations for various sites.
Imidacloprid	Advanced Lawn Season Long Grub Control	Intermediate	Best for nymphs; apply at egg hatch.
Lambda-cyhalothrin	Battle/Scimitar/Demand	Intermediate	Best for nymphs; apply after egg hatch.
Trichlorfon	Advanced Lawn 24 Hour Grub Control	Short	Low odor; controls nymphs and adults.
Acephate	Orthene, Pinpoint, Velocity	Short	Standard for nymphs in summer.
Baits	Baits	Baits	Baits
Carbaryl	Sevin	Short	Good for mid- and late-season nymphs.
Indoxycarb	Advion	Short	Quick acting. Good for larger nymphs.
Chlorpyrifos	Mole Cricket Bait, Dursban	Short	Do not water in. Apply in evening.

*Not effective on white grubs.

month. No registered insecticide provides outstanding control of adults in a single application at this time. Spot treating the most damaged areas is currently the most economical means of control. Parasitic nematodes also work best on adult crickets; thus, they may be considered at this time.

The parasitic nematodes, *Steinernema scapterisci* and *S. riobravis*, and the red-eyed Brazilian fly, *Ormia depleta*, are being utilized as biological control agents against mole crickets. These natural enemies were imported from South America and are specific mole cricket parasites, while harmless to non-target organisms. The nematodes enter the crickets through the mouth or spiracles. They penetrate the gut and enter the hemocoel where bacteria is released in the hemolymph. The mole cricket then dies from bacterial poisoning. The nematodes pass through several generations inside the dead mole cricket. About 100,000 nematodes can emerge from a single insect. The red-eyed fly, a tachinid, locates mole crickets by their singing and deposits live maggots on or near their host.

As with most biological control agents, the beneficial nematodes and the red-eyed fly are slower to control the mole cricket host and control will never be 100 percent. However, as the populations of these beneficial organisms increase, control effectiveness also increases. The parasitic nematodes are most effective on adult crickets that are prevalent during early spring (e.g., March in the Carolinas) and early fall (October to November, before frost).

Providing good soil moisture also is necessary for survival of these parasitic nematodes. Tawny mole crickets avoid contact with endopathogenic fungi (*Beauveria busiana and Metarhizium anidopliae*), suggesting these could potentially be used in mole cricket management.

White Grubs

Species. White grubs (order Coleoptera, family Scarabaeidae), the larvae of scarab beetles, are among the most serious insect pests in the United States. Although over 1,500 different scarab beetles occur in North America, the most common in turf include **(Figure 9–13)**:

- Japanese beetle, *Popillia japonica* Newman.
- May beetle, *Phyllophaga* sp.
- Black turfgrass ataenius, *Ataenius spretulus* Haldeman.
- Green June beetle, *Cotinis nitida* (Linnaeus).
- Masked chafer, *Cyclocephala borealis* and *C. lurida*.
- European chafer, *Rhizotrogus majalis* (Razoumowsky).
- Asiatic garden beetle (*Maladera castanea*).
- Oriental beetle (*Anomala orientalis*)

Native species to the United States include masked chafers, black ataenius, and various May or June beetles. Introduced species include Japanese beetle, European chafer, Asiatic garden beetle, and Oriental beetles (*Anomala orientalis*).

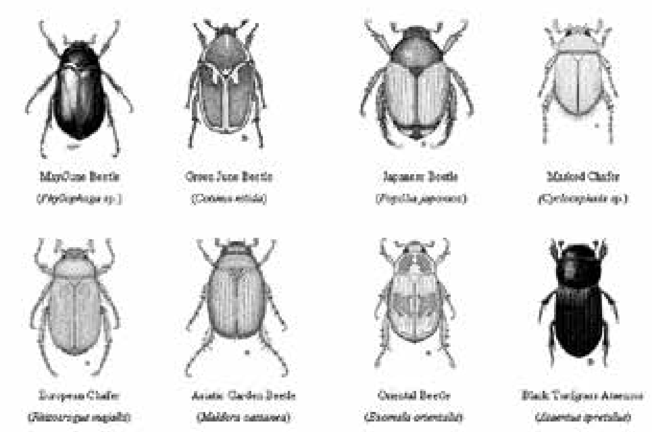


Figure 9–13. Illustrations of various white grub adults (USDA).

Insect Description. The grubs of different species are similar in appearance. They have white to cream-colored robust bodies with brown heads, have three pairs of small legs, and have a dark area at the rear of their 10-segmented abdomen. Depending on the species, they range from three-eighths to two inches (1 to 5 cm) long when mature and rest in a C-shaped position, especially when disturbed.

Black turfgrass ataenius (BTA) grubs are quite small, ¼ inch (0.6 cm), compared to almost 2 inches for grubs of May and June beetles. They are sometimes mistaken for young grubs of Japanese beetles, masked chafers, or other larger species. BTA grubs can be distinguished by a pair of pad-like bumps at the tip of the abdomen, just in front of the anal slit. These are fairly easy to discern with a 10X hand lens. The main blood vessel, which runs longitudinally down the back, typically appears almost black in contrast to the gray-white body. The black ataenius grubs tend to be a more serious problem in northern states, especially on bluegrass and bentgrass roots. Specific identification of larvae is difficult and is based on the form, shape, and arrangement of coarse hair, bristles, or spines (the raster) on the end abdominal segments **(Figure 9–14) (Table 9–4)**.

Eggs of various species are similar in appearance. Eggs are typically shiny and white, but vary in size depending on the species. The eggs of black turfgrass ataenius are less than 1/32 inch (0.7 mm), whereas those of green June beetles are 1/16 to 1/8 inch (1.5-3 mm) long. They are roughly oval when first laid in the soil (at about 1 to 4 inches deep), and become more spherical as they absorb moisture from the soil.

Biology and Distribution. Most scarab beetles, including the Asiatic garden beetle, the European chafer, the green June beetle, the Japanese beetle, the Oriental beetle and the

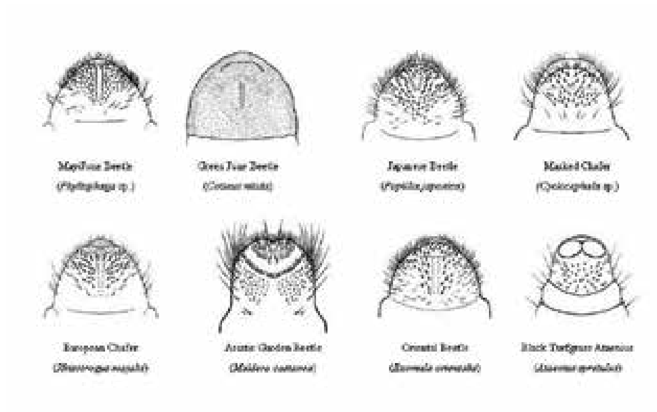


Figure 9–14. Raster location used for identification on white grub beetles.

masked chafers, have a one-year life-cycle. There are two generations of black turfgrass ataenius per year, whereas each generation of May beetles takes 2 to 4 years to complete. May beetles and other species with an annual life-cycle overwinter as large grubs. Adults of these species start flying in May or June, with peak flight activity in June in South Carolina. In the southern states, overwintering black turfgrass ataenius adults begin flight in April, the adults from the first generation begin flight in July-August, and the adults from the second generation that are dispersing to overwintering sites begin flight in October-November.

Adults of many scarab beetle species, such as the Japanese and May beetles, feed on ornamental plants and other crops. Some species, such as the masked chafers, do not feed as adults. From May to August, females burrow into the soil and deposit eggs in the first two inches below the soil surface. During July through August, eggs hatch, and the first instar larvae begin feeding on turfgrass roots. Grubs continue feeding on the grass roots, molt twice, and grow larger until winter before working their way deeper into the soil just below the frost line to overwinter. The following spring they return to the rootzone and continue to feed on grass roots until April to June. They then pupate a few inches below the soil surface. Adult beetles emerge during late May through early July to mate and lay eggs. Turf damage from grubs with annual life-cycles usually is most evident in late summer (late August and September), with less damage apparent during the spring feeding season. May beetles spend the extra years in the grub stage, feeding throughout the growing season and moving deeper into the soil each winter.

Damage Symptoms/Signs. Grubs feed on all species of grass, although green June beetle grubs tend to feed mainly on decaying organic matter. They feed on the roots at, or just below, the soil-thatch interface and cause large patches of turf to die. Damage is most pronounced from mature grubs in late summer and early fall (August through October) and less so during spring (April and May). During heavy infestations, the soil surface may become very loose and spongy to walk on. In severe cases, roots are pruned so extensively that the turf mat can be rolled back like a carpet exposing the C-shaped white grubs. Damage is ill-timed, being just prior to summer stress for cool-season grasses and just prior to dormancy for warm-season grasses. Symptoms of grub infestation include a gradual decline forming a yellow mosaic pattern, or consistently wilting grass in an area even though adequate water is available **(Figure 9-15)**. Continued feeding causes larger patches of turf to thin and die, allowing weeds to invade. Additional damage may occur from predatory animals such as armadillos, birds, hogs, skunks, raccoons, moles, or opossums. Unlike the other white grubs, green June beetle grubs do not feed primarily on plant roots but uproot the grass and push-up small mounds of soil. Adult scarab beetles do not feed on turfgrasses; however, some adult scarab beetles (e.g., Japanese beetle) aggressively feed on ornamental plants and trees during June and July.

Inspection and Control. Good turf management such as adequate moisture and fertilization help the turf withstand moderate grub infestations. Adult beetles are often found in swimming pools, in areas under lights, or slowly crawling across turf areas. To check for grubs, use a spade to cut three sides of a one-foot square (0.3 m^2) piece of sod. The cuts should be two inches (5 cm) deep at the edge of one of the off-color areas. Force the spade under the sod and lay it back. See if the grass roots are chewed off and sift through the soil looking for the larvae. Check several places in the turf area. As a rule of thumb, if an average of three to seven grubs is found per square foot, an insecticide should be applied. However, irrigated areas and lower-maintenance areas can withstand 25 to 50 grubs per square foot (270 to 540/m^2), depending on the species and size.

The Japanese beetle is one of the easier species to manage, while oriental beetles and European chafers are more problematic. Biological control has been provided by strains of the bacterium, *Bacillus popilliae* and *B. thuringiensis* (Bt), and parasitic nematodes, *Heterorhadbitis bacte-*

Figure 9–15. Above-ground turf damage symptoms from white grub feeding.

Table 9-4. . Identification of adult scarab beetles and white grubs.

		WHITE GRUB	
SPECIES	**ADULT**	**SPINE OR RASTER PATTERN**	**ANAL SLIT SHAPE + ADDITIONAL CHARACTERISTICS**
Asiatic garden beetle	1. Body 5/16 to 7/16 inch (8-11 mm) long; 3/16 to 1/4 inch (5-6.4 mm) wide. 2. Dull chestnut brown; velvety or hairy. 3. Wing covers do not reach the tip of abdomen, exposing the last two abdominal segments. 4. Small erected hairs in the top of head.	Tightly packed semicircle of spines just in front of the anal slit.	• Anal slit branched; • A cream-colored tumor-like expansion on the sides of the mandibles on the head
Black turfgrass ataenius	1. Body 3/16 to ¼ inch (3.6-5.5 mm) long; about half as wide as long. 2. Shiny black; with grooves running along the wing covers.	No distinct pattern of spines is present	• Anal slit branched; • A pair of pad-like bumps at the tips of the abdomen, just in front of the anal slit; • A distinguishable black-colored blood vessel running down the back.
European chafer	1. Body 9/16 inch (13 mm) long. 2. Light reddish brown, with a slightly darker head and pronotum. 3. Wing covers have longitudinal grooves and minute punctures.	Two rows, roughly parallel to each other, resembling a partly open zipper.	• Anal slit branched.
Green June beetle	1. Body ¾ to 1 inch (19-25 mm) long; ½ inch (12.5 mm) wide. 2. Upperside ranges from dull brown with lengthwise stripes of green, to velvety forest green. Underside is shiny metallic green to gold.	Two short rows of spines, parallel to each other. Few additional spines are present.	• Anal slit transverse; • Legs are very small compare to the body.
Japanese beetle	1. Body 5/16 to 7/16 inch (8-11 mm) long; ¼ inch (12.5 mm) wide. 2. Head and body are shiny metallic green; wing covers coppery-brown; legs dark green. 3. Each side of abdomen has patches of white hairs.	Distinct V-shaped pattern of spines pointing toward the insect's head.	• Anal slit transverse.
May beetles	1. Most species are 5/8 to 1 inch (11-25.4 mm) long. 2. Color range from tan, light brown to reddish brown or black. 3. Some species are hairless, but others are hairy. 4. Adult identification by experts is recommended.	Two rows, roughly parallel to each other.	• Anal slit V or Y-shaped.
Masked chafers	1. Body 7/16 to ½ inch (11-12 mm) long; ¼ inch (6 mm) wide. 2. Dull yellow-brown (northern masked chafer); shiny, reddish brown (southern masked chafer). 3. A chocolate-brown band across the head (between the eyes). 4. Adult identification best performed by experts.	No distinctive pattern; 25-30 spines randomly scattered in the anal region. Adults and grubs of southern and northern masked chafers are virtually indistinguishable.	• Anal slit transverse.
Oriental beetle	1. Body 3/8 inch (9-10 mm) long. 2. Straw-colored to brownish-black; head is solidly brown. 3. Wing covers have variable black markings, and longitudinal grooves.	With two parallel rows of 10 to 16 short inward-pointing spines.	• Anal slit transverse.

riophora and *Steinernema* sp. The milky disease from these bacteria is most active on Japanese beetle grubs. Grubs ingest this while feeding and the bacteria causes the grubs body fluids to turn a milky white color (hence, the name) prior to death. Bts produce crystalline proteins that destroy the insect's gut lining. Bacteria population build up and control require an extended time period, typically three to five years. The parasitic nematodes show promise but must be applied yearly within moist soil. A dark-colored, hairy wasp, Scolia dubia, is often seen hovering over turf in late August or September. Female wasps sting a grub to paralyze it and deposit an egg; upon hatching, the wasp larva consumes the grub. These wasps are virtually harmless to humans unless picked up or stepped on with bare feet.

Commercial insecticides are partially (75 to 90 percent) effective. This is due, in part, to the subterranean habit of the larvae, which reduces the effectiveness of most surface-applied insecticides. Timing is critical. Application should be made just after egg laying for targeted species when using systemic insecticides. A contact insecticide such as trichlorfon or carbaryl also may be needed in spring if damage is excessive by overwintering second instar grubs. Once grubs reach the third instar stage in late spring, insecticides become less effective than when grubs are small and actively feeding. Larger grubs in fall are much more difficult to control and tend to go deeper in the soil when temperatures cool. These grubs emerge in spring and are also very difficult to control.

Two windows of opportunity exist for maximum grub control: pre-grub damage and post-grub damage. Pre-grub damage occurs during the time from pre-egg lay to second instar grubs, typically early June through mid-July. Longer residual products such as chlorotraniliprole (Acelepryn), imidacloprid (Merit), clothianidin (Arena), thiamethoxam (Meridian), and halofenozide (Mach II) typically provide the best control then. Control is slow with these products, typically occurring 10 to 20 days after application. Although effective on small grubs, these materials are less efficacious on larger, more mature grubs.

Post-grub damage occurs when grubs are larger—late second to third instar, typically from late August through spring (March and April) of the following year. Turf damage from vertebrate pests also often occurs then. Trichlorfon (Dylox) and carbaryl (Sevin) provide quick knockdown as a rescue treatment during this time but control is usually only about 50 to 60%. Control is fairly quick, within one to two days after application. These, however, have a very short residual (<1 week) and require multiple applications for extended control. One common problem of using post-grub damage products against some species such as green June beetle grubs, is the presence of piles of dead, smelly grubs littering the soil surface that require a morning-after clean-up.

Control will be more effective if the soil is kept moist for several days before treatment to encourage grubs to come closer to the soil surface, and thereby more susceptible to insecticides. Apply as late in the afternoon as practical and irrigate immediately with one-fourth to one-half-inch (0.6 to 1.3-cm) of water for maximum effectiveness. Thatch control also is extremely important as excessive thatch tends to bind or tie-up most insecticides. Enhanced soil degradation of certain insecticides used for grub control also is currently suspected.

Ataenius control is best timed in spring (late May), when adults are laying eggs, using a longer residual product. If control methods are delayed until damage is evident, control becomes less effective since the grubs have finished feeding and are less affected by the insecticide. Insecticides should be lightly watered-in to move them into the thatch layer where the insects are located. Alternative control timing is when larvae begin to hatch from late May on. These applications should be thoroughly watered-in to move the materials through the thatch to the soil layer.

Billbugs

Species. In cool-season grasses: the bluegrass billbug, *Sphenophorus parvulus* Gyllenhal; the lesser billbug, *S. minimus*; and the Denver or Rocky Mountain billbug, *S. cicatristriatus* are most important. In warm-season grasses: the hunting billbug, *Sphenophorus venatus vestitus* Chittenden; and the Phoenix billbug, *S. phoeniciensis* on bermudagrass are most important. Billbugs are in the insect order Coleoptera, family Curculionidae.

Insect Description. Billbugs are weevils or beetles with distinguishable snouts (or bills). Adult beetles are about ⅜-inch (1-cm) long, typically weevil-like in appearance with a short, fairly broad recurved snout, and are relatively broad in their shoulder regions. They have chewing mouthparts at the tip of their distinctive snouts. They are gray to black but often are covered with soil, giving the beetle a dirty appearance. Eggs are generally white, bean-shaped, and about 1/16 inch (1.6 mm) long. Grubs are 3/8-inch (1-cm) long when mature, their body is white with a tan head and they are legless. Billbugs can be identified to species based on the wart patterns on their pronotum. However, life-cycle and biology are similar among the species. Billbugs generally have overlapping generations in the Carolinas, where all life stages can be found throughout the year.

Billbugs are not a persistent problem in turfgrass. Damage from this pest usually is sporadic. Several years may elapse before infestations reoccur. Zoysiagrass and bermudagrass grown in the warm-season and transition areas are the hunting billbug's favorite hosts; however, bahiagrass, St. Augustinegrass, and centipedegrass also are attacked. The bluegrass billbug is a pest of bluegrass and other cool-season grasses in the north from Washington State across to the East Coast. Billbugs are native to North America.

Biology and Distribution. Both larvae and adults injure turfgrasses. Adults feed by inserting their mouthparts into the center of the grass stem. However, adult billbug feeding is not considered very damaging. In cool-season grasses, adult female billbugs bore cavities in grass stems near the crown in spring (May and June) and deposit eggs in these cavities. Legless, grub-like larvae hatch in three to ten days and feed inside the grass stem and crown area to the degree that stems can easily be pulled out by hand by late June. Eventually the larvae destroy the crown and drop out the stem once they become too large to fit within the plant. In late June into early July, the mature (3/8-inch, 9.5-mm long) larvae dig one to two inches (2.5 to 5 cm) into the soil and form a pupal cell. In the cell or chamber, pupae gradually mature into adults over a two-week period. Adults begin to emerge in late July, and often are observed climbing walls and windows. They overwinter as adults, often in the junction of turf and sidewalks as well as hedgerows. During early spring (April and May) when daytime temperatures consistently reach 65 to 68°F, adults emerge from winter hibernation and are often visible crawling over paved surfaces on their way to feed and to deposit eggs on turf. Normally, only one generation occurs per year. Peak feeding activity for adults is during July.

In warm-season grasses, females chew holes into stems (stolons) of bermudagrass and zoysiagrass and insert their eggs. After hatching, larvae feed on the stems, drop into the soil, and feed externally on grass parts. Adults first appear in April and May and again in late summer (September to October). However, larvae may still be present throughout much of the year.

Larvae commonly remain active through the winter, feeding on dormant stolons and crowns. Damage often is not evident until spring when the bermudagrass or zoysiagrass starts to green-up. Damage is often mistaken for small spring dead spot disease or "delayed spring green-up syndrome."

Larvae mature from February into early May, pupate, and lay eggs as adults throughout the summer. Since turf growth is rapid in summer, feeding damage often goes unnoticed.

Damage Symptoms/Signs. Most damage on cool season turf is in June and July. Damage resembles fertilizer burn or disease; however, the grass easily breaks off at the crown ("tug test"). Grab several affected stems and tug up. Damaged stems easily break off just below the thatch level and tan sawdust-like frass is evident at the base. Lack of mobility of the legless larvae results in small irregular areas of dead grass, resembling dollar spot disease. When the stem is consumed, the larvae migrate downward and feed on roots. Damage to the turf from mature larvae resembles white grub damage with sloped, sunny areas often showing damage first. Larvae are found in the soil one to three inches deep, among roots and runners. The larval stage lasts three to five weeks. Pupation occurs in the soil. Turf injury is much more pronounced during extended dry weather than when ample rainfall or irrigation is available and damage often resembles drought or heat stress. Billbugs overwinter in any stage in the south, but overwinter mostly as adults in the north. Adults tend to be a problem in spring while grubs cause damage in summer, especially when the turf suffers from moisture stress. Adults tend to be a problem in spring while grubs cause damage in summer, especially when the turf suffers from moisture stress.

Inspection and Control. To determine if billbugs are causing problems, inspect the rootzone as with white grubs. Pitfall traps are used to monitor spring adult activity. Watching driveways, steep-walled sandtraps, and sidewalks for adult migration also aids in determining a pest presence. Damage usually occurs as spotty, brown patches, first along driveways and sidewalks. Control involves cultural (proper irrigation and fertilization), plant resistance (endophyte-enhanced ryegrass or fescue), and preventive and curative insecticides.

As a rule-of-thumb in cool season turf, if an average of 10 billbug larvae are found per square foot (107/m^2), an insecticide should be applied. Damage from moderate infestations may be masked with light fertilization and adequate water. Beneficial fungus, *Beauveria* sp., and nematodes, *Steinernema* sp., show promise for biological control. Endophyte-containing ryegrasses and fescues often are resistant or tolerant to attack. Once billbug damage is noticeable, pesticide control often is unsatisfactory. Successful control, therefore, focuses on preventative treatment. Control with insecticides has been most beneficial when timed in spring from April to mid-May when adults emerge from winter and are searching for oviposition sites. If more than five adults are observed during a five-minute period, a pesticide application may be warranted. Treat newly mowed turf and lightly water-in to move the insecticide into the thatch where grubs reside. Preventive control uses insecticides, such as neonicotinoids (clothianidin, dinotefuran, imidacloprid and thiamethoxam) and diamides (chlorantraniliprole and cyantraniliprole), for long-residual control of larvae. Tank-mixing a preventive insecticide with an organophosphate (chlorpyrifos) or pyrethroid (such as bifenthrin, deltamethrin, cyhalothrin and permethrin) during the time of adult activity may reduce adults and larvae. Curative control with carbamates and organophosphates is difficult to achieve; it is best attempted in mid- to late June into July as a soil drench. Water-in products following treatment.

9.6 ADDITIONAL TURFGRASS INSECTS

Other insects can occasionally become important pests of various turfgrasses. However, their occurrence and damage is usually very regionalized and normally minor. Exceptional weather conditions (e.g., extremely dry) generally are associated with damage from these insects.

Grasshoppers

Numerous species (most often *Melanoplus* spp.) of grasshoppers (order Orthoptera, family Acrididae) are found throughout the world. They are turfgrass pests mostly during periods of exceptional drought in locations of low annual rainfall such as the Great Plains. They feed by chewing the foliage of a wide range of plants. Well-maintained turfgrass rarely has problems unless the grasshoppers are present in high numbers on adjacent crops. Generally, one or two generations occur yearly and they overwinter as eggs in the soil. If grasshoppers become a turfgrass problem then they can be managed using insecticides such as azadirachtin, carbamates, indoxacarb, organophosphates and pyrethroids.

Crane Flies

The European crane fly, *Tipula paludosa* Meigen, and the common crane fly, *Tipula oleracea* L. (order Diptera, family Tipulidae), are pests most commonly found in the Pacific Northwest. Adults have very long legs and resemble large mosquitoes with their large bodies, approximately one-inch (2.5-cm) long. Larvae initially are white, worm-like maggots and have four instars. Later, they become small, gray-brown, worm-like creatures, 1.2 to 1.6 inches (3 to 4 cm) in length, with a tough leathery looking skin giving them their common name "leather jackets." The third instar is the overwintering stage; the third and fourth instars do the most turf damage in spring. The larvae feed on turfgrass roots and crowns, causing browning when threshold numbers approach 20 to 25 per square foot (215 to 269/m^2). Feeding by larvae progresses slowly in winter, with most damage to turf occurring in spring. Leather jackets rest during the day in the soil and feed mostly at night. When adults are ready to emerge, the pupae wriggle to the surface; the pupal skin left on the turf surface is a telltale sign of infestation. Adults may congregate near houses, often exciting homeowners into thinking immediate control is necessary. However, they do not bite or sting and cause no damage to houses. Control may be necessary for sod operations to prevent accidental shipment of larvae to un-infested areas, as well as for golf greens that are expensive to replace if extensive damage occurs. Preventive insecticide treatment is best made in September to October against eggs or small larvae. Larvae are sensitive to dry conditions; therefore, careful management of the timing and frequency of irrigation and better drainage can allow the turf area to dry and be less habitable to the crane fly larvae.

Two-lined Spittlebug

Spittlebugs, *Prosapia bicincta* (Say) (order Homoptera, family Cercopidae) are an occasional pest of turfgrasses, especially centipedegrass and, to a lesser degree, St. Augustinegrass, bermudagrass, and ornamentals (especially holly). Other grasses attacked by spittlebugs include bahiagrass, pangolagrass, and ryegrasses. They occur from Maine to Florida and westward to Iowa, Kansas, and Oklahoma. The nymphs are initially reddish, but turn white and live within a white frothy mass or "spittle." Nymphs and adults feed by sucking juices from the grass through their needle-like mouthparts. Infested grass will have spittle masses present, and tips of the grass will turn yellow, followed by browning and curling. Generally two generations occur yearly (peaking in late spring and late summer). They overwinter as eggs in hollow stems or among plant debris. Spittlebugs prefer a thick thatch layer; therefore, the first step in management is to dethatch and topdress at appropriate times. Insecticide application targeting nymphs of the second generation (i.e. in July) may be most effective. Also avoid planting Japanese hollies near turf area as the hollies can serve as a host plant and attractant for the adult spittlebugs.

Chinch Bugs

Chinch bugs include the southern chinch bug, *Blissus insularis* Barber, the common chinch bug, *Blissus leucopterus leucopterus* Say, the western chinch bug, *Blissus occiduus* Barber, and the hairy chinch bug, *Blissus leucopterus hirtus* Montandon (order Hemiptera, family Lygaeidae). The most serious insect pest of St. Augustinegrass is the southern chinch bug; it may also attack bermudagrass and zoysiagrass. The hairy chinch bug is a pest of bluegrass, ryegrass, zoysiagrass, bentgrass, and fescue in the north and upper midwestern United States.

Chinch bugs damage turf by piercing plant tissue and sucking sap with their needle-like mouthparts. They may also introduce toxic saliva into the plant during this feeding process that may block xylem and phloem tissue. Chinch bug nymphs do the most damage. Affected areas appear as yellow spots or patches 3 to 10 feet in diameter and often are noticed first along concrete or asphalt paved edges or in water-stressed areas where the grass is growing in full sun. By blocking xylem and phloem tissue, leaves wither as in drought and food from photosynthesis does not translocate to the roots. Plants eventually die.

Adults are about one-fifth inch (0.5-cm) long, and black, with white patches on their wings. Nymphs range from 1/20-inch (1.3-mm) long to nearly adult size. There are five nymphal instars. The small nymphs are bright red with a white band across the back, but become black and white in color as they mature. Chinch bugs overwinter as inactive adults and become active in spring, where they feed and mate. Two to three generations occur in the Carolinas, while up to seven occur in south Florida. Eggs are laid in sheaths or pushed into soft soil and protected places. In summer, eggs hatch in 10 days to two weeks, and the young develop to adults in three weeks. Adults become active when daytime temperatures reach 70°F (21°C).

Detection of chinch bugs begins by parting grass on the edge of infested areas and observing the soil surface. All stages can be seen moving through the loose duff on the soil surface. In extremely heavy infestations, some can be seen crawling over grass blades, sidewalks, and outside walls of houses. Their presence can also be confirmed by using the flotation method.

Control begins by preventing drought stress, since damage symptoms are reduced when grass is well-watered. Reduce summer fertilization with quick-release nitrogen sources as the resulting lush grass growth is more susceptible to damage. Spot spraying before extensive damage occurs is best. Threshold levels of 15 to 20 per square foot (160 to 215/m^2) may warrant control. Most insecticides for chinch bugs should not be watered-in. To achieve greatest efficacy, the insecticides should be applied at high volume (e.g. 1.2 gallons/1,000 ft^2) to deliver the active ingredients to the thatch layer where the insects are feeding. When using a granular product, water-in should be done soon after an application to push and dissolve the product in the thatch layer. Repeated applications are often needed in areas with heavy infestation or damage. Use products of different modes of action during each application. Several chinch bug-resistant St. Augustinegrass varieties – "Floratam", "Floralawn" and "Captiva" - are available. Beneficial fungi, *Beauveria bassiana*, can also be applied repeatedly to the infested turf with good results.

Ground Pearls

Margarodes meridionalis Morrill (order Homoptera, family Margarodidae) are tiny scale insects that live in the soil and suck juices from grass roots. Ground pearls are most damaging to centipedegrass, but they will also feed on bermudagrass, St Augustinegrass and zoysiagrass. The slow growth habit of centipedegrass makes it more susceptible to damage from ground pearls. Ground pearls are distributed from North Carolina across to southern California. They are spherical and range in size from a grain of sand to about one-eighth-inch (3 mm) diameter. They are pearly white to yellowish in color and look very much like pearls. Adult females are soft-bodied, pink, and about 1.16 inch (1.6 mm) long. Adult females emerge from cysts in the spring, and move around slowly in the thatch and soil. Eggs are laid in the soil from March to June. The first nymphal instar, called the crawler, locates a grass root, attaches itself, and begins to cover itself with a yellowish to light-pearl-colored hard wax coating. The nymphs continue developing inside this shell and overwinter in this stage. The life-cycle from egg to adult requires one, possibly two, years. Severely infested grass turns yellow, then brown, resembling drought stress occurring in irregular patches. Chemical control is currently unavailable for ground pearls since they are covered by a hard, waxy, practically impenetrable shell. In addition, ground pearls live at depths up to 10 inches (25 cm). Infested grass should be grown to follow best management practices such as raising the mowing height, providing good soil moisture, and providing adequate soil potassium to encourage rooting.

Imported Fire Ants

Fire ants are small reddish-brown to nearly black ants in the genus *Solenopsis*. They range in size from about 1/8 to 3/8 inch (3 to 9.5 mm). Fire ant nests are easily recognized by their characteristic dome shape, size, and apparent lack of an entrance hole **(Figure 9-16)**. Although they do not directly feed on turfgrasses, their mounds often desiccate turf areas, disrupt the turfgrass surface, cause mowing problems, smother closely mowed grass, clog machinery, and are a nuisance to golfers and maintenance personnel. In sandy soil, mounds may not maintain their shape.

Disturbance of a mound creates a characteristic aggressive "boiling" effect of ants coming out of the mound in a defensive action, attacking and stinging all intruders. Each nest may contain anywhere from a few hundred ants to 350,000 ants. It is not uncommon for infestations with 300 or more mounds per acre to occur.

Nests are usually located in open areas such as lawns, pastures, and golf courses. They frequently will take advantage of protective structures such as rocks, pavement, stumps, rotten logs, and so forth. Fire ants also reduce the yield of some 40 different crops, cause damage to electrical

Figure 9–16. Fire ant dome-shaped mounds without an apparent entrance hole.

units (a favorite nesting location), and also damage mowing machinery.

Wildlife is also greatly impacted by the fire ants' presence. Bob White Quail populations have been reduced by competition for their primary food source, namely small insects. Other species have fallen prey to the fire ants' omnivorous appetite.

History. Two major species of fire ants occur in the United States, *Solenopsis invicta*, the red imported fire ant, and *Solenopsis ricteri*, the black imported fire ant. There are also several native species of fire ants.

The two imported species were accidentally imported through the port of Mobile, Alabama in 1918. Their spread has continued at a rate of about five miles per year since.

It is currently estimated that imported fire ants infest more than 300 million acres throughout the states of Alabama, Arkansas, California, Florida, Georgia, Louisiana, Mississippi, North Carolina, Oklahoma, South Carolina, Tennessee, Texas, and Puerto Rico. Spot infestations have occurred in Arizona, Delaware, Maryland, Nevada, and Virginia as well.

To limit the spread of imported fire ants, federal quarantine laws restrict the movement of soil, potted plants, plants with soil attached, grass sod, hay, and used soil-moving equipment to un-infested areas of the United States. These items must be certified to be free from infestation.

Biology. An understanding of their biology is critical in understanding the management of fire ants. The following are some of the highlights of the fire ants' life history as it relates to matters of control.

Establishing a Colony. When a colony reaches a critical size and resources are suitably abundant, the queen ant will begin to lay eggs that will develop into sexually reproductive winged ants called alates. These alates will have a mating flight when the temperature is between 70 and 95°F (21 and 35°C) with high humidity, and usually occurs within 24 hours of a rain. Throughout much of the southeastern United States, these conditions can occur anytime throughout the year, and indeed mating flights have been recorded during 12 months of the year. The bulk of the mating flights take place in the spring and the fall. It is important to note re-infestation of a treated area can occur throughout the year.

Mating flights take place in the air. The males die immediately after the mating takes place, having served their only function within the colony. All of the other ants are female. The female usually lands within a mile or two of her mother colony, but with a tail wind some have been recorded to fly as far as 10 to 12 miles (16 to 19 km). This is important because it demonstrates a treated area can be re-infested from fairly long distances.

After landing, the newly-mated queen breaks her wings off and begins the search for a suitable nest site. This is a very dangerous time for the queen, as she is vulnerable to desiccation and numerous predators. Fewer than 1 percent of queens ever survive to establish a viable colony. This demonstrates the tremendous reproductive potential of the fire ant.

After finding a suitable site, the queen forms a waterproof chamber sealed with soil and saliva where she will lay her eggs. This chamber may be as deep as six to eight inches (15 to 20 cm) below the surface of the soil, making it difficult to reach with pesticides. The queen will lay between 45 and 150 eggs in her founding brood. She will rear the larvae to adulthood, living off of the energy provided by digesting her wing muscles. Once the young mature into adults they begin to take on the work of the colony and take care of the queen. The queen, relieved of other maternal duties, begins producing eggs as her only duty. She may lay as many as 1,500 eggs per day or 350,000 eggs per year. Since she may live as long as seven years, it is imperative for any control measures to eliminate the queen.

The Caste System. Fire ants are social insects. This means they have overlapping generations that care for the young and a caste system with specific jobs for each caste to perform. In general the youngest ants serve as nursery workers and take care of the larvae and pupae (called brood). The middle-aged workers serve as reserves, providing help wherever needed. The oldest workers serve as foragers, venturing from the colony in search of food. Even the larvae have a job to do. Fire ants cannot eat solid food, so one stage of the larvae has a big "lip" called a bucal pouch. Solid food is placed on this "lip" and the larvae secretes digestive enzymes that liquefy the solid food. Nurse ants then stroke the larvae with their antennae and the larvae regurgitates an oily liquid. Other ants then repeat this process with the nurse ants and so on. This process of passing food from one individual to another within the colony is called **tropholaxis**. Tropholaxis serves as an efficient filtering system for food. Foods that prove toxic or unsuitable are discarded, as are any sick ants. The queen is among the last ant to get any food—to minimize her risk. Baits with toxicants used for control must act slowly enough so all of the ants including the queen receive a lethal dose before any effects of the toxicant are revealed.

In the absence of larvae to digest food, adults can survive on liquid oils and sugars provided in the environment. Therefore, you can treat a mound and kill the queen, and a colony can still persist for up to six months.

The Mound. In general there is as much mound below ground as there is above ground. However, the ants constantly change the mound—raising the mound to capture radiant heat when it is cold, and lowering the mound to reduce the effect of the sun's rays when it is too hot. The ants move up and down within the soil profile searching for the ideal temperature of 70 and 95°F (21 to 35°C). Some colonies have been found as deep as 12 to 14 feet (3.6 to 4.3 m).

The fire ants can also regulate moisture and humidity levels just as they do for heat. This is why fresh mounds are often seen after a rain even though the colony was always there. Each colony also contains deep tunnels to groundwater regardless of how deep that is.

Each colony has forage tunnels radiating out like the spokes of a wagon wheel in all directions. The tunnels have periodic openings that are used by the foragers. They will search for food around the opening, then return. If they don't find food, they continue down the tunnel and try at another opening. If they find food, they release a chemical called a pheromone that recruits other workers to help. Forage tunnels may reach as far as 100 yards (91 m) away from the colony.

The Sting Though most people refer to fire ant "bites," in reality this is a sting. The stinger is like a hypodermic needle delivering the venom below the skin that then burns "like fire." The stingers are used for both defense and subduing prey. The venom also contains 1 to 2 percent protein, which causes the allergic reaction many people experience.

When getting ready to sting, the fire ant will grab the victim with its mandibles, or jaws, and place the stinger precisely between the mandible and into the victim. At the same time, the ant releases an alarm pheromone, which is simply a chemical that tells the other ants to sting as well. Thus, the perception that the entire colony gets on you and they all sting at the same time has some basis in fact.

Management Strategies for the Fire Ant. A large number of products are labeled for fire ant control. Most are effective when used properly, but none are permanently effective. As a result, retreatment will be necessary. It is very easy to control individual mounds of fire ants, as there is no known pesticide resistance. Population levels, however, are difficult to reduce. The fire ant's ability to move vertically and horizontally within the soil profile, lack of ecological competition, high reproductive potential, ability to traverse relatively great distances, and biological behaviors make population reduction a difficult proposition. Three basic questions need to be addressed when choosing products: (1) speed of control, (2) duration of control, and (3) costs.

Most management strategies fall into one of four categories.

1. Bait applications
2. Individual mound treatments (IMT)
3. Combination of bait and IMT
4. General broadcast treatments

Baits. Most fire ant baits are formulated using defatted corn grit as the bait matrix and soybean oil as the carrier. The solid yellow stuff is defatted corn grit and the active ingredient is added to soybean oil, which is then added to the defatted corn grit. The soybean oil is what attracts the ants and is an important part of the bait. Over time, soybean oil can go rancid and become unattractive to the ants. Therefore, it is imperative fresh bait be used.

Baits, when used properly, have a number of advantages that make them an appealing choice for fire ant management.

1. They have a low level of toxicity to non-target organisms.
2. They are easy to find in most retail stores.
3. They can be quickly applied.
4. You can kill mounds you cannot see or reach.
5. They work well for sensitive areas such as ponds or wells.
6. They are relatively inexpensive when properly used.
7. They kill the queen and the rest of the colony.
8. They kill colonies outside of the treatment area.
9. Active ingredients do not persist in the environment.

Disadvantages include:

1. If used as an individual mound treatment, they can be expensive.
2. They are often very slow acting.
3. A knowledge of fire ant biology is necessary for optimum control.
4. Control levels rarely exceed a 95 percent reduction.
5. Rebound of the population is usually about three months.
6. Active ingredients break down quickly in sunlight and water.

The active ingredients used in baits can be grouped into two general categories. The first group includes the compounds that use a toxin as the active ingredient. The second group uses insect growth regulators **(IGR)** as active ingredients.

In general, research demonstrates most baits provide a similar level of control—between 85 percent and 95 percent reduction in the fire ant population. Differences become evident when you start to look at how quickly a population reduction occurs and how long this lasts.

The insect growth regulators take longer to see an effect, but they also tend to give control for an extended period of time when compared to those products using toxins as the active ingredient.

Several things should be remembered to ensure success with any fire ant bait used. First, because the products break down quickly, they need to be applied when the fire ants are foraging. Remember fire ants forage when the surface soil temperature is between 70 and 95°F (21 and 35°C). The easiest way to tell if fire ants are foraging is to place a small amount of test bait or a potato, corn or cheese chip in the treatment area and wait about 30 minutes. If fire ants are foraging they will find the bait or food in that amount of time and bait can be applied. If fire ants are not foraging, do not apply the bait.

Secondly, the most effective method of bait application is to broadcast it. However, one of the greatest difficulties with broadcast treatment of fire ant bait formulations is the low rate. Most call for 1 to 1.5 pounds per acre (1.1 to 1.7 kg/ha). This is a small amount for a large area and over-application is common. For best results:

- **Use fresh baits**—As previously stated, the baits can spoil and become unattractive to the fire ants. Buy only what you need for a single application.
- **Apply baits on a dry surface and when rain is not expected for at least 12 hours.**
- **Apply baits when ants are actively foraging**—These products break down quickly in sunlight and water. If the ants are actively foraging, they will pick up the bait before the bait's effectiveness is reduced. If the fire ants are active, their ability to outcompete other ants will reduce the effect of the bait on non-target ant species.
- **Do not mix baits with other materials such as fertilizer or seed**—Ants have a very good sense of smell and will not pick up bait tainted with undesirable odors. Make sure the spreader you are using is clean, or better yet, used only for spreading fire ant bait.
- **Calibrate and measure properly.**

Individual Mound Treatments (IMT). Products labeled for individual mound treatments are, as a whole, very effective in eliminating 98 percent or more of the mounds treated. The not-so-obvious disadvantage is they kill only the mounds that are treated. Many newly established colonies, or colonies in intensively managed areas, are difficult to see and are therefore missed with this form of treatment.

Advantages to IMT include:

- High percentage of mounds treated are eliminated.
- Most act very quickly and eliminate mounds within a few hours.
- Most are inexpensive.
- Most are readily available.
- They kill the queen and the rest of the colony.
- They are very fast acting.

Disadvantages to IMT include:

- Greater concentration of toxins.
- Not recommended for sensitive areas such as wells, ponds, playgrounds, and pet runs. See re-entry intervals listed on labels for these sites.
- It is easy to miss some mounds that are difficult to see.
- Some products require premixing, or drenching.
- If the queen isn't killed then the mound may relocate.

The Two Step. The two step method is a combination of the two methods previously discussed, and is the most commonly recommended method by researchers and extension personnel. All of the methods discussed for both baits and IMTs apply to this method of fire ant management. Broadcast fire ant baits while fire ants are foraging, wait 10 to 14 days, and then use individual mound treatments on mounds that continue to be a problem. The two step is recommended twice a year, usually in the April to May timeframe and again in the September to October timeframe.

Combining the use of baits and granular broadcast treatments also shows considerable promise. Strategies when using baits plus granular broadcast treatments include applying an area-wide bait treatment in spring and fall to outlying areas while using a granular broadcast treatment in early spring in critical areas. For example, on golf courses, roughs and out-of-play areas would be treated with baits in spring and fall, while fairways, tees, and greens would be considered critical areas and are treated in spring.

Mound-building Turfgrass Ants

Other than fire ants, most ant species do not pose a threat to humans, but can disrupt play and become a maintenance problem by their extensive mound construction on putting surfaces **(Figure 9-17)**. In addition to the mounds, predatory birds may cause further damage by probing the nest openings. The most common ant species that causes these mounds is the turfgrass ant, *Lasius neoniger* (order Hymenoptera: family Formicidae). These social insects are light to medium brown and about 0.10 inch (2.5 mm) long. Each colony consists of numerous sterile female workers and usually only one reproductive queen. The workers feed and tend to the queen ant and her eggs and larvae. The

Figure 9–17. Mound-building turfgrass ants on a golf green.

worker ants often feed on small insects and insect eggs, seed, flower nectar, and on the sugary honeydew produced by root aphids. Once food is found, worker ants deposit a pheromone trail as they return to the nest for additional worker ants to follow.

Mounds are passageways for the workers and interconnected chambers compose the underground living quarters, usually 10 to 15 inches (15 to 38 cm) below the soil surface. Each mound is a different nest entrance point. Seasonal mound-building typically first appears in late winter or early spring, peaking in early summer and declining by late summer. Most ant mounds are located on the perimeter of greens while the main nests, with queen and brood, are located in native soil outside the green's collar. These secondary nests located in the perimeter of greens contain only worker ants and appear to expand the area from which the colony collects food. These sub or secondary nests are connected via underground tunnels to main nests located just outside the collar.

Treating with fast-acting products often only temporarily suppresses ant mounding as this usually fails to control the queen in her underground nest chamber. If contact products such as pyrethroids (bifenthrin, cyfluthrin, deltamethrin, and lambda-cyhalothrin) are used, the best time for application is early in the growing season, just after mounds appear. These applications typically provide 50 to 70% mound suppression for four to six weeks. A combination treatment of a pyrethroid along with a neonic insecticide like imadacloprid (Merit), thiamethoxam (Meridian), or Arena (chlothianidin) often provides longer term control, up to 2 to 3 months. Fipronil is another longer-lasting product that has slow knockdown activity, allowing worker ants time to return to the nest and spread the product to other ants. However it is not as broad spectrum, does not kill all ant species, and must be used in fire ant regions in compliance with the label. Spot-treating with an insect bait such as hydramethylnon, often provides good control if certain precautions are followed. The baits are typically slow acting, allowing worker ants time to feed bait to the queen and her brood. Small amounts are sprinkled around mounds but must remain dry as ants are not attracted to wet bait. Once applied to dry turf, irrigation should be withheld for at least 12 hours to allow time for the worker ants to carry the bait to the queen. After the queen is eliminated, the colony cannot reproduce and dies out. About two days are needed to eliminate the colony. Baits are usually spot treated, most often by shaker cans. Early spring is best for applications, since nests are small and the build-up of mounds that occurs in late spring and summer is avoided.

Earthworm(s)

Earthworms, also referred to as night crawlers, angleworms, fishing worms, and dew worms, are generally considered beneficial as their presence indicates ecologically healthy turfgrass growing conditions. Their two primary requirements are moist soil and an organic matter food source. Their feeding and burrowing habits initiate thatch decomposition, stimulate microorganism activity, increase the availability of certain soil nutrients, increase soil aeration, and generally improve overall soil quality. However, aside from these benefits, earthworm casting on golf course fairways is an extremely challenging turfgrass management issue **(Figure 9-18)**. Casting occurs when earthworms ingest soil and leaf tissue to extract nutrients and then emerge from their burrows to deposit fecal matter (casts) as mounds of soil on the turfgrass surface. These castings interfere with maintenance practices, play, and overall turf aesthetics and are more prevalent on well-irrigated, shady sites. Turf beneath the leveled mounds is also smothered.

A major earthworm species in the United States is the common night crawler (*Lumbricus terrestris* Linnaeus). *Apporectodea calignosa* and *A. longa* are additional earthworms often found on golf courses. Peak casting is during the cool, wet weather in spring and late fall through winter. Night crawlers can live up to six to nine years; thus, they reoccur in the same place. Earthworms dig burrows in the soil and migrate upward with fluctuations in moisture content, soil temperature, and availability of food such as clippings and soil organic matter. It has been shown, however, that neither clipping removal nor aerification reduces earthworm casting.

No products are specific to control earthworm casting. Any pesticide application in the United States specifically targeting earthworm control is illegal, increasing the need for alternative, non-chemical management strategies. Products containing tea-seed meal have been shown to reduce earthworm castings. Other control attempts have involved changing soil pH (high or low), which does not influence night crawler activity. Other earthworm species, however, may respond differently to changes in soil pH. Since the outer skin (or cuticle) of earthworms is extremely sensitive, using abrasive substances such as sand may

Figure 9–18. Earthworm castings, when wet, easily smear and can smoother the turf.

irritate, thus, repel them. Control is currently focusing on the abrasiveness and desiccation ability of sand particles through aggressive topdressing. Due to the need for multiple applications, a long-term commitment of up to five years of topdressing is needed for success. Successful yearly total topdressing rates have been between 0.75 and 1.5 inches (1.9 and 3.8 cm). Due to the expense and labor required to perform this heavy rate of topdressing, it is suggested infestation areas be mapped and a priority be placed on the most infested sites. Additional research continues to evaluate irritants such as various hot peppers as possible deterrents. Member education about the benefits of earthworm and long-term commitment for casting control also are needed. Long-term use of sharply angular soil aggregates on injuring turf roots and shoots from foot and maintenance equipment pressure should be considered before use. Roots may die back, diseases become more prevalent, and turf wilting may occur more frequently.

Cicada Killer

Homeowners and golfers are often alarmed by the cicada killer, *Sphecius speciosus* (Drury), and other ground-nesting wasps (Order Hymenoptera, various families). The cicada killer is a large wasp, about 1 5/8 inch (40 mm) that resembles a giant hornet. They are widely distributed east of the Rocky Mountains. Females dig soil burrows ½ inch (1.2 cm) across and 6 to 9 inches (15 to 23 cm) deep that form a small U-shaped mound around the entrance on the turf surface. Often a "runway" leads to the entrance of the mound. There may be several mounds within the same area. Female cicada killers stock these mounds with cicadas to provision their larvae for development. Although their activity causes fear and interferes with human activity, the cicada killers are actually beneficial insects. The mounds are unsightly but are often more noticeable in the summer and disappear as the fall approaches. Covering sandy areas with turf or mulch can discourage mound building by cicada killers. Often chemical treatment is not needed, however, when needed, dusting the burrow entrance with carbaryl will kill the females as they enter and leave the nest.

Clover Mite

The clover mite, *Bryobia praetiosa* Koch, is a minor pest of cool-season turfgrasses and is distributed throughout the United States. The clover mite is dull reddish brown, with eight orange legs. The clover mite is most active in the spring and fall, and becomes dormant in the summer (as adults) and winter (as eggs). They often become a nuisance pest when a large population, which builds up on turfgrass through the spring and fall, begins to move into homes and buildings in the summer and winter to seek hibernation sites. Damaged turf appears yellowish or silvery, and often fails to green up in the spring. Although the mites do not bite humans or pets, they can be annoying and leave behind red stains when squashed. Avoiding excessive fertilization that promotes lush plant growth, and also favors mite development and reproduction, can help control the population. Repeated insecticide applications may be needed to reduce the mite population on turfgrass.

Greenbug

Greenbugs are a species of aphid, *Schizaphis graminum* (Rondani). Greebugs are a major pest of grain crops, but can occasionally become a pest in cool-season turfgrasses, particularly Kentucky bluegrass. Greenbugs are soft-bodied, light green with a dark green stripe down the back, and a pair of black tailpipes at the end of the abdomen. Greenbugs are sucking insects. They remove plant sap and cause yellowing and browning of turf; damage often appears as irregular patches of burnt orange, or yellowing in late spring. In turfgrass, damage often begins under shade trees. Populations are present year-round in the southern United States. There are many generations of greenbug each year, as each generation can be completed in 7 days at typical summer temperatures. They overwinter as eggs, which hatch in the spring to initiate a new generation. Endophyte-enriched cool-season turfgrasses are resistant to greenbugs. Greenbugs are very easy to control with contact and systemic insecticides applied as sprays. Spot treatment (with an extended treatment band of 6ft outside of the infested area) is sufficient to reduce localized infestations. Avoid irrigating the treated area for at least 24 hours after insecticide application.

Ground-Nesting Bees

Many bee species (order Hymenoptera, families Andrenidae, Anthophoridae, Colletidae, Halictidae and Megachilidae) nest in individual holes in the ground. The bees are of various sizes and colors (from reddish brown to metallic blue). Females build nests 6 or more inches (15 cm) deep in the ground. During the process of excavation, the females build mounds of soil with a central hole for entrance. These nests often appear in large numbers in sunny, well-drained, sandy or thinned turf area. The mounds often appear in the spring and can become a nuisance to turfgrass managers. The bees are pollinators and are not harmful to humans or pets. Chemical management of these ground-nesting bees is not recommended. Because the bees do not like wet soil, heavy irrigation can discourage nest building. Tilling the soil while adding organic matter also makes the area less suitable for nest building. The most effective approach to controlling the bees is to establish a dense, healthy turf.

Zoysiagrass mite

The zoysiagrass mite, *Eriophyes zoysiae* Baker et al., is a close relative of the bermudagrass mite. This species is becoming more problematic in zoysiagrass turf across the southern United States. The appearance and life-cycle of the zoysiagrass mite is similar to that of the bermudagrass mite. They are active mostly in the spring and summer. The zoysiagrass mite is specific to zoysiagrass, and does not attack any other grass species. Infested grass turns pale white or yellow, and is stunted. The upper leaf is rolled up and becomes caught within the older leaves, creating an arch; this type of damage is commonly termed "buggy whip." The "buggy whip" symptom is characteristic of zoysiagrass mite infestation; the leaf sheath can be pulled back and examined for the presence of the zoysiagrass mites. The slow growth habit of zoysiagrass makes recovery from mite damage difficult. "Royal" and "Emerald" zoysiagrass are resistant to zoysiagrass mite damage. Management options for the zoysiagrass mite are poorly known, but are likely to be similar to that of the bermudagrass mite.

10 TURFGRASS AND AQUATIC WEEDS AND PLANT GROWTH REGULATORS

10 TURFGRASS AND AQUATIC WEEDS AND PLANT GROWTH REGULATORS

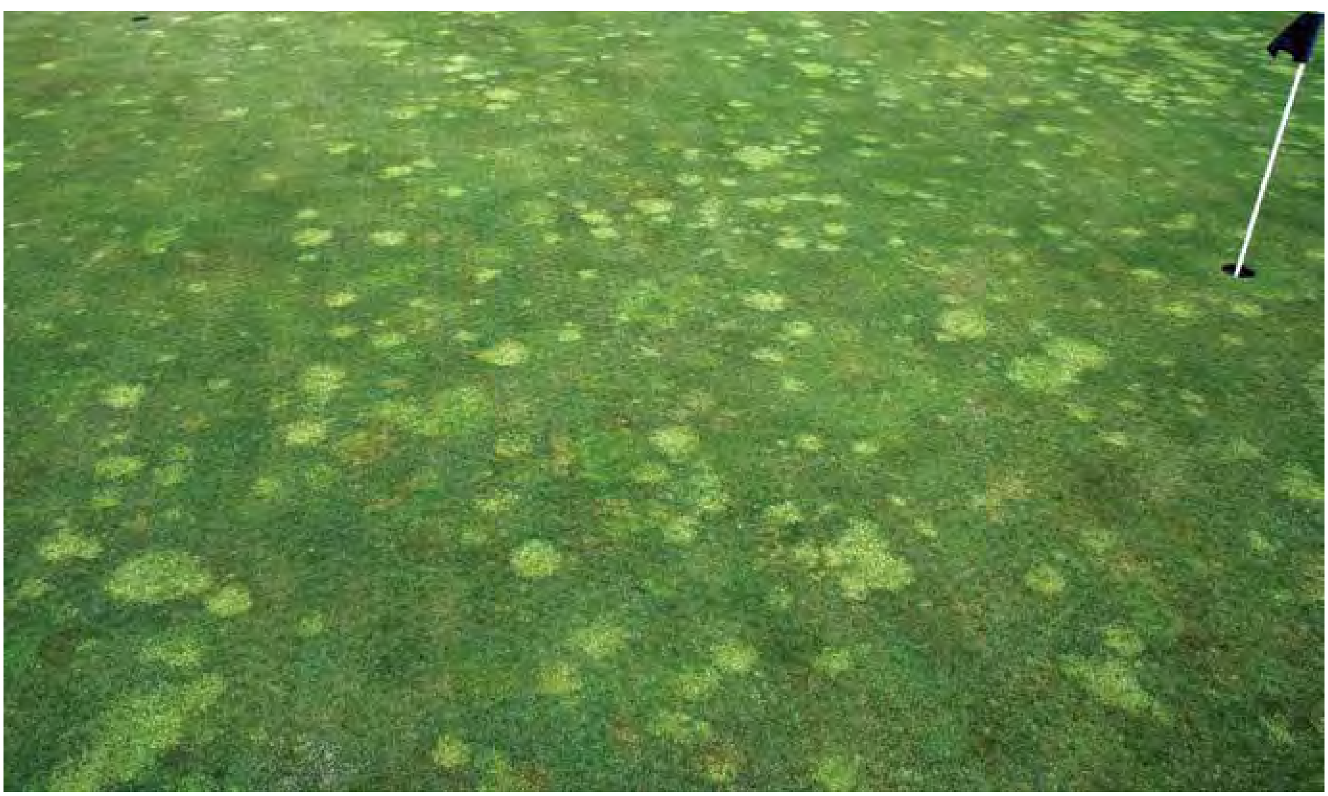
A weed can be defined as a plant growing where it is not wanted or growing out of place **(Figure 10–1)**. For example, tall fescue is considered a weed when grown in a pure stand of Kentucky bluegrass, but may be highly desirable when grown in a monoculture such as a golf course rough. In addition to being unsightly, weeds compete with turfgrasses for light, soil nutrients, soil moisture, and physical space. Weeds also are hosts for pests such as plant pathogens, nematodes, and insects. Certain weeds are irritants to humans when allergic reactions to pollen or chemicals occur. In addition, certain weeds are toxic to pets and livestock.

Weeds often are the result of a weakened turf, not the cause of it. Understanding this helps to explain the major reason for weed encroachment into a turf area (e.g., thin turf density and bare spots). Reasons for weak or bare turf areas are numerous, including (1) improper turf species selection not adapted to environmental conditions; (2) damage from turfgrass pests such as diseases, insects, nematodes, and animals; (3) environmental stresses such as excessive shade, drought, heat, and cold; (4) improper turf management practices such as misuse of fertilizer and chemicals, improper mowing height, insufficient drainage, or improper mowing frequency and improper soil aeration; and (5) physical damage and compaction from concentrated or constant traffic. Unless the parameters contributing to the decline of a turf area are corrected, continued problems with weed infestations should be expected.

10.1 DEVELOPING A WEED MANAGEMENT PROGRAM

Weed management is an integrated process where good cultural practices are employed to encourage desirable turfgrass ground cover as well as the intelligent selection

Figure 10-1. Weeds are plants growing out of place. Shown is an annual bluegrass infested creeping bentgrass golf green.



and use of herbicides. A successful weed management approach involves the following:

1. Proper weed identification,
2. Prevention of weed introduction,
3. Proper turfgrass management or cultural practices to encourage competitive turf growth against the weed,
4. If necessary, the proper selection and use of a herbicide.

Weed Identification

The first step to successful weed management is proper identification. Turf managers should be able to identify each weed to genus, and preferably to species, in order to select the appropriate control technique. Weed identification also is the first step in understanding why weeds occur and how to control them. For instance, most sedges prefer moist, wet areas while sandspurs and bahiagrass prefer drier sites.

Identification begins with classifying the weed type. **Broadleaves**, or dicotyledonous plants, have two seed cotyledons (young leaves) at emergence and have net-like veins in their true leaves **(Table 10–1)**. Broadleaves, which often have colorful flowers, include clover, dandelion, knotweed, lespedeza, plantains, henbit, pusley, beggarweed, spurges, and matchweed **(Figure 10–2)**. **Grasses,** or monocotyledonous plants, only have one seed cotyledon present when seedlings emerge from the soil. Grasses also have hollow, rounded stems with nodes (joints) and parallel veins in their true leaves **(Figure 10–3)**. Leaf sheaths are open. Most grass species have ligules, a projection at the inside junction of the leaf blade and collar. Ligules may be membrane-like, have a membrane with hairs on top, or be totally absent. Examples include crabgrass, goosegrass, dallisgrass, nimblewill, quackgrass, thin (bull) paspalum, and annual bluegrass.

Figure 10-2. Broadleaf weeds typically have netlike veins in their leaves and often produce colorful flowers such as dandelion (shown).

Figure 10-3. Grassy weeds have hollow, rounded stems with nodes (joints) and parallel veins in their leaves. Shown is dallisgrass.

Table 10–1. Distinguishing characteristics of monocots compared to dicots

CHARACTERISTIC	MONOCOT	DICOT
Seedling cotyledons	One	Two
Leaf veination	Parallel	Netted
Leaf attachment	Directly on stems	On short stalks called petioles
Ligules	Present, rarely absent	Absent
Vascular bundles	Scattered	Distinct (arranged in a ring of bundles surrounding a central pith)
Vascular tissue growth	Only primary	Primary & secondary; thus, they can become woody
Meristems	Basal	Terminal
Root system	Fibrous without cambium layer	Taproot with a cambium layer
Flowers	Not showy	Usually showy
Flower parts	Group of 3s	Usually groups of 4s or 5s

Table 10–2. Distinguishing characteristics between grasses, sedges, and rushes.

CHARACTERISTIC	GRASSES	SEDGES	RUSHES
Stem	Usually hollow, round, or flattened	Usually 3-sided, pithy, rarely hollow	Round and filled with sponge-like pith
Nodes	Very noticeable	Indistinct	Indistinct
Leaf arrangement	2-ranked	3-ranked	3-ranked
Leaf sheath	Usually split	Usually closed	Usually open
Leaf blade	Flat, often folded, hairy, or smooth	Flat, usually smooth	Round or flat, usually smooth, often with visible partitions
Leaf margin	Smooth, rough hairy, or sharp	Usually rough	Usually smooth
Collar	Often a distinct band	Indistinct	Indistinct
Auricles	Present or absent	Absent	Present or absent
Ligule	Present, rarely absent	Absent or only weakly developed	Absent or only weakly developed

Although most non-broadleaf weeds in turfgrasses are usually grasses, not all are grasses and they are often easily confused. **Sedges** and **rushes** generally favor a moist habitat and have a closed leaf sheath **(Figure 10–4)**. Their leaf arrangements are three-ranked, ligules are mostly absent, and they either have stems that are triangular-shaped and solid (**sedges**), or round and solid (**rushes**). The distinguishing characteristics that help distinguish between grasses from grasslike plants—sedges and rushes—are listed in **Table 10–2**.

Another group of turfgrass weeds are monocots but are neither grasses, sedges or rushes. These include weeds such as various dayflower species, doveweed, Spring Starflower, wild garlic, Star-of-Bethlehem and others.

In the past, proper weed identification was difficult to achieve due to the lack of a suitable guide. Most guides pictured weeds in unmowed conditions or did not list all the important turf weeds. Several newer turf weed identification publications are listed in the front matter of this book.

Figure 10-4. Sedges and kyllinga species have a three-ranked leaf arrangement and typically have triangularly shaped stems. Shown is perennial (or green) kyllinga.

Weed Life Cycles

Weeds complete their life cycles in either one growing season (**annuals**), two growing seasons (**biennials**), or three or more growing seasons (**perennials**). Annuals completing their life cycles from spring to fall are generally referred to as **summer annuals**, and those completing their life cycles from fall to spring are **winter annuals**. Summer annual grasses, as a class, are generally the most troublesome in turf.

Weed Prevention

Prevention involves avoiding the introduction of weeds into an area. There are national, state, and local prevention efforts against the introduction and spread of weeds. A local preventive program is one of the best methods of avoiding future weed problems. Many of these methods are commonsense approaches that ensure sanitary conditions and minimize weed introduction. Some of these methods include use of weed-free turf seeds, stolons, sprigs, plugs, or sod. Washing or blowing equipment between mowings, maintaining weed-free fence lines and ditch banks, and the use of clean mulch and topdressing material are additional examples of preventative methods.

Cultural

Cultural practices promoting a vigorous, dense turf are perhaps the most important and least recognized means of preventing weed encroachment and establishment. Soil fertility, aeration, and moisture levels should be maintained at an optimum level to promote turf cover. Since light is required for optimum germination of weeds such as crabgrass and goosegrass, cultural practices increasing turf density will prevent light from reaching the soil surface **(Figure 10–5)**. Preventing light from reaching the soil surface also delays spring germination of weed seeds requiring warmth because the soil surface is better insulated; thus, it remains cooler. Maintaining the highest cutting height possible and adequate fertility levels will help encourage a

Figure 10-5. Weeds are often a result of improper turf management practices. Shown is goosegrass in a highly compacted turf adjacent a cart path.

high shoot density and will also minimize light penetration to the soil surface.

High infestation levels of certain weeds also might indicate specific soil conditions that favor their presence. **Table 10–3** lists some of these soil conditions and associated weeds. Continual weed problems can be expected until these growth conditions are corrected.

Herbicide Classification and Nomenclature

Herbicides may be classified according to chemistry, method of application, timing of application, persistence, selectivity, and/or mode of action. Herbicides from the same class of chemistry are grouped into families in much the same way plants are grouped into genus and species. In general, members of a herbicide family are similarly absorbed and translocated and have a similar mode of action **(Table 10–4)**.

Timing of Herbicide Application

Herbicides are classified by the time the chemical is applied in respect to turfgrass and/or weed seed germination. Although the majority of herbicides may be classified into one category, atrazine (AAtrex), simazine (Princep), ethofumesate (Prograss), dithiopyr (Dimension), and pronamide (Kerb) are notable exceptions. They are used as both pre-emergence and post-emergence herbicides.

Preplant herbicides. Preplant herbicides are applied before turfgrass is established, usually to provide non-selective, complete control of all present weeds. Soil fumigants, such as metamsodium (Vapam), methyl bromide (Terr-O-Gas, Dowfume, Brom-O-Gas, others), and dazomet (Basamid), and nonselective herbicides such as glyphosate (Roundup Pro, others) may be used as non-selective preplant herbicides.

Pre-emergence herbicides. Pre-emergence herbicides are applied to the turfgrass prior to weed seed germination and form a barrier at, or just below, the soil surface **(Figure 10–6)**. Most pre-emergence herbicides prevent cell division during weed-seed germination as the emerging seedling comes into contact with the herbicide (Figure 10–1). It should be noted that pre-emergence herbicides do not prevent weed seed germination. Weeds already emerged (visible) at the time of application are not controlled consistently by pre-emergence herbicides because their primary growing points escape treatment. Pre-emergence herbicides also do not control dormant weed seeds.

Post-emergence herbicides. Post-emergence herbicides are applied directly to emerged weeds. In contrast to pre-emergence herbicides, this group of herbicides provides little, if any, soil residual control of weeds. A complete chemical weed control program can be accomplished with post-emergence herbicides, provided multiple applications are used throughout the year. However, due to the necessity of repeat applications and temporary turfgrass injury, most turfgrass managers use post-emergence herbicides in conjunction with a pre-emergence herbicide. Post-emergence herbicides are useful for controlling perennial grasses and broadleaf weeds not controlled by pre-emergence herbicides. Certain post-emergence herbicides also may be used on newly established turfgrasses.

Post-emergence herbicides enter the plant through microscopic cracks and crevices in the leaf cuticle. Herbicide uptake via plant stomates represent a tiny percentage of uptake and is not considered to be significant. The more active the plant growth, the easier it is for the herbicide to penetrate the cracks and crevices in the leaf surface. Plants not actively growing generally have a thicker cuticle, thus, penetration via the cuticle is more difficult.

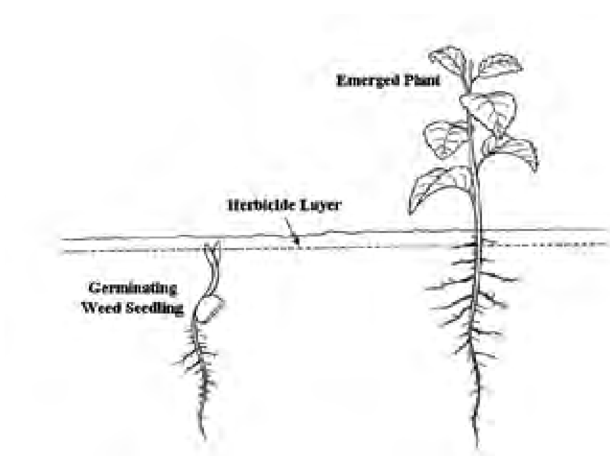


Figure 10-6. Pre-emergence herbicides form a barrier at or just below the soil surface and as weeds germinate, they encounter this layer. Weeds growing above or below this treated layer are not effectively controlled (redrawn from Emmons, 1995).

Table 10–3. Weeds as indicators of specific poor soil conditions. *Continued*

HERBICIDE FAMILIES	HERBICIDE COMMON NAMES
C. Inhibitors of Emerging Seedling Roots lipid synthesis	
Phosphorodithioate Benzofuran	- bensulide - ethofumesate
D. Inhibitors of very long chain fatty acids (Seedling Roots and Shoots)	
Acetamides or Amides Chloroacetamide	- napropamide - acetochlor, alachlor, butachlor, dimethenamid, metolachlor, propachlor
Inhibitors of Amino Acid Synthesis *A. Inhibitors of acetolactate synthase (ALS), also called acetohydroxyacid synthase (AHAS)*	
Sulfonylureas Imidazolinones Pyrimidinylbenzoic Acids Triazolopyrimidine sulfonanilides	- bensulfuron, chlorimuron, chlorsulfuron, ethametsulfuron, flazasulfuron, halosulfuron, imazosulfuron, iodosulfuron, metsulfuron, nicosulfuron, primisulfuron, prosulfuron, rimsulfuron, sulfometuron, sulfosulfuron, thifensulfuron, triasulfuron, tribenuron, trifloxysulfuron sodium, triflusulfuron - imazamethabenz, imazamox, imazapic, imazapyr, imazaquin, imazethapyr - bispyribac-sodium, pyrithiobac-sodium - flumetsulam, penoxsulam
B. Inhibitors of EPSP synthase	
Organophosphorus	- glyphosate
C. Inhibitors of glutamine synthetase	
Organophosphorus	- glufosinate
Lipid Biosynthesis Inhibitors *Inhibitors of Acetyl CoA Carboxylase (ACCase)*	
Cyclohexenediones Aryloxyphenoxy-propionates	- clethodim, sethoxydim, tralkoxydim - clodinafop, diclofop, fenoxaprop, fluazifop, quizalofop
Inhibitors of Cell Wall (Cellulose) Biosynthesis *A. Site A*	
not classified	- dilute sulfuric acid, monocarbamide dihydrogen sulfate, herbicidal oils
B. Induce Lipid Peroxidation - Photosynthesis I electron diverters	
Bipyridyliums	- diquat, paraquat
Inhibitors of protoporphyrinogen oxidase (Protox or PPO)	
Aryl triazinones Diphenylethers Dicarboximides Oxadiazole Phenylpyrazole	- carfentrazone-ethyl, sulfentrazone - acifluorfen, fomesafen, lactofen, oxyfluorfen - flumioxazin - oxadiazon, flumiclorac - pyraflufen-ethyl
Inhibits Dihydropteroate (DHP) Synthase	
Carbamates	- asulam
Unknown/ Miscellaneous	
Benzofurans Organic arsenicals Others	- ethofumesate - DSMA, MSMA, CMA - difenzoquat, endothall

Table 10–4. Classification of turfgrass herbicides based on their mode of action.

SOIL CONDITION	INDICATOR WEED(S)
Acid soils	bentgrasses (Agrostis spp.)
	red sorrel (Rumex acetosella)
Alkaline soils	plantains (Plantago spp.)
Compacted soils	annual bluegrass (Poa annua)
	bermudagrass (Cynodon dactylon)
	common chickweed (Stellaria media)
	goosegrass (Eleusine indica)
	knotweed (Polygonum aviculare)
	mouseear chickweed (Cerastium glomeratum)
	prostrate spurge (Chamaesyce humistrata)
	rushes (Juncus spp.)
	smutgrass (Sporobulus spp.)
Infertile/sandy soils	bahiagrass (Paspalum notatum)
	black medic (Medicago lupulina)
	broomsedge (Andropogon spp.)
	carpetweed (Mollugo verticillata)
	legumes (clover, lespedeza, medic)
	red sorrel (Rumex acetosella)
	poorjoe (Diodia teres)
	sandbur (Cenchrus pauciflorus)
	spurge (Chamaesyce spp.)
	quackgrass (Agropyron repens)
	white clover (Trifolium repens)
	yarrow (Achillea millefolium)
	yellow woodsorrel (Oxalis stricta)
High-fertility soils	annual bluegrass (Poa annua)
	bentgrasses (Agrostis spp.)
	bermudagrass (Cynodon dactylon)
	crabgrasses (Digitaria spp.)
	henbit (Lamium amplexicaule)
	purslane (Portulacca oleracea)
	ryegrass (Lolium spp.)
	yellow woodsorrel (Oxalis stricta)

SOIL CONDITION	INDICATOR WEED(S)
High or infrequent mowing	chicory (Cichorium intybus)
	clover (Trifolium spp.)
	thistle (Cirsium, Carduus spp.)
Low mowing	algae
	annual bluegrass (Poa annua)
	chickweeds
	crabgrass (Digitaria spp.)
	moss (Bryum spp.)
	pearlwort (Sagina procumbens)
Shaded soils	annual bluegrass (Poa annua)
	common chickweed (Stellaria media)
	ground ivy (Glechoma hederacea)
	mouseear chickweed (Cerastium glomeratum)
	nimblewill (Muhlenbergia schreberi)
	roughstalk bluegrass (Poa trivialis)
	violets (Viola spp.)
	Indian mock-strawberry (Duchesnea indica)
Wet soils	algae
	alligatorweed (Alternanthera philoxeroides)
	annual bluegrass (Poa annua)
	barnyardgrass (Echinochloa crusgalli)
	bentgrasses (Agrostis spp.)
	common chickweed (Stellaria media)
	ground ivy (Glechoma hederacea)
	kyllingas (Kyllinga spp.)
	mouseear chickweed (Cerastium glomeratum)
	moss (Bryum spp.)
	nutsedges (Cyperus spp.)
	pennywort (Hydrocotyle spp.)
	rushes (Juncus spp.)
	speedwells (Veronica spp.)
	violets (Viola spp.)

Figure 10-7. A common practice is fumigating soil prior to planting a new turf area to control a wide variety of pests. However, the use of methyl bromide has recently been cancelled by the USEPA.

Soil Fumigation for Non-selective Preplant Weed Control

Soil fumigants are volatile liquids or gases that control a wide range of soil-borne pests **(Figure 10–7)**. Soil fumigants are also *highly toxic* to plants and other biological organisms, and are also expensive. Their use is limited to small, high value crop acres such as tobacco, certain vegetables, fruits, bedding plants, and turf. The expense usually results from the impermeable cover necessary to trap the fumigant vapors in the soil. Fumigants control not only most weed species, but also many nematodes, bacteria, fungi, and insects. Weed species possessing a hard, water-impermeable seed coat such as sicklepod, white clover, common mallow, various vetch species, redstem filaree, and morning glory are not effectively controlled with soil fumigants. Important considerations before choosing a particular soil fumigant include expense, soil moisture level, soil temperature, and time available before planting. Repeated fumigant use will result in a buildup of weeds that are not controlled by fumigants.

10.2 SELECTIVE WEED CONTROL

Maintaining today's modern, multimillion dollar turf complexes at the desired level of aesthetics requires knowledge of specific weeds, their biology, and available control measures. The following sections discuss current selective weed control options turf managers have at their disposal. Weed control should be a carefully planned and coordinated program instead of being a hit-or-miss operation. Understanding how and why weeds are present on a site is more important than what control options are available once the weed is present.

When choosing a herbicide, the effectiveness at certain weed growth stages, tolerance or susceptibility of treated turf species, time required for its control, economics, and safety characteristics are important considerations when trying to choose among herbicides. The most effective herbicide is only as good as its application. Many variables influence successful herbicide application, including (1) proper equipment; (2) environmental factors at the time of application; (3) accurate and constant monitoring of calibration; and (4) adequate agitation. Most herbicide failures involve using the wrong chemical at the wrong date, or they are applied at an improper time or manner. It is not by failure of the herbicide itself.

10.3 PRE-EMERGENCE HERBICIDES

Pre-emergence herbicides are the foundation of a chemical weed control program in turfgrasses and are used primarily to control annual grasses and certain annual broadleaf weeds. Pre-emergence weed control was first suggested in 1927. Some of the first chemicals evaluated for pre-emergence weed control include calcium cyanide, arsenate, and naphthylacetic acid. In 1959, the first true pre-emergence herbicide that provided consistent control became available for turf managers. DCPA (dimethyl tetrachloroterephthalate) (Dacthal) provided more consistent control with less damage to the turf than was previously available. With the subsequent release of dinitroaniline herbicides, the widespread acceptance of pre-emergence weed control in turfgrass was established.

Turf Tolerance to Pre-emergence Herbicides

When considering any herbicide, one of the first questions is the tolerance of the desirable turfgrass species to the chemical in question. **Table 10–5** lists the most widely used turfgrass species on golf courses and their tolerance to currently available pre-emergence herbicides. Herbicides such as bensulide (Betasan), dithiopyr (Dimension), indaziflam (Specticle), and members of the dinitroaniline herbicide family (e.g., benefin [Balan], oryzalin [Surflan], pendimethalin [Pre-M], prodiamine [Barricade], trifluralin [Treflan]) should be used only on well-established turfgrasses.

Effectiveness of Pre-emergence Herbicides

The effectiveness of pre-emergence herbicides varies because of many factors, including application timing in relation to weed seed germination, soil type, environmental conditions (e.g., rainfall and temperature), target weed species and biotype, and cultural factors (e.g., aerification) that follow application. Pre-emergence herbicides generally are most effective for annual grass control, although some annual small seeded broadleaf weeds also are suppressed. Refer to the following websites for the latest available products and their effectiveness:

http://www.clemson.edu/extension/horticulture/turf/pest_guidelines/
http://www.turffiles.ncsu.edu/

Timing of Pre-emergence Herbicides

An important consideration in using pre-emergence herbicides is application timing. Most pre-emergence herbicides act as mitotic inhibitors, meaning they prevent cell division. Since the germinating shoot-and-root tips are the two major sites of cell division, pre-emergence herbicides must contact these plant structures in the soil. Application should therefore be timed prior to weed-seed germination since most pre-emergence herbicides are ineffective on emerged (visible) weeds. If applied too soon, natural herbicide degradation processes may reduce the herbicide concentration in the soil to a level resulting in ineffective or reduced control. It should be noted however, in areas where winter temperatures are cool to cold, pre-emergence herbicides do not degrade or degrade at a much slower rate because soil microorganisms are not active. If applied too late (e.g., weed seedlings are visible), the weeds have grown above the thin layer of pre-emergence herbicide located at the soil surface, resulting in the effectiveness of the materials being drastically reduced.

Crabgrass germinates from late winter through spring when soil temperatures at a four-inch (10-cm) depth reach 53 to 58°F (12 to 14°C). Alternating dry and wet conditions at the soil surface, as well as sunlight, greatly encourages crabgrass germination. Crabgrass germination often coincides with flowering of early spring plants such as forsythia, redbuds, pears, and cherry trees.

Goosegrass germinates in spring when soil temperatures at the four-inch (10-cm) level reach 60 to 65°F (16 to 18°C). Goosegrass also requires sunlight for optimum seed germination and is very competitive in compacted soils. Normally, because of higher temperature requirements for germination, goosegrass germinates two to four weeks later in spring than crabgrass. This often coincides with flowering of later plants such as dogwoods and azaleas. If herbicides are applied at the time for crabgrass control, the material will begin to break down in the soil and goosegrass control will be reduced. Therefore, when developing a goosegrass weed control program, delaying pre-emergence spring herbicide application three to four weeks after the targeted date for crabgrass control is more efficient.

Annual bluegrass (*Poa annua*) begins to germinate in late summer through early fall when daytime temperatures consistently drop into the mid-70°Fs (21°Cs). Typically, a second major flush of annual bluegrass germination occurs in early winter (December 20 to January 20) when days are bright, air temperatures are in the 60°Fs (16°Cs), and night temperatures are cold (<35°F, 2°C). Thin turf areas, slightly shady areas, and excessively wet areas generally have the earliest Poa germination.

Sequential or Repeat Applications

Repeat applications of pre-emergence herbicides are generally necessary for full season control for crabgrass, goosegrass, and annual bluegrass. Most herbicides begin to degrade soon after application when exposed to the environment. Usually, the level of degradation occurring from 6 to 16 weeks after application reduces the herbicide concentration to the point where poor control of later germinating weed seeds, such as goosegrass, occurs. A general rule-of-thumb on whether sequential applications are needed is if the growing season of a particular region is more than 175 days long, repeat applications are needed. Repeat applications, therefore, are necessary between 60 to 75 days after the initial application for season-long pre-emergence weed control.

Note: On those areas to be established with turf, most pre-emergence herbicides should not be used two to four months prior to planting. Severe root damage and reduced turfgrass seed germination may result.

Core Aerification and Pre-emergence Herbicides

Core aeration has not traditionally been recommended or practiced following a pre-emergence herbicide application. This procedure was believed to disrupt the herbicide barrier in the soil, thereby allowing weed germination. Research, however, indicates core aerification immediately prior to, or one, two, three, or four months after application of many pre-emergence herbicides does not stimulate large crabgrass emergence. Aeration at one or two months after application also has little effect on large crabgrass cover. Core aeration at one, two, or three months after an application of pre-emergence herbicide does not decrease goosegrass control on putting greens. However, greater amounts of crabgrass occur on greens aerified with the cores returned than non-aerified greens, or aerified greens with the cores removed.

Fertilizer-Based Pre-emergence Herbicide

A growing trend in the turfgrass industry is the use of granular pre-emergence herbicides. The low cost of granular applicators and public perception of spraying has contributed to this trend. Additionally, many turfgrass managers are using dry fertilizer-based pre-emergence herbicides. Fertilizer-herbicide mixtures enable a "weed-n-feed" treatment in the same application or trip over the turfgrass. Weed-n-feed treatments may be convenient; however, certain factors must be considered prior to application. Depending upon the turfgrass, the time of year a herbicide should be applied may not coincide with the time of year a fertilizer is needed. For example, unless a slow-release nitrogen fertilizer is used, bermudagrass should not receive spring fertilization until the grass has greened-up approximately 40 percent, the chances of frost have passed, or the grass has recovered from winter dormancy. At the full green-up stage of bermudagrass, it is usually too late to apply most pre-emergence herbicides since many summer annual weeds have already emerged.

When using herbicides formulated on a fertilizer carrier, it is also important to determine if the manufacturers' recommended rate of the product supplies sufficient amounts of fertilizer needed by the turfgrass and herbicide required for weed control. Supplemental applications of fertilizer or herbicide may be required if the product does not supply enough of each to meet these needs. A spread rate of material when using weed-n-feed products should be at least 300 lbs product per acre (34 g/m^2) to ensure adequate coverage. This is a general rule that applies to an average-size fertilizer particle. Smaller particles often used in more expensive premium products can provide adequate coverage with slightly lower product coverage rates.

Corn Gluten for Pre-emergence Weed Control

The concept of using corn gluten meal as a natural herbicide originated at Iowa State University in the 1980s. Accidentally discovered while using corn meal as a growing medium for *Pythium*, raw corn meal was applied in adjacent plots several weeks before seed bed planting. Secondary observations were made when germination of grass seed was inhibited by the raw corn meal. It was later found an organic substance in the corn meal was destroyed when it was cultured with the fungal organism *Pythium*. Corn gluten is a byproduct of the wet milling process of corn grain. Corn gluten contains 60 percent protein and 10 percent nitrogen (N) by weight, which may make an excellent fertilizer for plants with an established root system. The inhibitory substance of corn gluten prevents the formation of roots on germinating seedlings of a variety of grass and broadleaf plants. Five individual dipeptides (combinations of two amino acids) inhibit root formation of germinating seedlings. These dipeptides are glutaminyl-glutamine, glycinyl-alanine, alaninyl-glutamine, alaninyl-asparagine, and alaninyl-alanine. The application rate is 20 pounds of product (2 pounds of N, 0.9 kg) per 1,000 square feet (98 g/m^2) in spring two to four weeks before the anticipated germination of summer annuals. The level of weed control provided by corn gluten meal is typically less than commercial herbicides.

Pre-emergence Herbicides for Golf Greens

Few pre-emergence herbicides are recommended for use by the manufacturer on golf greens due to the liability associated with these valuable areas. However, several are available for either bermudagrass or bentgrass greens. Several can be used on either grass; however, the user should check the latest herbicide label to ensure these are still available for green use.

10.4 POST-EMERGENCE HERBICIDES

Post-emergence herbicides are generally effective only on those weeds that have germinated and are visible. Most post-emergence herbicides are relatively ineffective as pre-emergence herbicides. The timing of application should be when weeds are young (two- to four-leaf stage) and actively growing. At this stage, herbicide uptake and translocation is favored, and turfgrasses are better able to fill in voids left by the dying weeds. The tolerances of different turfgrass species to post-emergence herbicides are listed on the following websites:
http://www.clemson.edu/extension/horticulture/turf/pest_guidelines/
http://www.turffiles.ncsu.edu/

Broadleaf Weed Control

Broadleaf weeds in turf have traditionally been controlled with members of the phenoxy herbicide family (e.g., 2,4-D, dichlorprop, MCPA, and mecoprop) and benzoic acid herbicide family (e.g., dicamba). All are selective, systemic foliar-applied herbicides. Only a very few broadleaf weeds, especially perennials, are controlled with just one of these materials. Usually, two- or three-way combinations of these herbicides and possible repeat applications are necessary for satisfactory weed control. Special formulations of three-way type mixtures of 2,4-D, dichlorprop (2,4-DP), MCPP, MCPA, triclopyr, fluoxypyr, and dicamba are available. Various MCPP formulations also are available. Manufacturers also are pre-mixing a quicker acting product with these traditional 2- and 3-way mixtures to increase control and reduce the time for herbicides symptoms to show. Carfentrazone, sulfentrazone, and pyraflufen-ethyl quickly disrupt plant membranes, causing quicker herbicides symptoms. Sequential applications for all products should be spaced 10 to 14 days apart and only healthy-growing, non-stressed turf should be treated.

Until recently, these various herbicide combinations were the main chemicals for broadleaf weed control. Clopyralid (Lontrel), triclopyr (Turflon), and various combinations with other herbicides have been introduced as alternatives to phenoxy herbicides for broadleaf weed control.

Triclopyr belongs to the Picolinic Acid herbicide family. Compounds in this family are noted for their high degree of activity. These herbicides are up to 10 times more potent than 2,4-D on certain broadleaf weed species. They are rapidly absorbed by roots and foliage of broadleaf plants, and are readily translocated throughout the plants via both xylem and phloem tissues. Problems with this herbicide family include its soil mobility and extreme ornamental sensitivity. Clopyralid also is one of the newer members of this herbicide family. It is currently marketed in a mixture with triclopyr (Confront) for use on labeled cool- and warm-season turfgrasses. Clopyralid is especially effective on most leguminous plants (nitrogen producing) such as black medic, clover, kudzu, lespedeza, and vetch. Penoxsulam is the most recently introduced broadleaf herbicide. It is noted for control of English daisy, Florida betony, and dollarweed and better turf tolerance. It also can be formulated as a granule.

Chlorsulfuron (Corsair) and metsulfuron (Manor, Blade) are sulfonylurea herbicides labeled for selective broadleaf and tall fescue control in certain cool- and warm-season turfgrasses. Rates range from 0.25 to 5 **ounces** of product per acre (17.5 to 350 g/ha), depending on the weed species present and herbicides used. The following websites list the effectiveness of commonly used post-emergence herbicides for broadleaf weed control:
http://www.clemson.edu/extension/horticulture/turf/pest_guidelines/
http://www.turffiles.ncsu.edu/

Grass Weed Control

Traditionally, for tolerant turfgrass species, post-emergence grass weed control was through single and repeat applications of the organic arsenicals (e.g., MSMA, DSMA, CMA). Two to four applications, spaced seven days apart, generally are required for complete control. The rate and number of applications necessary for weed control usually increase as weeds mature. On cool-season turfgrasses, and zoysiagrass, organic arsenicals can be very phytotoxic, especially when used during high temperatures (>90°F, 32°C). Control also is reduced if rainfall occurs within 24 hours of treatment. Recently, new herbicide releases have provided alternatives to the arsenicals for post-emergence grass weed control. Decreased phytotoxicity as well as reduced number of applications are often associated with these herbicides. The following sections discuss herbicides available for various turfgrass species.

Nutsedge and Kyllinga

Sedges generally thrive in soils that remain wet for extended periods of time due to poor drainage or excessive irrigation. The first step in sedge weed control is, therefore, to correct the cause of continuously wet soils. Do not over-irrigate an area; if necessary, provide surface and subsurface drainage. In addition, sedges can also be found around putting greens that receive overspray from irrigation heads. Mapping the spray pattern of irrigation heads can often explain the presence of sedges in these areas.

Yellow and purple nutsedge are low-growing perennials resembling grasses. Sedges, in general, are yellow-green to dark-green, with triangular stems bearing three-ranked leaves—unlike the two-ranked leaves of the grass family. Yellow and purple nutsedge have fibrous root systems with deep-rooted tubers or nutlets for reproduction. Seedhead color is often used to distinguish between these two major nutsedges. Yellow nutsedge has a yellowish- to straw-colored inflorescence, while purple nutsedge has a reddish to purple inflorescence. Leaf tip shape is another distinguishing method. Leaf tips of purple nutsedge are generally thicker and more rounded than yellow nutsedge leaf tips that are very narrow, ultimately forming a needlelike end. Yellow and purple nutsedge have a great capacity to reproduce and spread due in part to their massive underground tuber and rhizome systems. They are not believed to produce viable seed.

Historically, chemical control of most sedges was with repeat applications of 2,4-D or the organic arsenicals (MSMA, DSMA). Although effective, these treatments are slow to kill the weeds and repeat applications are generally necessary, resulting in extensive damage in certain turf species. The following websites list the effectiveness of commonly used post-emergence herbicides for grass, nutsedge, and kyllinga control:

http://www.clemson.edu/extension/horticulture/turf/pest_guidelines/

http://www.turffiles.ncsu.edu/

10.5 SPECIAL WEED MANAGEMENT SITUATIONS

Herbicide-Resistant Weeds

Herbicide resistant weeds have plagued the row-crop sector of weed science for the past 15 or so years. However, more recently, turfgrass herbicide resistance has become a major issue for golf courses **(Figure 10–8)**. Resistance problems generally begin to show up when a class of compounds with a similar mode of action, is continuously used over an approximately 7- to 10-year period. These herbicides selectively control those susceptible biotypes, thereby gradually allowing the resistant biotypes to spread and increase over time. Just as turf managers should rotate between fungicide groups to prevent disease resistance, herbicides with different modes of action should also be rotated to prevent weed resistance. Herbicide resistant weeds in turf, such as *Poa annua*, spurges, goosegrass, nutsedges, and crabgrass, are becoming more prevalent. Fortunately, this can be contained if prudent action is taken. **Table 10–5**

Figure 10-8. A recent problem in turfgrass weed control is herbicide resistance. Shown is a typical scenario where herbicide resistant annual bluegrass plants are intermingled with susceptible ones.

summarizes the main herbicides used in turf including their timing (pre- vs post-emergence), their mechanism of action within the plant (how they control them), and the various active ingredients. Rotating between and tank-mixing herbicides with different mechanisms of action are keys to delaying or preventing herbicide resistant weeds from dominating a population.

Precautionary Statements

When using any post-emergence herbicide, certain precautions should be followed to minimize any problems. Treat the weeds when they are young (e.g., two- to four-leaf stage). Larger weeds require repeat applications, which will result in an increased chance of phytotoxicity and increased labor costs with added wear-and-tear on equipment. Treat when weeds, and preferably the turf, are actively growing and good soil moisture is present. Treating when the weed is actively growing results in better herbicide up-take and translocation, resulting in better efficacy. If weeds are treated after they begin to flower or produce seedheads, herbicide activity will be reduced and repeat applications will be necessary. If seedheads or flowers are present, mow the weeds as low as possible, wait several days until regrowth is evident, and then make the herbicide application. Allowing weeds to produce seedheads may add to the soil's weed-seed reserve; therefore, mowing or herbicide treatments should be in advance of seedhead development.

An adjuvant (surfactant, wetting agent, or crop oil concentrate) is generally needed by most post-emergence herbicides. The label should be consulted, however, as many post-emergence herbicides already contain them. If other pesticides are to be tank-mixed with herbicides, always conduct a compatibility test unless the specific tank-mix is recommended on the herbicide label. Indiscriminate tank-mixing can lead to chemical compatibility problems (e.g., flakes, gels, precipitates) in the spray tank and may result in excessive turfgrass injury. As application volumes and pre- or post-treatment irrigation recommendations dramatically vary between herbicides, fungicides, and insecticides, it usually is not advisable to tank-mix the various types of pesticides. Compatibility tests should also be conducted when mixing herbicides with liquid fertilizers.

Disclaimer. All mentioned chemicals are for reference only and may not be available for turf use. They may be restricted by some state, province, or federal agencies; thus, be sure to check the current status of the pesticide being considered for use. Always read and follow the manufacturer's label as registered under the Federal Insecticide, Fungicide, and Rodenticide Act. Mention of a proprietary product does not constitute a guarantee or warranty of the product by the authors or the publishers and does not imply approval to the exclusion of other products that also may be suitable.

Aquatic Weed Management

Aquatic weeds in ponds or lakes used as sources for irrigation water can be controlled by physical removal, biological control, or herbicides **(Figure 10–9)**. The method, or combination of methods, used will depend on factors such as target weeds, non-target plants, and what the water is used to irrigate (refer to **Chapter 2** for more information on proper management of lakes, ponds, and streams). Physical removal can be accomplished manually or with machinery. It is time consuming, expensive and normally used alone if other methods are not feasible. However, a certain amount of physical removal may be necessary in combination with the use of biological control and herbicides.

Biological control is an option for certain aquatic weeds. The major advantages are ease of application and no concern over damage to plants irrigated with treated water. Triploid grass carp can control many submerged vascular aquatic weeds. Grass carp are usually used to control all vegetation in a pond, rather than selectively controlling certain vegetation. Replacement stocking of grass carp is necessary when fish are lost. A permit is required to stock grass carp, and only triploid fish can be legally used in most states. Tilapia are stocked in the spring and control most algae species. The concern with tilapia is that they are tropical animals and usually die during cold winters thereby requiring an annual stocking. Check with your Department of Natural Resources to determine if grass carp and tilapia are legal to stock and if a permit is required.

Diquat, endothall, glyphosate, fluridone, triclopyr, copper, sodium carbonate peroxyhydrate, 2,4-D, carfentrazone, imazapyr, penoxsulam, and imazamox compounds can be used safely in ponds used as irrigation sources if the manufacturer's label directions are followed. Certain waiting periods may be required before using water for irrigation after the herbicide is applied, while in some cases waiting periods are not required. Various chemicals have

Figure 10-9. Aquatic weeds are not only unsightly and interfere with normal irrigation practices, they often contribute to fish kill as aquatic oxygen is depleted when such plants die and decompose.

Table 10–5. Cross reference of herbicides, their use timing, and mechanism of action to help aid in managing possible herbicide resistance.

TIMING	MECHANISM OF ACTION	ACTIVE INGREDIENT (TRADE NAME EXAMPLE)*
Pre-emergence	Cellulose biosynthesis inhibition	Indaziflam (Specticle) Isoxaben (Gallery)
	Mitotic (microtubule) inhibition	Benefin (Balan) Dithiopyr (Dimension) Oryzalin (Surflan) Pendimethalin (Pendulum) Prodiamine (Barricade) Trifluralin (Treflan)
	Lipid biosynthesis inhibition	Bensulide (Bensumec)
	Long chain fatty acid biosynthesis inhibition	Metolachlor (Pennant)
	Protoporphyrinogen oxidase (PPO) inhibition	Oxadiazon (Ronstar)
Pre-/Post-emergence	Cellulose biosynthesis (grasses), synthetic auxin inhibition (broadleaves)	Quinclorac (Drive)
	Mitotic inhibition	Dimethenamid (Tower) Pronamide (Kerb)
	Photosystem II inhibition	Atrazine (Aatrex) Metribuzin (Sencor) Simazine (Princep)
	Lipid biosynthesis inhibition	Ethofumesate (Prograss)
	Protoporphyrinogen oxidase (PPO) inhibition	Flumioxazin (SureGuard)
Post-emergence	Acetyl CoA Carboxylase (ACCase) enzyme inhibition	Clethodim (Envoy) Diclofop (Illoxan) Fenoxaprop-ethyl (Acclaim Extra) Fluazifop-P (Fusilade II) Sethoxydim (Vantage)
	Acetolactate synthase (ALS) enzyme inhibition	Bispyribac-sodium (Velocity) Chlorsulfuron (Corsair) Flazasulfuron (Katana) Foramsulfuron (Revolver) Imazaquin (Image) Metsulfuron (Manor) Rimsulfuron (TranXit) Sulfosulfuron (Certainty) Thiencarbazone-methyl Trifloxysulfuron (Monument)
	Carotenoid biosynthesis (HPPD) inhibitors	Mesotrione (Tenacity) Topramezone (Pylex)
	Enolpyruvyl Shikimate-3 Phosphate (EPSP) synthase inhibition	Glyphosate (Roundup)
	Glutamine synthetase inhibition	Glufosinate (Finale)
	Nucleic acid inhibition	MSMA, DSMA
	Photosystem I inhibition	Diquat (Reward)
	Photosystem II inhibition	Amicarbazone (Xonerate) Bentazon (Basagran) Siduron (Tupersan)
	Protoporphyrinogen oxidase (PPO) inhibition	Carfentrazone-ethyl (Quicksilver) Sulfentrazone (Dismiss)
*Acre foot = 1 surface acre of	Synthetic auxin inhibition	2,4-D, dicamba, MCPP, 2,4-DP, MCPA Clopyralid (Confront) Fluroxypyr (Spotlight) Triclopyr (Turflon)

Figure 10-10. Using plant growth retardants to suppress the seedheads of annual bluegrass in creeping bentgrass.

Figure 10-11. Plant growth retardants are useful to slow turf growth in hard-to-reach areas.

different product formulations; only aquatic labeled pesticides and surfactants/adjuvants may be used in aquatic applications, by law. **Tables 10–6, 7, & 8** list the amount of product formulation is needed for treatment of aquatic weeds, the relative effectiveness of these products, and water use waiting restrictions following application.

Turfgrass Plant Growth Regulators

Plant growth regulators (PGRs) or inhibitors are increasingly being used on golf courses to suppress seedheads and vegetative growth of desirable turfgrasses, enhance turfgrass quality, and manage annual bluegrass (*Poa annua*) growth and development **(Figure 10–10)**. Depending upon the turfgrass and situation, PGRs may reduce mowing costs, prevent scalping, increase turf density, and decrease the need to mow steep slopes. Traditionally, PGRs were used in the United States to suppress bahiagrass (*Paspalum notatum*), Kentucky bluegrass (*Poa pratensis*), and tall fescue (*Festuca arundinacea*) seedhead production in low-maintenance areas such as highway roadsides, airports, and golf course roughs. However, products have been registered for use in most high-maintenance turfgrasses.

PGRs are recommended for use only on certain turfgrass species. Additionally, the use of a PGR is often determined by the type of turfgrass area and level of maintenance. For example, imazapic (Plateau) is recommended for use on low-maintenance sites such as roadsides and airports **(Figure 10–11)**. However, flurprimidol (Cutless), paclobutrazol (Trimmit), and trinexapacethyl (Primo) may be used on putting green turfgrasses. The PGR label should always be consulted for information concerning turfgrass species and application sites **(Table 10–9)**.

Prior to the development of PGRs for fine turfgrasses, several undesirable characteristics were associated with the PGRs used on low-maintenance, or rough, turfgrass sites, including: (1) phytotoxicity (burn) of treated leaves for four to six weeks following applications, (2) reduced recuperative potential when the PGR-treated turfgrass was physically damaged, and (3) increased weed pressure due to reduced competition from treated turfgrasses. However, because most PGRs were historically used in low-maintenance areas, these undesirable characteristics did not pose a problem to most managers.

Fine-turfgrass PGRs suppress vertical top growth, but usually do not radically influence the lateral or horizontal spread of stolons. The most noticeable effect is usually a reduction in the amount of clippings, and a reduction in mowing frequency **(Figure 10–12)**. On tee boxes and fairway landing areas, turf recovery from golf club divots and other injuries occurs while vertical top growth remains suppressed. Depending upon the product, fine-turfgrass PGRs also enable superintendents to reduce mowing frequency on fairways, suppress annual bluegrass in creeping bentgrass greens, improve ball lie or playability, and suppress the growth of bermudagrass during overseeding with a cool-season turfgrass. In the case of a mixture of Poa annua and creeping bentgrass, trinexpacethyl can be used to "level" or "smooth" the putting surface by helping to reduce the bumpiness caused by more rapid upright growth by Poa annua.

Figure 10-12. Plant growth retardants regulate clipping production when routine mowing is disrupted.

Table 10–6. Amount of product formulation for treatment of aquatic weeds.

HERBICIDE	RATE*
Aquathol	0.3 to 2.6 gal/acre foot of 4.2 L or 13 to 108 lb of 10G/acre foot or 2.2 to 22.0 lb of 63G/acre foot.
Carfentrazone	3.4 to 13.5 fl. oz. per surface acre for floating vegetation – 0.143 to 0.286 gal/acre foot for submerged vegetation.
Copper Compounds	0.6 to 3.4 gal of Chelated Copper/acre foot or 0.1 to 0.5 ppm elemental copper.
2,4-D	1 to 2 gal/surface acre of 3.8 L or 150 to 200 lb of 20G/surface acre.
Diquat	1 to 2 gal/surface acre of 2L.
Flumioxazin	6 to 12 oz/surface acre or 200 to 400 ppb for subsurface. Check with Company rep. for exact use rates.
Fluridone	10 to 90 ppb. Follow label and check with company rep. for exact recommended rates.
Glyphosate	4.5 to 7.5 pt/surface acre of 5.4L.
Hydrothol	0.3 to 3.4 gal/acre foot of 2L or 11 to 136 lb of 11G/acre foot.
Imazamox	32 to 64 fl. oz. per surface acre broadcast foliar application. 50 to 500 ppb in water treatment.
Imazapyr	2 to 6 pints per acre.
Penoxsulam	10 to 150 ppb, not to exceed 150 ppb per growing season. Follow label for specific rates.
Triclopyr	2 to 8 quarts per surface acre of 3L.
Sodium Carbonate Peroxyhydrate	3 to 170 pounds per acre-foot of 50G.

*Acre foot = 1 surface acre of water (43,560 ft2) 1 foot deep.

Table 10–7. Effectiveness of products for aquatic weed control.

				ENDOTHALL										
WEED	COPPER COMPLEXES, COPPER SULFATE	2,4-D	DIQUAT (REWARD)	AQUATHOL K & G	HYDROTHOL G & 191	FLUMIOXAZIN	FLURIDONE	GLYPHOSATE	SODIUM CARBONATE PEROXYHYDRATE	TRICLOPYR	IMAZAPYR	IMAZAMOX	CARFENTRAZONE	PENOXSULAM
ALGAE														
Filamentous	E	P	P	_	G	G	P	P	E	_	_	_	_	_
Planktonic	E	P	G	_	G	_	P	P	E	_	_	_	_	_
Branched (Chara)	E	P	G	_	G	_	P	P	P	_	_	_	_	_
Nitella	E	P	G	_	G	_	P	P	P	_	_	_	_	_
FLOATING PLANTS														
Bladderwort	P	P	E	_	_	_	E	_	P	_	_	G	_	_
Duckweeds	P	P	G	P	P	E	E	P	P	_	G	_	E	E
Water hyacinth	P	E	E	_	_	_	P	G	P	E	E	E	E	E
Watermeal	P	P	P	_	_	_	G	P	P	_	_	_	G	G
SUBMERSED PLANTS														
Broadleaf watermilfoil	P	_	E	E	E	_	E	P	P	E	_	_	G	E
Coontail	P	G	G	E	E	G	E	P	P	_	_	_	_	_
Egeria	G	P	G	P	P	_	E	P	P	_	_	_	_	E
Elodea	G	_	E	P	P	_	E	P	P	_	_	_	_	E

WEED				ENDOTHALL										
	COPPER COMPLEXES, COPPER SULFATE	2,4-D	DIQUAT (REWARD)	AQUATHOL K & G	HYDROTHOL G & 191	FLUMIOXAZIN	FLURIDONE	GLYPHOSATE	SODIUM CARBONATE PEROXYHYDRATE	TRICLOPYR	IMAZAPYR	IMAZAMOX	CARFENTRAZONE	PENOXSULAM
Eurasian watermilfoil	P	E	G	E	E	G	E	P	P	E	_	F	G	E
Fanwort	P	F	G	E	E	G	E	P	P	_	_	_	_	_
Hydrilla	G	P	G	G	G	G	E	P	P	_	_	G	_	E
Naiads	P	F	E	G	G	G	E	P	P	_	_	_	_	G
Parrotfeather	P	E	E	G	G	_	_	F	P	G	E	G	G	G
Pondweeds (Potamogeton)	P	P	G	E	E	E	E	P	P	_	_	G	_	E
EMERGENT PLANTS														
Alders	P	E	F	P	P	_	P	E	P	_	_	_	_	_
Alligatorweed	P	F	P	P	P	_	G	E	P	E	E	G	G	G
American lotus	P	E	P	P	P	_	F	G	P	E	E	G	_	_
Arrowhead	P	E	G	G	G	_	_	E	P	_	E	_	_	G
Buttonbush	P	E	F	P	P	_	P	G	P	_	E	_	_	_
Cattails	P	G	G	P	P	_	F	E	P	_	E	E	_	_
Common reed	P	P	P	P	P	_	P	G	P	_	E	F-G	_	_
Fragrant & white waterlily	P	E	P	P	P	_	E	E	P	E	E	G	_	_
Frogbit	P	E	E	_	_	_	_	_	P	E	E	E	_	_
Maidencane	P	P	F	_	_	_	F	E	P	_	E	_	_	_
Most grasses	P	P	P	P	P	_	P	G	P	_	E	F	_	_
Pickerelweed	P	G	G	_	_	_	P	F	P	E	E	E	_	G
Pond edge annuals	P	_	G	_	_	_	E	E	P	_	E	_	_	_
Rush	P	P	F	P	P	_	F	E	P	_	E	_	_	_
Sedges and rushes	P	F	F	P	P	_	P	G	P	_	E	_	_	_
Slender spikerush	P	_	G	_	_	_	E	P	P	_	_	F	_	G
Smartweed	P	E	F	_	_	_	F	E	P	E	E	G	_	G
Spatterdock	P	E	P	P	P	_	E	G-E	P	E	E	G	_	_
Southern watergrass	P	P	_	_	_	_	G	E	P	_	_	_	_	_
Torpedograss	P	P	P	_	_	_	F	G	P	_	E	_	_	_
Watershield	P	E	P	_	_	_	E	G	P	_	_	G	_	_
Water pennywort	P	G	G	P	P	G	P	G	P	E	E	E	_	E
Water primrose	P	E	F	_	_	_	F	E	P	E	E	F	G	_
Willows	P	E	F	P	P	_	P	E	P	_	E	_	_	_

E=excellent control (90 to 100%); G=good control (80 to 89%); F=fair control (70 to 79%); P=poor control (<70%). A blank space indicates weed response is not known. [1]Ester formulations only. [2]Copper complex only.

For more information on aquatic weed identification and control, these internet sites are recommended:
http://aquaplant.tamu.edu/
http://el.erdc.usace.army.mil/aqua/
http://el.erdc.usace.army.mil/aqua/apis/apishelp.htm
http://plants.ifas.ufl.edu/

Table 10–8. Waiting period (days) before using water after product application for aquatic weed management.

COMMON NAME	TRADE NAME	IRRIGATION	FISH CONSUMPTION	WATERING LIVESTOCK	SWIMMING
Carfentrazone	Stingray	0-14[1]	NR[2]	0 to 1	NR
Copper	Crystalline copper sulfate and various liquid organic copper complexes	NR	NR	NR	NR
2,4-D	Various formulations and manufacturers[3]	Water use restrictions vary by formulation and manufacturer. Certain labels allow irrigation if an approved chemical assay has reached acceptable levels. A few labels allow irrigation with specific waiting periods. Certain labels may allow irrigation on established turf, immediately. CHECK INDIVIDUAL LABEL.			
Diquat	Reward	1 to 3[4]	NR	1	NR
	Weedtrine D	5	NR	5	NR
Endothall	Aquathol K	7 to 25	NR	7 to 25	NR
	Aquathol granular	7 to 25	NR	7 to 25	NR
	Aquathol Super K	7 to 25	NR	7 to 25	NR
	Hydrothol 191	7 to 25	NR	7 to 25	NR
	Hydrothol 191 granular	7 to 25	NR	7 to 25	NR
Flumioxazin	Clipper	5	NR	NR	
Fluridone	Avast, Sonar AS, Sonar SRP, Sonar PR, Sonar Q	7-30+	NR	NR	NR
Glyphosate	Rodeo, AquaNeat, Aqua-Master, AquaPro	NR	NR	NR	
Imazamox	Clearcast	See note 5	NR	NR	NR
Imazapyr	Habitat	120	NR	NR	
Penoxsulam	Galleon	<30 ppb Turf <1 ppb Others	NR	NR	NR
Sodium Carbonate Peroxyhydrate	Green Clean, Pak 27, Phyco-mycin	NR	NR	NR	NR
Triclopyr	Renovate 3 & Garlon 3A	120[6]		NR[7]	NR

1 1 day if <20% of surface acreage is treated. 14 days if >than 20% is treated. Certified lab test of <5 ppb.
2 NR = No restrictions.
3 Most formulations do not permit application to ponds used for irrigation or for watering dairy cattle.
4 Three days for irrigation of turf and non-food crops; five days for irrigation of food crops (including tobacco) or for preparation of agricultural sprays.
5 DO NOT use treated water for greenhouses, nurseries or hydroponics - bioassay for canola, onions, potatoes or sugar beets - other crops, 1 day.
6 No restriction for established grasses and assay to reduce restriction time.
7 14 day restriction on grazing site and growing. Season grazing restriction on lactating livestock after irrigating pasture.

Table 10–9. Labeled plant growth regulators for various turfgrass species.

	TURFGRASS USES												SITE OF UPTAKE		SPECIFIC USES			
ACTIVE INGREDIENT (TRADE NAME EXAMPLE)	BAHIAGRASS	BERMUDAGRASS	CENTIPEDEGRASS	CREEPING BENTGRASS	FINE FESCUES	KY. BLUEGRASS	KIKUYUGRASS	PERENNIAL RYEGRASS	*POA ANNUA*	ST. AUGUSTINEGRASS	TALL FESCUE	ZOYSIAGRASS	ROOT	FOLIAR	OVER-SEEDING AID	GOLF GREENS	SEEDHEAD SUPPRESSION	MODE OF ACTION
Ethephon (Proxy)	–	–	–	Y	Y	Y	–	Y	–	–	Y	–	–	Y	–	–	–	Promotes ethylene which reduces cell elongation
Flurprimidol (Cutless)	–	Y	–	Y	–	Y	–	Y	–	Y	–	Y	Y	–	–	Y	–	Type II GA inhibitor of cell elongation
Gibberellic acid (RyzUp)	–	Y	–	–	–	–	–	–	–	–	–	–	–	Y	–	–	–	Chlorophyll (color) retention
Indolebutyric acid + gibberellic acid	–	Y	Y	Y	Y	Y	Y	Y	–	Y	Y	Y	–	Y	–	Y	–	Enhance root growth & plant vigor
Maleic hydrazide (Slo Gro)	Y	Y	–	–	Y	Y	–	Y	–	–	Y	–	–	Y	Y	–	Y	Type I growth & seed-head inhibitor
Mefluidide (Embark 2S)	–	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	–	Y	Y	–	Y	Type I growth & seed-head inhibitor
Paclobutrazol (Trimmit/TGR)	–	Y	–	Y	Y	Y	–	Y	–	Y	Y	–	Y	–	Y	Y	Y	Type II GA inhibitor of cell elongation
Trinexapac-ethyl (Primo)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	–	Y	Y	Y	–	Type II GA inhibitor of cell elongation
Prohexadione-Ca (Anuew 27.5WP)	–	Y	–	Y	–	Y	–	Y	–	–	–	–	–	Y	–	Y	–	Type II GA inhibitor of cell elongation
Amidochlor (Limit)	–	–	–	–	–	Y	–	Y	–	–	Y	–	Y	–	–	–	Y	Type I cell division inhibitor

[1]Low-maintenance turfgrass sites: roadsides, airports, storage sites, hard-to-mow areas, and so forth.
Medium-maintenance turfgrass sites: industrial grounds, parks, cemeteries, golf course roughs, home lawns.
High-maintenance turfgrass sites: putting greens, tees, fairways, athletic fields, high-quality home lawns, and commercial properties.

10.6 PLANT GROWTH RETARDANT CLASSIFICATION

Similar to herbicides, PGRs are placed into groups based on mode of action, or the way they inhibit turfgrass growth. Classification schemes can vary; however, three distinct groups of PGRs are recongized.

Cell Division Inhibitors (also called Type I PGRs)

Cell division inhibitors are primarily foliage absorbed and inhibit cell division and differentiation in meristematic regions. They inhibit both vegetative growth and seedhead development. Growth inhibition is rapid, occurring within 4 to 10 days, and lasting three to four weeks, depending on the application rate. Mefluidide (Embark, Embark 0.2S) and maleic hydrazide (Royal Slo-Gro, others) are examples of cell division inhibitors. These products are primarily used on low- and medium-maintenance turfgrass areas, as phytotoxicity (yellowing) can be a problem. On golf courses, cell division inhibitors may be useful to reduce mowing on steep slopes, ditches, and other difficult-to-mow areas.

Herbicides

Various herbicides are used at low rates to suppress the growth or seedhead development of turfgrasses. Depending upon the chemical, herbicides inhibit turfgrass growth and development through interruption of amino acid synthesis (glyphosate, sulfometuron, chlorsulfuron, metsulfuron, imazapic, imazethapyr + imazapyr) or fatty acid biosynthesis (sethoxydim). Turfgrass tolerance can be marginal and is highly rate dependent. Herbicides are primarily used only on low-maintenance turfgrasses to reduce mowing and control weeds.

Gibberellin Biosynthesis Inhibitors (also called Type II PGRs)

Gibberellin is a plant-produced hormone needed for cell elongation, as well as normal growth and development. Numerous gibberellins are needed for normal plant growth and development. When gibberellin production is inhibited, plant cells do not elongate, internodes become shortened, and overall plant growth is reduced. Two types of gibberellins (aka, gibberellic acid, or GA) biosynthesis inhibitors are available for use on golf courses. Trinexapacethyl (Primo) and prohexadione-Ca (Anuew), two Class A gibberellin biosynthesis inhibitors, are foliar absorbed and inhibit the synthesis of gibberellin late in its biosynthetic pathway. Paclobutrazol (Trimmit) and flurprimidol (Cutless) are root-absorbed Class B gibberellin biosynthesis inhibitors and inhibit gibberellin biosynthesis in the early stages of this pathway. This early blockage prevents the synthesis of numerous gibberellins. Inhibition during the early stages of gibberellin biosynthesis can lead to increased injury when environmentally stressed turfgrasses are treated with Class B gibberellin biosynthesis inhibitors. Additionally, turfgrasses may exhibit various morphological responses such as the widening of creeping bentgrass leaf blades. Studies have shown that inhibiting gibberellin biosynthesis late in the pathway, as with trinexapacethyl and prohexadione-Ca, is less physiologically disruptive and injurious to turfgrasses, although as with all PGRs, plant phytotoxicity can still occur at higher rates. Class B gibberellin biosynthesis inhibitors, however, tend to provide better seedhead and/or seed stalk suppression than Class A inhibitors.

Non-classified

Ethephon (Proxy) is a PGR in the turfgrass market that does not neatly fall into any of the previous categories. When in the presence of water in treated plants, it is hydrolyzed into the gaseous growth hormone, ethylene. It is primarily shoot and stem absorbed and has limited downward (basipetal) movement in plants. Ethylene is a growth hormone noted as a fruit ripener and retardant in floriculture crops. In turfgrass, ethephon at 3.4 pounds active ingredient per acre (3.8 kg active ingredient per hectare) provides good Kentucky bluegrass, perennial ryegrass, and hard fescue growth suppression for approximately four weeks. Interestingly, ethephon-treated Kentucky bluegrass often develops elongated internodes, resembling a stoloniferous-like growth habit. Treated turf often has enhanced green leaf color, and tiller formation and root length are stimulated. Rhizome development, however, may be somewhat inhibited. Tall fescue growth appears less influenced by ethephon. Combinations of ethephon with other PGRs, such as trinexapacethyl, are currently being investigated.

When converted to ethylene in plants, ethephon suppresses seedhead production by delaying flowering, selectively aborts flowers, and reduces stem elongation. It can also create a lower cytokinin ratio which results in less energy for cell division needed for seedhead emergence. Ethylene also is known to accelerate leaf senescence, resulting in chlorophyll breakdown and color fading. It, like all PGRs, must be applied prior to seedhead initiation for best results and is typically reapplied every three weeks until seed-head production ceases. Ethephon should not be applied to creeping bentgrass golf greens just prior to or during normal summer heat stress as ethylene also restricts rooting.

Site of Absorption

Plant growth regulators are absorbed, or enter the turfgrass plant, by roots, foliage (or shoots), or with some products, both roots and foliage **(Table 10–9)**. Root-absorbed PGRs, such as paclobutrazol and flurprimidol, require irrigation or rainfall after application to move the material into the turfgrass rootzone. In contrast, trinexapacethyl is rapidly absorbed by turfgrass foliage, and irrigation after application is not necessary. Compared to cell division inhibitors, there is less likelihood of leaf burn due to improper spray pattern overlaps with the gibberellin biosynthesis inhibitor PGRs. Most foliar-absorbed materials (e.g., mefluidide, maleic hydrazide, and herbicides) require uniform, even coverage to prevent phytotoxicity and must be absorbed by turfgrass leaves before irrigation or rainfall occurs.

Growth Suppression

Cell division inhibitor PGRs quickly (five to seven days) suppress vegetative growth, but usually provide a shorter period of growth suppression than gibberellin biosynthesis inhibitors (three to six weeks). However, unlike gibberellin biosynthesis inhibitors, cell division inhibitors are highly effective in suppressing seedhead development. The growth suppression activity of gibberellin biosynthesis inhibitors is often not immediately evident. Compared to cell division inhibitors, paclobutrazol and flurprimidol are slower (10 to 14 days) in suppressing turfgrass growth, but their duration of activity is usually longer, lasting from four to eight weeks, depending on the application rate. Selective suppression of *Poa annua* in creeping bentgrass with paclobutrazol is from bentgrass being able to metabolize the PGR quicker than Poa, thus, has less suppression of the bentgrass. Trinexapac-ethyl has been shown to reduce common and hybrid bermudagrass clipping weights 50 percent at seven days after application. Depending upon the application rates and schedules, trinexapacethyl also provides long-term (four to eight weeks) growth suppression. As temperatures increases, however, the longevity of trinexapac-ethyl in plants is reduced, requiring more frequent applications to provide comparable growth suppression as in cooler environments. Another key difference is while gibberellin biosynthesis inhibitors decrease seedhead stalk height, they have little effect on the actual formation of seedheads. However, GA-inhibiting PGRs redirect plant growth from shoots to tiller production, encouraging thicker turf stands. If GA-inhibiting PGR use is suddenly stopped, many plants experience a "rebound" effect where a surge of growth in terms of clipping production results. Continuing to apply a PGR suppresses leaf elongation and the rebound effect.

Application Timing

Timing of application with PGRs is critical to achieve desired results. When used for seedhead suppression, the PGR must be applied before seedhead formation and emergence. Applications made after seedhead emergence will not be effective. For bahiagrass, mow the area as seedheads initially emerge (usually from May to mid-June) to provide a uniform, even appearance to the site. For tall fescue or blue-grass, mow the area in early spring (late March to late April). The PGR treatment should be applied about 7 to 10 days following mowing or just prior to new seedhead appearance. Additional applications six to eight weeks later may be required if new seedheads begin to emerge.

If PGRs are being used on creeping bentgrass golf greens, applications should be made during periods of active root growth. In most areas, this would be during the mid-fall and spring months. Applications should not be made during stressful mid-summer and mid-winter months. On warm-season turfgrasses, such as bermudagrass, the appropriate PGR should be applied to actively growing turfgrasses after full spring green-up and several mowings. Applications can be repeated during the summer months if additional growth regulation is needed.

Growing Degree Days

A growing degree day (GDD) model is a method to track the accumulated heat units needed for certain plant growth and development events. For example, accumulated GDDs can be used to determine when weeds might germinate or flower or when grasses might produce seedheads. GDDs also are used to help optimize application timing such as pre-emergence crabgrass herbicide use, when various insects emerge, breed, and feed, when reapplications of plant growth regulators should be made, or the best timing of various amine or ester formulations of herbicides for spring broadleaf weed control. When accumulated GDD are tracked, a window of the best time to apply these applications or when these events might occur is better predicted. For example, the PGR trinexapac-ethyl is known to last shorter during warmer portions of the year. To mathematically track this, it has been determined 200 GDDs is when trinexapac-ethyl reapplication intervals are maximized to sustain clipping yield suppression during summer without allowing the "rebound" effect to occur. Conversely, it has been suggested 350 GDD are needed to predict optimal reapplication timing for paclobutrazol. To calculate GDDS, the high and low air temperatures are averaged, subtracted from a base temperature where metabolism is minimal, and added to values from previous days. The formula for calculating GDD is:

$$\text{GDD} = \left[\frac{\text{max temperature} + \text{min temperature}}{2}\right] - \text{base temperature}$$

In the case of trinexapac-ethyl, the base termperature of 32 F (0 C) has been used. For example, if the high today was 75 F and the low was 51 F, and the base termpeature of 32 F is used, the calculation would be:

$$\text{GDD} = \left[\frac{75 + 51}{2}\right] - 32 = 31$$

One would then simply add the GDDs calculated each day and in the case of trinexapac-ethyl, when the sum reaches 200 GDDs, then a subsequent application would be made. Much research is still needed to verify the accuracy of GDDs in different environments, when using various product rates, or when mixing products with different modes of action.

Weed Control Considerations

An integrated weed management program must accompany any PGR use as PGRs usually do not suppress weed growth, particularly that of broadleaf weeds. In addition, after the PGR has been applied, annual and perennial weeds can become a problem, as PGR-treated turfgrass often does not compete well with weeds. On high-maintenance turfgrasses, it usually is advisable to continue pre-emergence herbicide use to control annual grass weeds. For post-emergence control, 2,4-D, dicamba, or various two- and three-way herbicide mixtures are normally used to control broadleaf weeds. Other post-emergence herbicides such as MSMA, used for annual grass weed control, or nutsedge control herbicides may also be needed in some situations. Post-emergence herbicides often cause temporary phytotoxicity to turfgrasses. Post-emergence herbicides can be tank-mixed with PGRs; however, turfgrass injury is often greater than when either type of product is used alone. Therefore, on high-maintenance turfgrasses, where color and appearance may be of utmost importance, it is advisable not to tank-mix post-emergence herbicides with PGRs. Additionally, if a post-emergence herbicide has injured the turfgrass, PGR application should be delayed until the turfgrass has fully recovered. The PGR label and personal experience provide the best guide to determine the suitability of tank-mixing PGRs and post-emergence herbicides.

10.7 PLANT GROWTH PROMOTERS

An available plant growth promoter is gibberellic acid (GA) that encourages cell division and elongation. When used, GA helps initiate or maintain growth and prevent color changes (e.g., purpling) during periods of cold stress and light frosts on bermudagrass such as Tifdwarf and Tifgreen **(Figure 10–13)**. Oftentimes, fall golf tournaments may experience an early light frost before the overseeding has become established. GA helps the turf recover from this discoloration. A plant growth promoter also may be used for anecdotal purposes if excessive rates of a gibberellic acid inhibitory PGR, like trinexapac-ethyl, prohexadione-Ca, paclobutrazol, or flurprimidol, is applied. GA containing products should be used carefully and only where necessary because unacceptable yellowing of turf can occur.

Figure 10-13. Plant growth promoters are often used to help restore color to bermudagrass damaged by cool temperatures or as an antidote if excessive rates of certain plant growth retardants are applied.

11 EFFECTIVE AND SAFE USE OF PESTICIDES

11 EFFECTIVE AND SAFE USE OF PESTICIDES

Pesticides are tools used to help develop desirable plants and are among the main reasons we enjoy a high quality and quantity of food. Correct pesticide use is critical to the protection of the environment and is best ensured by following the label directions as required by law **(Figure 11–1)**. In addition, individual states have specific laws and regulations concerning pesticide storage and disposal. The following material is related to pesticides and their safe and judicious use. The state pesticide regulatory agency, County Extension Office, and the state environmental regulatory agency should be consulted for their exact safe use requirements. The pesticide regulatory agency for North Carolina is the N.C. Department of Agriculture and Consumer Services (NCDA&CS) Structural Pest Control and Pesticide Division, and for South Carolina the Department of Pesticide Regulation (a unit of Clemson University). The environmental protection agency for North Carolina is the NC Department of Environment and Natural Resources (NCDENR) and for South Carolina the SC Department of Health and Environmental Control (SCDHEC).

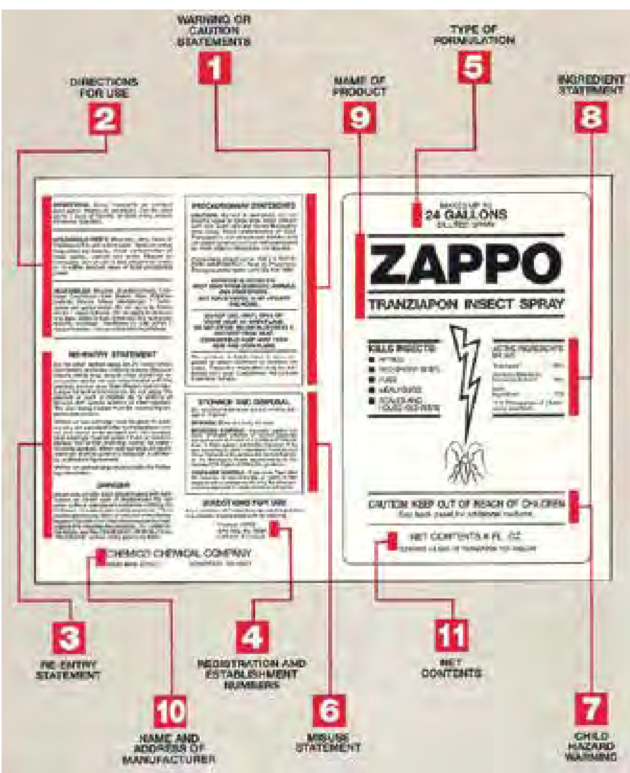


Figure 11–1. Pesticide labels contain a wealth of information such as directions for use and a variety of safety information.

11.1 PESTICIDE NOMENCLATURE

A **pesticide** is defined by regulation as any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest, and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant. Three types of names are normally associated with a pesticide. The **chemical name** describes the chemistry of the compound, which is usually technical and lengthy. The **common name** is a term often assigned to the chemical that is often a simpler version of the chemical name. Chemical and common names must be approved by an appropriate authority. The **trade name** or brand name, or product name, is used by the chemical company for marketing purposes to promote a specific product's sale. It often is the most recognizable pesticide name. A pesticide with one common name can have a number of trade names. For example, Fungo, Cleary 3336, and SysTec 1998 are **trade names** for the fungicide thiophanate methyl. Thiophanate methyl is the **common name**, while the **chemical name** is dimethyl 4,4'-o-phenylenebis[3-thioallophanate]. Due to the number of trade names and their constant changes, and because a given chemical has specific characteristics regardless of what product it is found in, most scientific journals and university publications refer to pesticides by their common name.

11.2 PESTICIDE REGISTRATION

Registering a new pesticide is a time-consuming, complicated, and expensive venture. Only one successful pesticide product reaches the market out of every 140,000 compounds tested. Discovering, developing, and registering a new pesticide costs over $200 million, with an additional $50 million to $100 million required to build a production plant. Nine to 10 years of testing normally are required before a compound reaches the market. Because a patent protects a compound for up to 20 years, less than 10 years of exclusive marketing can be expected to protect the investment of development and continued research and still provide a profit.

Much of the money needed for pesticide development is used to generate required data from extensive and rigorous testing **(Figure 11–2)**. Testing of the chemical and breakdown chemicals for crop safety, pest control efficacy, environmental fate and hazards, and a wide array of toxicological issues is conducted. Further, both Environmental Protection Agency and state registration costs for pesticide products have dramatically increased over time. These

Figure 11–2. Developing new pest control products is an expensive, time-consuming process to ensure turf safety, pest control efficacy, environmental fate, and to provide a wide array of toxicological tests.

increasing costs and regulations have contributed to a significant reduction in the number of companies developing new pesticides.

Data is submitted to the EPA for review and possible registration. The EPA has the responsibility of ensuring the pesticide poses no unreasonable environmental and health hazards when used as instructed. It is not the responsibility of the EPA to document efficacy. A label providing sufficient use instructions and warnings on safe and proper handling must accompany each product **(Figure 11–3)**. The EPA must approve the pesticide product label before the product can be registered.

The United States congressional law regulating the registration, manufacture, transportation, and use of pesticides is the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA). A legally registered pesticide will have an EPA registration number on its label. The EPA registers pesticides; it does not "approve" them.

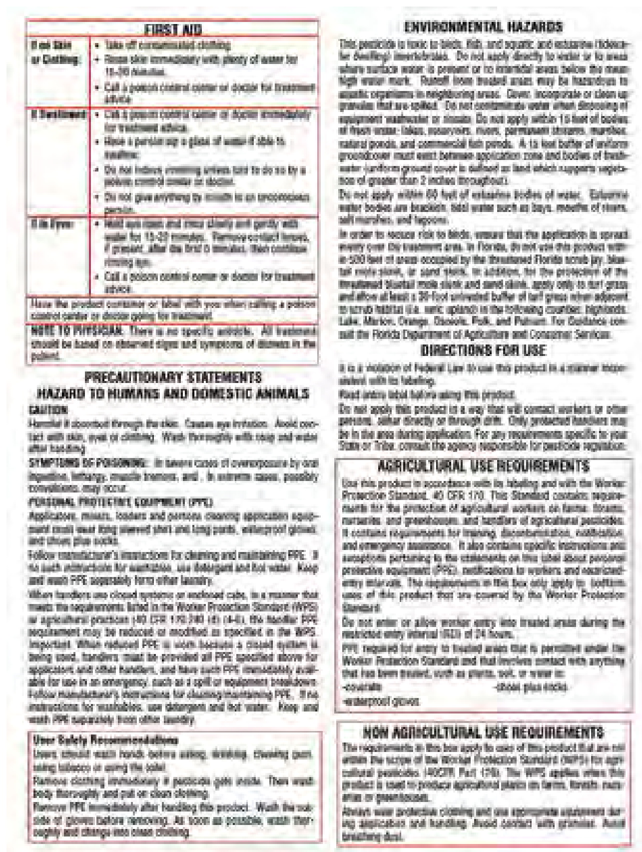
The law provides:

1. All pesticides must be used only as directed on the label.
2. All pesticides must be classified as "unclassified (general-use)" or "restricted-use" pesticides.
3. Persons who buy or use "restricted-use" pesticides must be certified as competent pesticide applicators, or must be supervised directly by a certified applicator.
4. Persons who do not obey the law will be subject to civil and/or criminal penalties including fines and jail terms.

Pesticide Classification

Unclassified (general-use) pesticides. These are pesticides the EPA determines will not cause unreasonably adverse effects to humans or to the environment. They may be purchased and applied by the general public when used according to label directions **(Table 11–1)**. However, in some states, anyone applying any pesticide for monetary compensation or to public property (including golf courses) must have a license or be directly supervised by someone with a license. **Restricted-use pesticides** are pesticides that pose some risk to the environment or human health even when used according to the label. These pesticides must be applied by certified applicators, or persons under their direct supervision, who have shown the ability to use these materials safely and properly. Persons handling both general-use and restricted-use pesticides must wear approved personal protective equipment (PPE). The pesticide label states whether a pesticide is classified as a restricted-use product.

A state may be allowed to register additional uses for a federally registered (EPA) pesticide under certain circumstances. This is called a **24(C) registration, or Special Local Needs (SLN) registration**. These registrations often involve adding application sites, pests, or alternate techniques to those already listed on the federally registered pesticide label. The EPA registration number will have the initials "SLN" and the two-letter abbreviation for the state that issues the special registration. The applicator must have a copy of an SLN label in his or her possession in order to apply the pesticide for the purpose listed on it.



FIRST AID

PRECAUTIONARY STATEMENTS

HAZARD TO HUMANS AND DOMESTIC ANIMALS

CAUTION

ENVIRONMENTAL HAZARDS

DIRECTIONS FOR USE

AGRICULTURAL USE REQUIREMENTS

NON AGRICULTURAL USE REQUIREMENTS

Figure 11–3. Pesticide labels provide instructions and warnings on safe and proper handling of the product.

Table 11–1. Table of pesticide toxicity hazard categories.

	CATEGORIES			
	I	II	III	IV
Oral LD_{50} (mg/kg)	0 to 50	50 to 500	500 to 5,000	>5,000
Inhalation LC_{50} (mg/L)	0 to 0.2	0.2 to 2	2 to 20	>20
Dermal LD_{50} (mg/kg)	0 to 200	200 to 2,000	2,000 to 20,000	>20,000
Eye effects	Corneal opacity not reversible within 7 days	Corneal opacity reversible within 7 days:irritation	No corneal opacity; irritation reversible within 7 days	No irritation
Skin effects	Corrosive	Severe irritation at 72 hours	Moderate irritation at 72 hours	Mild or slight irritation at 72 hours
Signal words/symbols	DANGER/POISON with skull and cross-bones symbol	WARNING	CAUTION	CAUTION
Description	Very highly toxic	Highly toxic	Moderately toxic	Low toxicity
Oral dosage lethal to human adults	Few drops to one teaspoon	One teaspoon to two tablespoons	One ounce to one pint	> One pint

A **Section 18** is another special temporary registration allowed under formally declared emergency situations where an unregistered pesticide may be used. Such situations require that no alternate control method is available and significant economic or health problems would exist if the pest is left uncontrolled. Non-food or non-fiber commodities such as turf and ornamentals rarely are granted Section 18 exemptions.

An **Experimental Use Permit (EUP)** is often granted by the EPA for products during the final stages of development to allow companies to expand their database under actual field conditions and commercial applications before full registration. Only a limited amount of the product can be used or sold in specific geographical locations under an EUP. These are also time-limited.

Certified pesticide applicators for golf courses in most states are regulated by the state's pesticide regulatory agency—Department of Agriculture, Department of Pesticide Regulation, or a similar department. Two tests must be completed before a person can obtain a restricted-use pesticide applicator license. The first test queries a person's knowledge of general areas of safe pesticide use and handling (core test), while the second covers specific information concerning pesticide use for turfgrass and ornamental pest control (category test). These tests are administered by the state regulatory agency at various locations. Testing may be available online. Study guides for the tests can be obtained from the state pesticide agency or Cooperative Extension. Once the license has been obtained, it must be renewed by accumulating credits, such as continuing education units (CEUs) or continuing certification credits (CCCs), over a prescribed period of years. Lapsed licenses usually require retaking tests. Programs that provide recertification credits are offered by a number of agencies, trade organizations or private entities throughout the year. The EPA recently proposed new requirements for recertification (2015) so be sure to be aware of any changes affecting your license.

Restricted-Use Pesticides. As previously indicated, restricted-use pesticides must be applied by a licensed, certified pesticide applicator, or by persons under the direct supervision of a licensed, certified pesticide applicator. "Direct supervision" is legally defined under federal and state law. If an unlicensed worker is applying the pesticide, the licensed supervisor may be required by law to tell or provide written or printed information to unlicensed workers including:

- Exact location to be treated.
- Safety procedures to be followed as given on the label.
- Safety clothing and equipment to be used.
- Common symptoms of pesticide poisoning.
- Dangers of eating, drinking, smoking, or toileting while handling pesticides.
- How to contact the supervising certified applicator
- Where to obtain emergency medical treatment **(Table 11–2).**

The licensed certified pesticide applicator must maintain records of the use of restricted-use pesticides. This information also should be maintained for general-use pesticides. The records must usually be kept for a state-prescribed length of time and usually include (exact requirements are state-specific):

- Date and time of treatment.
- Specific location of property.
- Pests to be controlled.
- Size of area or number of items or animals treated.

Table 11–2. Pesticide poison centers and record keeping in the Carolinas.

Anywhere: 1-800-222-1222	(call automatically directed to state poison control center)
South Carolina: 1-800-922-1117	
North Carolina: 1-800-848-6946	Georgia: 1-800-282-5846
If victim has collapsed or is not breathing, call 911.	
National Pesticide Information Center (NPIC): 1-800-858-7378 For a pesticide chemical emergency or for any pesticide information: nptn@ace.orst.edu http://hpc.orst.edu/	
For small pesticide spills: call the manufacturer (see product label or safety data sheet (SDS)), or NPIC at 1-800-858-7378.	
In South Carolina see:	
PIP- 43 - Pesticide Recordkeeping Requirements for Commercial and Non-commercial Applicators - In SC, commercial and non-commercial pesticide applicators may be required to maintain records on pesticide applications under more than one regulation. http://www.clemson.edu/extension/pest_ed/pdfs/pipsheets/pip43comm.pdf	
PIP- 44 - Pesticide Application Information Disclosure Requirements - In SC, all pesticide applica-tors are required to maintain records or display information about their pesticide applications, and often, under more than one regulation. http://www.clemson.edu/extension/pest_ed/pdfs/pipsheets/pip44disclos.pdf	
Note: EPA Soil Fumigation Information website: http://www2.epa.gov/soil-fumigants.	

- Owner or person authorizing application.
- Name of applicator.
- Pesticide used, including trade name and/or common name and/or active ingredient and or EPA registration number, amount of product or active ingredient.

Simplifying record keeping makes it less of an added burden. For example, superintendents can use a computer to print out customized forms with blanks to be filled in for each pesticide application. Another simplification of record keeping is the use of a rubber stamp that can be made at local office supply stores. Stamp the book pages and fill in the blanks accordingly. While pesticide record keeping is required by law, good records can help you duplicate successful applications and trouble-shoot pest control failures a s well as manage your pesticide purchases and inventory. An example of the minimum amount of information recorded for each pesticide application is shown on the Pesticide Application Record form on the following page.

11.3 PESTICIDE FORMULATIONS AND CARRIERS

Pesticides are not sold to end-users as pure chemicals but are formulated or combined with appropriate solvents, diluents, or adjuvants to form a material called a **formulation**. The primary function of formulating a pesticide is to permit uniform application. However, formulations also allow the pesticide to be used in different use situations, extend the stability and storage life of pesticides, enhance pesticide activity, allow pesticides to be packaged in convenient containers, and allow for safer use. They also may vary in their effectiveness on pests and the tolerance of turf and ornamentals to the pesticide. Some formulations are more costly than others, and the ease of application and compatibility with your application equipment can vary according to the formulation. Pesticides are available in a variety of formulations, and often the same pesticide is sold as several different formulations **(Table 11–3)**. A Safety Data Sheet (SDS) for each formulation of a pesticide must be obtained and maintained as legally required.

Pesticides are applied to the target site with the use of a carrier. A carrier is a gas, liquid, or solid substance used to propel, dilute, or suspend a pesticide during its application. Water is the most commonly used liquid carrier, although fluid fertilizers also may be used. Granules and pellets consisting of clay, corn cobs, ground nut hulls, sand, or dry fertilizer serve as carriers for dry pesticide formulations.

Sprayable formulations are applied with liquid carriers, usually water. The amount of liquid carrier required to uniformly cover the turfgrass will be indicated on the label. Use the label recommendation for each pesticide you apply, because amounts above the label rate are illegal and those below the label rate may be ineffective. Dry pesticide formulations are not applied with liquid carriers but are applied as purchased. Dry pesticide formulations have relatively low concentrations on the dry carrier to aid in uniform distribution.

PESTICIDE APPLICATION RECORD

Company Name _____________________________ Commercial Applicator ________________________ License No.____________

Pesticide License Category _____________ Trade Name ___________________ Active Ingredient & Formulation _______________

% Active Concentration ________ Manufacturer ___________________ EPA Registration No. ____________ Lot No.___________

Restricted-entry Interval (REI)__________________________________ PPE Needed/Worn ________________________________

APPLICATION INFORMATION

Application Start Time ______________Treated Site Location ____________________ Type of Area Treated___________________

Target Pest(s)________________ Total Treated Area____________ Application Rate (e.g., per acre or per 1000 sq. ft.) __________

Timing _________ Amount of Pesticide Mixed ____________ Per __________Gallons of Water: Gallon Per Acre (GPA)__________

Additives (Surfactant/Wetting Agent/Crop Oil, etc.)________________________________ Rate _____________________________

WEATHER CONDITIONS

Air Temperature (F)_________ Relative Humidity (%)__________ Dew Present (Y/N________ Initial Wind Speed (MPH_________

Wind Direction _______; First Hour_______; Second Hour_______; Third Hour_______; Soil Temperature at 4 inches (F) ________

Soil Moisture ____________ Cloud Cover (%)_________ Rainfall/Irrigation after application (date/time/amount) _______________

APPLICATION EQUIPMENT

Method of Application ________ Speed (mph)________ Motor Speed (RPM)_________Nozzle Type_________ Number_________

Nozzle Height_______________ Spacing_______________ Boom Width________________ Spray Pressure (PSI)_________________

Nontarget Plant, Animal, or Human Exposure: Yes No (If yes, identify and list corrective or emergency action taken)

Other Comments:

Signature____ Date ____

Table 11–3. Comparisons of commonly used pesticide formulations (read individual labels for product specific information).

FORMULATION (ABBREVIATION)	MIXING/ LOADING HAZARDS	PLANT P HYTOTOXICITY	EFFECT ON APPLICATION EQUIPMENT	AGITATION REQUIRED	VISIBLE RESIDUES	COMPATIBLE WITH OTHER FORMULATIONS
Dry flowables/water-dispersible granules (DF or WDG)	Minimum	Safe	Abrasive	Yes	Yes	Good
Emulsifiable concentrates (EC)	Spills & splashes	Possible	May affect rubber pump parts	Yes	No	Fair
Flowables (F)	Spills & splashes	Possible	May affect rubber pump parts; also abrasive	Yes	Yes	Fair
Dusts (D)	Severe inhalation hazards	Safe	—	----	Yes	—
Granules (G) & pellets (P or Ps)	Minimal	Safe	—	No	No	—
Microencapsulated (M)	Spills & splashes	Safe	None	Yes	—	Fair
Solutions (S)	Spills & splashes	Safe	Nonabrasive	No	No	Fair
Soluble powders (SP)	Dust inhalation	Safe	Nonabrasive	No	Some	Fair
Wettable powders (WP)	Dust inhalation	Safe	Abrasive	Yes	Yes	Highly

Adjuvants

An **adjuvant** is a spray additive enhancing the performance, safety, or handling characteristics of a pesticide. “Adjuvant” is a broad term and includes **surfactants, crop oils, crop oil concentrates, antifoaming agents, drift control agents, pH modifiers, and compatibility agents.** These help modify the surface properties of liquids by enhancing and facilitating emulsifying, dispersing, wetting, spreading, sticking, and penetrating of liquids into plants and soil. Surfactants, crop oils, and crop oil concentrates are added according to label directions since indiscriminate use may cause severe turfgrass injury or decreased pesticide performance. Some pesticides, such as post-emergence herbicides, and a few fungicides have surfactants included in their formulation; therefore, additional surfactant is unnecessary. Always read the pesticide label before adding any adjuvants. Look for recommendations as to the type of adjuvant to add. Use only the recommended rates as too much of some adjuvants can cause an unsprayable tank-mix. Surfactants are the most common type of adjuvant and are most often used in liquid (soluble, emulsifiable) and dry (wettable powders, others) formulations applied in aqueous sprays.

Surfactants. Substances without affinity for each other (such as water and leaf wax) tend to repel. To “bind” the two surfaces, surfactants with a lipophilic (oil-loving) portion and a hydrophilic (water-loving) portion on the same molecule are used. **Surfactant** is an acronym for **surface-active agent**. Surfactants change surface properties of other materials. At low concentrations, surfactants reduce surface tension between spray droplets and the waxy leaf surface, allowing the spray droplets to spread out and contact a greater portion of the leaf. This aids in penetration and helps prevent droplets from rolling off the leaf. At higher concentrations, surfactants help dissolve the wax in the leaf cuticles, allowing easier penetration of the leaf by the pesticide. However, this also accounts for undesirable phytotoxicity to the turfgrass if excessive rates are used.

Three major types of surfactants include **emulsifiers, wetting agents,** and **stickers**. **Emulsifiers** stabilize the dispersal of oil-soluble pesticides in water so the pesticide will not separate or settle out in the spray tank. These allow petroleum-based formulations such as emulsifiable concentrates (E or EC) to mix with water. These usually are added by the chemical company during the pesticide formulation process. **Invert emulsifier**s allow water-based pesticides to mix with petroleum-based carriers and are most often used for vegetation control. **Stickers** (or adhesives) cause the spray droplet to adhere to the leaf surface and reduce spray run-off during application and wash-off by rain or irrigation. Stickers often are combined with wetting agents (spreader-stickers) to increase adhesion and spray droplet coverage.

Dispersing agents also are surfactants that enhance the dispersal of a powder in a solid-liquid suspension. As with wetting agents, the lipophilic (oil-loving) end of the dispersing agent molecule partitions into the suspended particle while the hydrophilic (water-loving) end partitions into the surrounding water medium, reducing the water tension and enabling the particle to repel other particles and remains in suspension. So, they help prevent clumping of the pesticide.

Wetting agents help the spray droplet to spread over the leaf surface by reducing the interfacial tension between the leaf surface and spray droplets. Wetting agents also allow wettable powders to mix with water. The three types of wetting agents (**anionic, cationic,** and **nonionic**) are classified based on how they ionize or separate into charged particles in water. **Nonionic** surfactants do not ionize; thus, they remain uncharged. They are the most commonly used type of surfactant and are compatible with most pesticides. They are unaffected by water containing high levels of calcium, magnesium, or ferric (iron) ions. They also can be used in strong acid solutions. **Anionic** surfactants ionize with water to form a negative charge while **cationic** surfactants ionize with water to form a positive charge. These are only occasionally used. A pesticide mixed with an anionic surfactant will stick to the leaf tissue because of its charge but will not be absorbed by the plant. These should be used with pesticides that remain on the plant surface (contact pesticides).

A pesticide mixed with a nonionic surfactant will help the pesticide penetrate plant cuticles. These are best used with systemic pesticides that need to be absorbed by the plant to be effective. Cationic surfactants are extremely phytotoxic. Do not use them unless it is specifically stated on a pesticide label.

Crop Oils. **Crop oils** and **crop oil concentrates** are light oils containing varying percentages of surfactants and primarily emulsifiers. These are phytobland (they tend to be non-phytotoxic within normal temperature ranges) petroleum or vegetable oils increasing pesticide absorption through leaf cuticles (or waxy layer). Crop oils contain 1 to 10 percent surfactant and commonly are used at concentrations of one gallon per acre. Crop oil concentrates contain 17 to 20 percent surfactant and are generally used at concentrations of one quart per acre. Crop oil concentrates have replaced crop oils because reduced amounts of the adjuvant are required.

Methylated Seed Oil. An MSO is a methylated seed oil, such as soybean oil, produced by reacting methanol with whole soybean oil in a process called "transesterification," that changes soybean triglyceride into soybean methyl ester. MSOs are especially effective in post-emergence weed control as the MSO dissolves the protective wax cuticles formed by weeds. Control can often be achieved at a rate of 1 to 2 pints per acre (1.12 to 2.3 L/ha), compared to a quart or more for other types of adjuvants per acre (2.3 L/ha).

Miscellaneous Adjuvants. The use of **anti-foaming agents** (or defoamers) minimizes air entrapment during agitation and may be necessary if excessive foaming occurs in the spray tank. **Drift control agents** (or thickeners) reduce spray droplet drift by reducing the percentage of very fine spray particles in the spray mist and play an increasingly important role as drift reduction requirements become more stringent. **Stickers** reduce losses of spray droplets from leaf surfaces by increasing the viscosity of spray droplets and reducing the interfacial tension between the spray droplet and the leaf surface. The droplets then resist washing off and, at the same time, spread out on the leaf surface. **Compatibility agents** are added to fluid fertilizer and pesticide mixtures to prevent these individual components from separating or clumping. Follow label directions closely for mixing compatibility agents. However, before adding any such mixture to a spray tank, test the mixture in a small jar to ensure there will be no clumping or separation (see procedure below).

Penetrants allow pesticides to enter the outer surface of plants while **spreaders** allow a uniform coating layer over the treated surface.

Some pesticides will be inactivated if the pH is too high or too low. **Modifiers** are compounds, either buffers or acidifiers, available to adjust the pH of the water, especially if used as the pesticide carrier. Buffers change the pH to a desired level, and then keep it relatively constant. Acidifiers neutralize alkaline solutions (lower the pH) but will not maintain the pH at this level as well as buffers do. Lower solution pH with an acidifier after the pesticide is added to the tank. Ask your sales representative to provide you with the manufacturer's recommendation for the pH of the carrier.

Pesticide Compatibility

Two or more pesticides, or one that can be mixed with fertilizer, are compatible if no adverse effects occur as a result of the mixture. Possible effects of mixing incompatible chemicals include:

- Effectiveness of one or both compounds may be reduced.
- A precipitate may form in the tank, clogging screens and nozzles of application equipment **(Figure 11–4)**.
- Plant phytotoxicity, stunting, or reduced seed germination and production may occur.
- Excessive residues.
- Excessive run-off.

Figure 11–4. Undesirable layering when mixing products which are incompatible.

Figure 11–5. When unfamiliar with mixing products, a jar test should be performed to ensure they are compatible.

Before tank-mixing pesticides, surfactants and/or fluid fertilizers, a proper order exists for adding them to the spray tank. However, chemicals can potentially react with each other and/or change the characteristics of the carrier water. These interactions can change the efficacy of pesticides in both positive and negative ways. Potential positive effects include: enhancement, additive effects, and synergism. Negative effects of products being incompatible include: antagonism, incompatibilities, and possible pesticide resistance **(Figure 11–5)**.

Compatibility Test. A compatibility test (the jar test) should be made well before mixing chemicals for application. Some pesticide labels give the procedure for this, but a general procedure is:

1. Measure 1 pint of carrier water in a clear quart jar that is not used for any other purpose.
2. Add ingredients in the proper mixing order ***(Table 11–4)***, stirring each time a new chemical is added. Check for the formation of foam, flakes, sludge, gels, oil films, scum or precipitates after adding each ingredient. It is sometimes necessary to premix (slurry) some chemicals (some wettable powder (WP), dry flowable (DF), water-dispersing granule (WDG), or liquid flowable formulations as indicated on the labels) before adding to the jar. *Do not mix the chemicals together without dilution before adding to the jar or spray tank.*
3. Let the mixture sit for 15 minutes. Check for foam, scum and precipitates and other unexpected results or appearance (for example, wettable powders will not dissolve). Feel the side of the jar to gauge temperature. If it is warm, let the jar sit and recheck in another 15 minutes.

Mixing Compatible Chemicals. Mixing some pesticides requires premixing, making a slurry, in a smaller, separate container or tank.

1. Always add a wettable powder first. Make a slurry with it in a separate container by adding a small amount of water until it forms a gravy-like consistency. Slowly add this slurry to the tank with the spray tank agitator running.
2. Dry flowable or water-dispersible granules are added second. Flowables should be premixed (one part flowable to one part water) and poured slowly into the tank **(Table 11–4)**.
3. Liquid flowables should be added third, after dry flowables. Liquids should also be premixed (one part liquid chemical to two parts water or liquid fertilizer) before blending in the tank. Many labels provide the proper mixing sequence.
4. Emulsifiable concentrates and water-soluble liquids should be added last.

Proper Order for Tank-Mixing Various Pesticide Formulations

WP → DF → F → EC → S

Table 11–4. Proper mixing procedures for tank-mixing chemicals and amount of each chemical needed to perform a jar test. Agitate (vigorously mix or shake) the mixture following each step.

ORDER OF ADDITION	CHEMICAL	AMOUNT FOR JAR TEST (PER 40 TO 50 GPA OF SPRAY VOLUME)
1	Water conditioning agents and activators	1 teaspoon for each pint
2	Wettable powders and dry flowables	1 tablespoon for each pound
3	Water soluble concentrates or solutions	1 teaspoon for each pint
4	Soluble powders	1 teaspoon for each pound
5	Emulsifiable concentrates	1 teaspoon for each pint
6	Surfactants and oils	1 teaspoon for each pint proportional
7	Fertilizers	

Table 11–5. Spray-tank pH levels and precautionary statements.

pH RANGE	COMMENTS
3.5 to 6.0	Satisfactory for spraying and short-term storage of most spray mixtures in the spray tank.
6.1 to 7.0	Adequate for immediate spraying of most pesticides. *Do not allow mixture to sit over one to two hours to prevent loss of effectiveness.*
≥7.1	Should add buffer or acidifier, do not allow to sit in direct sunlight, and use immediately following mixing.

pH Problems

The measure of pH (how alkaline [or basic] or acidic a solution is - pH 7 is neutral) can greatly influence how pesticide and other products perform. Most waters are slightly basic because of the presence of dissolved carbonate and bicarbonate salts. The water pH greatly affects the breakdown (or hydrolysis) of pesticides. In general, high pH water conditions (basic) cause a shorter chemical half-life (the time it takes for half of the pesticide to break down) of the pesticide. Insecticides are especially affected by spray-tank water pH. For example, acephate (Orthene) has a half-life of 65 days at a pH of 3 (acidic), and a half-life of 16 days at pH 9 (basic). Carbaryl (Sevin) has a half-life of 100 to 150 days at pH 6, but only 24 hours at pH 9.

The pH of spray-tank water should be adjusted with buffers or acidifiers to within a certain range for adequate usage **(Table 11–5)**.

To test and adjust the pH of water to be used for mixing pesticides, do the following:

1. Test the water by using a clean container to obtain a one-pint sample of water to be used. Check the pH using a pH meter, test kit, or test paper and determine if the pH needs to be adjusted.
2. Adjust the pH by using a standard eyedropper to add three drops of buffer or acidifier to the measured pint of water. Stir well with a clean glass rod or clean, nonporous utensil. Check pH as above and, if further adjustments are needed, repeat the previous steps until proper pH is obtained, recording the number of times three drops of buffer or acidifier were added.
3. Correct the pH in the spray tank by filling the tank with water and your pesticide. Add two ounces of buffer or acidifier for each time three drops were used in the previous jar test, in every 100 gallons of water in the spray tank. Recheck the pH of the tank mix and adjust, if necessary.

11.4 HANDLING PESTICIDES SAFELY

Pesticide "handling" includes virtually all transport, storage, mixing, loading, applying, and disposal activities.

Pesticide Storage

Proper storage of pesticides not only helps protect against accidental spills and leaks, but also influences the shelf life and efficacy of relied-upon products. Factors such as air temperature, humidity, sunlight, and ventilation should be carefully considered. The following are some storage suggestions; however, the best source of specific product storage and spill control information is the product SDS.

The Storage Facility and Site ***(Figure 11–6)***

- Keep the amount of storage space to a minimum to discourage storing unneeded pesticides, but large enough to handle what might reasonably be kept on hand. This should include not only newly purchased chemicals, but also opened containers; empty, clean containers; and waste pesticides held for proper disposal.
- Locate the storage site in a safe location: a place not flooded by rivers, ditches, run-off, or tides.
- To prevent moisture accumulation, elevate the storage facility above the immediate ground level by at least 12 inches (0.3 m). Free moisture will disintegrate paper or cardboard packaging; make labels unreadable; cause labels to detach; cause dry formulation to clump, cake, break down, or dissolve; rust metal containers; and possibly cause pesticides to spread or move from the storage area.
- Use a portable storage building for best storage. These can be repositioned relatively easily in case of flooding or change in the area use patterns.
- Use tie-downs on portable storage buildings to prevent tipping, rolling, or movement due to wind or water.

Figure 11–6. A prefabricated pesticide storage facility.

- Select a site with as little run-off as possible to prevent contamination of surface waters in case of a leak or spill.
- Locate the storage facility at least 100 feet (30 m) from surface waters and wells, animal feeding stations or shelters, and food or feed storage and dwellings. Check your state regulations.
- Determine the direction of prevailing winds and consider what is downwind from your storage site. This may be important in the event of spills or fires.
- Locate your storage site so it is easily accessible by vehicles for pesticide delivery and pick-up, as well as emergency vehicles.
- Consider using barriers, such as posts/bollards, to prevent damage to the storage unit by vehicles delivering pesticides or picking them up for applications.
- Determine and comply with any applicable local zoning and building codes.

Physical Construction of the Storage Unit

- Use a separate storage unit made of non-flammable materials to reduce fire hazard.
- The best storage is a detached structure positioned far enough away from other structures that could threaten the storage if they should burn.
- Use sealed floors—metal; sealed concrete; epoxy-coated metal, wood, or concrete; no-wax sheet flooring; or other easily cleaned, non-absorbent material. Dirt or unsealed wood flooring should not be used.
- Use non-absorbing materials throughout. The best shelving is metal with a lip. Consider leak-proof plastic trays on shelves.
- Have a built-in sump, or drain to a sump. Locate any external sump adjacent the building instead of under it for easy access if you need to remove spilled materials. Protect sumps from filling with water from rain or run-off.
- Have a continuous internal lip or curb two to four inches (5 to 10 cm) high to prevent spills from overflowing and going outside the building **(Figure 11–7)**.
- If possible, provide electrical power to the storage unit. This allows interior lighting, as well as an exhaust fan and heater. It also allows exterior security lighting and alarms. Explosion-proof wiring and switches are best. The light/fan switch should be on the outside of the storage unit and weatherproof.
- Have good lighting; explosion-proof lighting is best. Good lighting lets you:
- read labeling
- note leaks and damaged containers
- clean-up spills
- record inventory changes

Storage Environment

- Keep the storage unit dry. Keep doors and windows to the outside closed and locked, unless windows are needed for ventilation.
- Keep the unit well-ventilated by passive ventilation, mechanical ventilation, or both.
- Locate a louvered vent or exhaust fan high at one end (back) of the unit and an air makeup louvered vent low at the other end (e.g., in the lower part of the door). This allows vapors to flow away from anyone entering or inside the storage unit.
- One recommendation for mechanical ventilation is an exhaust fan capable of exchanging air in the unit at least once every six minutes; increase to every three minutes when pesticide handlers are in the unit. For best operation, wire the fan to the light switch so the fan is always on or increases speed whenever pesticide handlers are in the unit. If possible, also wire the fan to a thermostat set between 75 and 85°F (24 and 29°C).
- Keep pesticides from freezing and extremely high temperatures. Most pesticides should be stored at above 40 and below 90°F (4.4 and 32°C). Read your pesticide labels and SDSs.
- Freezing can cause containers to burst or develop intermittent leaks. Freezing may cause formulations to separate. Many pesticide labels say "Store in a cool, dry place." Some must be stored at temperatures below 90°F (32°C).
- High temperatures can cause plastic to melt or become brittle, or glass to burst. Pressure caused by high temperatures may cause intermittent leaks, swelling, or a spill when the product is opened. High temperatures can break down some chemicals or cause some chemicals to volatilize. Heat can also cause explosion or fire.
- Insulate the unit to prevent freezing or overheating.
- Install a heater, ideally an explosion-proof one.
- Keep containers out of direct sunlight. Don't put containers, especially glass or aerosol containers, in windows, even temporarily.

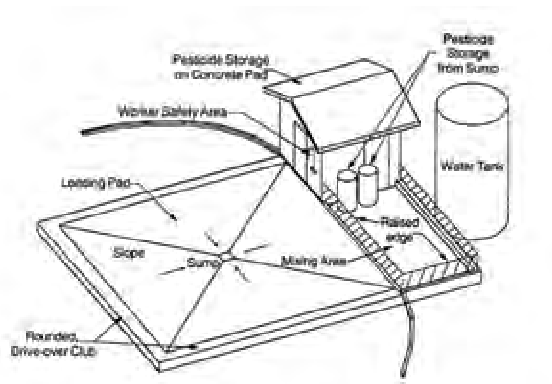


Figure 11–7. Illustration of a pesticide mix/load site with a loading pad with sump and curb, pesticide storage tanks from this sump, and a water tank for emergencies.

Low-Temperature Considerations

1. When temperatures drop too low, solvents may precipitate out of the solution and crystallize on the inside surfaces of plastic containers. If these crystals are allowed to remain inside the container when the product is poured, there will be an altered ratio of active ingredient per amount of solvent. The result is an incorrect application rate. Some products can be shaken to get the active ingredient back into the solution.
2. Because plastic jugs may become brittle under very cold temperatures, they should be stored on shelves low enough to minimize the effect of dropping. In general, try to avoid storing liquid products above other products in the unlikely event a container leaks. Shelves should be constructed of metal, not wood.

High-Temperature Considerations

1. Excessive heat can cause some products to decompose and lose efficacy. This same decomposition process may also result in the creation of gasses within the container. Under extreme conditions, these gasses may create sufficient pressure that some product is sprayed out of the jug upon opening or at least is mixed into the air during mixing. Always work in well-ventilated areas.
2. High heat coupled with high humidity may weaken cardboard containers in which pesticides are packaged.

Storage Security

- Store pesticides in a separate location, preferably in a separate locked storage building just for them.
- Always lock pesticide storage cabinets, closets, rooms, and buildings.
- Besides locking a storage building, it is a good idea to fence it in and lock the gate.
- Limit access to pesticide storage—allow access to only essential persons. Take necessary steps to keep out any unauthorized persons—children, workers who do not use pesticides, visitors, and so forth.
- Consider installing security lighting and possibly an alarm system.
- If pesticide storage is located within a larger structure, have storage access through a separate, outside door.
- Post signs on the door, building, or fence indicating pesticide storage that tell people to stay out: "Danger—Pesticides—Unauthorized Persons KEEP OUT." Consider writing this information in an additional language, such as Spanish **(Figure 11–8)**.
- Signs should have at least two emergency phone numbers. One person should not be the sole contact in an accident, as that person could be the victim of an accidental exposure. At least one phone number should be for emergency response (fire, rescue, etc.). Poison Control Center phone numbers are a good additional choice.
- Indicate the location of the nearest accessible telephone.
- Post NO SMOKING signs and do not allow smoking in or near your storage area or facility.

Safe Storage Practices

Good storage practices are in part good pesticide handling behaviors. While a good storage unit remains essential, these practices are the real key to safe pesticide storage:

- Read the label and comply with all product storage requirements.
- Store pesticides in their original containers. While this is familiar advice, storing pesticides in other than the original container is one of, if not the, most frequent pesticide storage violations.
- Be sure all opened (used) containers are kept securely closed or sealed. If a container is not emptied with a given use, mark the opening date on the container before storing.
- Be sure all pesticide labels and containers are intact. Obtain necessary replacement labels from your dealer or chemical sales representative. A product name penciled on masking tape is not a label. A substitute label, if needed, should have at least the product name, the active ingredient name, the EPA registration number for the product, the manufacturer's name, and any emergency phone numbers listed on the original label.
- Be sure to:
- Store pesticides separately from food and feeds.
- Follow any specific storage separation requirements on the label. An example is the required separate storage for phenoxy herbicides (e.g., 2,4-D). Vapors can cross-contaminate other stored chemicals.

Figure 11–8. Signs in English and Spanish indicating the entrance to a pesticide storage facility.

- Keep any food, drinks, veterinary supplies or medications, first aid supplies, and clothing or protective equipment, especially respiratory protection, out of the storage area. These can easily be contaminated by dusts, vapors, or spills.
- Use a sharp knife or scissors to open paper containers and not tear them unevenly.
- When pouring from a container, keep it at or below eye level and avoid splashing or spilling on your face or protective clothing.
- Never use your mouth to siphon a pesticide from a container.
- As much as you can (especially if the label so states):
- Store all pesticides separately from other chemicals, such as fertilizers.
- Store pesticides separately from gasoline and other fuels.
- Separate insecticides, fungicides, and so forth, from herbicides.
- Store volatile and flammable materials separately.
- Store liquid formulations below dry formulations.
- Store any glass containers on the lowest level.
- Store containers off the floor.
- Store empty, clean containers separately from full and in-use containers.
- Keep measuring devices (spoons, cups, scales) in the pesticide storage area and label them to prevent their accidental use for other purposes.
- Keep spill control supplies in the storage unit; for example, clean-up materials such as cat litter, vermiculite, spill pillows, and so on; broom, dust pan; activated charcoal, lime, or bleach for decontamination; plastic bags; gloves, eye protection; and plastic sealable container(s).
- Collect spilled pesticides for possible reuse. Remember, clean-up materials become hazardous waste.
- Update your pesticide inventory. You will need an up-to-date inventory for determining future purchases, and in case of spills, fire, weather-related damage, or theft. Keep copies at the storage site, filed at the office, and with your local emergency response agency.
- File copies of your storage location map, storage unit floor plan, and current or seasonal inventory in a secure place away from the storage unit, along with your fire department or other first responders, and with your Local Emergency Planning Committee (LEPC), if required.
- Have a plan. Develop a contingency plan for your establishment with your fire department/rescue unit, especially considering your pesticide storage. In case of a fire in a chemical storage facility, the preferred course of action is to let it burn. Remember, firefighters are trained to put out fires. Work with these agencies before you need them.
- Fire control—have an ABC fire extinguisher and fire/rescue telephone numbers outside the storage building.
- Keep SDS sheets in an accessible location.

Other Considerations

- Store products away from heat sources such as gas or electric heaters.
- Segregate products according to hazard class (flammables in one corner, non-flammables in another corner, and poisons in another).
- Chemical storage areas should be a safe distance from water sources, and should be kept locked when not in use.
- Regularly inspect containers for leaks.
- Dry bags should be raised on pallets to prevent them from getting wet. Liquids should be stored below dry materials, not above them.
- Segregate pesticide types to prevent cross-contamination and to minimize the potential for misapplication.
- Keep a spill kit handy, and make sure employees know how to use it.
- Maintain emergency showers and eye wash stations within close proximity of storage and mixing areas.
- Fire extinguishers should be located near every exit of your storage building and should have a 2-A rating (at minimum, 10-pound,, 4.5 kg, ABC).
- Post emergency telephone numbers where they can be readily found, if needed. This list should include company managers as well as local fire and rescue units.
- Maintain an up-to-date inventory record of all stored products, and keep it in a separate location. In case of a fire or spill, the fire department or other emergency personnel will want to know exactly what products are involved.
- When adding water to a spray mixture, keep the water hose end above the level of the mixture and not in it. This prevents contamination of the hose and avoids the possibility of back-siphoning. Do not leave equipment unattended when it is being filled.

Additional Safe Storage Practices

- Conduct regularly scheduled safety and maintenance inspections of the storage unit or facility.
- Have a nearby source of clean water for decontaminating skin, eyes, and so forth.
- Eye wash stations are desirable and may be required by pesticide labeling or chemical safety regulations depending on how your storage unit is sited. Mount eye wash stations outside a smaller storage unit to prevent contamination.

- In a larger facility you may want or need emergency deluge-type showers in addition to eye wash fountains.
- Locate a telephone in or near the storage area for reporting emergencies.
- Know what your insurance policy covers. Check limitations on coverage. You may need riders for complete coverage. Keep your policy in a safe place.
- If you consider modifying your present storage unit and practices or purchasing new storage, you will undoubtedly consider the costs of these measures. When you balance costs and benefits you should consider:
- the dollar value of your stored pesticides (are they insured?)
- the ease and cost of spill clean-up in substandard storage
- your liability in the event of a spill or fire where there is an environmental impact
- your liability if any person or animal is injured or killed
- the potential cost of EPA/state fines for improperly storing your pesticides, or OSHA fines for improper chemical storage or related violations
- your cost and time-frame for changes needed to correct violations
- The final advice must be the original advice: Follow label instructions—the label is the law.

So How Safe is Your Pesticide Storage?

- Do you store your pesticides in a detached structure?
- Does your storage building have a sound roof?
- Does your storage building have sound, liquid-proof flooring?
- Are the pesticides you store in their original containers?
- Do the pesticides you store have intact, readable labels?
- Do you store your pesticides separately from gasoline and other fuels?

Reusing Stored Pesticides

Stored pesticides should be examined before they are used to determine if they have deteriorated **(Table 11–6)**. Check containers for leaks, cracks, tears, erosion, seal failures, or the development of gases. Some formulations, such as those containing emulsifiers, may stratify at low temperatures and should be thoroughly stirred or shaken and allowed to sit for 30 minutes. These should then be rechecked to see if the formulation stays in solution. If not, then it should be properly disposed and not used.

Re-suspending crystals that have separated out is done by carefully heating the mixture to 100 to 140°F (38 to 60°C) using electrically heated warming blankets, hot water baths, or steam, but never by using an open flame. This should be performed by experienced pesticide handlers and not by the general public. If the pesticide appears normal but there are doubts about its effectiveness, test a small amount according to label instructions. Product-specific information on reuse may be found on the product SDS and the label. If a pesticide exhibits any of the signs of deterioration listed in **Table 11–5** and cannot be restored to usable condition, it should be properly disposed of.

Pesticide Containment Area

A pesticide containment area is designed to keep storage, mixing, and loading isolated from other operations. It usually consists of a concrete pad on which a storage building is built and where a drainage system can collect spills and washwater into a holding tank. The key concept is that spills and equipment washwater can be easily contained, temporarily stored, and then added back to the spray tank as mix water to be sprayed according to the label, or properly disposed of.

The concrete pads must be sufficiently reinforced and thick enough to accommodate the gross weight of any item or combination of items to be washed without any structural damage. The area also should exclude run-off in the case of excessive rainfall. State and local laws may govern the proper design and construction of pesticide storage and containment areas and should be consulted when construction is planned on such a facility. Pesticide con-

Table 11–6. General signs of deterioration in pesticide formulations.

FORMULATION	GENERAL SIGNS OF DETERIORATION
Dusts and granulars	Excessive lumping.
Emulsifiable	Milky coloration does not occur with the addition of concentrate to water; sludge or separation of components is evident.
Oil sprays	Milky coloration does not occur by addition of water.
Solutions	Crystallization, precipitation.
Wettable powders	Lumping occurs and powder will not suspend in water.

tainment and the wash pad site should be concrete. This prevents the accumulation of rainwater and overflow.

No one design fits all situations, and it is better to set up your own containment area so it is used effectively in your operations. Some considerations include:

- The storage building should be on the pad so spills within the building can be washed into a dead-end drain for collection and later application. As a precaution, keep absorbents such as cat litter or dry soil in the building for spill clean-up.
- The pad should be sloped to a drain that can be routed directly to a storage tank, usually through a sump pump. Spills and equipment rinses can be washed into the storage tank, and this mix can be used as makeup water in the next tank mix. Appropriate filters will be needed so the spray nozzles do not become clogged; likewise, keeping mud and debris off the pad is important.
- A roof over the pad eliminates the need to handle rain falling on it. If no roof is possible, the pad drain should have a valve to allow rain to drain freely; this valve can be closed during spray operations. Any materials spilled on the pad should be washed into the storage tank before the valve is opened.

A puncture-type pressure rinse nozzle should be available to rinse empty containers into the spray tank. Bags should be shaken clean and disposed of in an approved landfill.

Worker Protection Standard

The **Worker Protection Standard (WPS)** applies to agricultural workers performing tasks related to the cultivation and harvesting of agricultural plants on farms, nurseries, greenhouses, and in forests. The law also applies to employees who handle (mix, load, apply, repair application equipment, etc.) pesticides in these work environments. The WPS specifically excludes many turf uses of pesticides (maintaining turfgrasses, e.g., golf courses and recreational areas but not others (producing turfgrasses, e.g., turf [sod] farms). In either case, follow all precautions possible to protect employees from exposure and keep up with the latest changes in laws and regulations.

Personal Protective Equipment

To determine the specific protective clothing and equipment required for a particular product, you must refer to the instructions on the product label (Figure 11–9). These instructions carry the weight of law. The toxicity level of the product determines the correct body protection. The pesticide label should list a toxicity class, or so-called signal word, with Class I ("Danger") being the most toxic, followed by Class II ("Warning") for moderately toxic, and Class III and IV ("Caution") for the least-toxic chemicals. The safety data sheet (SDS) provides additional information in helping to determine personal protection. The following are some general guidelines regarding **Personal Protection Equipment (PPE)** and safe handling practices.

1. At a minimum, wear a long-sleeved shirt and full-length pants (or coveralls), unlined waterproof gloves at least 14 mil thick, and rubber or chemical-resistant boots. Never use leather, paper, or fabric gloves, because these may absorb and retain pesticides. Protective eyewear such as goggles and some type of hat, preferably a hard hat, should be worn. Wear additional protection such as a chemical-resistant apron and respirator whenever the label so states, or if you want additional protection. When applying "Danger" or "Warning" class (Class I or II) products, wear coveralls that are completely liquid-proof such as polyethylene-coated or poly-vinyl chloride PPE.
2. Keep in mind the most common form of pesticide exposure is through direct contact with the skin. During mixing and loading an applying pesticides hands and forearms are especially vulnerable.
3. Wash the outside of gloves and boots with detergent and water before removing them. Then wash them inside and out with detergent and water. Allow them to dry in a well-ventilated location.
4. Clothing worn during pesticide application should be washed daily in hot, soapy water. Use heavy-duty powdered detergents, and do not mix other non-exposed clothes in same wash load. Run a cycle with hot water and detergent (but no clothes) afterward to minimize the potential for contaminating the next batch of clothes. If clothes become heavily saturated with pesticide, they should be placed in plastic garbage bags and disposed of properly.

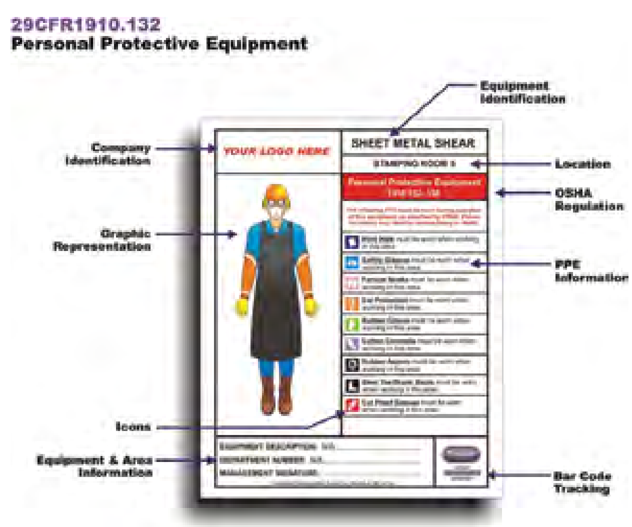


Figure 11–9. A sign indicating the appropriate personal protective equipment needed to mix and apply a certain product.

5. Two main types of respirators are used when handling pesticides: mechanical filter respirators, which are only effective in filtering dusts; and chemical cartridge or canister respirators, which protect only against gasses and vapors. Combination respirators that perform the functions of both types are also available. Respirators must be certified by the National Institute for Occupational Safety and Health (NIOSH). The pesticide label will have the NIOSH approval number for the respirator to be worn. A written policy must be developed and employees trained on the proper fitting and use of various respirators.
6. Earplugs or other acceptable hearing protection devices should be available and used with any power equipment. Annual hearing tests are often required to detect if a gradual hearing loss is occurring.
7. Someone on the staff should be trained in CPR.

Mixing and Loading

Opening pesticide containers, connecting application equipment, or transferring pesticides to another container for application all entail the possibility of exposure. Having an appropriate pesticide mixing center provides a place where the operator can perform all mixing and loading duties without spills escaping into the environment. The following are encouraged standards to consider when designing or building such a facility.

1. Loading and mixing of pesticides should be performed over an impermeable source such as a concrete pad treated with a sealant and sloped to a liquid-tight sump where all spilled liquids can be recycled. Absorbents such as cat litter, clay, soil, or sand should be available for small spills, while hydrated lime and bleach can be used to neutralize and clean surfaces where spills occur.
2. To minimize water (including rainfall) waste from the chemical mixing pad, a roof with a minimum 30 degree overhang on all sides is advised.
3. Spills and rinsates from the pad should be saved and used as make-up water for the next time the same material is used. To minimize a build-up of sediments in the pump, tires and equipment should be cleaned (e.g., air-blown) prior to entering onto the pad.
4. Empty pesticide containers should be cleaned by pressure-rinsing or triple-rinsing and the rinse water drained into the sprayer as part of the make-up water before beginning spraying. Non-rigid bags should be shaken clean and stored out of the rain until they can be disposed of in an approved landfill or recycled. Do not recycle other pesticide containers in household recycling programs.
5. People and animals must be kept away from the loading/handling area.

Disposal of Pesticide Wastes

Proper pesticide waste disposal is an important part of responsible pesticide use by the applicator. Improper disposal can lead to contamination of soil and ground and surface water, causing serious liability problems for the pesticide user. Federal and state laws, including the Federal Insecticide Fungicide and Rodenticide Act (FIFRA), regulate the disposal of pesticide waste.

Pesticide wastes include: (1) empty containers, (2) excess mixture, (3) rinse water from containers and application equipment, and (4) material generated from the clean-up of spills and leaks. These types of pesticide wastes are classified as either hazardous waste or solid waste. Pesticides classified as hazardous wastes are regulated by the Federal Resource Conservation and Recovery Act (RCRA). This waste must be disposed of properly, usually by a licensed hazardous waste contractor. Properly rinsed empty containers are solid waste.

Pesticides not classified as hazardous wastes may be disposed of as regular solid waste or trash. This is regulated under state law and must be disposed of in a careful manner according to label instructions. Ask your state pesticide regulatory agency about the specific laws and regulations affecting your area.

Emergency Planning and Community Right-to-Know

In 1986, in a response to the 1984 toxic gas disaster in pesticide production in Bhopal, India, Title III of the Superfund Amendment and Reauthorization Act (SARA) mandated a federal program subtitled the Emergency Planning and Community Right-to-Know Act (EPCRA). The intent of EPCRA is to ensure information regarding hazardous chemicals is made available to emergency response agencies and the general public. The responsibilities of these efforts are assigned to the EPA and individual states. Four separate categories are covered by this legislation.

1. Emergency planning involving extremely hazardous substances.
2. Reporting spills and leaks of extremely hazardous substances.
3. Reporting hazardous substances in the workplace.
4. Reporting toxic chemical releases.

Contact your local emergency planning committee or law enforcement agencies, or first responders for more information on local and state requirements involving compliance.

Equipment Clean-up

After each day's or pesticide's use, application equipment should be flushed with water inside and out to prevent chemical accumulation. The cleaning area should be chosen with care to prevent cleaning water from contaminating water supplies and streams, or injuring plants. The cleaning water should be stored and reused to dilute the next batch of spray solution containing the same chemical(s). When changing chemicals or finishing spraying for an extended time, clean the sprayer thoroughly inside and out by following these steps:

1. Completely hose down the inside of the tank, filling it about 10 percent full of water, and then flush it out through the nozzles by operating the sprayer for at least 30 seconds. Repeat this step twice more.
2. Remove nozzle tips and screens and check for wear. Clean them in kerosene or detergent solution using a soft brush. Do not use a knife, wire, or other hard material to clean nozzle tips because the finely machined tip surfaces can be easily damaged, causing spray pattern distortion and an increased application rate.
3. Fill the tank half full of water and add about a pound of detergent for every 50 gallons (2.4 kg/L) of water.
4. Operate the pump to circulate the detergent solution through the sprayer for about 30 minutes, then flush it out through the bottom.
5. If 2,4-D or an organophosphate insecticide has been used, follow the steps below, in addition to the final flush using water:

a. Replace the screens and nozzle tips.
b. Fill the tank half full of water and add one pint (473 ml) of household ammonia for every 25 gallons of water (95 L).
c. Operate the pump to circulate the ammonia solution through to the sprayer for about five minutes, and discharge a small amount through the boom and nozzles.
d. Keep the remaining solution in the sprayer overnight.
e. In the next day, agitate the system and flush out all ammonia solution through the nozzles by operating the sprayer.
f. Finally, fill the tank about half full of clean water while hosing down both the inside and outside, then flush out through the boom. When finished with the sprayer for an extended period, remove and store the nozzle tips, strainers, and screens in light oil. Store the sprayer in a clean, dry shed. If the pump cannot be completely drained, store it where it will not freeze, or run antifreeze through the pump.

11.5 PESTICIDE LABELS AND LABELLING

Safety Data Sheets

Each pesticide product has a Safety Data Sheet (SDS) written by the manufacturer. These sheets provide information on:

1. Chemical product/company identification
2. Composition/information on ingredients
3. Hazardous identification
4. First aid measures
5. Firefighting measures
6. Accidental release measures
7. Handling and storage
8. Exposure controls/personal protection
9. Physical and chemical properties
10. Stability and reactivity
11. Toxicological information
12. Ecological information
13. Disposal considerations
14. Transportation information
15. Regulatory information
16. Other information

Safety Data Sheets for each pesticide formulation must be kept readily available for workers to read prior to handling the pesticide and to refer to in emergency situations.

Technical Information Bulletins

It has become quite common for some golf courses to submit pesticide use plans to water management districts or other state agencies. In most cases, the information required may either be found on the label or on the SDS for the pesticide. However, some information may only be found in technical bulletins. These also are written by the company manufacturing the product, but normally are not provided to the pesticide user. If a specific piece of information cannot be located on the label or SDS, contact the company representative (salesperson, sales manager, R&D representative, etc.) and request technical bulletins.

Labeling Is the Law

It is extremely important to remember the pesticide label is the law. Pesticides may not be used in a manner not permitted by the labeling. Pesticide uses inconsistent with the label include:

1. Applying pesticides to plants, animals, or sites not specified in the directions for use. If the label does not state it is for use on turfgrass, then it is not legal to use on turfgrass.

2. Using higher dosages, higher concentrations, or more frequent applications than specified on the label.
3. Not following the directions for use, safety, diluting, storage, and disposal. This also includes any restrictions on course re-entry, not only for employees but for golfers as well.

The law does allow you to:

1. Apply pesticides at dosages, concentrations, and frequencies less than those listed on the label, if you obtain expert opinion or have data to justify the lower rate.
2. Apply a pesticide against any target pest not listed on the label if the application is to a crop/plant, animal, or site listed on the label. In other words, if a new weed suddenly appears, it is legal to use a herbicide for control as long as turfgrass is listed on the label and you know the material will control the weed.
3. Mix a pesticide with a fertilizer unless the mixture is prohibited by the label.
4. Mix two or more pesticides together if all the dosages are at or below the labeled rate(s), unless the mixture is prohibited by any of the labels.

Read the *entire* label of any pesticide before you buy, mix, apply, store, or dispose of it. If you have questions on how to use a pesticide, it is quite likely other applicators have the same questions. Be a good consumer and tell the manufacturer your concerns. They may not realize there are problems or questions with the label directions. The label must contain the items listed below.

1. Trade name
2. Ingredient statement

a. Active ingredient (chemical name; common name may be present)

b. Inert ingredient(s)

3. Type of pesticide (herbicide, insecticide, nematicide, fungicide, etc.)
4. Net contents
5. Name and address of manufacturer—establishment number
6. EPA registration number—indicates the label is approved by the EPA
7. Signal word and symbols
    a. Danger: highly toxic; some products may also carry the word “Poison” printed in red plus the skull and crossbones symbol (category I) or
    b. Warning: moderately toxic (category II) or
    c. Caution: slightly toxic (categories III and IV)
8. Precautionary statements
    a. Route of entry (to the body) statements
    b. Specific action statements (to prevent poisoning accidents)
    c. Protective clothing and equipment statements (required PPE)
    d. Other statements may be listed in regards to precautions to take while handling the product
9. Statement of practical treatment – first aid - in case of poisoning
10. Environment hazards
    a. Special toxicity statements (e.g., toxic to bees, fish, etc.)
    b. General environmental statements
11. Physical or chemical hazards
12. Classification statement: if restricted-use pesticide
13. Re-entry statement
14. Storage and disposal information
15. Directions for use

Note: The toxicity category is not found on the label or the SDS.

11.6 PREPARING AGROCHEMICAL STORAGE FACILITIES FOR A MAJOR DISASTER

Hurricanes, floods, tornadoes, and other severe storms can seriously damage agricultural and similar chemical storage facilities and the chemicals they contain. Storm-damaged facilities may adversely affect the environment and people. The following are steps to consider if a storm approaches and damages an agrochemical storage facility.

Inventory

Do an inventory of what pesticides and other chemicals you have on hand. Such an inventory will be useful for insurance purposes, or in the event of necessary pesticide or chemical clean-ups. Include product and active ingredient names and container sizes. Receipts for the purchase of these materials are useful for this, or in some cases may suffice themselves. *Put the inventory in a safe location*. In the case of large scale storms it may be useful to make a copy of your inventory and mail, fax or e-mail it to a friend or business associate living outside of the potentially affected area.

Insurance

Know where your insurance policy is and know exactly what kind of coverage you have. Does it cover your chemical inventory and the damage it could cause? Find out now because if you need to know later, your insurance agent will be very busy.

Chemical Use

At this point, consider not using or making applications of agricultural chemicals, or at least holding off, until the potential of the impending severe weather event is resolved. Delay purchase or delivery of additional chemicals to your operation until after the impending storm risk is past. If deliveries are scheduled for the coming week it may be best to cancel them.

Chemical Storage and Security

Secure all chemicals including fertilizers, pesticides, solvents, fuels, and so forth. Close and secure container lids, moving containers and application equipment to the most secure location. Raise chemicals from the floor or cover materials potentially damaged by water. Do what you can to protect product labels and labeling. Doors, windows, and other points of access to storage locations should be secured and locked. Consider boarding up the pesticide and other chemical storage areas. Don't leave chemicals in vehicles or application equipment. Be sure all of the stored items are compatible. Don't, for instance, put pesticides and fuels in the same building with animals, or animal feeds. Ever!

Now is the time to read the storage and spill containment sections of your SDS. Gather and secure pesticide and other chemical SDS sheets and provide local emergency first responders with a copy, along with a copy of your chemical inventory. Also secure your personal protective equipment. This may be needed as part of the clean-up operations after the storm.

Secure buildings as much as possible. Are the roofs tied into the building? Can you tie-down small storage buildings and storage tanks? Also, if you leave your location during a severe weather event, be sure the pesticide storage building is well signed.

Have all emergency phone numbers needed on hand and consult your chemical dealer and insurance agent for additional suggestions, but do it soon.

Storm-Damaged Agrochemical Storage Facilities

Area Security. Following a severe storm, keep unauthorized people away from the chemical storage facility and adjacent areas. Post the area to indicate which potentially hazardous chemicals are present; erect fencing or rope cordons, and inform persons entering the property of the presence of an agricultural chemical storage facility. The idea is to keep people and animals out of the surrounding area.

Personal Safety. Make personal safety a priority. When dealing with a storm-damaged facility, wear the necessary personal protective equipment (PPE) to protect a person handling the most dangerous material present. This usually means respirator, eye protection, unlined nitrile gloves, rubber boots, long-sleeved shirt, work trousers, and a chemical-resistant apron. Before using any personal protective equipment, check to see that it is in serviceable condition. Be alert for signs or symptoms of pesticide poisoning: nausea, headache, difficult breathing, pinpoint pupils, or convulsions. If these appear and pesticide poisoning is suspected, seek medical attention immediately.

Site Inspection. As soon as possible, inspect the site for storm damage. Focus on (1) the presence of damaged containers, (2) if and where the storm has moved pesticide containers off-site, (3) structural damage to the storage facility, and (4) ways to avoid further weather damage.

Spill Management. Finding broken packages or ruptured containers indicates the need for spill management efforts. To manage spills, use a stepwise procedure and focus on:

1. *Controlling* actively spilled materials by standing containers upright, plugging holes, and so forth.
2. *Containing* spilled chemicals by installing absorbent barriers.
3. *Collecting* spilled product and absorbents and placing these in sturdy containers.
4. *Storing* all containers of spilled or leaking agrochemicals in an area where further disturbance is likely to be minimal.

Spill Prevention. Consolidate agrochemicals that have intact packaging. Sort these according to package type (glass, paper, plastic, metal), substance type (insecticides, herbicides, etc.), and reactivity group (flammables, corrosives, etc.); then, put them in areas protected from weather, flooding, and building collapse.

Consider alternatives such as pallets placed on blocks and covered with tarpaulins or plastic sheeting. The idea is that consolidating intact containers and providing sheltered storage will help prevent container deterioration and subsequent spills.

Product Identity and Labels. Knowing the contents of an agrochemical container is extremely important. Make every effort to preserve and protect container labeling. Containers lacking labeling will likely end up being considered unknowns—and disposal of unknowns is often very costly. Exposure to severe storms, heavy rain, or flood waters will often cause labels to loosen or to become unreadable. Refasten all loose labeling. Use non-water-soluble glue or sturdy transparent packaging tape to refasten loose labels. Never refasten labels with rubber bands (they quickly rot and easily break) or non-transparent tapes such as duct or masking tape (they can obscure important product caution statements or label directions for product usage). As a supplement to marred or badly damaged labels, fasten a baggage tag to the container handle. On the tag write the product name, active ingredient, EPA registration number, formulation, concentration of active ingredient(s), and date of product purchase. If there is any question about the contents of a container, set it aside for disposal.

Salvage. If the labeling is legible and secure, agrochemicals in intact waterproof containers, and formulated as liquids, emulsifiable concentrates, flowables, or oil solutions, are often salvageable. Check each container for hidden damage. In particular, determine whether or not the pour spout seal has been broken.

Upon finding a broken seal, examine the contents for evidence of contamination—especially water-induced damage. In general, liquid formulations with a milky appearance have been compromised by water encroachment. In most cases, these should be set aside for disposal.

Oil solutions can often be salvaged. Water is easily detected in oil solutions. Because oil floats on water, carefully pour off the oil and leave the water behind. Handle the water as a container rinsate (e.g., use it as make-up water); thereafter, return the oil solution to its original container. Triple rinse the temporary container and handle the rinsate as dilute pesticide (e.g., include in a batch of spray mix).

The salvageability of dry formulations (baits, dusts, wettable powders, granules, dry flowables, etc.) is more difficult to assess. In general, products held in paper packaging are more vulnerable to severe-storm-induced damage. However, paper is not the sole problem. Plastic and foil-lined bags are also difficult to assess for pinholes and unsound seams. As a rule, avoid opening large quantities of dry formulation packaging and examining contents in detail. Again, when in doubt, set the container aside for later disposal.

Temporary Storage. Temporary storage is another key concern for pesticide chemical facilities damaged by severe storms. In addition to the aspects of storage discussed earlier (see spill prevention), other points merit mention.

1. Designate three separate storage areas, one for salvaged materials, a second for materials intended for disposal, and a third one for materials in the process of being re-collected and evaluated.
2. Make sure each storage area is secure and not readily accessible to persons or animals.
3. Provide each area with protection from further weather- and debris-induced damage; keep each of the three stockpiles away from each other and supplies of water, foods, fuels, machinery, and personal protective equipment.

Handling and Transport. All post-storm movement of agrochemicals and their containers (including re-collection of off-site containers) requires care and greater-than-normal safeguards. Labeling must be preserved (even for those ultimately requiring disposal). Storm-damaged packaging is more leak and spill prone. Also, for certain agrochemicals, moisture can sometimes increase the reactivity and fire hazard. Handling and transport efforts must take these considerations into account before movement of the product is attempted. Consult your SDS sheets. Finally, before moving agrochemicals whose packaging is suspected to be weakened and likely to spill, have temporary containment or over-pack vessels (such as garbage cans lined with plastic bags) on hand.

Disposal. Disposal of natural-disaster-induced agrochemical waste should proceed only after proper authorities have been contacted. In certain cases, part of the disposal costs might be paid by disaster-relief funds. If you have severe-storm-damaged agrochemicals, contact your state environmental protection department for information on their disposal.

11.7 ACTIVATED CHARCOAL TO DEACTIVATE PESTICIDES

Activated charcoal (also called activated carbon) is often used to adsorb or deactivate organic chemicals such as pesticides **(Figure 11–10)**. Charcoal is a porous, soft, black substance made by heating, in a restricted amount of air, substances containing carbon such as material from hardwood trees and coconut shells. Powdered activated charcoal is made up of very small carbon particles with a high affinity for organic chemicals such as pesticides. Activated charcoal has a large surface area and can absorb 100 to 200 times its own weight. Activated charcoal has been used for many years to remove organic contaminants from wastewaters and in water purification systems. Because most pesticides are organic chemicals, activated charcoal can effectively be used to deactivate or "tie-up" these products in soil. Once the pesticide has been adsorbed onto activated charcoal, it is biologically inactive and cannot cause injury to the turfgrass. Therefore, this product can be beneficial to turfgrass managers in the case of an accidental pesticide

Figure 11–10. Activated charcoal has a wide array of uses such as deactivating unwanted pesticide applications or for artificially warming soils.

spill or where a herbicide needs to be inactivated for seeding or sprigging of turfgrasses.

Due to its dark color, and its consequent ability to absorb heat, activated charcoal is also used to artificially warm the soil to minimize the effects of light frosts or to allow earlier seeding of an area.

The amount of activated charcoal to apply to a pesticide-contaminated area varies with the chemical characteristics of the particular pesticide. Rates generally range from about 100 to 400 pounds of activated charcoal per acre, 110 to 450 kg/ha (2.3 to 9.2 lbs/1,000 sq.ft., 11 to 45 g/m^2) for each pound of active ingredient of a pesticide applied per acre (1.12 kg/ha). A general rule is to apply about 200 pounds of activated charcoal per acre, 224 kg/ha (4.6 lbs/1,000 sq.ft., 20 g/m^2) for each pound of pesticide active ingredient per acre **(Table 11–7)**.

Example:
Suppose Balan 2.5G was inadvertently applied at two pounds of active ingredient per acre to an area designated to be seeded with a turfgrass. To completely inactivate this herbicide, an application of activated charcoal at 400 pounds per acre, 450 kg/ha (or 9.2 lbs/1,000 sq.ft., 45 g/m^2) would be needed.

Application Methods

Activated charcoal can be applied by various methods. It can be applied in the dry form with a drop spreader. However, activated charcoal particles are very light and very fine and are easily moved by wind, so it may be difficult to distribute the charcoal evenly when applied in the dry form. The easiest method is to suspend the charcoal in water and apply it by hand with a watering can (for small areas) or a power sprayer. Because activated charcoal does not mix easily with water, a 0.5 percent solution of a nonionic surfactant (equivalent to 1 quart per 50 gallons) will enhance its suspension in water. Note charcoal particles are very abrasive and can damage spray equipment (particularly rotary type pumps). Therefore, if a sprayer is used to apply activated charcoal, care should be taken to thoroughly clean the equipment when finished.

When deactivating a pesticide in a seedbed, the activated charcoal should be incorporated with a rotary tiller or other appropriate equipment so the charcoal is placed in the upper few inches of soil. The objective is to get the activated charcoal in the same place as the pesticide. Uniform application of activated charcoal followed by thorough mixing is the key to inactivating a pesticide-contaminated area. If the pesticide is on the turf, in the thatch layer, or on the uppermost surface of the soil (for instance, if the pesticide has not been watered-in), the pesticide can be inactivated by simply applying the charcoal to the area and thoroughly watering once charcoal application is complete. Again, the objective is to place the charcoal in the same place as the pesticide. If activated carbon is applied and either incorporated or watered correctly, inactivation of the pesticide will be successfully accomplished. For application convenience, activated charcoal can be applied as a water slurry. To minimize dusting, always add activated charcoal to water slowly, keeping the bag as close to the water surface as possible. The following steps are suggested when mixing and applying charcoal.

Spray Application

1. Make sure spray equipment, tubing, and nozzles are completely clean. Screens should be removed if practical.
2. The final spray mixture should contain one to two pounds of charcoal per gallon of water.
3. Add sufficient water to begin moderate agitation. Simultaneously add the balance of required water and charcoal. Continue agitation until a uniform mixture is obtained.
4. Maintain moderate agitation while spraying.

It is important to understand situations where activat-

Table 11–7. Rates of activated charcoal used for spills and deactivating turf pesticides.

APPLICATION	RECOMMENDATION	COMMENTS
Spills	For reducing the effects from spills of organic pesticides, some petroleum products, and hydraulic fluids.	Use 100 to 400 pounds of activated charcoal to every pound of active material spilled per acre, 110 to 450 kg/ha (2.3 to 9.2 lbs/1,000 sq.ft., 11 to 45 g/m^2). If the active material has not been diluted with water at the time of spill, apply the charcoal directly as a dry powder. If the active material has been diluted with water, apply the activated charcoal in a slurry with a sprinkle can or common sprayer equipment. The charcoal must be incorporated into the contaminated soil, preferably to a depth of six inches. With severe spills, some of the contaminated soils may need removal prior to activated charcoal application.
"Deactivating" turf herbicides and soil warming	Turf areas treated with pre-emergence herbicides can be reseeded earlier than normal by treating with activated charcoal.	Whenever it is desirable to terminate a pre-emergence herbicide, apply charcoal slurry at a rate of two to four pounds per 1,000 square feet (9 to 19 g/m^2). Water the slurry into the soil. Make sure the grass is washed free of heavy charcoal deposits. Where possible, it is desirable to thoroughly rake the charcoal into the soil. The area can be seeded 24 hours after treatment.

ed charcoal will *not* work. If a herbicide has been applied for several weeks and rainfall has occurred and/or irrigation water has been applied, the herbicide is most likely past the thatch layer and probably in the upper inch or so of the soil. In this case, activated charcoal would have to be physically incorporated with a rotary tiller or other implement to get the charcoal in contact with the herbicide. The reason is activated charcoal will not leach through soil. If activated charcoal is applied to the soil surface and watered, the charcoal will remain on top of the soil and will not move and not inactivate the herbicide below the soil surface. Activated charcoal is not effective for inorganic pesticides such as arsenates, lead compounds, sodium chlorate, sulfur, borax, and so forth, and water-soluble organic pesticides such as, but not limited to, MSMA and DSMA.

Activated carbon is available from most suppliers of turfgrass products. It is a good idea to keep several bags on hand so it can be applied immediately instead of having to wait for delivery. Several different brands and formulations are on the market. There appears to be little, if any, difference in the effectiveness of the different brands. However, some may be easier to apply than others, depending on the particular situation where it is to be used.

APPENDIX A
PESTICIDE CALIBRATION FORMULAS AND METRIC CONVERSION

APPENDIX A
PESTICIDE CALIBRATION FORMULAS AND METRIC CONVERSION

Acres covered/hour: =	MPH x Swath (ft) x 0.1212	or	MPH x Swath (ft) / 8.25
Gallons Per Acre (GPA): =	GPM (whole boom) x 495 / MPH x Swath (ft)	or	GPM per nozzle x 495 / MPH x nozzle spacing (ft)
	GPM per nozzle x 5940 / MPH x nozzle spacing (inches)	or	GPM per nozzle x 5940 / MPH x width of nozzle spray (inches)
	fl.oz collected per nozzle in 100 ft x 40.8375 / nozzle spacing (inches)	or	fl.oz. collected per nozzle x 4084 / ft. traveled x nozzle spacing (inches)
	gallons collected per nozzle x no. nozzles x 43560 / ft. traveled x Swath (ft)	or	gallons per 1000 sq.ft. / 0.023
Gallons per 1000 sq.ft. =	0.023 x GPA	or	
Ounces per 1000 sq.ft. =	2.94 x GPA	or	
Gallons Per Minute (GPM): =	GPA x MPH x Swath (ft) / 495	or	fl.oz per minute / 128
	GPA x MPH x nozzle spacing (inches) x no. nozzles / 5940		
GPM/Nozzle: =	GPA x MPH x nozzle spacing (inches) / 5940	or	GPA x MPH x nozzle spacing (ft) / 495
	Test jar fl.oz x 0.46875 / seconds to fill test jar	or	7.5 / seconds to fill 1 pint (16 fl.oz.)
	15 / seconds to fill 1 quart (32 fl.oz.)		
Minutes/Acre: =	495 / MPH x Swath (ft)		
Acres covered per tank:	Gallons per tank / GPA		
Minutes/load:	gallons/load x 495 / MPH x GPA x Swath (ft)		
Material needed per tank	rate/A x gallons/tank / GPA		
Travel Speed (Miles Per Hour, MPH)	Distance traveled (ft) x 0.68 / time (seconds) to travel distance		

Flow Rate (as influenced by pressure):		
$\frac{GPA_1}{GPA_2} = \frac{\sqrt{PSI_1}}{\sqrt{PSI_2}}$ OR	$GPA_2 = GPA_1 \times \frac{\sqrt{PSI_1}}{\sqrt{PSI_2}}$ OR	$PSI_2 = PSI_1 \times \left(\frac{GPA_2}{GPA_1}\right)^2$
For any change in travel speed (mph), calculate the resulting GPA2 by:		
$GPA_2 = \frac{GPA_1 \times MPH_1}{MPH_2}$	$\frac{GPA_1}{GPA_2} = \frac{MPH_2}{MPH_1}$	$MPH_2 = \frac{GPA_1 \times MPH_1}{GPA_2}$

Fluid Application			
lbs/acre nutrient applied =	0.226464 x element concentration (ppm) x acre inches of solution applied		
PPM =	$\frac{1{,}000{,}000 \times \text{lbs ai used}}{\text{gal/tank} \times 8.34}$	or	$\frac{\text{wt. of material to be used (lbs)} \times 1{,}000{,}000}{\text{wt. of tank mixture (lbs)}}$
	$\frac{1{,}000{,}000 \times \text{oz commercial material used} \times \text{\% ai (decimal)}}{\text{gal/tank} \times 8.34 \times 16}$	or	$\frac{1{,}000{,}000 \times \text{fl.oz. used} \times \text{lb ai/gal}}{\text{gal/tank} \times 8.34 \times 128}$
lbs nutrients applied/acre=	ppm of the element in the water x acre-inches water applied x 0.226464		
lb ai to use per tank =	$\frac{\text{PPM desired} \times \text{gal/tank} \times 8.34}{1{,}000{,}000}$	or	$\frac{\text{ppm desired} \times \text{gal/tank} \times 8.34}{1{,}000{,}000 \times \text{\% ai}}$
lb commercial material to use per tank =	$\frac{\text{PPM desired} \times \text{gal/tank} \times 8.34}{1{,}000{,}000 \times \text{\% ai (decimal)}}$	or	$\frac{\text{\% desired} \times \text{gal/tank} \times 8.34}{\text{\% ai (decimal)}}$
fl. oz. to use per tank =	$\frac{\text{PPM desired} \times \text{gal/tank} \times 8.34 \times 128}{1{,}000{,}000 \times \text{ai per gal}}$		
gal commercial material to use per tank =	$\frac{\text{ai (decimal)} \times 8.34 \times \text{gal/tank}}{\text{ai per gal} \times 100}$		
% ai in a spray mix =	$\frac{\text{lbs. commercial material used} \times \text{\% ai (decimal)}}{\text{gal/tank} \times 8.34}$		
gal commercial material for total treated acres =	$\frac{\text{PPM desired} \times \text{GPA} \times \text{acres} \times 8.34}{1{,}000{,}000 \times \text{lb ai/gal}}$		

Active Ingredients (ai)			
lbs commercial material/acre	$\frac{\text{lbs ai to be applied per acre}}{\text{\% ai of material}}$		
gal commercial material/tank	$\frac{\text{gallons/tank} \times \text{lb ai to be applied per acre}}{\text{gallons/acre} \times \text{lbs ai per gallon}}$		
gal commercial material/acre	$\frac{\text{lbs ai to be applied per acre}}{\text{lbs ai per gallon}}$		

Time (seconds) required to cover a specific distance to obtain a desired speed (MPH).				
		Time Required (Seconds) to Travel a Distance of		
Desired MPH	**Feet per minute**	**100 ft.**	**200 ft.**	**300 ft.**
2.0	176	34	68	102
2.5	220	27	54	81
3.0	264	23	45	68
3.5	308	20	39	58
4.0	352	17	43	51
4.5	395	15	30	45
5.0	440	14	27	41
6.0	528	--	23	34
7.0	616	--	19	29
8.0	704	--	17	26
9.0	792	--	15	23

Metric Prefix Definitions (basic metric unit = 1)					
tera	=	10^{12}	deci	=	10^{-1}
giga	=	10^{9}	centi	=	10^{-2}
mega	=	10^{6}	milli	=	10^{-3}
kilo	=	10^{3}	micro	=	10^{-6}
hecto	=	10^{2}	nano	=	10^{-9}
deca	=	10^{1}	pico	=	10^{-12}

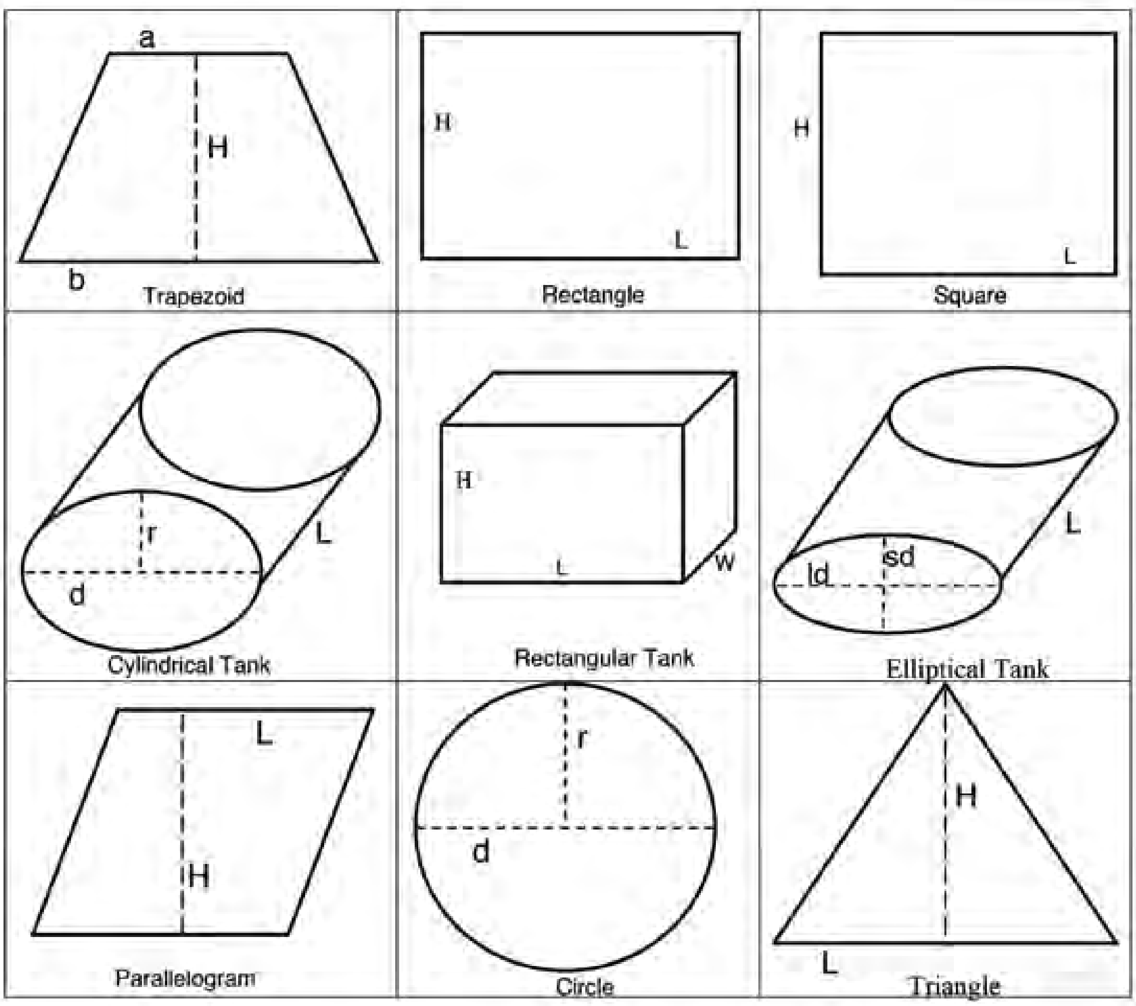
Metric Prefix Example (weight)								
1 kg	=	10^{3} g	=	10^{6} mg	=	10^{9} µg	=	10^{12} ng
1 g	=	10^{-3} kg	=	10^{3} mg	=	10^{6} µg	=	10^{9} ng
1 mg	=	10^{-6} kg	=	10^{-3} g	=	10^{3} µg	=	10^{6} ng
1 µg	=	10^{-9} kg	=	10^{-6} g	=	10^{-3} mg	=	10^{3} ng
1 ng	=	10^{12} kg	=	10^{-9} g	=	10^{-6} mg	=	10^{-3} µg

Metric Prefix Example (volume)				
1 L	=	10^{3} mL	=	10^{6} µL
1 mL	=	10^{-3} L	=	10^{-6} µL
1 µL	=	10^{-6} L	=	10^{-3} mL

Approximate Rates of Application Equivalents					
Weights			Liquid		
1 oz/ft²	= 2722.5 lbs/A		1 oz/1000 ft²	= 43.56 oz/A	= 1.4 qt/A
1 oz/yd²	= 302.5 lbs/A		1 pt/1000 ft²	= 5.4 gal/A	
1 oz/100 ft²	= 27.2 lbs/A		100 gal/A	= 2.3 gal/1000 ft²	= 1 qt/100 ft²
1 oz/1000 ft²	= 43.46 oz/A	= 2.72 lbs/A			
1 lb/A	= 1 oz/2733 ft²	= 8.5 g/1000 ft²			
100 lb/A	= 2.5 lb/1000 ft²				
1 yd³ sand	= 1.3 to 1.5 tons				
1 bushel	= 1¼ ft³	= 0.046 yd³			

Calculations and Formulas for Various Shapes:					
Rectangle, square or parallelogram:	area	=	length (L) x width (W)		
Trapezoid:	area	=	[a + (b x h)] ÷ 2		
Circle:	area	=	radius (r)^2 x 3.1416 (or π)	=	diameter (d)2 x 0.7854
	radius	=	d ÷ 2		
	diameter	=	r x 2		
	circumference	=	π x d		
Sphere:	volume	=	r^3 x 4.1888	=	d3 x 0.5236
Triangle:	area	=	½(b x h)		
Cylinder:	volume	=	$r^2 \pi L$		
Cone:	area	=	⅓($\pi r^2 h$)		
Cube:	volume	=	length x L x L		

Finding Tank Capacity (gallons):			
Cylindrical tanks:	(inches)	=	L x d^2 x 0.0034
	(feet)	=	L x d^2 x 5.875
Rectangle tanks:	(inches)	=	L x W x height x 0.004329
	(feet)	=	L x W x height x 7.48
Elliptical tanks:	(inches)	=	L x short diameter (sd) x long diameter (ld) x 0.0034
	(feet)	=	L x sd x ld x 5.875



Metric System Conversion Factors

Area Equivalents												
1 acre	=	43,560 ft^2	=	4840 yd^2	=	0.4047 hectares (ha)	=	160 rods^2	=	4047 m^2	=	0.0016 mi^2
1 ha	=	10,000 m^2	=	100 are	=	2.471 acres	=	107,639 ft^2				
1 yd^2	=	9 ft^2	=	0.836 m^2				1 yd^3	=	27 ft^3	=	0.765 m^3
1 ft^2	=	144 in^2	=	929.03 cm^2	=	0.09290 m^2		1 m^2	=	10,000 cm^2		
1 ft^3	=	1728 in^3	=	0.037 yd^3	=	0.02832 m^3	=	28,320 cm^3				
1 acre-inch	=	102.8 m^3	=	27,154 gal	=	3630 ft3						

Liquid Equivalents																
1 gal	=	4 qt	=	8 pt	=	16 cups	=	128 fl oz	=	8.337 lb				1 barrel	=	42 gal
	=	231 in^3	=	256 tbsp	=	0.134 ft^3	=	3.785 L	=	3785 ml						
1 qt	=	0.9463 L	=	2 pt	=	4 cups	=	32 fl oz	=	64 tbsp	=	57.75 in^3	=	946.4 ml		
1 L	=	2.113 pt	=	1000 ml	=	1.057 qt	=	33.8 fl oz	=	0.26 gal	=	0.0001m^2	=	1,000 cm^3		
1 pt	=	16 fl oz	=	2 cups	=	473.2 ml	=	32 tbsp	=	0.125 gal	=	0.5 qt				
1 cup	=	8 fl oz	=	0.5 pt	=	16 tbsp	=	236.6 ml		1 tbsp	=	14.8 ml	=	3 tsp	=	0.5 fl oz
1 floz	=	29.57 ml	=	2 tbsp	=	6 tsp	=	0.0313 qt		1 tsp	=	4.93 ml	=	0.1667 floz	=	80 drops
1 ft^3 of water	=	7.5 gal	=	62.4 lb	=	28.3 L		1 ml	=	1 cm^3	=	0.034 floz	=	0.002 pts		

Pressure Equivalents											Temperature Equivalents				
1 mmHg	=	133.32 Pa	=	0.133 kPa	=	133,333 mPa					ºC	=	(°F-32)	x	5/9
1Pa	=	10-3 kPa	=	10-6 mPa							ºF	=	(°Cx9/5)	+	32
1 PSI	=	6.9 kPa	=	2.31 ft head											
1mPa	=	103 kPa	=	106 Pa	=	10 bar	=	10.2 kg cm^{-2}	=	100 N cm^{-2}					
1 atm	=	760 mmHg	=	29.92 in Hg	=	1.013 x 105 Pa	=	1.013 bar	=	14.69 psi	=	33.89 ft water		
1kPa	=	0.001mPa	=	10 cm H2O	=	10 mbar	=	0.01 bar	=	1J kg-1	=	0.0099 atm	=	0.145 psi

Length Equivalents										
km	=	0.621 statute mile	=	1,000 m	=	100,000 cm	=	3,281 ft	=	39,370 in
m	=	3.28 ft	=	39.4 in	=	100 cm	=	1.094 yd	=	1,000 mm
cm	=	0.3937 in	=	0.01 m	=	0.03281 ft				
in	=	2.54 cm	=	25.4 mm	=	0.0254 m	=	0.08333 ft		
ft	=	0.3048 m	=	30.48 cm	=	12 in				
yd	=	0.9144 m	=	3 ft	=	91.44 cm				
statute mile	=	1,760 yd	=	5,280 ft	=	1.61 km	=	1609 m		

Mixture Ratios				
1 mg g^{-1}	=	1000 ppm	=	1 fl oz gal^{-1}
1 floz 100 gal^{-1}	=	75 ppm	=	1 qt 100 gal^{-1}
1 pt 100 gal^{-1}	=	1 tsp gal^{-1}		

Flow						
7490 ppm	=	1 gpm	=	0.134 ft3 min^{-1}	=	0.06308 L sec^{-1}
2 tbsp gal^{-1}	=	1 ft^3 min^{-1}	=	448.83 gal hr^{-1}	=	7.481 gal min^{-1}
1 ft3sec^{-1}	=	448.83 gal min^{-1}				

Weight Equivalents														
1 ton (US)	=	2,000 lb	=	0.907 metric tons	=	907.2 kg		**1 metric ton**	=	106 g	=	1,000 kg	=	2,205 lb
1 lb	=	16 oz	=	453.6 g	=	0.4536 kg				**1 oz (wt)**	=	28.35 g	=	0.0625 lb
1 g	=	1,000 mg	=	0.0353 oz	=	0.001 kg	=	0.002205 lb		**1 mg**	=	0.001 g		
1 kg	=	1,000 g	=	35.3 oz	=	2.205 lbs				**1 µg**	=	10^{-6} g	=	0.001 mg
ng	=	10-9 g	=	0.001 micrograms (µg)				**picogram**	=	10^{-12} g				
1% (v/v)	=	1.28 fl oz gal^{-1}	=	1 gal 100 gal^{-1}	=	10,000 ppm	=	10g L^{-1}	=	1g 100ml^{-1}	=	1.33 oz (wt) gal^{-1}	=	8.34 lb 100 gal^{-1}
1 ppm	=	0.0001%	=	1 mg kg^{-1}	=	1 mg L^{-1}	=	1 µg g^{-1}	=	1µl L^{-1}	=	1µg ml^{-1}		
	=	0.379 g 100 gal^{-1}	=	8.34 x 10-6 lb gal^{-1}	=	0.013 fl oz 100 gal^{-1}		**10 ppm**	=	0.001%	=	10 mg L^{-1}		
100 ppm	=	0.01%	=	100 mg L^{-1}				**1,000 ppm**	=	1 mg g^{-1}	=	0.1%	=	1,000 mg L^{-1}
1 ppb	=	1 µg kg^{-1}	=	1 µg L^{-1}	=	1 ng ml^{-1}	=	1 ng 1,000,000,000-1		1 ppt	=	1 pico-gram g^{-1}		

Approximate Weight of Dry Soil				
Type	**Bulk Density**	**Weight**		
	g cm^{-3}	**lb ft^{-3}**	**kg m^{-2}**	**lbs acre-^{1} (6-in deep)**
sand	1.6	100 (or 2700 lb yd^{-3})	1,623	2,143,000
loam	1.3 to 1.55	80-95	1,299-1,542	1,714,000
clay or silt	1.0 to 1.30	65-80	1,055-1,299	1,286,000
muck	0.65	40	649	860,000
peat (compact)	0.325	20	325	430,000
Sand weights (tons):	= yd^{3} x 1.3			
Gravel weights (tons):	= ft^{3} x 110			
	-0.5- to 1-in diameter gravel = 2,700 lb/ton			
	-0.25- to 0.375-in diameter gravel = 3,000 lb/ton			

Approximate Organic Materials for 6-inch depth per 1,000 ft^{2} (weight variance in materials may occur).				
Organic Material Volume in Mix	**Approximate thickness applied to soil surfaces**		**Organic Material Needed**	
%	**in**	**cm**	**yd^{3} 1,000 ft^{-2}**	**m3 100 m^{-2}**
5	0.33	0.84	1.0	0.83
10	0.67	1.70	2.0	1.70
15	1.00	2.54	3.0	2.48
20	1.33	3.38	4.0	3.30
25	1.67	4.24	5.0	4.16
30	2.00	5.08	6.0	4.95
Example: If 10% organic materials is incorporated into the top 6-inches of a 1,000 ft^{2} area, the organic material is applied to a depth of 0.67-in and 2.0 yd^{3} will be needed (1.7 cm and 1.7 m3 100 m^{2}).				

Peat Moss Coverage		
Depth (inches)	Coverage (sq.ft.)	
	5.6 ft^3 Bale (compressed) covers	4.0 ft^3 Bale (compressed) covers
0.25	480	346
0.50	240	173
1.00	120	86
2.00	60	43
3.00	40	29
4.00	30	22
6.00	20	14

Conversions for determining turfgrass irrigation needs						
1 acre-inch	=	27,154 gal	=	43,560 in^3	=	3,630 ft^3
1 inch 1,000 ft^{-1}	=	620 gal	=	83 ft^3		
1 gallon	=	0.134 ft^3	=	8.34 lb		
1 million gallon	=	3.07 acre-feet				
7½ gallons	=	1 ft^3	=	231 in^3		
1 acre-foot	=	325,851 gal	=	43,560 ft^3		
1 pound of water	=	0.1199 gal				
Precipitation rate (in/hr)	=	$\frac{\text{gpm x 96.3}}{\text{area (ft}^2\text{)}}$				

Water and Soil Calculations											
1 mmhos cm^{-1}	=	1,000 µmhos cm^{-1}	=	1 dS m^{-1}	=	0.1 S m^{-1}	=	1mS cm^{-1}	=	10 meq L^{-1}	
1 meq L^{-1}	=	1 mmol L^{-1}	=	1mol m^{-3}							
1 meq 100g^{-1}	=	1mmol 100g^{-1}	=	cmol kg^{-1}							
Electrical conductivity (mmhos cm-1 or dS m-1)					x 640	= Total dissolved salts (mg L-1 or ppm)					
Total dissolved salts (mg L-1 or ppm)					x 0.0016	= Electrical conductivity (mmhos cm-1 or ds m^{-1})					

Energy		
1 calorie (cal)	=	4.184 Joule (J)
Joule (J)	=	1 kg m^2 s^{-2}
1 kcal	=	4.184 kJ

Slopes									
10%	=	6E	=	10:1	33%	=	18E	=	3:1
18%	=	10E	=	6:1	50%	=	26E	=	2:1
25%	=	14E	=	4:1	100%	=	45E	=	1:1

Decimal and Millimeter Length Equivalents		
Fraction (inch)	**Decimals (inch)**	**Millimeters**
1	**1.00**	**25.4**
15/16	0.9375	23.812
7/8	0.875	22.225
13/16	0.8125	20.638
¾	**0.75**	**19.05**
11/16	0.6875	17.462
5/8	0.625	15.875
9/16	0.5625	14.288
½	**0.5**	**12.70**
7/16	0.4375	11.112
3/8	0.3750	9.525
11/32	0.34375	8.731
5/16	0.3125	7.938
9/32	0.28125	7.144
¼	**0.25**	**6.350**
15/64	0.234375	5.953
7/32	0.21875	5.556
13/64	0.203125	5.159
1/5	0.200	5.08
3/16	0.1875	4.762
23/128	0.1797	4.564
11/64	0.171875	4.366
1/6	0.167	4.242
21/128	0.1641	4.168
5/32	0.15625	3.969
1/7	0.143	3.633
19/128	0.1484	3.769
9/64	0.140625	3.572
⅛	**0.1250**	**3.175**
7/64	0.109375	2.778
1/10	0.100	2.540
3/32	0.09375	2.381
5/64	0.078125	1.984
1/16	0.0625	1.588
3/64	0.046875	1.191
1/32	0.03125	0.794
1/64	0.015625	0.397

Spacing	Tine Diameter	Tine Diameter	Holes ft^{-2}	Surface Area Impacted	Dry Sand to Fill Holes 3-in Depth	
in	in	mm	no.	%	~ft3 1,000 ft^{-2}	~lb 1,000 ft^{-2}
1.0 x 1.0	0.250	6.350	144	4.91	12.3	1227
	0.375	9.525	144	11.04	27.6	2761
	0.500	12.700	144	19.63	49.1	4909
	0.625	15.875	144	30.68	76.7	7670
	0.750	19.050	144	44.16	110.4	11040
	1.000	25.400	144	78.50	196.4	19640
1.0 x 2.0	0.250	6.350	72	2.45	6.1	614
	0.375	9.525	72	5.52	13.8	1381
	0.500	12.700	72	9.82	24.5	2454
	0.625	15.875	72	15.34	38.4	3855
	0.750	19.050	72	22.09	55.2	5520
	1.000	25.400	72	39.27	98.2	9820
1.5 x 1.5	0.250	6.350	64	2.18	5.5	550
	0.375	9.525	64	4.91	12.3	1230
	0.500	12.700	64	8.72	21.8	2180
	0.625	15.875	64	13.63	34.1	3410
	0.750	19.050	64	19.63	49.1	4910
	1.000	25.400	64	34.89	87.3	8730
2.0 x 2.0	0.250	6.350	36	1.23	3.1	307
	0.375	9.525	36	2.76	6.9	690
	0.500	12.700	36	4.91	12.3	1227
	0.625	15.875	36	7.67	19.2	1917
	0.750	19.050	36	11.04	27.6	2760
	1.000	25.400	36	19.63	49.1	4910
7.0 x 7.0 (drill & fill)	0.750	19.050	2.94	0.90	2.3	230
	1.000	25.400	2.94	1.60	4.0	400

Metric Conversion		
To Convert	**Multiply by**	**To Obtain**
Acres (a)	0.4047	hectare (ha)
Acres	43,560	sq. feet (ft^2)
Acres	0.00405	sq. kilometer (km^2)
Acres	4047	sq. meter (m^2)
Acres	4840	sq. yards (yd^2)
Acre-feet	325,851	sq. feet (ft^2)
Acre-feet	43560	cu. feet (ft^3)
Acre-feet	1233.5	cu. meter (m^3)
Acre-inch	102.8	m^3
Bar	14.5	lb/in^2
Bar	1019.7	g/cm^3
Bar	29.53	inches Hg @ 0oC
Bar	75	cm Hg @ 0oC
Bar	0.001	J/kg
Bar	100	kPa
Bushels - dry	0.03524	m^2
Bushels	1.245	ft^3
Calorie (cal)	4.184	Joules (J)
Centimeters (cm)	0.03281	feet (ft)
cm	0.3937	inches (in)
cm	0.1094	yards (yd)
cm	0.01	meters (m)
cm	10	millimeters (mm)
cm/sec = cm sec^{-1} = cm per sec	1.9685	ft/min
cm/sec	0.0223694	miles per hour (MPH)
cm^2 (square centimeters)	0.001076	ft^2
cm^2	0.1550	in^2
cm^2	0.01	sq. decimeter
cm^3 (cubic centimeters)	0.0610237	in^3
cm^3	0.0338	fl oz
cm^3	0.001057	qt3
cm^3	0.000264172	gal
cm^3	0.001	cu. decimeter
Cup	8	fl oz
Cup	236.6	cm^3
Feet (ft)	30.48	cm
ft	0.3048	m
ft	305	mm
ft^2 (square feet)	929	cm^2
ft^2	0.0929	m^2
ft^2	9.294 x 10-6	hectares (ha)
ft^2	144	in^2
ft^3 (cubic feet)	0.0283	m^3

Metric Conversion		
To Convert	**Multiply by**	**To Obtain**
ft^3	7.4805	gallons
ft^3	1728	cubic inches (in^3)
ft^3	0.037	cubic yards (yd^3)
ft^3	28.32	liters (L)
ft^3/1,000 ft^2	0.030463	m^3/100 m^2
Feet per minute	0.01136	mph
Feet head of water	0.433	psi
Foot candle	10.764	lux
Gallons (gal)	3.785	liters
Gal	3785	ml
Gal	128	ounces (liquid)
Gal	0.13368	ft^3
Gal	231	in^3
Gal	3,785	cm^3
Gal per acre (gpa)	9.354	L/ha
gpa	0.09354	L/100 m^2
gpa	2.938	oz/1,000 ft^2 (liquid)
Gal/1,000 ft^2	4.0746	L/100 m^2
Gal/minute	2.228×10^{-3}	ft^3/second
Gal/min	0.06309	L/sec
Gal/min	0.227125	m^3/hr
Grams (g)	0.002205	lb
Gram	0.035274	oz
g/cm^3	0.036127	lb/in^3
g/cm^3	62.428	lb/ft^3
g/ft^2	96	lb/acre
g/ha	0.000893	lbs/acre
g/ha	0.014275	oz/acre
g/kg	0.10	percent (%)
g/liter	1000	PPM
g/liter	10	%
g/liter	0.00834595	lb/gal
g/liter	0.13351	oz/gal
g/m^2	0.00020481	lb/ft^2
g/m^2	0.20481	lb/1,000 ft^2
Hectares (ha)	2.471	Acres
Ha	107,639	ft^2
Ha	107.64	1,000 ft^2
horsepower (electrical or mechanical)	746	watts
hp	550	ft-lbs/sec
hp	33,000	ft-lbs/min
hp	1.014	metric horsepower
hp	33,000	ft lbs/min

Metric Conversion		
To Convert	**Multiply by**	**To Obtain**
Inches (in)	2.540	cm
Inches	0.0254	m
Inches	25.40	ml
Inches of mercury	3.4	kilopascals (kPa)
in/ft	0.083	mm/mm
in^2	6.4516	cm^2
in^3	16.3871	cm^3
in^3	0.55411	fl oz
in^3	0.01732	qt
in^3/hr	0.00434	gal/hr
Joules per kilograms (J/kg)	1	kPa
Kilograms (kg)	2.2046	lb
kg/hectare	0.892	lb/acre
kg/ha	0.02048	lb/1,000 ft^2
kg/100 m^2	2.048	lbs/1,000 ft^2
kg/L	8.3454	lb/gal
Kilometers (Km)	100,000	cm
Kilometers	3281	ft
Kilometers	1000	m
Kilometers	0.6214	miles
Kilometers	1094	yd
Km/h	0.62137	mph
Km/h	54.6807	ft/min
Kilopascals (kPa)	0.145	lbs/in^2 (psi)
kPa	1	0.01 bar
kPa	1	J/kg
Liters (L)	0.2642	gallons
L	33.814	fl.oz.
L	2.113	pt
L	1.057	qt
L	0.035315	ft^3
L/m^2	3.2808	ft^3/1,000 ft^2
L/100 m^2	0.2454	gal/1,000 ft^2
L/100 m^2	1.9634	pt/1,000 ft^2
Liters/hectare	0.107	gal/A
L/ha	0.0025	gal/1,000 ft^2
L/ha	0.314	oz/1,000 ft^2
L/ha	0.855	pt/A
L/min	15.85	gal/hr
Meters (m)	3.281	ft
Meters	39.37	in
Meters	1.094	yd
Meters	100	cm

Metric Conversion		
To Convert	**Multiply by**	**To Obtain**
Meters	0.001	km
Meters	1000	mm
Meters/sec	2.2369	mph
M^2 (square meters)	10.764	ft^2
M^2	1,550	in^2
M^2	1.196	yd^2
M^3 (cubic meters)	35.3147	ft^3
M^3	1.30795	yd^3
M^3	1,000	L
M^3/ha	14.29	ft^3/acre
M^3/ha	0.0122	yd^3/1,000 ft^2
M^3/ha	0.328	ft^3/1,000 ft^2
mil	0.001	in
mil	0.0254	mm
Miles (nautical)	1.1508	miles (statute)
Miles (nautical)	6,076	ft
Miles (statute)	160,900	cm
Miles	5280	ft
Miles	1.609	km
Miles	1760	yards
Miles per hour (mph)	1.467	ft/sec
mph	88	ft/mine
mph	1.61	km/hr
mph	0.447	m/sec
mg/kg	1	parts per million (ppm)
Milliequivalents per liter (meq/L)	1	millimoles per liter (mmol/L)
Milliequivalents per 100 g (meq/100g)	Eq. wt. x 10	parts per million (ppm)
Millimhos per centimeter (mmhos/cm)	1	decisiemens per meter (dS/m)
mmhos/cm	1,000	micromhos per centimeter (µmhos/cm)
Milliliters (ml)	0.0338	oz (fluid)
ml	0.0002642	gal
ml/m^2	3.14	oz/1,000 ft^2
ml/l	0.12793	oz/gal
ml/10,000 L	0.0128	fl oz/1,000 gal
Millimeters (mm)	0.03937	in
1 mm Hg @ 0 C	0.13332	kPa
1 mm Hg	133333.3	mPa
Ounces (fluid) (oz)	0.02957	L
Ounces (fluid)	29.573	ml
Ounces (fluid)	0.03125	qt.
Oz (fluid)/gal	7.81	ml/L
Ounces (fluid)/acre	0.0731	L/ha
Ounces (fluid)/acre	73.1	ml/ha

Metric Conversion		
To Convert	**Multiply by**	**To Obtain**
Ounces (fluid)/1,000 ft^2	3.18	L/ha
oz (weight)	28.35	g
oz (weight)	0.0625	lb
oz (weight)/acre	0.07	kg/ha
oz (weight)/acre	70	g/ha
oz (weight)/1,000 ft^2	3.05	kg/ha
oz (weight)/ft^2	305.15	g/m^2
oz (weight)/gal	7.5	g/L
oz (weight)/1,000 ft^2	0.305	g/m^2
Percent (%)	10	g/kg
Pint (liquid) (pt)	0.473	liter
pt/A	1.1692	L/ha
pt/A	0.3673	oz/1,000 ft^2
pt/1,000 ft^2	0.50932	L/100 m^2
Parts per million (ppm)	2.719	lb ai/acre foot of water
PPM	2.0	lbs/acre slice 7-in. deep
PPM	2.25	kg/ha slice 7-in. deep
PPM	0.001	g/L
PPM	8.34	lb/million gal
PPM	1	mg/kg
PPM	0.013	oz/100 gal of water
PPM	0.3295	gal/acre-foot of water
PPM	8.2897	lbs/million gal of water
Pounds (lb)	0.4536	kilograms (kg)
lb	453.6	g
lb/acre	1,120	g/ha
lb /acre	1.12	kg/ha
lb /acre	1.0413	g/100 ft^2
lb / acre	0.02296	lb/1,000 ft^2
lb /acre	0.112	g/m^2
lb /acre-foot	0.3682	g/m^3
lb /acre-foot	0.0003682	kg/m^3
lb / ft^2	4883	g/m^2
lb /ft^3	16.23	kg/m^3
lb /1,000 ft^2	4.88	g/m^2
lb /1,000 ft^2	48.83	kg/ha
lb /1,000 ft^2	43.5597	lb/A
lb /1,000 ft^2	488	g/100 m^2
lb /1,000 ft^2	0.4883	kg/100 m^2
lb /1,000 ft^2	0.91	lbs/100 yd^2
lb /1,000 ft^2	1.1	lbs/1,000 ft^2
lb /yd^3	0.0005937	g/cm^3
lb /yd^3	594	g/m^3

Metric Conversion		
To Convert	**Multiply by**	**To Obtain**
lb /yd^3	0.5932	kg/m^3
lb /gallon	0.12	kg/liter
lb /1,000 gal	0.12	g/1,000 L
pounds per square inch (PSI)	6.89	kilopascals (kPa)
PSI	0.06895	bar
PSI	0.068046	atmosphere (atm)
PSI	2.31	feet head of water
Quarts (qt)	0.9463	L
Quarts	946	ml
Qt/A	2.3385	L/ha
Qt/A	0.7346	oz/1,000 ft^2
Qt/100 gal	2.5	ml/L
Temperature, °C + 17.98	1.8	temperature, °F
Temperature, °F - 32	0.5555	temperature, °C
Ton (2,000 lbs)	907	kg
Ton (2,000 lbs)/acre	2240	kg/ha
Ton (2,000 lbs)	0.907	ton (metric)
Ton (2,000 lbs)/acre	2.241	ton (metric)/ha
Ton (metric)	2,205	lb
Ton (metric)	1,000	kg
Ton (metric)	1.102	ton (2,000 lb)
Yards (yd)	91.44	cm
Yards	0.9144	m
Yards	914.4	mm
square yards (yd^2)	0.836	m^2
yd^2	9	ft^2
yd^2	1,296	in^2
cubic yards (yd^3)	27	ft^3
yd^3	46,656	in^3
yd^3	0.7645	m^3
yd^3	765	L
yd^3/1,000 ft^2	0.825	m^3/100 m^2
P_2O_5	0.437	P
K_2O	0.830	K
CaO	0.715	Ca
MgO	0.602	Mg
meq Ca^{+2}/100 g soil	400	lb Ca^{+2} per acre furrow slice
meq K^+/100 g soil	780	lb K^+ per acre furrow slice
meq Na^+/100 g soil	460	lb Na^+ per acre furrow slice
meq Mg^{+2}/100 g soil	109	lb Mg^{+2} per acre furrow slice
meq Fe^{+3}/100 g soil	372	lb Fe^{+3} per acre furrow slice
meq Zn^{+2}/100 g soil	654	lb Zn^{+2} per acre furrow slice
meq H^+/100 g soil	20	lb H^+ per acre furrow slice

Metric Conversion		
To Convert	**Multiply by**	**To Obtain**
meq Al^{+3}/100 g soil	180	lb Al^{+3} per acre furrow slice
meq Ca^{+2}/100 g soil	9.2	lb Ca^{+2} per 1,000 ft2 furrow slice
meq K^{+}/100 g soil	18	lb K^{+} per 1,000 ft2 furrow slice
meq Na^{+}/100 g soil	10.6	lb Na^{+} per 1,000 ft2 furrow slice
meq Mg^{+2}/100 g soil	2.5	lb Mg^{+2} per 1,000 ft2 furrow slice
meq Fe^{+3}/100 g soil	8.5	lb Fe^{+3} per 1,000 ft2 furrow slice
meq Zn^{+2}/100 g soil	15	lb Zn^{+2} per 1,000 ft2 furrow slice
meq H^{+}/100 g soil	0.46	lb H^{+} per 1,000 ft2 furrow slice
meq Al^{+3}/100 g soil	4.1	lbs Al^{+3} per 1,000 ft2 furrow slice

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