The Minnesota Golf Course Reference Handbook of Management Practices

In conjunction with the MGCSA BMP Initiative
January 2018

This Environmental Stewardship Project is Endorsed and Sponsored by:

Foreword

As current and past Presidents of the Minnesota Golf Course Superintendents Association, It is our honor and privilege to introduce the 1st edition of *The Minnesota Golf Course Reference Handbook of Management Practices*.

This product, one of four manuals focused on Best Management Practices applied to golf courses in Minnesota, was created through a collaborative effort including many individuals in the Minnesota Department of Natural Resources, Minnesota Department of Agriculture, University of Minnesota, Minnesota Golf Association, Upper Midwest Chapter of the Club Managers Association, Minnesota Chapter of the Professional Golfers Association, Midwest Chapter of the Golf Course Owners Association, and the MGCSA. The intent of the materials is to educate the public and provide a platform for non-regulatory guidelines as they pertain to golf course stewardship including water conservation, water quality, pesticide/fertilizer application, and habitat management.

Brandon Schindele

Environmental Stewardship is something that Minnesota golf course superintendents strive for on a regular basis through efficient and responsible management practices. Golf Courses provide tremendous benefit to communities by being their “largest rain garden” as well as accomplishing the following:

- 70,000 acres of semi-managed wildlife corridor
- 30% or more of most course properties provide natural and native habitat
- Carbon sequestration
- Storm-water management
- Groundwater recharge
- Natural noise dampening
- Oxygen regeneration
- Pollution abatement
- Erosion control by means of natural perennial buffer strips
- Glare and solar radiation suppression
- Heat dissipation and temperature moderation
- Soil restoration and phytoremediation

The document will serve as an educational piece for elected officials, regulators, developers, and interested parties that want to know what goes into maintaining a golf course and the affect that it is has on the environment.

This is not a static document, it will need to change as science and innovation move forward and answer questions that we currently can't answer as it relates to our profession due to research and technology limitations at this time. As information and theories are proven and better strategies are developed these BMPs will need to be amended with the aid of the University of Minnesota, the MN DNR, and MN Department of Agriculture.

Erin McManus

As any of these concepts and management practices are amended in the future, it will always be necessary to take into account the following factors:

- Physical and technical limitations
- Operational and management limitations
- Pollutant reduction/water conservation effects
- Profitability/cost considerations
- Other benefits or disadvantages
- Public acceptance

By formally applying agency and industry BMPs, and common sense stewardship, golf courses will be able to document and support the good things they have been doing for years in the protection of our natural resources, the environment, and the diverse wildlife that calls golf courses their home.

Sincerely,

Brandon Schindele, 2018 MGCSA President, Golf Course Superintendent, Edina Country Club

Erin McManus, 2017 MGCSA President, Golf Course Superintendent, Medina Country Club

Acknowledgements

Many individuals have spent time in making the manuals generated through the 2017 Golf Industry BMP Initiative a reality for the state of Minnesota. Thank you to the following for their input and time:

- The GCSAA for the BMP Template process and EIFG Grant to develop this manual
- Past and present members of the Board of Directors for the MGCSA and the membership who have provided input over the years on the BMP development
- The Florida GCSA for allowing their BMPs to be used as guidance in the development of the Minnesota Golf Course Reference Book of Management Practices
- Sam Bauer, The University of Minnesota
- Jamie Bezanson, Golf Course Superintendent, Highland National Golf Club
- Troy Carson, The Toro Corporation
- Kevin Clunis, Past President of the MGCSA, Golf Course Superintendent, Luck Golf Course
- Kip Cowell, Past President of the Minnesota Golf Association

Eric Counselman, Past Superintendent Somerby Golf Club, Sales with Superior Turf
- Dave Kazmierczak, CGCS, Past President of the MGCSA, Golf Course Superintendent Prestwick Golf Club
- Paul Diegnau, CGCS, Past President of the MGCSA, Golf Course Superintendent of Keller Golf Course
- Scottie Hines, CGCS, Past President of the MGCSA, Golf Course Superintendent of Windsong Farm Golf Club
- Dr. Brian Horgan, The University of Minnesota
- Robert McKinney, Past Golf Course Superintendent, Mendakota Golf Club
- Matt McKinnon, Golf Course Superintendent, Legacy Courses at Cragun's Resort
- Bob Porter, Past Golf Course Superintendent, City of Minneapolis Courses
- Dan Raskob, General Manager, Bellwood Oaks Golf Club
- Rollie Carlson, Executive Director of the Upper Midwest Chapter of the Club Manager's Association of America
- Tom Ryan, Executive Director of the Minnesota Golf Association
- Jake Schmitz, Past President of the MGCSA, Golf Course Superintendent, Olympic Hills Golf Club
- Tom Smith, Vice President of the Minnesota Golf Association, Owner Brackett's Crossing Country Club
- Roger Stewart, CGCS, Past President of the MGCSA, Past Golf Course Superintendent TPC Twin Cities
- Jon Tollette, COO of the MN PGA
- Jack MacKenzie, CGCS, Executive Director of the MGCSA, Past Golf Course Superintendent North Oaks Golf Club
- Special thanks to the final proof editor Kristine Moncada

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Introduction

This document on golf course management in Minnesota covers many of the aspects of operating a golf course in an environmentally sound manner. Environmental stewardship begins with an understanding of the environment and how it can be harmed. From there, it is not difficult to look at each task turf managers do, and take steps to prevent contamination, waste, and habitat loss. Then individual courses can look at ways to correct past errors and lessen the effects of existing situations, striving to live in balance with the environment. The golf industry appreciates that it can never reach a point where courses have no effect upon the environment; after all, as human beings we are part of it. However, through sound environmental stewardship and employing best management practices the business of golf course maintenance can do a lot to minimize our harmful effects.

Golf is one of the most popular sports in America today, for both men and women. It provides recreation, exercise, business opportunities, and a chance to get outdoors and enjoy nature for more than 9 million people every year.

With over 10,000 lakes and 500 golf courses, tourism and recreation thrive in Minnesota. Golf is a key driver of Minnesota's tourism and recreation industries, but the breadth of economic activity generated by the game of golf makes it a critical industry sector in its own right. Golf brings visitors to the state, drives new construction and residential development, generates retail sales, and creates demand for a myriad of goods and services.

In 2006, the size of Minnesota's direct golf economy was approximately $1.2 billion. When the total economic impact of these golf related activities is considered, Minnesota's golf industry generated approximately $2.4 billion of direct, indirect and induced economic output, $776.7 million of wage income and 34,653 jobs in 2006.

Minnesota's highly diversified economy includes a range of manufacturing industries (processed food; computers and electronics; machinery; etc.) and service industries (health; management; professional, technical and scientific; etc.) The golf industry ($1.2 billion) is on par with several other important industries: surgical and medical instruments ($1.1 billion), printed circuit assembly ($1.3 billion) and accounting, tax and payroll services ($1.4 billion), according to a 2006 Minnesota Golf Association Economic Impact Study.

Many supporters of golf, including the United States Golf Association (USGA), the Golf Course Superintendents Association of America (GCSAA), and the American Society of Golf Course Architects, are actively promoting environmentally friendly golf course design and management. Audubon International has more than 3,800 courses enrolled in the Cooperative Sanctuary Program, more than 500 of which have become certified sanctuaries. The U.S. Fish and Wildlife Service's (FWS) Safe Harbor Program is available for courses that have crucial habitat for threatened or endangered species.

In the past, relationships within our ecosystems were not well understood, and it seemed that the capacity of the oceans, rivers, lakes, and the soil itself was limitless. We know better now, and many golf courses are leading the way through environmental stewardship of their properties.

During the mid-1990s, the Center for Resource Management brought together a diverse group of golf and environmental organizations and developed a manual titled *Environmental Principles for Golf Courses in the United States*. Sixteen organizations were involved, ranging from the U.S. Environmental Protection Agency (EPA) and the USGA, to the Sierra Club and Audubon International. Permission to use excerpts from these principles has been graciously granted, and they are used throughout this manual. The following are the basic precepts of the manual:

- To enhance local communities ecologically and economically
- To develop environmentally responsible golf courses that are economically viable
- To offer and protect habitat for wildlife and plant species
- To recognize that every golf course must be developed and managed with consideration for the unique conditions of the ecosystem of which it is a part
- To provide important green space benefits
- To use natural resources efficiently
- To respect adjacent land use when planning, constructing, maintaining, and operating golf courses
- To create desirable playing conditions through practices that preserve environmental quality
- To support ongoing research to scientifically establish new and better ways to develop and manage golf courses in harmony with the environment
- To document outstanding development and management practices to promote more widespread implementation of environmentally sound golf
- To educate golfers and potential developers about the principles of environmental responsibility and to promote the understanding that environmentally sound golf courses are quality golf courses

The process begins with site selection and initial design by the developer and golf course architect; obviously these factors cannot be changed for existing golf courses. However, most environmental impacts are created at least as much, if not more so, by day-to-day decisions and operations. In addition, some golf course managers rework holes and make changes over time that can allow many of those initial decisions to be modified. Irrigation systems do not need to be torn out and replaced all at once, but state of the art components can be installed on one or two holes per year as greens are rebuilt and other changes occur. Other practices, such as the use of integrated pest management (IPM) and Best Management Practices (BMPs) for turf management involving cultural practices, nutrition, and irrigation timing and duration cost little or nothing to implement. They require only the education, thought, and skills of the golf course personnel. Best of all, these BMPs may save money and can be implemented almost immediately.

While no one would claim that a golf course has no environmental impact, golf courses do provide environmental benefits. In an otherwise paved urban area, they provide valuable green space. Turfgrass and other, often native, plants provide cooling evapotranspiration (ET) to an urban heat island, oxygen from photosynthesis, the absorption of storm water and its pollutants, habitat for birds and other wildlife, and myriad more subtle advantages over other types of urban development.

These BMP measures are not regulatory or enforcement based. In some situations, however, the law may provide substantial incentives should they be formally adopted, and there are situations in which BMP use could reduce legal or regulatory exposure. Golf course operators are requested to maintain records and provide documentation regarding the implementation of all BMPs used and applied on their facilities, and to document why certain BMPs are not applicable to their specific situations. Adequate records are very important for the documentation of BMP implementation and are an integral part of any BMP program. The priorities for BMP implementation are as follows:

1. To correct any identified existing water quality/quantity problems
2. To minimize water quality/quantity problems resulting from land use and operations
3. To improve the effectiveness of existing BMPs implemented
4. To seek additional improvement of BMPs based on new, quantifiable information

All golf course superintendents are encouraged to perform an environmental assessment of their operations. This resource allocation assessment process is a tool to aid in identifying which BMPs should be considered to achieve the greatest economic and environmental benefit based on site specific circumstances. The incentives for adopting BMPs include the following:

- Improved turf quality
- Improved golf outing experiences
- Reduced environmental impacts
- Improved worker safety
- Efficient allocation of resources
- Reduced maintenance expenditures
- Reduced regulatory requirements
- Opportunity for industry self regulation

Additional research is still needed in many areas. As new knowledge is gained, these BMPs will be revised over time to reflect changes in our level of knowledge. This is a living document. As this is published in January 2018, new technologies, such as mower mounted sensing of water and disease stresses and computerized irrigation that is corrected for overnight rainfall, show promise of further reductions in adverse environmental effects and better, more cost effective opportunities for golf course management.

This manual will not have all of the answers to every question that comes up. Other references are available with far more detail on almost every subject. Many are listed throughout the text and in the References section. It is hoped that the principles described in these chapters will give direction and understanding to the search for those answers.

The Minnesota Golf Course Mannagement Reference Handbook also brings together goals, objectives, and program information from several sources:

The Environmental Institute for Golf

The Environmental Institute for Golf (http://www.eifg.org/) is the philanthropic arm of the Golf Course Superintendents Association of America. The Institute is "committed to strengthening the compatibility of the game of golf with our natural environment."

In pursuit of that mission, they have implemented a multipart Golf Course Environmental Profile that covers golf courses throughout the United States. Surveys are being used to produce a series of detailed reports for the Profile. Volumes in phase one included, *Property Profile and Environmental Stewardship of Golf Courses*, *Water Use and Conservation on U.S. Golf Courses, Nutrient Use and Management on U.S. Golf Courses, Energy Use and Conservation Practices on U.S. Golf Courses*, and *Pesticide Management Practices on U.S. Golf Courses* were conducted ten years ago. These were followed up recently by phase two and include, *Nutrient Use and Management on US Golf Courses*, *Water Use and Conservation on U.S. Golf Courses,* and *Pesticide Management Practices on US Golf Courses*.

The differences in the two series of surveys indicate a dramatic step up in environmental stewardship upon golf courses. The full reports are available here.

Golf & the Environment

Golf & The Environment, according to its website (www.golfandenvironment.com), "is a partnership of the United States Golf Association, The PGA of America, and Audubon International dedicated to the game of golf and the protection and enhancement of our natural environment. Your involvement can make our partnership a winning foursome. Together with the help of other golf organizations, we are striving to foster environmental awareness, action, and positive results throughout the game."

The Golf & the Environment website is an excellent resource for information related to the environmental stewardship and management of golf courses.

Audubon International

To achieve Audubon Certification, a golf facility is required to demonstrate that it is maintaining the highest degree of environmental quality in several areas including Environmental Planning, Wildlife & Habitat Management, Outreach & Education, Chemical Use Reduction & Safety, Water Conservation, and Water Quality Management.

Some years ago, Audubon International recognized that, with stewardship-based management, golf courses hold enormous value as environmental havens. They have become extensively involved with golf course superintendents, managers and owners, and architects and builders who recognize that golf courses are a valuable part of the conservation landscape and practice eco-friendly management. Audubon International is a partner in Golf & the Environment (see above).

Audubon International programs of particular interest are the Audubon Cooperative Sanctuary Program for Golf Courses and the Audubon Signature Programs. Learn more about these programs at www.auduboninternational.org.

In Minnesota, the following courses have attained Audubon Certification:

Baker National Golf Course	**Somerby Golf Club**
Birnamwood Golf Course	**Somerset Country Club**
Braemar Golf Course	**Superior National at Lutsen**
Columbia Golf Club	**The Minikahda Club**
Dacotah Ridge Golf Club	**The Wilderness Golf Course at Fortune Bay**
Dwan Golf Course	**Theodore Wirth Golf Course**
Gross National Golf Club	**Town & Country Club**
Keller Golf Course	**TPC Twin Cities**
Legends Club	**Wayzata Country Club**
Meadowbrook Golf Club	**White Bear Yacht Club**
Minnesota Valley Country Club	**Woodhill Country Club**

The following Minnesota allied golf associations endorse this document:

The Minnesota Golf Course Superintendents Association was created to advance the art and science of Golf Course Management, to collect and disseminate among other member Superintendents practical solutions to problems with a view to more efficient and economical maintenance and production of golf courses, and to promote the welfare of the Superintendent and the profession.

The mission of the Minnesota PGA is to promote the enjoyment and involvement in the game of golf and to contribute to its growth by providing services to golf professionals and the golf industry. In so doing, the Minnesota PGA will elevate the standards of the golf Professional's vocation, enhance the economic well-being of the individual member, stimulate interest in the game of golf, and promote the overall vitality of the game.

The Upper Midwest Chapter of the Club Managers Association of America advances the profession of club management by fulfilling the educational and related needs of its members with the expertise to deliver an exceptional club experience that fulfills the unexpressed needs and desires of its members and guests consistent with their lifestyles.

The Midwest Golf Course Owners Association is a professional association utilizing education and networking for better management of the business of the game of golf.

The Minnesota Golf Association's mission is to uphold and promote the game of golf and its values for all golfers in Minnesota. Founded in 1901 with only seven golf clubs, the Minnesota Golf Association's membership has grown to more than 400 clubs and 66,000 individual members throughout the state.

DISCLAIMER

The mention of a specific product or company is for information purposes only and does not constitute an endorsement of that product or company.

The Golf Course, Basic Understanding of a Complex Site

Environmental Concepts

To preserve healthy conditions for wildlife, plants, and humans, it is important to protect the physical environment in which all living things exist. This environment consists of the air we breathe; the water we drink and bathe in, which supports the water-based organisms we depend on to maintain higher life on earth; and the soil beneath our feet. These are completely intertwined in a complex web called an *ecosystem*. Soil may become airborne dust and be inhaled. The plants that we eat or feed to our livestock depend on the soil, water, and air. Air, in turn, receives its life-giving oxygen from land- and sea-based plants that use sunlight to convert carbon dioxide (CO_2).

It is essential that we all do what we can to avoid disturbing the delicate ecosystem. It is helpful to remember that while the situation may eventually rebalance, the swings can be unpleasant.

AIR QUALITY

For the most part, golf courses have a positive impact on air quality, compared with most other urban uses.

The air-purifying actions of healthy turf and plant life are offset only by impacts such as the limited air pollution of the landscape maintenance machinery, increased traffic, and the energy used to heat and cool the buildings and run the irrigation system.

Good design and proper maintenance practices can do much to minimize these effects; energy-efficient facilities can be designed, and engine-driven equipment can be kept properly tuned up and running at peak efficiency. Minimizing pesticide spray drift and solvent use, and carrying out educational efforts to remind golfers to keep their cars tuned up, can also reduce air pollution.

SOIL AND WATER QUALITY

There are several components to the issues of soil and water quality, but only a few are significant environmental concerns for golf courses. These concerns primarily relate to plant nutrients, pesticides, and the handling and disposal of waste materials.

NUTRIENTS

There are three major nutrients required for plants that are supplied, if indicated through soil testing, by the addition of fertilizer: nitrogen (N), phosphorus (P), and potassium (K). All are essential for plant growth. Potassium, unlike nitrogen and phosphorus, is not normally considered an environmental problem.

Nitrates are a form of nitrogen of special concern to ground water. The federal standard for nitrate-nitrogen (NO_3-N) in drinking water is 10 parts per million (ppm). The environmental effect of contributing excess nutrients depends on the ecosystem.

For the golf course, nutrient problems are addressed by the development of proper nutrient management plans and the careful execution of those plans. These issues will be reviewed in another BMP focused upon nutrient fate.

PESTICIDES

Pesticide use on golf courses may be the most publicly controversial topic of all when it comes to environmental issues. Pesticides differ in their mode of action, chemical properties, and the effects they exert on non-target organisms such as pets, fish, and humans. Some pesticides are toxic to the bees needed for pollination, or affect birds, wildlife, fish, or other aquatic life in rivers, streams, and lakes. Some golfers or people living nearby may also be particularly sensitive to certain chemicals.

Pest control on a golf course should not begin with pesticides. The fundamental basis of an environmentally-sound pest control program is a process called *Integrated Pest Management* or IPM. This focuses on the basics of identifying the pests, choosing pest-resistant varieties of grasses and other plants, enhancing the habitat for natural pest predators, scouting to determine pest populations and determining acceptable thresholds, and applying biological and other nontoxic alternatives to chemical pesticides whenever possible. Chemical pesticide applications are carefully chosen for effective and site-specific pest control that has a minimal effect on beneficial organisms and the environment, and to minimize the development of pesticide resistance by varying the type of pesticide used so that resistant strains do not thrive.

Pesticides primarily enter our environment in three ways. Wind may move pesticides away from their target while being applied. This is called *spray drift*. They may also leach through the soil into ground water, or be carried in stormwater runoff to surface water. As with nutrients, proper management is the key to minimizing the adverse effects of pesticides on the environment. Many of the older, environmentally unacceptable pesticides were taken off the market decades ago. However, traces may still remain in the soil and ground water. A number of pesticides have been removed from the market more recently, and still others are undergoing review by state and federal agencies as this manual is being published.

The professional pesticide applicators on golf courses are licensed by the state only after receiving specialized training and passing state-administered examinations. In addition, they must obtain additional continuing education credits to renew their license every four years. This continuing education ensures that those responsible for pesticide applications on golf courses are aware of the least toxic and most environmentally-sound methods of pest control.

WASTE MANAGEMENT

The disposal of waste products on golf courses presents the same sort of problems as it does throughout our society. The improper disposal of wastes can pollute soil and water, fill up landfills, and create nuisance odors and unsightly areas.

Grass clippings and other plant material can be composted and used in gardens and other landscaped areas around the course, or provided to homeowners. As at any office or home, paper, cans, glass, and many other materials can be recycled.

Mixing pesticides and cleaning equipment of residual material must be handled properly in accordance with the pesticide label. Usually, the best way is to place the diluted wash water back into the sprayer and apply it as a weak pesticide to an appropriate site.

Solvents, oils, and other regulated or hazardous wastes must be properly disposed of by recycling or by transport by a licensed transporter to an appropriate facility. In most cases, the amount of hazardous waste can be greatly reduced through the use of alternative solvents or other practices.

A superintendent can save substantial money with an aggressive pollution prevention program. Again, the key factor in determining a facility's impact on the environment is the management of a golf course by its superintendent.

Environmental Monitoring

The fragmentation, destruction, or elimination of wildlife habitat and wildlife corridors through the urbanization of both natural and agricultural areas has increased the need to preserve future urban green space for wildlife habitat. In today's modern urban world where parks and green spaces are limited, few cities have had the foresight to place large tracts as off limits to development; Chicago's Grant Park, Savannah's historic squares, or New York's Central Park are examples of these large, undeveloped areas. In many Minnesota cities, golf courses are some of the few sources of open green space. They are increasingly being recognized for their potential to provide valuable wildlife habitat. Unfortunately, the public perception of this benefit is limited.

It has been shown that most golf courses are capable of providing significant, high quality habitat to a large and diverse population of birds, mammals, and other wildlife. By maintaining most of the nonplay areas in varied types of native vegetation; leaving dead trees (snags) where they do not pose a hazard; winding natural areas through the course to provide movement corridors with shelter, concealment, and food; providing native shoreline and aquatic plants where play is not affected; using sound IPM, fertilization, and cultural maintenance practices; and providing nesting boxes and selecting food and cover plants for butterflies and hummingbirds, the modern golf course can truly become an urban wildlife sanctuary. Even endangered and threatened species may coexist if proper care is taken to avoid disturbing nesting places and dens, and if adequate food and protection from predators are provided.

WATER CONSERVATION

BMPs and educational programs are necessary to change the public's mindset toward the inevitable changes in water-related issues. This requires all of us to shift our thinking and develop new habits. There are many ways to conserve water on a golf course. Ideally, only the play and practice areas should be irrigated under normal conditions. Selecting drought-varieties of turf grasses can help maintain an attractive and high-quality playing surface, while minimizing water use. Nonplay areas may be planted with drought-resistant native or other well-adapted, noninvasive plants that provide an attractive and low maintenance landscape. Native plant species are important in providing wildlife with habitat and food sources.

After establishment, site-appropriate plants normally require little to no irrigation. New courses are being designed using a "target golf" concept that minimizes the acreage of irrigated turf. Existing golf courses can make an effort to convert out-of-play areas from irrigated, mowed turf to native plants and grasses to reduce water use and augment the site's aesthetic appeal. A well-designed irrigation system that is maintained at peak efficiency helps to ensure that the water used is not wasted. The system should be operated to provide only the water that is actually needed by the plants, or to meet occasional special needs such as salt removal. Modern irrigation systems that are computer controlled with weather stations, automatic rain and soil moisture sensing controls, and multiple zones can water different areas accordingly. This allows specific areas on a course that were missed by a passing storm to be irrigated, while suspending irrigation in areas that don't need additional water.

The source of irrigation water can also significantly reduce water use. Some sources provide lower quality water for irrigation to conserve the dwindling potable water supply. If properly designed, rain and runoff captured in water hazards and storm water ponds may provide most or all of the supplemental water necessary under normal conditions, though backup sources may be needed during severe drought. Other golf courses may be located where nonpotable reuse water from a water treatment plant is available. Such water is highly treated and safe to use for irrigation.

Design and Construction

For almost any site, local environmental issues and conditions will need to be addressed. Therefore, the careful evaluation of design criteria and proper routing/siting of golf amenities are essential during the planning process. Developers, designers, and others involved in golf course development are encouraged to work closely with local community groups and regulatory/permitting agencies during planning and siting, and throughout the development process. Early input from these groups and agencies is very important to the development and approval process.

There are four key steps to designing, building, and operating an environmentally responsible golf course. While the following steps are very general, each is subsequently broken down into more detail as a project proceeds:

1. Consider the property and its surroundings in relationship to the local watershed and ecological community.
2. Identify biologic, agronomic, hydrogeologic and topographic resources and features. Determine areas that merit special protection.
3. Identify those management practices that protect environmental resources during the construction phase and later during golf course operation. Create a natural resources management plan.
4. Implement an environmental monitoring program.

This establishes a baseline for conditions when the project started and provides an early warning of potential problems that may arise, before they become serious or expensive to address. It also may defuse potential controversy later on, if problems should occur, by demonstrating the good stewardship provided by the golf course.

The design of a course should be based on the information gathered in the first three steps listed above. A good design flows in harmony with the landscape. The course should be designed and routed to preserve and enhance wildlife habitat, and the design should be environmentally proactive, with creative design used to enhance ecological sensitivity and biodiversity.

Although many operational and maintenance BMPs do not come into play until a golf course is fully operational, considering these BMPs up front, including the IPM program, allows the designer to get it right the first time and reduces later costs, while maximizing both environmental and financial returns. Developing comprehensive BMP and IPM plans ensures that maintenance facilities, especially chemical storage and handling areas, equipment cleaning and maintenance areas, and fueling areas, are designed with their specialized needs in mind.

SITE SELECTION AND DESIGN

The site selection for a golf course and subsequent routing plan largely determine the course's environmental compatibility within the community. The involvement of a golf course architect, land use specialists, water resource managers, and geotechnical professionals is critical in selecting a site and a routing that provide environmental benefits.

Identifying the resources at a site is necessary to understand how to design the course and surrounding development, to understand the long-term maintenance procedures and associated operational costs to be incurred, and to know how best to protect the site's environmental resources.

WETLANDS

Minnesota law protects wetlands as waters of the state. Wetlands act both as filters for pollutant removal and as nurseries for many species in Minnesota. Many people do not realize the vital role they play in purifying surface waters. What fewer people realize is that wetlands are the spawning grounds and nurseries for hundreds of species of birds, insects, fish and many other animals important to the state's diverse environment. The biological activity of plants, fish, animals, insects, and especially bacteria and fungi in a healthy, diverse wetland is the recycling factory of our ecosystem.

While wetlands do pose a special concern, their mere presence is not incompatible with the game of golf. With care, many fine courses have been threaded through sensitive areas, and with proper design and management can be an acceptable neighbor. When incorporated into a golf course design, wetlands should be maintained as preserves and separated from managed turf areas with native vegetation or structural buffers. Constructed or disturbed wetlands may be permitted to be an integral part of the stormwater management system.

That said, it is usually better to avoid construction upon wetlands if practical. Permitting requirements can be daunting, with multiple overlapping jurisdiction of federal, state, and local agencies. At the federal level alone, the U.S. Army Corps of Engineers (USACOE), EPA, FWS, National Oceanic and Atmospheric Administration (NOAA), and maritime agencies may all be involved. Combined with state and local watershed regulations, and concerns of non-governmental environmental or other citizen groups, it is important to approach wetlands with caution.

If you are considering construction along wetlands, contact your local government and/or local agencies or water management district office before drawing up engineering plans. Staff in these agencies can give an early indication as to what may, or may not, be permitted and may be able to point out alternatives that save money and speed up the review process. Remember, most obstacles are easily avoided with enough notice.

STORMWATER

Stormwater pollutants may be dissolved in the water or carried as fine particles, called suspended solids. These solids may be fine soil particles, organic material, or other kinds of particles, but all may have other chemical pollutants attached to them. One kind of stormwater treatment involves separating out these particles. Other types of treatment include biological or chemical processes, which are often used to remove dissolved materials such as pesticides or nutrients.

The control of stormwater on a golf course is more than just preventing the flooding of the clubhouse, maintenance, and play areas. In addition to controlling the amount and rate of water leaving the course, it also involves storing irrigation water, controlling erosion and sediment, enhancing wildlife habitat, removing water-borne pollutants, and addressing aesthetic and playability concerns. Keep in mind that not all stormwater on a golf course originates there; some may be from adjoining lands, including residential or commercial developments. Most golf courses in Minnesota plan their lakes and water hazards to be a part of the stormwater control and treatment system. This usually works out well for all concerned. However, natural waters of the state cannot be considered treatment systems and must be protected. Lakes and ponds may also be used as a source of irrigation water.

It is important to consider these functions when designing and constructing the ponds. Peninsular projections and long, narrow fingers may prevent mixing. Ponds that are too shallow may reach high temperatures, leading to low oxygen levels and promoting algal growth and excess sedimentation. Swales and slight berms around the water's edge, along with buffer strips, can greatly reduce the nutrients and contamination that can affect water quality. Careful design may significantly reduce future operating expenses for lake and aquatic plant management.

Stormwater Treatment Train

Stormwater treatment is best accomplished by a "treatment train" approach, in which water is conveyed from one treatment to another by conveyances that themselves contribute to the treatment. For example, stormwater can be directed across a vegetated filter strip (such as turfgrass), through a swale into a wet detention pond, and then out through another swale to a constructed wetland system.

Source Controls

Source controls are the first car on the BMP treatment train. They help to prevent the generation of stormwater or introduction of pollutants into stormwater. The most effective method of stormwater treatment is not to generate stormwater in the first place, or to remove it as it is generated. There are several options for accomplishing this. The most important is eliminating as much directly-connected impervious area (DCIA) as possible. DCIA is any area of impervious surface that drains directly to a water body without treatment; for example, a roof that drains to a parking lot, down a road, and into a ditch leading to a stream.

Sedimentation Control

During construction, temporary barriers and traps must be used to prevent sediments from being washed off-site into water bodies. Wherever possible, keep a vegetative cover on the site until it is actually ready for construction, and then plant, sod, or otherwise cover it as soon as possible to prevent erosion.

Once construction is completed, permanent barriers and traps can be used to control sediments. For example, depressed landscape islands in parking lots catch, filter, and infiltrate water instead of letting it run off. When hard rains occur, an elevated stormwater drain inlet allows the island to hold the "first flush" and settle out sediments, while allowing the overflow to drain away.

Water Quality Buffers

Buffers around the shore of a water body or other sensitive areas filter and purify runoff as it passes across the buffer. Ideally, plant buffers with native species provide a triple play of water quality benefits, pleasing aesthetics, and habitat and food sources for wildlife. It is important to continue these plantings into the water to provide emergent vegetation for aquatic life, even if the pond is not used for stormwater treatment. Effective BMPs in these areas include site-specific natural/organic fertilization and limited pesticide use to primarily focus on control of invasive species.

A measure of protection can be achieved by instituting Special Management Zones around water bodies. In managed areas around a golf course, the first 25 feet landward is a No Spray Zone (no pesticides used), and from 25 to 50 feet landward is a Limited Spray Zone (selected pesticide use, based on a risk assessment protective of aquatic life).

The No Spray Zones and buffers occupy the same space. It is important to note, however, that Limited Spray Zones and a policy of "no direct discharge" provide advantages to all wildlife by maintaining water quality. All other efforts are completely wasted if water quality is not sufficient for wildlife use. Some species, especially aquatic animals that cannot move large distances, are extremely sensitive to even trace amounts of standard fertilizers and pesticides. It is critical to have a design that incorporates protective measures to maintain water quality.

The only downside to native vegetation buffers usually concerns the play of the golf game. Sometimes a water body is situated such that a native buffer would take up too much space, obstruct the view, or otherwise interfere with the play of the game. In this case, a grass buffer may be used. A 25-foot buffer of turf mowed at three inches and only minimally fertilized with slow-release or organic-based products provides an effective buffer from a water-quality standpoint, although many of the wildlife benefits are lost. Pesticides should be applied by spot treatment only, as needed.

Retention facilities allow the water to percolate through the soil into groundwater. This traps most of the pollutants in the soil where they can be biologically degraded over time. They are usually designed to trap the first flush of 0.5 to 1 inch of rain and allow additional flow to bypass to another system. In many drainage watersheds, this first flush washes most of the pollutants off the surface and may carry 90% or more of the pollutants from even a large storm. These "offline" retention systems can approach 100% pollutant removal efficiency but take up a lot of space and are dry most of the year.

Wet detention facilities are similar, in that they slow the rate of water discharge to provide flood control, but are designed to have water in them at all times. These areas are biologically active ponds that allow solids to settle. A wet detention pond should have at least 30% of its area as a shallow littoral zone; this is where much of the biological activity takes place. A properly designed and maintained wet detention pond can attain efficiencies of up to 90% solids removal; 40% minimum slope of ten-foot horizontal to one-foot vertical is recommended. Planting on slopes less than six-foot horizontal to one-foot vertical may not be as successful over the long term. On the other hand, these slopes should not be perfectly graded. Random small dips and ridges of a few inches to a foot or so promote diversity within the plant community and provide a healthier and more productive littoral zone.

Habitat for Aquatic Life

All or most of the out-of-play water bodies should have shoreline buffers planted with native or well-adapted, noninvasive vegetation to provide food and shelter for wildlife. These buffer areas not only protect water quality but provide very important habitat for many wildlife species. Birds, mammals, frogs, fish, and turtles spend some or all of their life cycles in or around the water. Many species depend on this habitat for breeding, foraging, hunting, fishing, and other essential activities. In addition to serving as habitat, shoreline buffers can also serve as wildlife corridors that connect different ecosystems and allow the movement of species with larger territories. Shoreline buffers should be coordinated with littoral shelf planting to provide as natural a habitat as possible for wildlife, with plenty of emergent vegetation in shallow areas.

PLAY AREAS

Up to 300 rounds of golf per day may be played at many courses at certain times of the year, and some public courses record up to 40,000 rounds of golf played in a year. Therefore, the sizing and placement of major playing areas should be carefully evaluated to ensure adequate wear. Turf grown in the proper agronomic environment requires less intense maintenance and fewer pesticide applications.

Greens

Greens typically occupy only about 2% of the total course area but account for about 40% of the strokes scored. Careful design and very intensive turf management are required to maintain a good putting surface under these conditions. The nature of the game calls for very short mowing, usually daily, which also limits the size of the root system. As a result, frequent watering and fertilizing are necessary. This high-stress environment also makes the turf more susceptible to pests.

No procedure or method of greens construction provides an absolute guarantee of success. Success depends on the quality of the materials used, the quality of the installation, and the quality of subsequent management.

Location

Locating a putting surface is almost as much an art as a science. Many elements are important in providing the aesthetic background or challenging hole play that make any round of golf a success. The natural surroundings, such as a body of water, hillside, or depression, the overview of a scenic area, and the strategic use of natural hazards such as trees, in addition to adjacent golf holes, are all incorporated into the location, shape, and size of a green. Environmental and agronomic factors such as surrounding soils or severe slopes, trees, and water bodies must also be considered, as well as housing developments, highways, and high population areas.

Greens require full sunlight to maximize photosynthesis and to dry out after heavy precipitation. Shade may reduce the cooling effects of air flow across a green’s surface. In addition, frost on shade-covered greens melts more slowly. When planning a course, remember that the sun is lower on the horizon during the fall months. Trees south and southwest of the greens cast longer shadows during these months and may cause problems.

Drainage

Being able to control soil moisture is a key factor in the success or failure of a green. Drainage and runoff from surrounding areas into the desired location of a green can be key to regulating internal water content. The placement of a green downward from a hill-side location can create a problem. Surface water runoff from the higher surrounding ground should not flow over the green, and water flow from slopes should be intercepted and redirected away from the green.

The surface runoff and water from these drainage lines must be directed so that it does not cause environmental harm. This may be achieved by creating swales and buffer strips using nearby fairways, rough, and out-of-play areas before allowing the water to enter a water hazard or other part of the stormwater system. This water should never be allowed to discharge directly into a wetland, stream, or other water body not meant to treat stormwater.

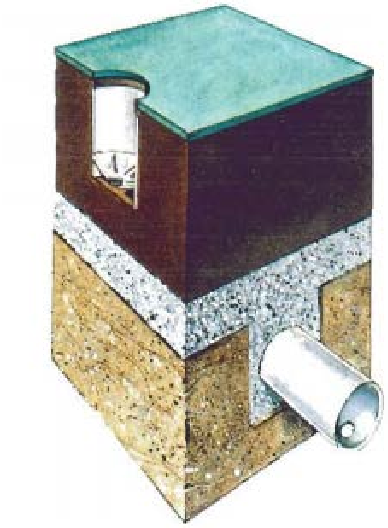
Size

A golf green should be large enough to allow for the adequate selection of a hole location but not so large as to become a financial and/or agronomic maintenance burden. Smaller-sized greens readily show the effects of concentrated traffic, while larger ones may have increased maintenance costs. In general, golf greens range from 3,000 to more than 7,500 square feet in size.

Profile of the Green

There are many construction techniques for greens. Again, a qualified golf architect working with experienced agronomic professionals should determine the appropriate technique and methods for greens construction. No matter what method is used, developing a consistent profile throughout all the greens is important for a golf course's maintenance practices.

The USGA has developed the following two recommendations for greens construction that attempt to create a universal standard:



1. A 12-to-14-inch root-zone medium is overlaid on a 2-to-4-inch layer of coarse ("choker") sand that covers a 4-inch layer of gravel.

2. A 12-to-14-inch root-zone medium is overlaid on a 4-inch gravel layer that is properly graded in relationship to the root-zone mix.

With both methods, tile lines are embedded in gravel to provide outfall drainage. These methods create a *perched* water table that does not move (or percolate) readily from the finer to coarser layer until the soil water content of the finer layer is at or near saturation. Many other methods used throughout Minnesota provide acceptable conditions when constructed properly.

A BMP plan must address both surface and internal greens drainage. This water should not be directly discharged into wetlands, streams, or other water bodies not meant to treat stormwater. As discussed earlier, water should be allowed to filter through swales or buffer strips before entering water bodies.

Irrigation Installation

The putting surfaces of the greens are the most intensely managed areas on a golf course. Because the most frequent mowing, cultivation, fertilization, and pest management practices are performed on greens, the irrigation system should be designed and installed so that the putting surface, and the slopes and surrounds, can be watered independently. With standard single-head coverage around the greens, either the putting surface or surrounds is often watered unnecessarily, wasting water and promoting poor root structure and fungal growth.

Soil Fumigation (Optional)

Fumigation controls most undesirable weeds, insects, and nematodes present in the root-zone mix. Those unfamiliar with soil fumigants should contract with a custom applicator in circumstances that may warrant the use of fumigants.

Planting

To ensure the quality of the grass on greens, use only certified grasses from an approved grower. To ensure the survival of new vegetation, it is vitally important to provide irrigation throughout the entire planting operation. Greens are typically seeded but can be sodded. When sodding, ensure that the sod is grown on a similar root-zone profile to avoid the layering of soil types.

Plant Selection: Sunlight, Shade, and Air Circulation

The fundamental principle for the environmentally-sound management of landscapes is Right Plant, Right Place. The ideal plant from an environmental standpoint is the one that nature and evolution placed there. It has adapted specifically to the soil, microclimate, rainfall and light patterns, insects and other pests, and endemic nutrient levels over thousands of years. As humans, we often have a need to change the natural landscape for living, working, and recreation. When we do so, our challenge becomes to use the most suitable plant materials for the new conditions that meet our design needs. The goal of the BMPs is to maintain as close to a natural ecosystem as practical, while meeting the needs of a golf course.

Under shaded conditions, turfgrasses develop elongated leaf blades and stems as they attempt to obtain sunlight by outgrowing their neighbors. This reduces their overall health and vigor. Coverage is also reduced and the bare ground that results is conducive to weed growth. It is generally not advisable to grow turfgrass in heavy shade. This is not usually a problem on the playing surfaces of a golf course but may be encountered in nonplay areas. Other ground covers or mulch can be used in these sites. For areas receiving moderate amounts of shade, however, certain species and cultivars are able to maintain suitable growth. Specific management practices discussed in the section on cultural practices can also encourage better turfgrass health under shaded conditions.

Adequate air circulation is also important. A design in which “dead spots” are created, especially if also partially shaded, can lead to moisture problems and increased fungal or disease pressure. In these conditions, BMPs for tree pruning, understory removal, and irrigation management must be constantly reviewed.

Bunkers

A good BMP-designed golf course must focus significant attention on bunker design and construction. Many questions must be addressed to build bunkers and bunker complexes that are successful over the long term.

Like greens, bunkers may or may not require subsurface drainage. When required, 4-inch perforated drain lines are typically installed in 8-inch-by-6-inch trenches and filled with appropriate gradation rock. A qualified golf architect determines patterns and placement to ensure that the drainage system is effective.

Bunker sand gradation and color are important considerations in the design process and should be carefully reviewed. New geotextile products are being used in heavy slope areas to minimize sand erosion, and some geotextiles are being used as separation blankets between subsurface conditions and bunker sand to avoid contamination.

A solid BMP plan addresses maintenance raking practices, entry/exit points for golfers and maintenance equipment, and any site-specific irrigation requirements that may be needed to prevent wind erosion under severe conditions. New bunker materials are being researched, such as recycled materials and limestone screenings.

Soil Amendments

Traditionally, USGA putting greens have been built using mixtures of sand and peat. Sand is used in relatively high percentages to enhance percolation rates, but high percolation rates can lead to the leaching of applied nutrients and contamination of subsurface water supplies. In addition, sands typically retain relatively small amounts of available water; thus they have low water use efficiency (WUE). WUE is defined as the quantity of dry matter produced per unit of water applied. The addition of clays, silt, or organic matter increases cation exchange capacity (CEC) and helps to retain nutrients, but their addition may reduce the percolation rate and lead to long-term drainage problems.

Numerous other amendments have been proposed for use in putting green construction. These include clinoptilolite zeolites, polyacrylamides (PAMs), diatomaceous earths, calcined clays, porous ceramics, and iron humates. Field tests suggest that the rankings for some of these amendments relative to their influence on soil-available water are as follows: iron humate > diatomaceous earths > calcined clays > peat > zeolites.

In recent studies, amendments with moderate levels of CEC and moderate levels of moisture retention (calcined clays and porous ceramics) produced the highest WUE. Amendments with a very high CEC but low moisture retention (zeolites) and those with a very low CEC but high moisture retention (diatomaceous earths) produced lower WUE. All amendments, however, produced higher WUE levels than sand or sand-peat mixtures. Iron humate has been shown to induce very high levels of WUE and significantly longer days to wilting when water is withheld than the other soil amendments listed above. An additional benefit to incorporating iron humate (2.5% V:V basis) in the root-zone mix for a USGA sand putting green is that phosphorus leaching is almost completely eliminated. No detectable levels of P were obtained in the leachate collected from a simulated USGA rootzone profile when iron humate was added as an amendment.

NONPLAY AREAS

As discussed earlier, one of the first steps in planning a golf course is to assess the site's general environment and ecology. Map any environmentally sensitive areas such as sinkholes, wetlands, or flood-prone areas, and identify federal and state endangered or threatened species, and state species of special concern. Whenever possible, habitats consisting of wetlands or other sensitive areas for wildlife should be preserved. Many difficulties associated with any development can be avoided by recognizing these issues in the beginning and managing them appropriately.

During the preconstruction process and after a course has been established, the amount of irrigated and maintained turfgrass should be looked at carefully to determine if it is functional. Many older golf courses and some new ones have more irrigated and maintained acres than are necessary. With the help of a golf course architect, golf professional, golf course superintendent, and other key personnel, the amount of functional turfgrass can be evaluated. Areas that are not in play or are not critical to the design of the course may be removed and replanted with native plant material that requires little to no maintenance after establishment. In fact, trees and shrubs may require more water than turfgrass during establishment, but once they are established, they may need very little maintenance if properly chosen and located.

As much natural vegetation as possible should be retained and enhanced through the supplemental planting of native trees, shrubs, and herbaceous vegetation to provide wildlife habitat in nonplay areas, and along watercourses to support fish and other water-dependent species. By leaving dead trees (snags) where they do not pose a hazard, a well-developed understory (brush and young trees), and supporting no-mow and native grass areas, the amount of labor and resources needed to prepare a course are reduced, while habitat for wildlife survival is maintained.

Golf Courses Are Wildlife Habitat

It is important to preserve natural surroundings when developing a course. It is easier to manage wildlife if existing natural conditions and wildlife habitats are preserved. When areas that have been disturbed are replanted, native trees, shrubs, and grasses should be used when possible. Avoid exotic species, particularly invasive plants, or plants that are not well adapted to the local environment. The primary wildlife will probably be small mammals and birds.

Natural cover around a course also serves as a buffer to reduce urban traffic noise and visual distractions, and filters pesticides and nutrients from runoff entering streams or ponds. A golf course design that incorporates areas of natural cover may be less expensive to maintain and construct. Cover provides and promotes important areas in a golf course that are significant for all species. It is a natural part of wildlife habitat and encompasses almost all the factors that wildlife need for their welfare, including shelter from weather; places to nest, rest, and feed; and concealment from predators or prey. Providing cover for wildlife is easy to accomplish by keeping 50 to 70%

of the nonplaying course area natural. Brush piles, a stand of trees, snags, riparian areas, and roughs are considered cover for some species.

Birds – Providing adequate food all year is important in establishing a healthy bird population. Appropriate trees, plants, and grass species can be planted, or preserved if they already exist. Foods can include various types of wild fruits, plants, herbs, and seeds, and a large variety of insects. Many bird species require insects so it is important to maintain insect populations. Fortunately, insects flourish in most areas. One of the greatest threats to insects is the application of broad-spectrum chemicals applied to a course to control specific pests. With the proper use of IPM on a wildlife-friendly course, insect populations should be adequate.

Nesting areas are important for maintaining healthy bird populations. Whenever possible, leave dead tree snags as long as they do not pose a hazard. Snags provide nesting cavities for many birds and are food sources for woodpeckers and other species that eat insects in the bark. Birdhouses and nesting boxes can be placed around a course near areas of appropriate cover and food supply. It is often possible to get players and their families interested in building and maintaining these nesting boxes at little or no cost to the golf course.

Animals – Most four-footed wildlife consists of small mammals, such as squirrels, rabbits, and fox. These animals need concealment from predators and adequate food supplies. Small brush piles can provide cover. Food sources include nuts, berries, and grubs. Corridors should be provided when possible to allow animals to move from place to place without being exposed to predators. Therefore, perimeter fences or walls should not be installed so that wide-ranging small and large animals can traverse the site. If walls are built, they should provide a minimum clearance of one foot between the ground and the lowest portion of a fence or wall, except where it is necessary to exclude feral animals. The animals also need burrows and nesting/bedding places. Whenever possible, these areas should not be disturbed, especially while young are present.

Aquatic Life – A good source of uncontaminated water is important to terrestrial species and is imperative for aquatic species. Proper pesticide management and the use of water quality buffers and riparian zones are important factors in keeping the water clean. Riparian areas (streamside vegetation), which play a vital role in the terrestrial/aquatic communities, should be protected. These areas are transition zones between water and land. They provide cover and food, and also help maintain a healthy water source. Vegetation along the water's edge can stabilize surrounding soils, help in flood control, and filter sediments and chemicals that are being transferred into the system.

Assess the condition of water hazards and ponds by measuring temperature, disolved oxygen, pH, conductivity, water hardness, and phosphorus and nitrogen concentrations. In addition, samples of plankton, algae, rooted aquatic plants, and terrestrial plants should be taken and identified. Observations of fish, wildlife, and general pond condition should be recorded.

The overgrowth of aquatic plants or algae is aesthetically unappealing and may lower oxygen levels in the water. As with all plants, aquatic vegetation thrives on nitrogen and phosphorus. Use natural riparian buffers or unfertilized turf buffers to minimize the entry of excessive nutrients.

As with any ecosystem, ponds and lakes require a complete food chain from bacteria to fish. These organisms cycle nutrients, control pests, and enhance the aesthetic value of water.

Forested Buffers

Protecting wildlife habitat on golf courses is especially important in urban environments where highly fragmented, forested areas often provide the best, and sometimes the only, habitat for many wildlife species. Forested buffers along golf course streams and wetland areas can provide large areas of key habitat and sanctuaries for birds and other wildlife, while protecting water quality. When riparian buffers connect isolated blocks of habitat, they also serve as important travel corridors for species that may not cross large open areas.

Forest vegetation protects aquatic habitat in several important ways. Trees and shrubs along streams provide temperature moderation through shade, which lowers water temperature in summer and increases it in winter. Shade can also reduce the growth of filamentous green algae and promote the production of diatoms, which are an important food source for aquatic macroinvertebrates. Fallen and submerged logs and the root systems of woody streamside vegetation provide cover for fish and invertebrates, while leaves, branches, limbs, fruits, and other types of forest detritus form the base of the aquatic food chain in headwater or low-order streams.

Well-designed forested buffers should contain a mixture of fast- and slow-growing native trees, shrubs, and grasses to provide a diverse habitat for wildlife. Proper design and the selection of appropriate vegetation ensure that these buffer areas do the following:

- Trap and remove upland sources of sediments, nutrients, and chemicals
- Protect fish and wildlife by supplying food, cover, and shade
- Maintain a healthy riparian ecosystem and stable stream channel

Gardens

Aesthetic gardens, window boxes, and container gardens should contain a variety of plants of different heights that provide nectar for bees, hummingbirds, and butterflies. Again, Right Plant, Right Place is the key to success.

Know the ultimate sizes and growth rates of trees, shrubs, and ground covers. This reduces the need for pruning and debris removal, and lowers maintenance costs. Also, adding proper soil amendments in garden areas can improve the soil's physical and chemical properties, increase its water holding capacity, and reduce the leaching of fertilizers. Amendments may be organic or inorganic; however, soil microorganisms rapidly decompose organic amendments such as peat or compost and thus requiring replenishment. Amendments are not usually recommended for trees.

The use of organic mulches in gardens and aesthetic areas increases the moisture-holding capacity of plantings and prevents weed growth when applied in sufficient depth. Organic amendments are decomposed by soil microorganisms and add to soil tilth.

Excess mulch or compacted mulch may be detrimental, causing water to shed away from the root zone and encouraging overwatering, especially when annual remulching is performed.

Aesthetic Turf

Turfgrass may be used for purely aesthetic reasons to provide a pleasing view around clubhouses, entries, and other areas. However, while it is perfectly acceptable to use turf in this fashion, remember that turf grasses provide minimum wildlife benefits and require considerable maintenance. Use turf as a landscape element where needed, but do not think of it as a default filler material. Garden plants, shrubbery, ground covers, or native plants may provide just as pleasing a view and also provide useful food, cover, or other environmental benefits to wildlife; they may also require less maintenance.

Plant Selection

As discussed earlier, the fundamental guide for the environmentally sound management of landscapes is Right Plant, Right Place. The ideal plant from an environmental standpoint is the one that nature and evolution placed there. It has adapted specifically to the soil, microclimate, rainfall and light patterns, insects and other pests, and endemic nutrient levels over hundreds or thousands of generations. Where these factors have changed, the challenge is find other suitable plants. A BMP goal is to maintain as close to a natural ecosystem as practical, while meeting the needs of the golf course.

MAINTENANCE FACILITIES

Maintenance facilities include areas for equipment fueling, washing, storage and repair; the superintendent's office; and areas for storing, mixing, and loading fertilizers and pesticides. Building codes may be more stringent for some of these facilities, so check with local building authorities.

Pesticide and Fertilizer Facility

The pesticide facility is one of the most important buildings on a golf course. Few other functional spaces offer the potential for such expensive liability, either for chemical contamination of the environment or for exposure to golf course workers. Proper thought and care in the design, construction, and operation of this facility can greatly reduce liability exposure, while failure to do so can greatly increase the likelihood of costly governmental or civil liability.

Pesticide and Fertilizer Storage – Design and build pesticide storage structures to keep pesticides secure and isolated from the surrounding environment. Store pesticides in a roofed concrete or metal structure with a lockable door. Locate this building at least 50 feet from other structures (to allow fire department access and space for a water curtain to protect adjacent structures). Keep pesticides in a separate facility or at least in a locked area separate from areas used to store other materials, especially fertilizers, feed, and seed. Do not store pesticides near burning materials, near hot work (welding, grinding), or in shop areas.

Common Golf Course Maintenance Practices

Cultural practices have a significant impact on turfgrass growth and playability. Certain cultural practices such as mowing, verticutting, and rolling are necessary to provide good playability, while others, such as aerification, are needed to enhance turf health. This chapter discusses the need for each practice and lists methods for cultivating turf for improved playability while decreasing water loss and encouraging environmental protection.

MOWING

Mowing is the most basic yet most important cultural practice a superintendent can use to provide desirable turf. Mowing affects other cultural practices and many aspects of turf quality, such as density, texture, color, root development, and wear tolerance. Failure to mow properly usually results in weakened turf with poor density and quality.

Turf grasses used on golf courses can be mowed close to the ground, since their terminal growing points (crowns) are located at or just below the soil surface. Regrowth 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 (growth points) tissue at the top or tip of their stems. Consequently, mowing removes this growing point, and many upright dicot weeds are thus easily eliminated from frequently-mowed turf.

Mowing affects turfgrass growth habit. Frequent mowing increases tillering and shoot density. Mowing decreases root and rhizome growth, because after mowing, food reserves are used for new shoot tissue development at the expense of root and rhizome growth. Improper mowing exacerbates this problem. If the correct mowing height and frequency are used, then the turf does not go through a stress period from the immediate loss of top growth and can recover more quickly. Infrequent mowing results in alternating cycles of elevated crowns followed by scalping thus depleting food reserves further. Remember, stressed turf means a weaker plant that is more vulnerable to drought, insects, and disease, and that needs more pesticides.

MOWING HEIGHT

Mowing height refers to the height of top growth immediately after the grass is cut. Determining this height accurately can be misleading to inexperienced mower operators. Often height is adjusted and checked on a level surface such as a worker's bench or roadway, and is thus referred to as the "bench setting." However, when operated, the mower wheels are forced down on grass shoots; as a result, the unit rides on top of them and the mower is actually raised higher than the bench setting. Conversely, when a mower is operated on soft ground or when a thick, spongy thatch layer is present, the mower cuts lower than the bench setting, often resulting in undesirable scalping.

Variables Influencing Mowing Height - Many factors influence the mowing height of grasses. Mowing heights for golf course turf are governed by the grass variety and its use.

For example, golf greens are mowed below 0.125 inch to provide the smooth, fast, and consistent playing surface that golfers desire. Other factors influencing mowing height include mowing frequency, shade, mowing equipment, time of year, root growth, and stress.

Shoot and leaf tissue is the site of photosynthesis. Any removal of this tissue strongly influences the physiological and developmental condition of a turfgrass plant. If grass is mowed too low or too infrequently, crown damage can occur, and excessive photosynthetic tissue is removed. This results in off-colored turf with a low recuperative potential.

Root-to-Shoot Ratio – If plants are mowed too low, their roots require a substantial amount of time to provide the food needed to produce tissue for future photosynthesis. Turf grasses have a ratio of root-to-shoot tissue that is optimum to support growing grass. If turf is mowed too low all at one time, the ratio becomes imbalanced, with more roots available than the plant physiologically requires. This excessive root mass is then sloughed off. Until the plant has time to regenerate new shoot tissue, it becomes weak and more susceptible to environmental and pest stresses. Root growth is least affected when no more than 30 to 40% of the leaf area is removed at one mowing.

Root Growth – A direct relationship exists between mowing height and root depth. As the mowing height is reduced, a corresponding reduction in root depth occurs. Less root depth is needed to support less top growth when the mowing height is lowered. This is why golf greens need to be watered and fertilized more frequently than other playing surfaces. Shallow roots have a decreased depth from which they can obtain moisture and nutrients from the soil. Roots (plus lateral stems) are where carbohydrate reserves are stored. Therefore, shallow roots on a putting green also mean that leaves and shoots have minimal carbohydrate reserves to draw from when the plants are stressed.

Shade – Under shady conditions, grass leaves grow more upright to capture as much of the filtered sunlight for photosynthesis as possible. As a result, the mowing height for grasses grown under these conditions needs to be raised at least 30%. If mowed continuously short, grasses grown under shaded conditions gradually thin due to the lack of sunlight needed for photosynthesis. To reduce irrigation, fertilization, and pesticide inputs, it is recommended that greens be mowed as high as the clientele will allow. Also, research suggests that applying the plant growth regulator Primo (trinexapac-ethyl) to shaded turf improves overall turf health.

Mower Type – Mowing height is also influenced by the mower type being used. Rotary and flail type mowers cut best at heights above one inch and are used primarily in roughs and out-of-play areas. Conversely, reel mowers cut best at heights below 1 inch and are used on most golf course play areas.

Season – The season of the year may also influence mowing height. In early spring, turf grasses have a more prostrate (decumbent) growth habit. They can be mowed closer without serious consequences than in other seasons. Close mowing in early spring controls thatch, increases turf density, removes excess residues or dead leaf tissue, and promotes earlier green-up. Green up is hastened because close mowing removes top growth and dead tissue that shades, and thus cools, the soil surface. If more solar radiation reaches the soil surface, it warms up more quickly than if the top growth is allowed to remain tall. In summer, when days are longer, grasses have a more upright growth habit and are healthier if the mowing height is raised to compensate for it. A higher mower setting at this time also increases turf rooting thus reducing water needs and improving the turf's ability to take up water and nutrients.

MOWING FREQUENCY

Mowing frequency often is a compromise between what is best for the turf and what is practical for the sport. The growth rate of the grass should determine the frequency of cut. The growth rate is influenced primarily by mowing height, the amount and source of nitrogen fertilizer applied, and the season or temperature. Higher amounts of nitrogen result in faster top growth, necessitating an increased mowing frequency. Raising the mowing height reduces cutting frequency, helping to compensate for faster growing turf.

One-Third Rule - The traditional rule is to mow often enough so that no more than one-third of the top growth is removed at any one time. Removing more than this amount decreases the recuperative ability of grass due to the extensive loss of leaf area needed for photosynthesis. A reduction in photosynthesis can result in the weakening or death of a large portion of the root system, because carbohydrates in roots are then used to restore new shoot tissue. Consequently, root growth may stop for a while, since the regeneration of new leaves (shoots) always takes priority over sustaining roots for food reserves following severe defoliation.

To determine how much growth to allow, multiply the height of cut (HOC) by 1.5. For example, if the HOC is 0.5 inches, the calculation is as follows:

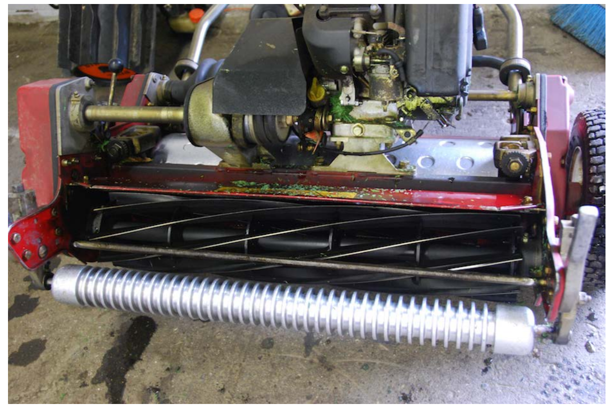
0.5" X 1.5 = 0.75"

The grass should be allowed to reach 0.75 inch and then mowed. Thus, 0.25 inch of clippings is removed (one-third) and 0.5 inch of verdure remains (two-thirds).

Scalping - If turf becomes too tall, it should not be mowed down to the intended height all at one time. Such severe scalping may stop root growth for extensive periods. Also, scalping reduces turf density, increasing weed establishment. Tall grass should be mowed frequently and the height gradually reduced with each mowing until the desired height is reached. The exception is when scalping is performed as a summertime cultivation practice, particularly on golf course roughs. Like verticutting, scalping is implemented to remove excess stem/leaf material and improve turf uniformity, but if the one-third rule is frequently violated, the result is usually gradual thinning and a disappointing reduction in turf quality.

MOWING EQUIPMENT

Mowing equipment has continued to increase in sophistication since the scythe was invented. The first reel mower was developed in 1830 by Edwin Budding, a textile engineer, who adapted the rotary shear that was used to cut carpet nap. Early mowers were operated using hand or animal power, but these were eventually replaced by gasoline- and diesel-powered units and more recently electric and natural gas. Today a vast array of mower types is available, with varying levels of sophistication and a wide range of costs.



Reel Mowers - Reel mowers consist of blades attached to a cylinder known as a reel. As this cylinder rotates, grass leaves are pushed against a sharp, stationary bedknife and clipped. A reel mower that is properly adjusted cuts grass as cleanly as a sharp pair of scissors and produces better quality results than other types of mowers. Reel mowers also require less power, consume less fuel, and, therefore, are more efficient to operate than rotary or flail mowers. In fact, reel mowers use up to 50% less fuel per acre of cut than rotary mowers when used at the same mowing speed.

Reel mowers do have some disadvantages, most notably their inability to mow grass maintained above approximately 1.5 inches and to cut coarse-textured turf. Similarly, tall seed heads, weeds, and tough seed stalks are not cut efficiently with reel mowers. Reel mowers, especially hydraulically driven ones, are more expensive than other mowers and usually require a higher level of maintenance and skill to adjust and operate.

Rotary Mowers - Rotary mowers are an impact type cutting mower. They have blades that are horizontally mounted to a vertical shaft that cuts grass by impact at a high rate of speed. The key to success with rotary mowers is to maintain a sharp, balanced blade. Rotary mowers cut grass like a machete. As long as the blade is sharp and balanced, the quality of cut is acceptable. A dull mower blade shreds leaf blades instead of cutting them, and leaf tips become jagged and frayed. When leaf tissue is mutilated by an unsharpened rotary blade, wounds heal slowly and greater water losses occur through evaporation, since the leaf area exposed to the environment is increased. Mutilated tissue also provides invasion points for diseases. This can increase the need for pesticides or fertilizers. If blades are nicked from hitting hard objects, they should be ground or filed to restore the original cutting edges.

Rotary mowers have the advantage of being relatively inexpensive and more versatile than reel mowers. They can be used to cut very tall or coarse-textured grass and tough weeds and seed stalks, while reel mowers cannot. Rotary mowers may also decrease herbicide use in golf course roughs by making weed seed heads less conspicuous. They also can be more easily maneuvered than reel mowers to trim around trees and buildings, and generally have lower initial costs and simpler maintenance requirements.

The disadvantages of rotary mowers include their inability to provide a quality turf at heights lower than one inch. Rotary mowers are dangerous if hands or feet are accidentally placed under the mowing deck while the blade is operating. Because the blades rotate at a high speed, they can turn any rocks or tree limbs that they encounter into dangerous projectiles. Rotary mowers are not usually designed to follow the surface contour as exactly as a reel mower. Therefore, at close mowing heights, the rotary mower is more likely to scalp turf as it travels across small mounds or ridges that often compose the turf surface.

Flail Mowers - Flail mowers, another impact-type cutting unit, have a number of small blades (knives) attached to a horizontal shaft. As the shaft rotates, the knives are held out by centrifugal force. Cut debris from flail mowers is re-cut until it is small enough to escape the close clearance between the knives and mower housing. The advantages of flail mowers include their ability to cut tall grass into finely ground mulch and the ability of each blade to recoil without damage to the mower. Unlike rotary mowers, they do not create a dangerous projectile if they strike a hard object such as a rock or tree limb. The disadvantages include the flail mower's inability to provide a close, quality turf surface and the difficulty of sharpening the small, numerous knives. Flail mowers are most often used on low maintenance utility turf, such as roughs or an out-of-play native area, which is mowed infrequently and does not have a high aesthetic requirement.

Equipment Care Equipment care is almost as important as initially choosing the right mower. Routine maintenance such as lubrication, oil changes, blade sharpening, tune-ups, belt adjustments, and proper cleaning are important in extending the useful life of equipment and in lowering operating costs. Adequate, accurate records need to be maintained and observed to help pinpoint the costs of operation and to justify the purchase of new equipment. In addition, proper storage should be available to minimize the exposure of equipment to weather, to prevent accidents, and to maintain security. When a job is finished, the unit should be cleaned and stored in a clean, dry, and secure area.

MOWING PATTERNS

The mowing patterns imposed by operators can influence both the aesthetic and functional characteristics of a turf surface. Aesthetic qualities are influenced by differing light reflections that occur in response to shifts in mowing direction. These shifts often result in alternating light and dark green strips that are generally more pronounced when walk-behind reel mowers are used, compared with triplex riding mowers or rotary deck mowers. Double-cutting at right angles produces a checkerboard appearance of light and dark green strips, as if two different nitrogen fertility levels or grasses had been used.

Mowing directions should not be repeated over the long term, even though this may produce alternating color differences. If turf is mowed repeatedly in the same direction, the grass leans or grows in the direction in which it is cut. This horizontal orientation of grass foliage in one direction is called *grain*. Grain results in an uneven cut, a streaked appearance, and a poor quality putting surface on golf greens. The ball tends to follow the grain. When a different grain is encountered, the ball reacts by altering its path slightly.

Varying the pattern of successive mowing easily prevents grain, encourages the upright growth of the shoots, minimizes the amount of leaf surface that the rolling golf ball encounters, and increases a green's putting speed and accuracy. The mowing patterns or directions of golf greens should be changed daily and cleanup laps routinely reversed or skipped. Often a rotating clock pattern is followed for mowing directions and is changed daily. Similarly, fairways should be mowed side to side and diagonally as well as longitudinally to minimize wear, compaction, and grain development.

Mowing continually in the same direction also scalps the same high spots and increases compaction and rutting by mower wheels. In addition, turning the mower at the same location and in the same direction encourages severe wear and soil compaction.

GRASS CLIPPINGS - Grass clippings are a source of nutrients. They contain 2 to 4% nitrogen based on dry weight and also significant amounts of phosphorus and potassium. If clippings are removed, additional fertilizer must be applied to compensate for these losses. Removing clippings can pose environmental and budgetary concerns, since municipal landfills no longer accept them. 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. They should be removed only when they are so heavy that they smother the grass or interfere with the playing surface, such as on golf greens.

By following the one-third rule on mowing frequency, large amounts of clippings are not deposited at one time. Soil organisms that naturally break down grass clippings have enough time to decompose them before the clippings accumulate. If excessive growth occurs because of heavy nitrogen fertilization or excessive scalping, natural decomposition may not be able to keep up with the amount of clippings deposited. A thatch problem may develop under these conditions.

Clippings collected from golf greens should be disposed of properly to prevent undesirable odors near play areas and to prevent fire hazards that can occur when clipping piles accumulate. One option is to compost the clippings. Develop compost piles by alternating layers of clippings with a mixture of soil and nitrogen fertilizer. When composted, the clippings can then be used as ground mulch in flower beds or inaccessible mowing areas. If not composted, the clippings should be dispersed so that piles do not form.

TURFGRASS CULTIVATION PRACTICES

Cultivation practices are an important part of turf management. Heavily used areas such as golf course greens often deteriorate due to compacted soil, thatch development, and excessive use. Soil problems from active use are usually confined to the upper three inches of the turf.

Unlike annual crops, where the soil is periodically tilled to correct such problems, turf managers do not have the opportunities for such physical disturbances without destroying the playing surface. Over the years, however, a number of mechanical devices have been developed that provide a degree of turf cultivation with minimum disturbance to the turf surface. Cultivation is accomplished by aerification, vertical mowing, spiking, and topdressing.

AERIFICATION Aerification, or *coring*, is the removal of small soil cores or plugs from the turf surface, leaving a hole in the sod. Beyond reducing soil compaction, it improves water infiltration, which in turn reduces dry spots, water use and runoff in other areas.

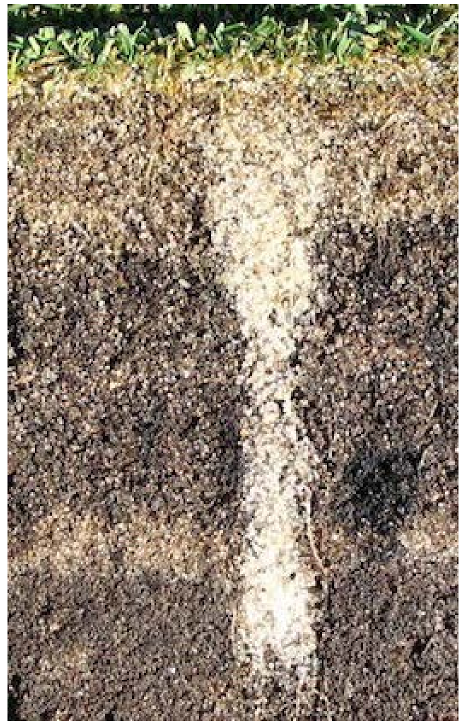
Holes are normally 0.25 to 0.75 inches in diameter; their depth and distance vary depending on type of machine used, forward speed, degree of soil compaction, and amount of soil moisture present. Traditional aerifying machines penetrate the upper two to four inches of soil surface, with cores spaced on two to six inch centers.

Recent innovations in aerification equipment provide options for creating holes to depths greater than 10 inches and diameters ranging from 0.125 to 1 inch. In addition, options are now available for creating the hole and core spacing. Generally, the benefits of aerification far outweigh any detrimental effects. Turf managers must decide which option is best to solve the existing problem. Excessive soil compaction and waterlogged soils are common problems limiting turf growth that may be improved by aerification:

ADVANTAGES OF AERIFICATION

- Relieves soil compaction
- Allows deeper, faster penetration of water, air, fertilizer, lime, and pesticides into the root zone
- Allows for the atmospheric release of toxic gases (e.g., carbon dioxide, carbon monoxide) from the root zone
- Improves drainage, helping to dry out saturated soils and prevent the formation of puddles
- Improves water penetration into dry or hydrophobic soils (e.g., relieves localized dry spots)
- Penetrates the soil layers that develop from topdressing with dissimilar materials
- Provides thatch control by stimulating the environmental conditions that promote healthy soil microorganism activity for thatch decomposition
- Increases rooting by constructing a medium more conducive to active root growth

DISADVANTAGES OF AERIFICATION



- Temporarily disrupts or damages playing surfaces
- Increases turf surface desiccation as roots are exposed
- Produces coring holes that provide a better habitat for cutworms and other insect pests

Soil Compaction One of the primary goals of core aerification is to relieve soil compaction, which occurs when mineral particles are pressed close together. This results from excessive or concentrated traffic, especially when soil is wet. Soil compaction reduces oxygen (porosity) levels in the soil. A soil should be composed of at least 25% air, on a volume basis, but compacted soil has as little as 5%.

Root function decreases under compaction due to the lack of oxygen needed for respiration and the buildup of toxic gases such as carbon dioxide. Also, roots may be unable to physically penetrate such a tightly packed soil mass. New roots are often abundant along the sides of the aerification holes, indicating the need for increased soil oxygen.

Compacted soil surfaces also reduce water infiltration and percolation. Dry soils in compacted areas are difficult to rewet. Conditions such as localized dry spots often develop, especially in areas with a high sand content. This encourages the overwatering of adjacent areas. On the other hand, compacted, saturated soils may not drain excessive water and often turn into mud with continued use. Such soils often remain wet for extended periods and become covered with an undesirable layer of algae or moss. The success of highly-maintained turf areas such as golf greens depends on the superintendent's control of soil moisture content.

The best method for preventing compaction is to build greens and tees with a predominately sandy soil and with proper surface drainage. Compaction is much more likely on fine-textured clay soil than on a coarser, sandy soil. Usually a coarse textured soil consisting of 80% or more sand is necessary to achieve the desired results. Soil containing a significant amount of clay (> 30%) or silt (> 5%) is unacceptable for golf green construction. All soils should be tested by an accredited soil laboratory before use. Proper surface contouring and subsurface drainage in the form of tile lines also hasten the removal of excessive surface water. For putting greens, the USGA formulated a construction method that provides good drainage and resistance to compaction. Created in 1960, it is still one of the most prevalent methods for constructing golf course putting greens today. This method is discussed in the USGA publication, *Recommendations for a Method of Putting Green Construction* available at: www.usga.org.

Reducing or redirecting traffic also relieves soil compaction. For example, the correct placement of cart paths and sidewalks is important. Cart paths should normally be a minimum of eight feet wide to allow two-way cart traffic and larger maintenance vehicles, such as tractors and trucks, an adequate passageway. Barriers such as curbs should be used adjacent to high-traffic areas such as tees and greens to prevent carts straying from the path.

Traffic should be minimized or prevented when soil is wet because water in the soil acts as a lubricant. Traffic during these periods further increases soil compaction, reducing turfgrass growth and vigor. Regulate traffic after heavy rains, and avoid mowing with large, heavy units. Use wide turf tires on all equipment to help distribute the weight of the vehicles over a larger area than is allowed by regular tires.

Core aerification usually softens hard, compacted turf surfaces. This is especially true when the spacing between holes does not exceed two inches. Aerifier tines should penetrate a minimum of three inches deep. This depth should be varied between aerifications to minimize the development of any compacted layering. Coring is most effective when soils are moist but should never be performed when soils are saturated.

Thatch Management Some thatch and organic matter are necessary for nutrient/water retention and good playability, but excessive amounts reduce root growth, encourage disease, and create undesirable playing conditions.

Aerification removes small cores of thatch and organic matter, and subsequent sand topdressing is incorporated to dilute the existing material. Putting greens must be core aerified several times each summer. Various aerifier tine diameters and spacing affect the percentage of putting surface affected.

Core Removal Aerifiers with hollow tines cut and bring a soil core to the surface, leaving a hole or cavity in the turf. A commonly asked question is whether to remove the cores that result from aerifying. For turf areas other than golf or bowling greens, it is most practical to leave the holes open. Cores also do not have to be removed if thatch control, temporary compaction reduction, or air and chemical entry are desired and the underlying soil is acceptable.

Dry Spots Localized dry spots are areas, usually ranging from 1 to several feet in diameter, that become very hydrophobic and repel water. This is most pronounced during hot, dry weather and with sand-based greens with excessive thatch. Aerifying with small diameter tines (< 0.5 inch) on close spacing (< 2 inches) allows better water infiltration. The routine use of granular or liquid wetting agents or surfactants applied to the dry spots in combination with aerification is also helpful. Solid quadtines, followed by wetting agent treatments, can alleviate dry spots with minimal disruption to the putting green surface.

Types of Aerifiers – Many types of core aerifiers or cultivators are available. Most fall into one of two categories: vertical- or circular-motion units. Vertical-motion core cultivators provide minimal surface disruption and are the preferred choice on closely-mowed turf surfaces such as golf greens. Vertical units have the drawback of being relatively slow due to the linking of vertical and forward operations. However, their speed and ease of operation have improved in recent years.

Circular-motion cultivators have tines or spoons mounted on a drum or metal wheels. The tines or spoons are forced into the soil as the drum or wheels turn in a circular motion. Hollow drum units remove extracted cores from the soil surface, while other units deposit cores back directly onto the surface. Circular-motion cultivators are preferred for aerifying large areas, since the rotating units can cover more ground in a given period than vertical-motion cultivators. However, they disrupt the turf surface more and do not penetrate as deeply.

If the root-zone mixture (soil) present is acceptable, then the cores should be broken up by lightly verticutting or dragging the area with a mat, brush, or piece of carpet. The remaining debris should be blown off or picked up with a follow-up mowing. Before the soil cores are matted, they should be allowed to dry enough so that they easily crumble between the fingers. If the cores are too dry when matted, they are hard and not easily broken up; if too wet they tend to smear and be aesthetically undesirable. Recent advances in mechanization allow the quick and easy windrowing of soil cores and their subsequent mechanical removal. Cores should be removed on putting greens, since organic matter removal/dilution is much more important on greens than on other playing surfaces.

Recent Developments Several recent developments in aerification technology provide turf managers with a wider choice of aerification strategies. One involves deep tine cultivators that are able to extract a 0.75 to 1 inch diameter core to a depth of 8 to 12 inches. Deep cultivator units enable the superintendent to relieve the soil compaction layer that develops when traditionally-used aerifiers penetrate consistently to three inches. Soil profiles consisting of many undesirable layers that develop with the use of different materials for topdressing are penetrated. This enhances water penetration, soil aeration, and rooting. For greens, an undesirable soil profile can be improved by topdressing with desirable soil following deep aerification.

Another development is the deep drill aerifier. Drill bits of varying lengths and diameter are drilled into the turf, leaving a small cast of soil on the surface around each hole. This soil is usually then matted back into the turf. The biggest advantage of the deep drill aerifier is the ability to provide a deep hole with the least disruption to the playing surface. These units, however, are relatively slow running and are generally more expensive to operate, as a high degree of mechanization and numerous drill bits are needed. Because a core is not physically extracted, the soil brought to the surface is difficult to remove.

Deep aerification creates more surface damage than shallow depth models. The initial expense also prevents many clubs from purchasing a unit, since it is more of a renovation tool than a regularly scheduled maintenance practice. These units are generally available for rental or contract use, however, or several clubs may choose to share the cost of purchasing a unit. Care must be used when aerifying golf greens built to the specifications outlined by the USGA, so as not to penetrate the two-to four-inch coarse sand layer, or four-inch gravel layer, that is located 12 to 14 inches deep. This violates the concept that greens maintain a "perched" water table for the turf to be grown in.

Another aerification technique is high pressure water or air injection. Fine streams of high velocity water or air are injected over the turf surface, resulting in minimal surface disruption. Play is not disrupted by aerification holes as it is by traditional machines. These high pressure units are also beneficial, because they wet hydrophobic soils, such as localized dry spots. The disadvantages are the initial high cost and the need for a water source, if using the water injection system, at all aerification sites. Thatch control is minimal and sand cannot be incorporated back into the green's profile, since the holes produced are not large enough. The hole spacing and penetration depth are, however, adjustable through multiple pulses, the changing of nozzle spacing, or varying speed. Water or air injection cultivation should supplement, not replace, traditional core aerification.

Frequency of Cultivation The frequency of core cultivation should be based on the traffic intensity that the turf is exposed to, and on the soil makeup, hardness of the soil surface, and degree of compaction. Areas receiving intense daily traffic, such as golf greens, approaches, landing areas, aprons, and tees require a minimum of two core aerifications annually. Additional aerifications may be needed on exceptionally small greens where traffic is more concentrated, on areas of heavy soils high in silt and/or clay that do not drain well, or on soils exposed to saline or effluent water. Such areas may need aerification with smaller diameter tines (0.38 inch or less) every four to six weeks during the active growing months. Failure to maintain an aggressive aerification program in these situations will probably result in poorly-drained soils, thin grass stands, and continued problems with algae.

Less-intense traffic areas should be aerified as needed. Most golf course fairways should be aerified twice yearly, with the first aerification timed in mid-spring once the grass is actively growing and the chance of a late freeze has passed. The second aerification should be in late summer.

Solid tines are sometimes used for coring instead of hollow tines. Creating holes by forcing solid tines into the turf is called *shatter-coring*. Tines do not remove soil cores and may compact soil along the sides and bottoms of the holes more severely than hollow tines. Areas receiving solid tine aerification will probably benefit only temporarily. Tines do not disrupt the playing surface as much as hollow tine cultivation.

Slicing and Spiking Two other cultural practices, slicing and spiking, help relieve surface compaction and promote better water penetration and aeration. A slicer has thin, V-shaped knives bolted at intervals to the perimeter of metal wheels that cut into the soil. The turf is sliced with narrow slits about 0.25 inch wide and two-to-four inches deep. Slicing can be performed much faster than coring and does not interfere with turf use, since there is no removal of soil cores; thus, no cleanup is necessary after the operation. Slicing is also performed on fairways and other large, heavily trafficked areas during midsummer stress periods, when coring may be too injurious or disruptive. However, it 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.

A spiker has an effect similar to that of a slicer, but penetration is limited to approximately one inch, and the distance between perforations along the turf's surface is shorter. For these reasons, and because spiking causes less surface disruption than coring, spiking is practiced primarily on greens and tees. A spiker is used to break up soil surface crusting, break up algae layers, and improve water penetration and aeration. Solid tines are associated with a spiker, and holes are punched by forcing soil downward and laterally. This results in some compaction at the bottoms 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 core aerification (e.g., every 4 to 8 weeks).

VERTICAL MOWING A vertical mower has 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.

Vertical mowing meets different objectives, depending on the depth of the penetrating knives. Grain is reduced on putting greens when the knives are set just to nick the surface of the turf. Shallow vertical mowing on tees and fairways breaks up cores following aerification, facilitating a topdressing effect. The deeper penetration of knives stimulates new growth when stolons and rhizomes are severed and removes accumulated thatch. Vertical mowing is also used to prepare seedbeds before overseeding.

The desired depth of thatch removal determines blade depth when dethatching is the objective. Vertical mowing should reach the bottom of the thatch layer, and preferably the soil surface beneath the thatch layer should be sliced. Dethatching is an aggressive practice that is not recommended on most golf course putting greens, due to increased disease susceptibility and time needed for recovery. There is a limit to the depth that blades can go. Be sure to verticut in different directions, just as with regular mowing.

Interchangeable vertical mower units are now available for many of today's triplex greens mowers. This equipment allows for frequent vertical mowing and simultaneous debris collection. For light surface grooming, the vertical blades on greens mowers should be set only to nick the surface of the turf so the surface is not impaired. By conducting frequent vertical mowing, the severe vertical mowing needed for renovation may be avoided. Large turf areas are vertically mowed by using units that operate off a tractor's power takeoff (PTO). Such units have heavily reinforced construction and large, thick (approximately 0.25-inch) blades that can penetrate to the soil surface.

Grooming and Brushing A miniature vertical mower can be attached in front of the reel cutting unit of greens mowers to lightly groom putting green turf. Likewise, brush attachments can be used in conjunction with daily mowing. These units improve the playing surface by standing up leaf blades before mowing, thus reducing surface grain. Slicing stolons also stimulates new shoot development, and thatch near the surface is removed.

Frequency The rate of thatch accumulation dictates the frequency of vertical mowing. Vertical mowing should begin once the thatch layer on golf greens exceeds 0.25 to 0.5 inch.

TOPDRESSING Topdressing adds a thin layer of sand to the turf surface that is then incorporated by dragging or brushing it in. On newly established turf, topdressing partially covers and stabilizes the newly planted material, smooths gaps that result from sodding, and minimizes turf grass 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, many superintendents have reduced the number of coring and topdressing procedures in recent years due to player complaints that these practices disrupt play. If eliminated, the quality of the putting green will diminish over time.

Topdressing Frequency and Amounts The frequency and rate of topdressing depend on the objective. Following coring and heavy verticutting, moderate to heavy topdressing helps to smooth the surface, fill cored holes, and cover exposed roots resulting from these two processes. Irregular play surfaces or soil profile renovation requires frequent and relatively heavy topdressing. Rates ranging from 0.125 to 0.25 inch (2 to 4 cubic yards of soil per 5,000 ft^2) are suggested. However, if the capacity of the turf to absorb the material is limited, less material should be used to prevent smothering the turf.

If the objective of topdressing is to change the characteristics of the underlying soil, then a heavy topdressing program following numerous deep core removal operations over a period of years is required. If thatch management is the main objective, then the rate of thatch accumulation governs the amount and frequency of topdressing. Thatch layering of 0.25 to 0.5 inch on golf greens is desirable, but it is necessary to dilute this layer with sand. The relatively thin thatch layer cushions (holds) the approaching golf shot better and also helps to protect turf crowns from traffic. When thatch is not excessive (≤ 0.5 inch), approximately 1 cubic yard per 5,000 ft^2 of topdressing is suggested at least once per month during the growing season. If over time this relatively light rate is not maintaining or reducing the thatch layer, then the frequency of application and the topdressing rate should be increased.

If the thatch layer exceeds 0.5 inch, then coring or deep verticutting is required to remove a portion of the thatch material. This should be followed with heavy topdressing. A distinct thatch (stem) layer greater than 0.5 inch that does not contain any sand must be prevented or eliminated. Such thatch layers either become hydrophobic (repel water) or create a perched water table at the surface that encourages roots to remain in the thatch layer and not grow down into the soil. In either situation, the turf is more susceptible to pests, mechanical damage, and environmental stresses.

If the objective of topdressing is only to provide routine smoothing of the playing surface, then light, frequent topdressings are suggested. The surface irregularities of the green are reduced and the area is somewhat leveled when a mat is used to drag sand into the turf canopy following topdressing. Topdressing with 0.5 to 1 cubic yard per 5,000 ft^2 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 green speed and provide a smoother putting surface. In addition, frequent, light topdressing should be applied to new greens every two to four weeks to cover stolons and to smooth the surface, until complete coverage or the desired smoothness is achieved.

Topdressing Materials Deciding what material to use for topdressing is one of a superintendent's most important long-term management decisions. Using undesirable materials can be disastrous and can ruin the integrity of initially well-built facilities. This usually occurs when the topdressing material used is finer in particle size than the size used in constructing the green.

Only weed-free materials should be used for topdressing. If the material's origin is not known, or if it has been piled and exposed over time, fumigation is highly recommended before use. Washed sands may not need sterilization before use but should be closely inspected to determine whether this is needed. Excess topdressing material should be properly stored to keep it dry and uncontaminated. Covered soil bins, sand silos, or polyethylene covers provide good storage conditions until the material is used.

When the underlying soil of the play surface (green or tee) is unsatisfactory, it must be determined whether to rebuild the facility or try to slowly change its composition through aggressive coring and topdressing. If the soil problem is severe, then reconstruction should be considered. With the introduction of deep core aerifiers, the process of changing the underlying soil characteristics may be expanded. Deep coring once per year followed by heavy topdressing with desirable sand should be practiced to improve poorly-draining greens. Between these corings, conventional aerification and topdressing should still be performed. Over several years, the use of this technique can radically improve the soil characteristics of the playing area.

If a topdressing program is chosen to improve the soil, then the next question is what material to use. Fine textured soils high in clay and/or silt predominate on most undesirable playing surfaces. A coarser soil texture, most notably sand, is introduced to improve water percolation and aeration. Current trends involve frequent topdressing with medium-fine (0.25 to 1.0 millimeter [mm]) sand. This size is usually coarse enough to change soil texture and fine enough to be easily worked into the turf surface. It is not so fine, however, as to seal the surface and impede air and water movement. A competent soil testing laboratory should test the sand in question before a superintendent attempts to slowly change the root zone of a green or tee by this method.

The most commonly observed problem is the formation of various alternating layers of soil when different top dressing materials are used over time. The differences in textural characteristics between layers of sand and organic matter result in poor root growth, caused by physical barriers, the lack of oxygen, the entrapment of toxic gases, micro perched water tables, and dry zones. Once these layers have formed, aggressive vertical mowing and coring are required to correct the problem. Aerification holes should extend at least one inch 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 desirable depths. Shallow spiking or coring above the layering is of questionable benefit.

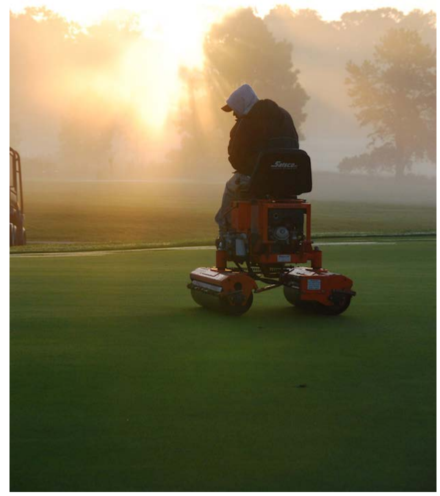
If conveyor-type top dressers are used, applied topdressing should be incorporated into the turf canopy by dragging a piece of chain link fence, brush, or piece of carpet over the area in several directions to evenly distribute the material. This should immediately be followed by watering to reduce soil drying and to encourage the material to settle.

ROLLING An older practice that has recently resurfaced, consists of rolling greens prior to a tournament to provide a smoother, faster playing surface. Two types of rollers are used today: first, a set of three drums that replaces the mowing units on a triplex mower, and second, a stand-alone unit that has a driver facing perpendicular to the direction the machine moves. This machine must be loaded and unloaded from a trailer at each green and requires a small tractor to pull it around.

Benefits Limited research on bent grass provides some guidelines on the expected increase in ball speed after rolling. Rolling once the morning before a tournament increases the speed of a green approximately 10%. However, to increase the speed by 20%, greens need to be rolled a total of four times. Rolling two or three times increases the speed between 10% and 20%. Rolling once per green per day is sufficient. It is interesting to note that the roller weight has not been found to influence the resulting green speed.

Limitations Any time pressure is applied to a soil surface, compaction may result. Therefore, to minimize the potential of compaction from rollers, use the lightest roller(s) available. As mentioned above, roller weight does not appear to influence resulting ball speed, but may influence the degree of resulting compaction.

Rolling should not be attempted when the soil is saturated, because moisture acts as a lubricant and allows the closer association of soil particles. Extra aerification to relieve any soil compaction may be required.



SHADE AND TREE MANAGEMENT In general, most turf grasses do best in full sun. Excessive shade reduces photosynthesis and moisture does not evaporate as quickly. Also, trees reduce air circulation, resulting in stagnant air. High heat and humidity quickly build in such areas. Whether from decreased sunlight or air circulation, the result is weaker turf that is more prone to disease and pest problems than turf in sunnier areas. Tree limbs and roots should be pruned yearly to reduce competition for sunlight, water, and nutrients with turf. Where possible, trees should be removed from around closely mown areas such as tees and greens to maintain good turf growth.

MANAGEMENT OF TURFGRASS GROWTH IN SHADE

- Increase mowing height. This allows for more leaf area to intercept as much available light as possible. In addition, leaf blades are longer and narrower in the shade, and a lower cutting height excessively reduces leaf length, which is not good for the grass. Increased mowing height also promotes deeper rooting, which is one of the key mechanisms of stress tolerance for turf grasses.
- Reduce fertilizer applications. Grass grows more slowly in a shaded environment, reducing its fertility needs. Too much nitrogen fertilizer depletes carbohydrates and produces a weaker turf system. If a normal yearly application is 3 lbs N per 1,000 ft^2, apply only 1.5 to 2 lbs to turf growing in the shade. Limit any single fertility application to no more than 0.5 lb N per 1,000 ft^2 at any one time.
- Adjust irrigation accordingly. If the irrigation system covers an area that is partially shaded and partially in sun, consider removing the sprinkler heads from the shaded areas and irrigate by hand when rainfall is inadequate. Not only does over-irrigation waste water and potentially leach pollutants, but the slower evapotranspiration (ET) rate in shaded areas can lead to fungal or other disease and pest problems.
- Reduce traffic. Shaded turf is more easily injured by traffic and may not be able to recover adequately. Also, traffic in shady areas may damage a tree’s roots, causing the tree to decline or die.
- Increase air circulation. Very few fungi can infect dry leaves. Where a green is boxed or pocketed by trees or other obstructions to the point where air circulation is inhibited, surface moisture builds up. This may lead to increased fungal disease, algae, or other problems. Both the root zone and the leaf tissues are susceptible to excessive moisture problems. To address this on an existing course, fans are often used to dry out the soil and increase ET by providing a 3 to 4 mile-per-hour breeze at the surface.

IRRIGATION

Although golf courses use natural rainfall as the greater part of their annual water budget, irrigation with the lowest acceptable quality water is an important part of maintenance. To ensure efficient watering, courses require well-designed irrigation systems with precision scheduling based on soil infiltration rates, soil water-holding capacity, plant water use requirements, the depth of the root zone, and the desired level of turfgrass appearance and performance. The Minnesota Department of Natural Resources provides water use permits (WUPs) allowing golf courses to pump enough water to meet their annual needs from reclaimed sources, surface water, or aquifers.

Soils contain a reservoir of water for plants. Water enters the plant through its roots, and then moves through the stem up to the leaves and then into the atmosphere through the leaf by a process termed *transpiration*. Transpiration serves several important functions. Water and nutrients are transported through the transpiration stream. The evaporation of water from the leaf surface results in evaporative cooling, thus moderating canopy temperature. This is important for maintaining plant cell metabolism. Humans have a similar process when perspiration evaporates and cools our bodies.

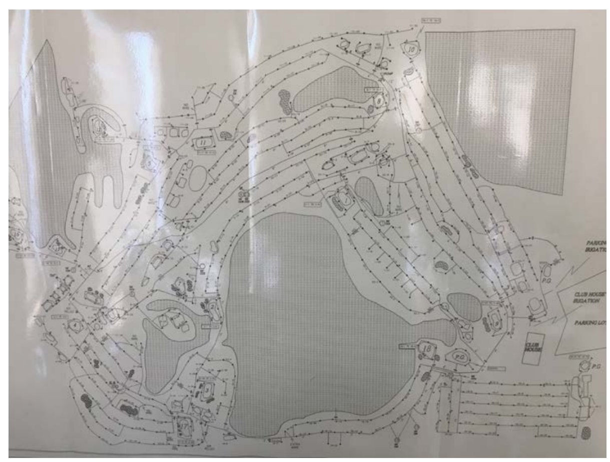
Evaporation is the flow, or loss, of water from the soil directly to the atmosphere. Collectively, evapotranspiration (ET) is the total water recycled back into the atmosphere by transpiration and evaporation. ET is largely controlled by solar radiation, humidity, wind velocity and temperature, and soil moisture content. Root system depth and cultural practices significantly affect the rate of ET.

WATER SOURCES Developers of new golf courses should understand the reliability of water sources before construction to ensure that sufficient supplies are available for turf grow-in and survival. Course owners and developers should consider all alternative sources that are available. These include, and are not limited to, wells, existing surface water, stormwater runoff detention ponds, and reclaimed water. The water management districts require that the lowest quality water appropriate to a use be considered first for water use permits.

RECLAIMED WATER The use of reclaimed water from large wastewater treatment plants for golf course irrigation is not common in Minnesota due to the seasonality of the irrigation cycle and necessity to blow out the infrastructure to prepare for winter.

SYSTEM DESIGN Irrigation system design is a complex issue and should be handled by trained professionals. These professionals should use existing standards and criteria, as well as manufacturers' recommendations, to design the most appropriate system for a location.

The irrigation design for a site depends on a number of factors, including location, soils, landscape vegetation, water supply, and water quality. An irrigation system needs to be designed to meet a site's peak water requirements. However, it should also be flexible enough to adapt to various water demands and local restrictions.



Operating pressure must be designed not to exceed the source pressure. Design operating pressure should account for low pressure during periods of high use (i.e., mornings) and for project build out when all of a development's landscape is in place. Irrigation systems designed to service both turf and landscape areas should have enough zones to meet each area's individual water needs. Emitter precipitation rates throughout the system must be selected so that the ability of the soil to absorb and retain the water applied is not exceeded during any one application.

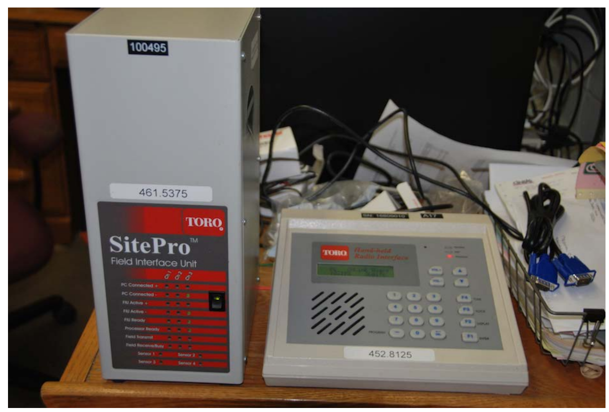
An irrigation system consists of four main components, as follows:

1. Water supply: this consists of a water source, pump, filters, and valves (including backflow valves).
2. Water conveyance: this is made up of a mainline, manifold, lateral lines, and spaghetti tubes and isolation valves.
3. Distribution devices: these include impact, oscillating, and rotary sprinklers. Smaller heads (sprays and small rotors) can be used for special areas such as tee tops and bunker faces to deliver extra water efficiently when it is needed.
4. A control system.

The design must account for different site characteristics and topographies. The proper design and installation of the components listed above optimizes their use and decreases any off-site impacts. To meet peak water use demands and have enough flexibility to reduce supply for different demand requirements, irrigation systems need to be designed with various control devices, including rain shutoff devices and/or soil moisture devices, and with backflow prevention to protect the water source from contamination.

Water conveyance systems should be designed with thrust blocks and air-release valves to prevent system damage. Water conveyance pipelines should provide the appropriate pressure required for maximum irrigation uniformity, and distribution devices should be designed for optimum uniform coverage. Reclaimed water systems typically are color-coded purple. Isolation valves should be installed between holes, so that a leak can be repaired while the rest of the course is still being irrigated. It may seem obvious, but a distribution system should not be designed to irrigate non-planted areas (such as driveways, cart paths, parking lots, roads, sidewalks, roof over-hangs, and natural buffer zones). An irrigation system should also be designed differently for play and non-play areas.

IRRIGATION FOR PLAY AREAS Irrigation for play areas should contain the following elements:



- Computerized control systems should be installed on all new course irrigation systems to help ensure efficient irrigation application. These allow for timing adjustments at every head. By adjusting the watering times based on actual site conditions for each head and zone, water can be conserved and used most efficiently. Appropriate cutoff devices should be installed so that line breaks do not cause a pump to run excessively, or improper valve alignment does not cause a pump to overheat.
- Weather stations help superintendents adjust irrigation run times based on current local meteorological data that are recorded and downloaded to the irrigation computer. Some stations automatically compute the daily ET rate and adjust preselected run times to meet the turf's moisture needs. Weather stations, however, do not replace the human factor. Recorded ET rates can be manually adjusted to reflect wet and dry areas on the course to ensure the maximum watering efficiency. Install rain switches, as required by Minnesota law, to shut down the system if enough rain falls in a zone. Soil moisture sensors will circumvent schedules if soil moisture is already adequate.
- Pump stations should be sized to provide adequate flow and pressure. They should be equipped with control systems that protect distribution piping, provide for emergency shutdown due to line breaks, and allow maximum system scheduling flexibility.
- Variable frequency drive pumping systems should be considered if dramatically variable flow rates are required, if electrical transients (such spikes and surges) are infrequent, and if the superintendent has access to qualified technical support.
- Heads and nozzles should be selected to maximize the uniformity of coverage. The proper spacing of heads during course design and construction is critical. Equipment should be designed and installed following manufacturers' and professional designer specifications. Improper overlap leads to dry spots that require extra watering, so that other areas are overwatered.
- Tee tops may be designed so that the only maintained turf is on the tee top and slopes. Plantings of native grasses around teeing grounds, where applicable, provide an effective alternative ground cover. Such tees should have fully adjustable or part circle heads installed to apply water only where needed. If new plant material needs irrigation to become established on the slope areas, the heads can be adjusted to provide the necessary water and then returned to tee top only coverage. The same principle can be applied to narrow fairways, bunker complexes, and the banks of lakes, ponds, and other water bodies.
- The irrigation of greens and green surrounds should be designed to provide inward and outward sprinkler coverage for maximum

efficiency and turf maintenance. With single head coverage around the greens, the slopes are often watered unnecessarily, which wastes water.

- Additionally, operational control of each head around the green is preferred over systems that provide total green or zone irrigation control. Individual head control increases irrigation flexibility by allowing for wind correction, watering localized dry spots, and meeting other special local needs.
- Separate irrigation zones should be provided for slopes and areas surrounding greens. Irrigation heads need to be strategically placed to minimize the amount of water applied to surrounding bunkers. The soils used for these areas may be heavier and poorly drained, compared with the modified soils in putting greens. Surrounds may hold water better and may not need to be irrigated as frequently as a well-drained green.

Watering bunkers can result in sand erosion, wet shots for the players, and algae and weed encroachment, and wastes valuable water resources. Bunker slopes, however, do need to be irrigated. Some extensive sand areas, although designed as non-irrigated spaces, may have automatic sprinklers installed to wet the sand. These are used only during extreme wind conditions to prevent sand blowout.

To ensure optimum uniformity, permanent irrigation sprinklers and other distribution devices should be spaced according to the manufacturer's recommendations. Typically, this spacing is based on average wind conditions during irrigation. After the system is constructed and operating, periodic "catch can" uniformity tests should be performed.

IRRIGATION FOR NONFLAT AND LANDSCAPE PLANTINGS Non-play areas include aesthetic turf around clubhouses, landscaped garden areas, and out-of-bounds or border areas. When mature, many of these areas, if planted with the Right Plant, Right Place motto in mind, may require little supplemental irrigation. In these cases, temporary systems may be installed while the plants are becoming established and then removed when the plants are mature. In general, non-play areas should be irrigated like any high-quality landscape using Minnesota-hardy landscaping principles.

SYSTEM OPERATION Plants don't waste water, people do. Using proper irrigation system design, installation, water management, and maintenance practices provides a multitude of benefits. An efficient irrigation system translates into cost savings and protection of our water resources.

Irrigation management is the cornerstone of water conservation and reduced nutrient and pesticide movement. Consistent management includes both scheduling the amount of water applied and when, and also maintaining system components, both to prevent and correct problems. Irrigation scheduling must take plant water requirements and soil intake capacity into account to prevent excess water use that could lead to leaching and runoff. Plant water needs are determined by evapotranspiration rates, recent rainfall, recent temperature extremes, and soil moisture. Whenever possible, cultural practices should be used to minimize plant stress and the amount of water needed. For example, superintendents can use mowing, verticutting, nutrition, and other cultural practices to control water loss and to encourage conservation. The discussion on cultural practices provides more information on how turfgrass cultural practices influence water use rates and efficiency.

IRRIGATION SCHEDULING Before a superintendent can properly develop an irrigation schedule, the system must be audited, or calibrated, so that the rate at which water is applied in each zone is known (see the section on System Maintenance in this chapter). Once the water delivery rate is known, determining when and how much to water is the next important step. Irrigation should not occur on a calendar-based schedule but should be based on ET rates and soil moisture replacement. Rain gauges are necessary measurement tools to track how much rain has fallen throughout the golf course. The use of soil moisture probes, inspections for visual symptoms such as wilting turf, computer models, and tensiometers may supplement these measurements. Computerized displays are available to help visualize the system.

Water loss rates decrease with reduced solar radiation, minimal wind, high relative humidity, and low air temperatures. A superintendent can take advantage of these factors by irrigating when conditions do not favor excessive evaporation. Irrigation should occur in the early morning hours before air temperatures rise and relative humidity drops. Irrigating at this time also removes dew from leaf blades and allows sufficient time for infiltration into the soil but does not encourage disease development.

Determining how much water to apply is the next step in water management. Enough water should be applied to wet the entire root zone. Wetting below the root zone is generally inefficient, as this is beyond a plant's range of access. Irrigating too shallowly encourages shallow rooting, increases soil compaction, and favors pest outbreaks. For golf greens and tees, the majority of roots are in the top four inches of soil. Irrigate to wet this depth unless the root zone extends deeper. For fairways and roughs, the top six inches of soil should become wet to supply sufficient water for plants and to encourage deep rooting. Soil moisture can be estimated by using a soil probe to feel the depth of the moisture and show the depth of the root zone.

Visual Symptoms The presence of visual symptoms of moisture stress is a simple method used to determine when irrigation is needed. Moisture stressed grass appears blue green or grayish green in color, recuperates slowly (longer than one minute) after one walks or drives across it, or wilts continuously. These symptoms occur when plant moisture is insufficient to maintain turgor. As a result, the plant rolls its leaves and wilts to conserve moisture. Certain areas or patches of turfgrass tend to wilt before others due to poor irrigation distribution, or to poorly-developed or damaged root systems.

Waiting until visual symptoms appear before irrigating is a method best used for low maintenance areas, such as golf course roughs and possibly fairways. Managers of golf greens cannot afford to wait until these symptoms occur, because unacceptable turf quality may result.

PREDICTIVE MODELS Predictive models based on weather station data and soil types are also available. These are relatively accurate and applicable, especially as long-term predictors of yearly turf water requirements. Weather data such as rainfall, air and soil temperatures, relative humidity, and wind speed are incorporated into certain model formulae, and soil moisture content is estimated. Models, however, are only as effective as the amount of data collected and the number of assumptions made. These models and programs should always be calibrated for local conditions, as they often use incorrect coefficients for Minnesota's climate and plant species. Accessible weather data must be available, as well as specialized computer equipment and programs. Computer programs allow for individual station settings to decrease or increase watering times for wet and dry areas. They also have "cycle and soak" features, so that water can be applied over several cycles and not puddle or run off.

Tensiometers Tensiometers and other soil moisture sensors are used to measure soil water status. Tensiometers are tubes filled with water with a porous ceramic cup at the base and a vacuum gauge at the top. As soil moisture is depleted, tension forms between the water in the soil and the water in the tube. This tension is registered by the vacuum gauge and provides a relatively accurate reading of soil moisture availability, registered in centibars. Soil field capacity (water "held" after drainage) is generally between 5 to 30 centibars, with higher values indicating decreasing soil moisture levels. Tensiometers remain accurate when tensions are less than 80 centibars. Commercial tensiometers models are available that can automatically regulate irrigation systems based on a pre-set tension threshold. A drawback of tensiometers is that the reading is only accurate in the area adjacent to the placement of the ceramic tips. Tensiometers may affect play. Placing tensiometers in golf greens is not recommended, since this interferes with management practices such as aerification.

Irrigation Control with Feedback Irrigation control with feedback simply means that the control system receives feedback from a sensor or sensors. These may consist of soil moisture sensors or meteorological sensors that are used to calculate the ET demands of the plants under irrigation. Irrigation with soil moisture sensors can consist of a sensor that has a user-adjustable threshold where the scheduled timer-based irrigation event is bypassed if the soil moisture content exceeds the threshold. This type of control is *bypass* control. The soil moisture sensor(s) should be installed in the root zone for each irrigation zone. If the sensor system only contains one soil moisture probe, then that probe should be installed in the driest irrigation zone of an irrigation system and all other irrigation zones should have their run times reduced to minimize overwatering.

Frequent irrigation events can be programmed into the irrigation timer and the sensor will allow irrigation as conditions in the root zone dictate in response to rainfall and ET. The second type of soil moisture control is *on demand* control where the soil moisture-based irrigation control system consists of a stand-alone controller and multiple soil moisture sensors. High and low limits are set so that irrigation only occurs within those limits. Currently, the bypass control devices are marketed for residential irrigation and on demand devices are marketed for agricultural or large commercial systems. However, both strategies could be adapted to golf course irrigation systems. Many types of soil moisture sensors have become commercially available. Historically, tensiometers have been recommended, but these devices require more maintenance than is acceptable for golf course irrigation.

Newer sensors are capacitance- or dielectrics-based devices and rely on the ability of the soil to conduct electricity and the fact that this property is strongly correlated to soil moisture content. It is important to place these sensors in a representative location within the irrigated root zone. Since the sensors require wires for communication and power, the wires must be buried below aerification depths and the locations of the sensors must be marked to prevent damage. Excessive salt content in some irrigation water can also interfere with the accurate operation of some types of sensors. Other than these issues, the devices are relatively maintenance free compared with tensiometers.

ET-Based Systems ET-based control systems have been available for many years. The oldest type, consisting of a full weather station that interfaces with a controller for a large irrigated area, is fairly common in golf course irrigation systems. However, a full weather station costs several thousand dollars and requires frequent maintenance for accurate measurements. ET is calculated based on the meteorological parameters measured by the weather station, and then the controller calculates a running soil water balance. Irrigation is scheduled automatically based on the application rate of the sprinklers in a particular irrigation zone and the calculated removal of water from the root zone.

The instruments on ET control systems should be periodically checked and their accuracy verified at least annually. In addition, an accepted method for the calculation of ET should be used along with the best available crop coefficients. One of the most widely accepted methods of ET calculation is the Penman Montieth method. A standardized form of this equation has been proposed by the ASCE EWRI Evapotranspiration in Irrigation and Hydrology Committee, (ASCE, 2005). For the most accurate calculation of irrigation water requirements, rainfall should be measured onsite. In the future, technology such as OneRain Corporation's high resolution, gage adjusted Doppler radar rainfall data may be used to provide spatially distributed irrigation scheduling.

OPERATING OLDER SYSTEMS Not all golf courses are so fortunate as to have a computerized irrigation system, variable frequency drive (VFD) pump station, or weather station. Many existing courses have pump stations that maintain pressure through the use of hydraulic pressure sustaining valves, which operate to maintain a constant downstream pressure in the piping system.

Golf courses with hydraulic pressure sustaining valves are much more prone to irrigation pipe and fitting breaks due to surges in the system, creating more downtime for older systems. A good preventive maintenance program for this type of station is very important to keep it operating efficiently. Maintaining the air relief and vacuum breaker valves is particularly important. The installation of a VFD system can lengthen the life of older pipes and fittings until the golf course can afford a new irrigation system.

Time clock–controlled irrigation systems preceded computer-controlled systems, and many are still in use today. Electric/mechanical time clocks cannot automatically adjust for changing ET rates, and therefore staff have to adjust them frequently to compensate for the needs of individual turfgrass areas. The reliability of station timing depends on the calibration of the timing devices; this should be done periodically but at least seasonally.

It is important to keep in mind that, while new technology makes many tasks easier or less labor intensive, it is the principles discussed in this BMP manual that are important. These principles may be applied to any course at almost any level of technology. All of us can improve something by examining our operations from a different perspective, and the principles outlined here can help you to look at your operation from an environmental perspective.

SYSTEM MAINTENANCE Irrigation system maintenance on a golf course involves four major efforts: calibration or auditing, preventive maintenance, corrective maintenance, and recordkeeping. The recordkeeping is an essential part of the other three, but is often overlooked. This manual also touches on system renovation.

CALIBRATING AN IRRIGATION SYSTEM There are three levels of irrigation audits or evaluations: a visual inspection, a pressure/flow check, and a catch can test. The level chosen depends on how much detailed information is required. Properly-trained technicians should perform irrigation audits.

First, if an irrigation system is in disrepair or coverage is obviously poor, then time is wasted doing a detailed catch can test. A visual inspection should first be conducted to identify any necessary repairs or corrective actions, and it is essential to make any repairs before carrying out other levels of evaluation. A visual inspection should be part of ongoing maintenance procedures. Pressure and flow should be evaluated to determine that the correct nozzles are being used and that the heads are performing according to the manufacturer’s specifications. Pressure and flow rates should be checked at each head. The data can be used to determine the average application rate in an area, which is a fundamental parameter for irrigation scheduling.

Catch can tests should be run to determine the uniformity of coverage. Catch can testing provides the most detailed information on coverage and thus allows a system operator to accurately determine irrigation run times. The information gathered from this test also identifies areas where coverage is poor and a redesign option should be considered.

Catch can testing should be conducted on the entire golf course to ensure that the system is operating at its highest efficiency. However, due to time and budget constraints, this can be accomplished over an extended period. Annual testing results in a high quality maintenance and scheduling program for the irrigation system.

PREVENTATIVE MAINTENANCE Personnel charged with maintaining any golf course irrigation system face numerous challenges. This is particularly true for courses with older or outdated equipment. Good system management starts with good preventive maintenance (PM) procedures and recordkeeping. Maintaining a system is more than just fixing heads. It also includes documenting system and maintenance-related details so that potential problems can be addressed before expensive repairs are needed. It also provides a basis for evaluating renovation or replacement options.

CORRECTIVE MAINTENANCE Corrective maintenance is simply the act of fixing what is broken. It may be as simple as cleaning a clogged orifice, or as complex as a complete renovation of the irrigation system. For the smaller day-to-day failures, BMPs simply call for timely action, maintaining the integrity of the system as designed, and good recordkeeping.

SYSTEM RENOVATION As maintenance costs increase, the question of whether to renovate arises. Renovating a golf course can improve system efficiencies, conserve water, improve playability, and lower operating costs. System renovation starts with evaluating the current system's maintenance requirements and operating costs. Focusing on longer-term objectives may demonstrate that it is cost effective to install a new system to reduce the accumulating and seemingly perpetual maintenance chores that older systems often require.

The process of identifying renovation needs starts with collecting as much information as possible about the system, including the following:

- Gather together all of the documentation collected as part of the PM program, along with corrective maintenance records. Correctly identifying problems and their costs helps to determine what renovations are appropriate.
- Determine the age of the system. Irrigation systems, like any asset, do not last forever. Checking the dates on any as-built and discussing the history of the course with other golf course personnel gives you a starting point.
- Determine the age of the pump station, which is one of the single costliest items in a system. While a system's age in years provides some information, the number of operating hours is often a better indicator of life expectancy.

Understand the operations and options of the current control system. If the system has not been renovated, it probably doesn't have a state-of-the-art control system.

To maximize the efficient use of the current system, three things should occur. First, you should recognize some improvement in system performance. Second, you should begin to develop a list of things that the current system doesn't accomplish, but that you would like a new system to do. Third, you should begin to gather the site information necessary for any renovation.

Identifying ways to improve system performance is only part of the information gathering stage. Collecting information on the cost of maintaining the system is also important. This information should include the cost of pipe repairs, sprinkler repairs, control system repairs, and power consumption. Be sure to include labor costs and the costs of lost revenue, when appropriate. After gathering as much information as possible, you will need to identify items that are beneficial to upgrade, including the following:

- Updating control systems
- Improving greens coverage
- Improving tees coverage
- Improving coverage on fairways and roughs
- Repairing/replacing elements of the system infrastructure
- Repairing/replacing the pump station
- All of the above

As you begin to identify areas or reasons for upgrading, you will need to find appropriate professionals (such as architects and consultants) to assist in renovation planning. These professionals are necessary not only to assist in prioritizing goals, but also to develop plans, specifications, phasing recommendations, and project budgets. They can also help identify how much of the course needs to be closed and for how long, which is a crucial consideration.

After a project has started, the involvement of current staff is essential. Understanding how a system was installed provides important information for developing an effective maintenance program. The fact that renovations have been completed does not indicate that the process of gathering information has ended. Continually documenting system performance is essential to maximize the effectiveness of the renovation.

Nutrition and Fertilization

OVERVIEW

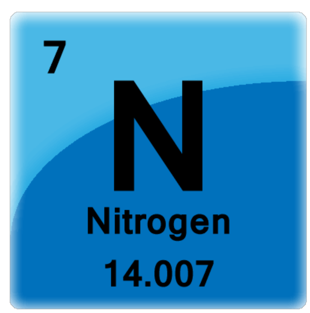
Proper fertilization is essential for turfgrasses to sustain desirable color, growth density, and vigor; to better resist diseases, weeds, and insects; and to provide satisfactory golf course playability. Depending on the species, plants need approximately 16 elements, which are divided into two categories: macronutrients and micronutrients. Macronutrients are further subdivided into primary nutrients (nitrogen, phosphorus, and potassium) and secondary nutrients (calcium, magnesium, and sulfur).

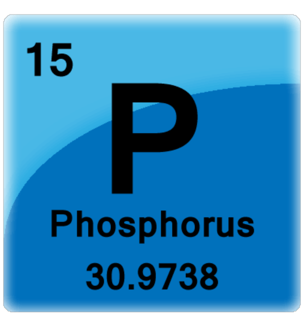
Macronutrients

Primary Nutrients – The primary nutrients – nitrogen, phosphorus, and potassium (N, P, and K, respectively) – receive the greatest attention because they are typically deficient in soils and must be applied regularly. These plant foods are required in the largest amounts. If not handled properly, however, nutrients can be a significant source of water pollution. Excessive nutrients can lead to algal blooms and stimulate the growth of noxious plants in lakes and streams. This can reduce the amount of oxygen available for game fish such as bass and sunfish, while promoting less desirable fish.

Nitrate is a special health concern, because excessive levels in drinking water can cause serious health problems in infants. Minnesota law requires all potentially potable ground water to meet drinking water standards. Under both federal and state regulations, this standard is 10 ppm for nitrate-nitrogen.

Nitrogen influences turfgrass color, shoot and root growth, and water use. Enough N should be applied to turf to meet its nutritional needs for maintaining growth, recuperative ability, color, and quality. Nitrogen generally increases shoot growth, shoot density, and leaf width; the latter increases the leaf area exposed to the atmosphere. Excessive N application may negatively influence root growth and result in N leaching. When turfgrass is fertilized excessively with N, top growth is promoted over root growth, which may result in less drought-tolerant turfgrass in the long term. If N is applied at the recommended and required rates for optimum turfgrass growth, a strong root system can develop.



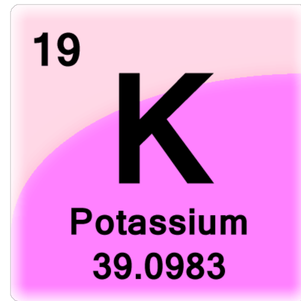


Phosphorus (P), an essential element for plant growth, is involved in the transfer of energy during metabolic processes. Unfortunately, it is often the limiting nutrient in many natural systems, including Minnesota's streams, lakes and wetlands. As such, many areas of the state are very sensitive to excess phosphorous. Phosphorus restrictions have been mandated in Minnesota.

First introduced as legislation by the Minnesota Department of Agriculture in 1999, the Minnesota Phosphorus Lawn Fertilizer Law was enacted in 2002 and amended in 2004. The law regulates the use of phosphorus fertilizer on lawns and turf with the intent of reducing unnecessary phosphorus fertilizer use and preventing enrichment of rivers, lakes, and wetlands with the nutrient phosphorus. The law prohibits use of phosphorus lawn fertilizer unless new turf is being established or a soil or tissue test shows need for phosphorus fertilization. Trained golf course staff and sod farms are exempt from these restrictions. The law also requires fertilizer of any type to be cleaned up immediately if spread or spilled on a paved surface, such as a street or driveway.

Many Minnesota soils have adequate, or even excessive, amounts of P. Always perform a soil test before adding P to the soil.

The effects of potassium (K) levels on water use are generally the opposite of those for nitrogen. Potassium nutrition increases leaf turgor, thus delaying wilting. Excessive N levels, however, can negate the positive effect of K. Optimum K fertilization has also been correlated with disease and pest resistance. Potassium is very important to root growth and a plant's overall health.

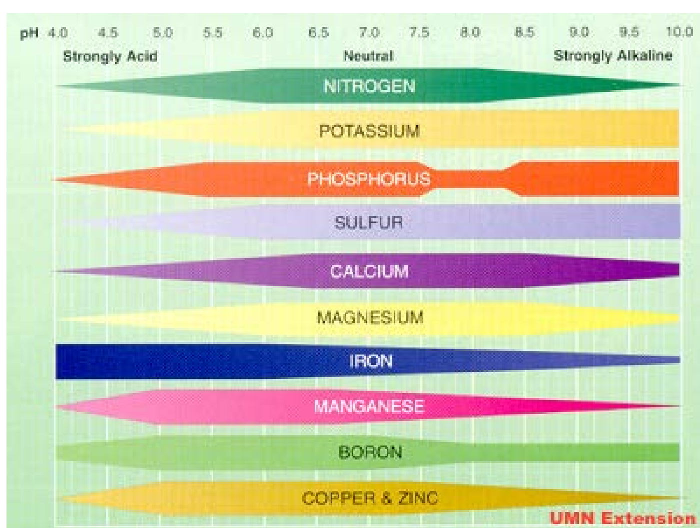


With a healthy root system, turfgrass assimilates more fertilizer, and leaching is reduced. Increased root depth increases the water available to a plant and may reduce irrigation needs.

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

Micronutrients

Micronutrients are essential elements required in small amounts by plants. Due to the high sand content of many golf greens and extremes in soil pH, micronutrient management is very important for Minnesota superintendents. For example, Iron (Fe) and manganese (Mn) can provide desirable turfgrass color without the excessive growth that may be produced by N. A number of turfgrass specialty fertilizers contain some, or all, of these micronutrients. The user should check the label before making an application.



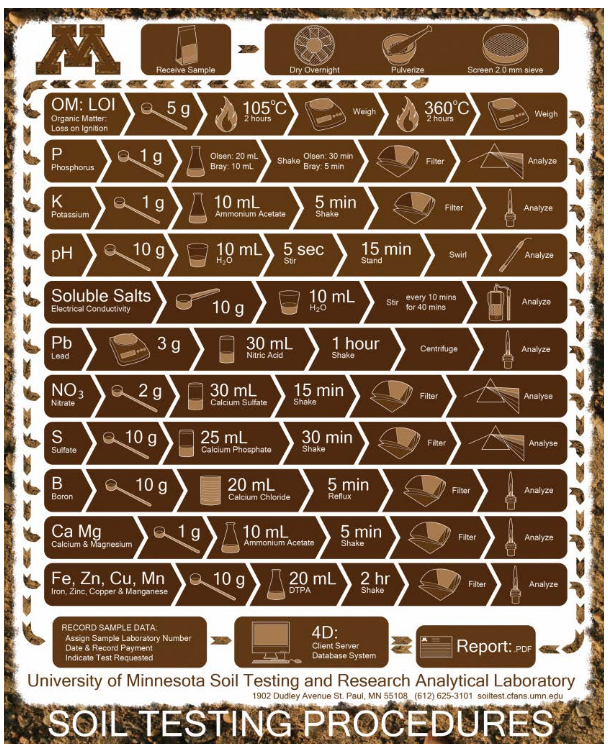
There are numerous fertilizer sources for many different needs. Vendors, independent soil consultants, or extension agents can provide education on particular formulations.

When fertilizing putting greens or other areas with a high sand content that are subject to rapid percolation and nutrient leaching, it is important to know that **at no time should more than 1/2 lb. of water-soluble nitrogen be distributed per 1,000 ft^2 in a single application.** This minimizes the chance of N leaching. Additional N may be applied in a controlled-release form in the same application. Where soils contain more clay and do not drain as rapidly, higher rates of N may be applied (up to 1 lb. of soluble N per 1,000 ft^2) when application equipment limitations on fairways and roughs cause inconsistent coverage at lower rates.

Many superintendents managing bentgrass fairways, tees, and greens have moved to a liquid fertilizer programs. This helps to ensure that nutrients are being “spoon-fed” and minimizes the chance of nutrient loss. Liquid fertilizer pumped through an irrigation system, or *fertigation*, is another, although less common way, to spoon-feed turfgrass. Fertigation reduces potential nutrient loss compared to dry fertilizers, because only small amounts of a nutrient are applied at one time. This allows the roots to quickly take up most of the nutrients, leaving little available to be leached.

SITE ANALYSIS

An overall site management plan should be established. It should be in a written format and shared with all parties associated with the management of a site. This is important so that all will understand what will happen to materials as they are applied.



Before an accurate nutrition program can be established for a golf course, a site assessment is useful. Whether a facility has yet to be built or is an established site, it is important to research soil types, water sources, drainage plans, and other special concerns on the property. Knowing soil types can be critical in selecting specific products, because some products leach quickly through certain soils. If water is high in sodium or bicarbonates, for example, it affects a plant’s ability to assimilate nutrients.

A complete water quality analysis should also be done on all waterbodies. This can be expensive, but it establishes a baseline for the site. Yearly testing and analysis help identify issues that might occur. Drainage plans should be reviewed for outfall locations. If a property has wetlands, streams, or other areas of concern, each needs to be addressed in the management plan.

If a new golf course is being built, you should identify ways to reduce potential nutrient losses. Building the greens to USGA recommendations, for example, enables you to become creative with the way in which water is discharged from the system. When designing drainage for bunkers, fairways, or roughs, you should incorporate a natural filtering system by letting the water filter through aquatic plants or through a grassed swale before it enters a waterbody or a retention area.

Soil samples help identify soil types and the elements needed for various turf types. Once the turfgrasses are established, soils should be sampled yearly. Nutrient choices and quantities are based on these results and the results of tissue samples.

FERTILIZER

Fertilizer means any substance that contains one or more recognized plant nutrients and promotes plant growth. Fertilizer *grade* or *analysis* is the percent by weight of nitrogen, phosphorus, and potassium guaranteed by the manufacturer to be in the fertilizer. Nitrogen is expressed as N, available phosphate as P_2O_5, and soluble potash as K_2O. The percent sign is not used, but instead the numbers are separated by dashes, and the order is always N, P_2O_5, and K_2O (for example, 15-0-15).

FERTILIZER ANALYSIS

The Minnesota fertilizer label is detailed and intended to be highly informative. By law, the product label is required to provide the following basic information: the brand and grade, manufacturer’s name and address, guaranteed analysis, sources from which the guaranteed primary and secondary nutrients are derived, and net weight.

In addition to the fertilizer grade, the label also identifies the breakdown of total N as nitrate-N, ammoniacal-N, water soluble or urea-N, and water insoluble N. This N breakdown supplies information on the immediate availability and/or leachability of the N in the bag. The Association of American Plant Food Control Officials (AAPFCO) defines *slow* or *controlled release* fertilizer as a fertilizer containing a plant nutrient in a form that delays its availability for plant uptake and use after application, or that extends its availability to the plant significantly longer than a reference “rapidly available nutrient fertilizer” such as ammonium nitrate or urea, ammonium phosphate, or potassium chloride.

This delay of initial availability or extended time of continued availability may occur through a variety of mechanisms. These include the controlled water solubility of the material (by semipermeable coatings; occlusion; or the inherent water insolubility of polymers, organics, protein materials or other chemical forms, or the slow hydrolysis of water-soluble, low molecular weight compounds.

In most cases, the higher the water insoluble N percentage in the mix, the longer lasting the fertilizer. This is where most of the N from natural organic and slow release sources appears. A fertilizer that contains all of its N as nitrate-N, ammoniacal-N, and/or water-soluble N is referred to as a soluble N fertilizer, which may provide a high potential for leaching. It should not be applied at rates greater than 1/2 lb. N/1,000 ft^2 per application on soils of high sand content that are subject to rapid water percolation.

A fertilizer label also contains a *derived from* section that identifies the materials from which the fertilizer was formulated.

Secondary nutrients and micronutrients, identified in the lower portion of the label, are expressed in their elemental form. Sulfur (S) is expressed as *combined* (usually expressed as SO_4) and as *free* (elemental S form). The reason for this distinction is that free S is very acidifying when placed in the soil. Magnesium (Mg), iron (Fe), copper (Cu), manganese (Mn), and zinc (Zn) must be expressed as total and/or soluble or water soluble, depending on the source materials formulated in the fertilizer. Chelated elements are guaranteed separately when a chelating agent is denoted in the derivation statement below the guaranteed analysis.

NITROGEN

Nitrogen is the most important element for turfgrass maintenance due to its influence on color, growth rate, density, and stress tolerance. The total dry matter of turfgrasses consists of 1 to 5% N. It is applied in the greatest quantity and is required in larger quantities than any other element except carbon, hydrogen, and oxygen. Excessive N, however, increases shoot growth and the incidence of certain diseases, and lowers turf 's stress tolerance of heat, cold, drought, and traffic. Most important, root and lateral shoot growth may also be reduced. Root growth suppression reduces turf tolerance of heat and drought. Additionally, excessive N fertilization may adversely affect the environment by contaminating ground water.

Origins and Losses

Turfgrasses may obtain N from the decomposition of organic matter and, to a small degree, from air as N that has been oxidized by lightning and dispersed by rainfall. In soil, the ammonium (NH_4) and nitrite (NO_2) forms are the most important compounds; they originate either from the aerobic decomposition of organic matter or from the addition of commercial fertilizers. The ammonium and nitrate forms of N are the only ones used by turf plants. No matter what the N source applied (e.g., manure, crop residues, organic matter, or commercial fertilizer), it must be changed to one of these two forms for plant use.

<u>Mineralization</u> – Mineralization is the process through which soil microorganisms break down or transform organic matter, organic fertilizers, and some slow-release fertilizers to provide available ammonium and nitrate forms for plants. Mineralization is a three-step process involving aminization, ammonification, and nitrification. In aminization and ammonification, proteins, amines, and amino acids from organic matter or humus are converted to ammonium, a source of N used by plants.

<u>Nitrification</u> – The transformation of ammonium nitrogen to nitrate nitrogen is referred to as nitrification. Nitrification depends on environmental conditions that favor soil microbiological activity. Warm temperatures, adequate soil moisture, and soil oxygen are necessary for this activity. However, nitrification does not readily occur under extreme temperatures (e.g., below 40° F or above 105° F), in saturated or poorly-aerated soil, in excessively dry soil, or in low-pH soil (< 4.8). Under these unfavorable conditions, microorganisms do not perform nitrification, and ammonium may accumulate. Ammonium nitrogen also may become toxic to turfgrasses grown under cool, low-light conditions, such as those in late winter or early spring.

Nitrate nitrogen is readily soluble in water and may be repelled by negatively-charged exchange sites of the soil components. Therefore, unless grasses rapidly use this form, it may be lost through leaching if excessive water is applied. In addition to nitrate and water, hydrogen ions (H+) also are produced during nitrification, and a reduction in soil pH may be observed. This reduction is especially acute when a high rate of N is applied on sandy soils that are low in calcium. Such soils are poorly buffered against pH changes induced through the acidifying effect of nitrification.

Denitrification and Volatilization – Besides leaching and crop removal, additional avenues of N loss are denitrification and volatilization. Denitrification is the conversion of nitrate nitrogen under anaerobic conditions to gaseous nitrogen. Low soil oxygen levels and/or high soil moisture, alkaline (high-pH) soils, and high temperatures favor denitrification. In soils that are compacted or waterlogged and have a high pH (> 7.5), denitrification can result in losses of up to 70% of the applied nitrogen.

Volatilization is the conversion of ammonium nitrogen (NH_4) to ammonia gas (NH_3). If ammonium nitrogen comes in direct contact with free calcium carbonate in the soil, ammonium bicarbonate is formed. Upon exposure to the sun, this relatively unstable compound decomposes into ammonia, carbon dioxide, and water.

The volatilization of ammonia nitrogen can usually be avoided by incorporating the ammonium nitrogen fertilizer into the soil. In addition, the surface application of an ammonium nitrogen fertilizer to a sandy soil free of lime or calcium carbonate, does not result in the volatile loss of ammonia nitrogen. Furthermore, irrigating with approximately 0.25 to 0.5 inch of water after fertilizer application minimizes this potential N loss.

Nitrogen Effects on Turfgrasses

Nitrogen is one of the most important elements turf managers apply to turfgrasses. In addition to affecting turf color and growth rate, N influences thatch accumulation, the incidence of diseases and insects, cold tolerance, heat and drought stress, nematode tolerance, lime requirements, and, most important to the player, putting speed. Turf managers often measure N needs based on turf color, density, and/or clipping amount. However, it is the effect of N on other aspects of turf management that often influences a superintendent's success or failure.

Improper N fertilization can have an undesirable effect on turfgrass rooting. Turfgrass, in general, uses carbohydrates stored in its roots to support shoot growth. These are replenished by products resulting from photosynthesis. If heavy amounts of N are used, excessive shoot growth occurs at the expense of roots. As a result, roots may not have enough recovery time to replenish their carbohydrates before being forced to support excessive shoot growth when N is reapplied.

In addition to forcing excessive shoot growth at the expense of root growth, improper N fertilization can also cause physiological changes such as cell-wall thinning, succulent tissue growth, and reduced root carbohydrate levels. Accordingly, increased susceptibility to stress makes the plant less hardy. When plants are deficient in N, the initial leaf color is an overall pale yellow-green color, called *chlorosis*.

Chlorosis reflects a reduction in chlorophyll production. Nitrogen is a part of chlorophyll and is thus essential in its manufacture. Chlorosis usually appears first on the lower (older) leaves, eventually changing to yellow as the deficiency symptoms progress to the base of the plant. In addition, the plant's growth rate and density may decrease, resulting in weak turf that has difficulty recovering from stresses.

Other factors that also contribute to, or may cause, symptoms similar to those of N deficiency are a deficiency in nutrients such as iron, sulfur, or manganese. Sandy soils, many of which are alkaline, often are lacking these elements. To the untrained observer, the symptoms appear similar to a lack of N. Compounding the problem are soils with poor water holding capacity; these can result in reduced rooting and increased water stress. Therefore, turf managers should determine the cause of chlorosis and turf thinning before indiscriminately applying an N or micronutrient fertilizer.

In general, N has a direct impact on turf growth and recovery from injuries such as divots or ball marks. However, the clipping matter produced can be a poor indicator of N needs. If adequate color and density are present, do not universally use clipping matter or weight to gauge N needs. If turf begins to thin or excessive damage occurs, turf growth and density may become relatively good indicators of N needs.

Soluble Sources

Soluble or quickly available N sources result in rapid shoot growth and greening. These occur approximately 2 to 5 days after application, peak in 7 to 10 days, and taper off to their original levels in 3 to 6 weeks, depending on the application rate and subsequent amount of water applied.

Soluble N sources have salt-like characteristics. They dissolve readily in water to form cations and anions. The greater availability of these ions corresponds to a greater burn potential for the fertilizer. Burn potential can be lowered by making applications only to dry turf surfaces when air temperatures are cooler than 80° F. Watering in soluble N immediately following application further reduces the chance of burning plant tissue. Other disadvantages of using soluble N sources can be minimized by applying small amounts frequently. Rates at or below 0.5 lb. N per 1,000 ft^2 minimize these problems but increase application frequency and treatment costs.

Advantages of soluble nitrogen sources:

- Rapid initial color and growth response
- High in total nitrogen
- Odorless
- Maintenance of satisfactory nitrogen levels if applied frequently in small amounts
- Minimum temperature dependence for availability
- Low cost per unit of N
- Versatile—can be applied in granular or liquid forms

Disadvantages of soluble nitrogen sources:

- High potential for foliar burn, especially at higher rates and temperatures
- Potential undesirable growth surge

- Relatively short residual plant response, so frequent applications are needed, which increases labor costs
- Greater potential for N loss from volatility, leaching, and runoff

Urea – Urea is one of the most widely used N sources due to its relatively low cost and solubility. It is formed by reacting ammonia gas and carbon dioxide. Once applied, urea is hydrolyzed and in the presence of urease is converted to ammonium carbonate. This ammonia form of N is prone to volatilization. If left on the surface and exposed to the sun's heating action, the ammonium carbonate decomposes into ammonia and carbon dioxide, and the applied N volatilizes. Research has shown that as much as 70% of surface-applied urea can be lost through volatilization. The easiest and simplest way to avoid this volatile N loss is to irrigate with 0.25 to 0.5 inch of water shortly after urea application. Urea is nonionic when solubilized. Nitrogen from urea is prone to leaching; if excessive irrigation or rainfall occurs shortly after application, it may leach below the root zone.

Urea has a quick initial release rate of short duration and a low foliar burn potential. Urea-based fertilizer programs for putting greens should therefore involve light applications (< 0.5 lb. N per 1,000 ft^2) made frequently (e.g., every two to four weeks) to reduce these potential losses.

Ammonium or Nitrate Salts – Ammonium sulfate, ammonium nitrate, ammonium phosphate, potassium nitrate, and calcium nitrate are other commonly-used, water-soluble N sources, collectively referred to as inorganic salts. Once the ammonium fertilizers solubilize in soil, ammonium ions can be adsorbed by the negatively-charged clay or organic matter. As with urea, soil bacteria convert this ammonium to nitrate, which is the main form available to plants. Unlike ammonium sulfate and phosphate, potassium nitrate and calcium nitrate fertilizers do not need to undergo conversion by bacteria, since their N source is already in nitrate forms.

Slow-Release Nitrogen Sources

In an attempt to overcome some of the disadvantages of soluble N sources, fertilizer manufacturers have developed an array of slow or controlled release products. These generally provide a more uniform growth response and longer residual plant response. They also have less potential for N 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 N may vary with fertilizer timing, source, temperature, moisture, pH, and particle size.

The drawbacks of slow-release N sources include high per-unit cost and slow initial plant response. Most sources also are not adaptable to liquid application systems. Turf managers should understand the various N sources and conditions favoring N release before formulating their yearly fertilizer program.

Coated N fertilizers consist of urea or other soluble sources that are coated with a semipermeable barrier. Their release rate is slow because the coating prevents the wetting of the soluble N source. Release rates depend on coating degradation or the physical integrity of the coating. Other controlled release fertilizers are created by a reaction between urea with isobutryaldehyde (IBDU) or formaldehyde (urea-formaldehyde). Release rates depend on water hydrolysis or the microbial degradation of the product.

Sulfur-Coated Urea – Sulfur-coated urea (SCU) is formulated by moving granulated or prilled, preheated urea pellets through a stream of molten sulfur using a rotating drum. Urea gradually diffuses through the coating through cracks, pinholes, and imperfections that naturally occur in the surface as the particles cool.

Because of the nonuniformity and lack of integrity in the coating process, the urea granules crack at differing times, thus exhibiting variable N release rates. The granules also may be damaged during transportation, blending, and application, or by the weight of mower reels, rollers, or wheels. Therefore, handling should be kept to a minimum and drop spreaders avoided when applying SCU.

The rate of urea diffusion from SCU depends on the coating's thickness and integrity. Nitrogen release from SCU increases with warm temperatures, moist soils, and neutral soil pH. Heavy sulfur coatings result in larger fertilizer granules, which release the N more slowly. Problems with mower crushing or pickup may occur with these larger granules. To minimize this, a fine prilled product is produced for greens application that has a more rapid N release rate.

SCU has little effect on soil salinity but can reduce soil pH slightly due to the sulfur coating. The sulfur coating also is a sulfur source for plants. Sulfur-coated urea is less costly than many other coated, slow release N sources. Leaching and volatilization losses generally are low, assuming that excessive moisture is not applied. The N content of SCU ranges from 32 to 38%, depending on the thickness of the sulfur coating.

Plastic/Resin-Coated Urea – A relatively new but similar technology to SCU is a resin-coating (or polymer-coating) process that coats a soluble N source, such as urea, nitrate, or ammonium, with resin or a plastic. Resin-coated fertilizers rely on osmosis rather than coating imperfections to release N. Low concentrations of salts on one side of the resin or plastic membrane allow the diffusion of high salt concentrations to the other side through the coating. As the fertilizer particle swells, internal pressure either causes the pellet to crack open, releasing the urea, or the urea is forced out through the pores. Since the coating is semipermeable, the N is time released.

Release rates generally vary from 70 to 270 days, depending on the thickness of the coating and dissolution of water into the prill. Soil temperature also influences the release rates of coated materials, since the release is by diffusion. The diffusion rate is temperature mediated. Thus, the polymer-coated materials tend to release N more slowly in the cool season than in the warm season. The major disadvantage of polymer coating is that it costs more other slow release fertilizers.

The multiple coating of urea is a recent development. Urea is first coated with sulfur to form one layer and then coated with a polymer that further protects the nutrients and, in combination with the sulfur layer, delays the rate of release. The N is released through diffusion, which can be regulated by varying the levels of each of the coating components. One advantage, in addition to the controlled release rate, is better resistance to abrasion than SCU. Dust problems when handling the material are also minimal.

Another coating process involves two coats of resin instead of one, plus one coat of sulfur. The first resin coating reacts with the urea, and the second coating reacts with the first to form a hard coating that does not break easily on handling. The coatings are very thin but effective.

The thickness of the coating can be controlled to produce varying release rates. The dissolution of water into the prill also controls the N release rate.

Isobutylidene Diurea – Isobutylidene diurea (IBDU) is formed by reacting isobutyraldehyde with urea in an acid solution. The resulting product contains 31% N, 90% of which is water insoluble. In the presence of water, IBDU hydrolyzes back to urea and butyric acid. IBDU's nitrogen release rate is predominantly affected by soil moisture and particle sizes, and is not as dependent on temperature. With IBDU, an optimum pH range for N release is between 5 and 8, with a significant rate reduction occurring outside these ranges. Nitrogen release is independent of microbial activity. Therefore, IBDU nitrogen is released more readily during cool weather compared with other slow release sources. The influence of IBDU on soil salinity and pH is minimal.

Ureaformaldehyde – Ureaformaldehyde (UF) is a generic designation for several methylene urea polymers that are formed by reacting urea with formaldehyde. These products have varying length polymers of methylene urea, ranging from water-soluble molecules to highly water-insoluble molecules, to provide controlled N release. The smaller the ratio of urea to formaldehyde, the longer the chain of polymers formed. As polymer lengths and the number of longer polymers increase, solubility decreases, and N is released more slowly. Ureaform fertilizers contain a minimum of 38% N and are commercially available as Nitroform™, Nutralane™, Ureaform™, and Blue-Chip™; several additional methylene urea materials are marketed under other trade names.

All UF products depend on microbial breakdown for N availability. Therefore, environmental conditions favoring microbial activity (e.g., warm temperatures [> 55° F], neutral soil pH, and adequate soil moisture and oxygen) promote N release. Conversely, low temperatures, acid soils, and low soil oxygen inhibit N release from UF. Unlike IBDU and SCU, where N is released into soil as urea, N from UF is released as ammonium.

Shorter chained, water-soluble polymers are readily digestible by soil microorganisms and release N in a relatively short time. Longer chained polymers contain water-insoluble N, which is more slowly digested by soil bacteria. A lag in N availability may occur when using UF.

As with any N source, UF losses by mower pickup can be significant, especially immediately after application. Grass catcher boxes can be removed to allow clippings and fertilizer granules to return to the soil surface.

The losses of N by leaching and volatilization are less for UF than for readily-available N sources. Over time, UF sources are about equal to soluble sources in terms of N use efficiency. Under conditions favoring leaching and volatilization, however, UF sources often are more efficient. Labor costs for applying fertilizer also must be weighed, since UF applications are less frequent. Soil pH or salinity are little affected by UF, and its burn potential is low.

Several new liquid materials that have better slow release characteristics are now commercially available for foliar feeding and fertigation. These allow heavier rates to be applied less frequently without undesirable surges in growth or color. In addition, these slow release materials minimize turf foliar burn potential. These solutions are generally composed of mixtures of short chain methylene ureas, triazones, amines, and soluble urea. They are generally marketed as 28 to 30% N solutions containing about 30% soluble urea. In general, the responses observed for the various materials are very similar and generally last for no more than 60 days.

Natural Organic Nitrogen Sources

Natural organic N sources usually involve various levels of compost or waste (either human or animal) materials. Manure, biosolids, bone meal, humates, and composted plant residues are traditional sources of natural organic N. The advantages of these substances include a low burn potential due to limited water-soluble N, little effect on pH, low leaching losses, and the presence of other nutrients in the materials. The physical condition of soils, especially sandy ones, may improve with their use. Depending on the local source, natural organic N sources may be readily available at competitive prices.

Some considerations before using these sources include their low N content and slow N release during cool weather due to reduced microbial activity. Large amounts of material may need to be applied. These materials may be more costly per pound of nutrients than soluble sources. Natural organic N sources may be difficult to store and to apply uniformly, especially when the turf is already established. Some natural organic sources produce objectionable odors after application and contain undesirable salts, heavy metals, and weed seeds. Natural organic sources such as manures and composted crop residues should not be used on golf greens because of potential hindrances to soil drainage resulting from the large amounts of material applied.

PHOSPHORUS

Phosphorus is an essential element for plant growth. Unfortunately, it is often the limiting nutrient in many natural systems, such as the many ponds, streams, rivers, lakes and wetlands in Minnesota. As such, many areas of the state are very sensitive to excess P. Phosphorus is abundant in some soils and should never be added to turf without a specific reason. Soil or tissue should almost always be tested before fertilizing with P.

Phosphorus is involved in the transfer of energy during metabolic processes. P content may range from 0.1 to 1% by weight, with sufficiency values from 0.2 to 0.4% in newly mature leaf tissue. Phosphorus is considered deficient when levels are below 0.2% and excessive above 1%. The highest concentration of P is in new leaves and their growing points, but it is readily mobile in plants.

The symptoms of P deficiency include slow growth and weak, stunted plants with dark green lower (older) leaves. These older leaves eventually turn a dull blue-green color, with reddish-purple pigmentation along the leaf blade margins. Eventually, the leaf tips turn reddish and may then develop with streaks down the blade. Since P is fairly mobile in plants, deficiency symptoms initially occur in older tissue.

Phosphorous deficiency symptoms normally occur when the root growth of turf plants is restricted. Similarly, deficiencies often occur during cool season turfgrass establishment, resulting from the initial restricted rooting of new seedlings. Cool season turfgrasses tend to respond positively to P fertilizer applications, even in soils with high P levels. A reduction in tissue nitrogen content appears to result from applying P to a soil containing high levels of extractable P.

The most common P fertilizers used in turf include triple (or treble) superphosphate, and monoammonium and diammonium phosphate (MAP and DAP, respectively). Triple superphosphate is formed when rock phosphate is treated with phosphoric acid, while ammonium phosphates are produced by reacting ammonia with phosphoric acid.

A soil test is probably the best indicator of the P fertilization requirement. Indiscriminate P application can result in high levels. Phosphorus is most readily available to plants with a soil pH range of 5.5 to 6.5. At low pH (< 5.0), soils containing iron and aluminum form an insoluble complex with P; as a result, neither nutrient is easily available to the grass.

Sandy soils, such as those under many golf greens, lack iron or aluminum and do not form insoluble P complexes. Under these conditions, P is more available at a lower pH. However, one must be very careful to avoid leaching or runoff when adding P to low-pH, uncoated, sand putting greens. In alkaline soils (pH > 7.5), calcium forms insoluble complexes with P to render it unavailable as dicalcium phosphate ($CaHPO_4$). Applied P becomes less soluble over time and thus unavailable to the turf.

POTASSIUM

Potassium is an essential element not usually associated with a prominent, easily seen response in a plant's shoot color or density. It does help a plant overcome some of the negative effect of excessive nitrogen fertilization, such as decreased stress tolerance to cold, heat, drought, diseases, and wear. It often is called the "health" element, since an ample supply of K increases a plant's tolerance of these stresses. Potassium is directly involved in maintaining the water status of a plant, the turgor pressure of the cells, and the opening and closing of the stomata. As the P concentration increases in a plant, the tissue water content increases and the plant become more turgid, because K regulates the stomatal opening. This is because K provides much of the osmotic pressure necessary to pull water into plant roots and thus improves a plant's drought tolerance. Cold tolerance is influenced by a plant's P-to-K relationship.

The dry matter of turfgrass leaf tissue consists of 1 to 3% K. Sufficient values range from 1 to 3% in recently matured leaf tissue. K deficiency occurs when levels are less than 1% and amounts greater than 3% are excessive. An inverse relationship also exists between K, magnesium, and calcium in plants. As K levels increase, magnesium deficiencies are the first to show, while at higher concentrations, calcium deficiencies occur. An inverse relationship can occur in saline soils, where calcium, magnesium, or sodium ions compete with K for plant uptake.

Potassium deficiency symptoms include the interveinal yellowing of older leaves and the rolling and burning of the leaf tip. Leaf veins finally appear yellow and margins look scorched. The turf stand loses density, with spindly growth of individual plants. Potassium is a mobile element within plants and thus can be translocated to younger, meristematic tissues from older leaves if a shortage occurs.

Potassium fertilizer often is referred to as *potash*. The soluble K content of a fertilizer is expressed as K_2O. Early settlers coined the name from producing potassium carbonate needed to make soap by evaporating water filtered through wood ashes. The ashlike residue in the large iron pots was called potash, and this process was the first U.S.-registered patent. Muriate of potash (potassium chloride), the most often used K-containing fertilizer, originates from potassium salt deposits that have been mined and processed. Potassium sulfate has a lower salt index than muriate of potash and should be used in high-salt situations.

The available form for plant use, the potassium ion (K^+), is absorbed primarily from the soil solution. Potassium is not readily held in sandy soils (low-CEC soils) and can be lost by leaching. This problem is not always appreciated, especially when growing grass subjected to heavy rainfall or watering. Soils containing appreciable clay retain more K, because clay particles hold this element.

There is competition in plant uptake between K and calcium and magnesium. Soils high in either calcium or magnesium, or both, need additional K fertilization to satisfy plant needs. In sandy soils, or where turf clippings are not returned, research shows that K application equal to or in excess of the N rate does not result in additional growth or K in turfgrass tissue. Frequent light applications of K may be beneficial due to the high leaching potential of K in sand-based greens. High rates of K application may induce tissue magnesium deficiencies on soils where exchangeable magnesium levels are marginal. On fairways where clippings are returned, optimum tissue K levels can be maintained when a 2-to-1 N-to-K fertilization ratio is used.

SECONDARY PLANT NUTRIENTS

The elements calcium (Ca), magnesium (Mg), and sulfur (S) are required in almost the same quantities as phosphorus. Calcium's functions include strengthening cell walls to prevent their collapse; enhancing cell division; encouraging plant growth, protein synthesis, and carbohydrate movement; and balancing cell acidity. Calcium also improves root formation and growth. Contrary to other nutrient elements, most plant calcium is obtained by mass flow created by the transpiration stream. Deficiencies may occur in sandy soils, acidic soils ($pH < 5.0$), or soils saturated with sodium. Deficiency symptoms include young leaves that are distorted in appearance, leaves that turn reddish-brown along their margins before becoming rose-red, and leaf tips and margins that wither and die. Roots also are short and bunched. Excessive calcium may tie up other soil nutrients, especially phosphorus, magnesium, manganese, iron, zinc, and boron.

Calcium is an immobile element within plants. It does not move from older leaves to new ones and must be supplied continuously. Calcium is usually added in a liming program or by irrigation with water containing high levels of calcium. Commercial sources include calcitic and dolomitic limestone, gypsum, superphosphates, shells, slags, and water treatment residue.

Magnesium is essential for chlorophyll production in plants. Chlorophyll molecules contain approximately 7% magnesium. Magnesium also is essential for many energy reactions, such as sugar formation; acts as a carrier of phosphorus; and regulates the uptake of other plant nutrients. Deficiencies occur mostly in sandy soils (low CEC) or soils with extremely high pH, especially when clippings are continuously removed. Deficiencies can occur in soils with less than 40 lbs. per acre of Mehlich-1 extractable magnesium. High calcium and phosphorus levels also tend to reduce magnesium uptake.

Magnesium is a mobile element in plants and is easily translocated from older to younger plant parts as needed. Symptoms of deficiency include a general loss of green color starting at the bottom leaves. Veins remain green. Older leaf margins turn a blotchy cherry-red, with stripes of light yellow or white between the parallel veins. Necrosis eventually develops. Sources of magnesium include dolomitic limestone, sulfates of potash and magnesium, magnesium sulfate (Epsom salt), oxide, and chelates.

Sulfur is essential for selective amino acid production. It is used for building blocks of proteins and also reduces the incidence of disease. Content in leaf tissue ranges from 0.15 to 0.50% of the dry weight.

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 where grass clippings are removed, excessive watering occurs, and sandy soils predominate. Deficiency symptoms include an initial light yellow-green color in the leaves, with the yellowing most pronounced in younger leaves, as sulfur is mobile in plants. Older leaves become pale and then turn yellowish-green in interveinal areas. Leaf tips are scorched along the margins.

Over 90% of available sulfur exists in the organic matter, which has a nitrogen-to-sulfur ratio of approximately 10 to 1. Deficiencies may occur when the ratio is greater than 20 to 1 or at a high soil pH (> 7.0). Sulfur may be precipitated as calcium sulfate ($CaSO_4$), while at lower pH levels (< 4.0), the sulfate anion may be adsorbed by aluminum and/or iron oxides.

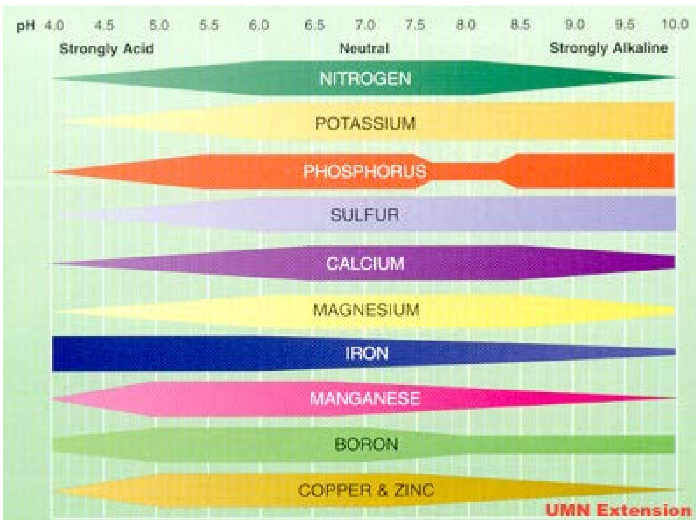
Turf clippings with a high nitrogen-to-sulfur ratio (> 20 to 1) decompose slowly and may slow thatch biodegradation. Microorganisms require sulfur to decompose plant residues. Sulfur is supplied as a contaminant in some fertilizer sources, such as superphosphate. However, many new high-analysis fertilizers frequently do not contain appreciable sulfur.

In poorly-drained and waterlogged soils where soil oxygen is exhausted, sulfate-reducing bacteria can convert SO_4 and sulfur-containing organic matter to toxic hydrogen sulfide (H_2S). Excessive applications of elemental sulfur also may encourage the buildup of hydrogen sulfide in greens where excessive irrigation is practiced or drainage is poor. Insoluble sulfides also may form by reacting with soil iron.

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 a distinct hydrogen sulfide (e.g., sewer or rotten egg) smell. Low soil oxygen also can reduce levels of manganese, copper, and iron, resulting in gray and blue colored subsoils. This often occurs in poorly-drained soils and in greens receiving excessive irrigation. The black layer can usually be controlled by proper water management.

MICRONUTRIENTS

Micronutrients are essential elements needed in relatively small amounts (e.g., < 50 ppm). Many soils in the United States supply sufficient levels of micronutrients. In other cases, enough micronutrients are supplied in fertilizers as impurities. In Minnesota, however, with its areas of sandy and peat or muck soils, pockets of high-pH and phosphorus-containing soil, poor drainage, and periods of extended, heavy rainfall, deficiencies in micronutrients can become a problem. For example, as soil pH increases, iron changes from its available (soluble) ionic form to hydroxy ions and finally to insoluble or unusable hydroxide, or oxide forms.



Soil pH has many effects on plants but probably influences them most by affecting the availability of important nutrients. For example, at lower pH values (< 5), aluminum, iron, and manganese are highly soluble. High levels of aluminum can reduce plant uptake of phosphorus, calcium, magnesium, and iron. At higher pH values (> 7.0), nutrients such as iron, manganese, copper, and zinc are less soluble and therefore relatively unavailable for plant uptake, although molybdenum (Mo) availability actually increases with high pH. The availability of phosphorus and boron also may be hindered by a soil pH value greater than 7.

A balance of micronutrients is particularly important, because many plant functions require more than one element. Regular tissue testing is the best approach to preventing nutrient deficiency problems. Iron and manganese are two of the most common micronutrient deficiencies that turf managers experience. Micronutrient deficiency symptoms can easily be confused with pest occurrences or other stresses. These problems, however, usually are more localized and appear as irregular spots or in circular patterns.

Chelates

Chelates, chelating agents, or sequestering agents are cyclic structures of a normally nonsoluble metal atom bonded with an organic component. They are soluble in water. Commercially available sequestered metallic ions are iron, copper, zinc, and manganese. Organic compounds with the ability to chelate or sequester these metallic ions include ethylenediaminetetraacetic acid (EDTA), diethylenetriaminepentaacetic acid (DTPA), cyclohexanediaminetetraacetic acid (CDTA), and ethyl-enediaminedi (o-hydroxyphenylacetic acid; EDDHA). A plant can absorb the soluble chelate forms of the metal ions.

Beneficial Elements

Recent research suggests that silicon may be beneficial to the growth of turfgrasses. Disease incidence, particularly grey leaf spot, may be reduced and wear tolerance may be improved by the application of silicon to turfgrasses growing in soils low in soluble silicon. In some countries, but not in the United States, silicon is recognized as an essential element for some plants. See the comment on sodium below regarding C4 plants, and keep up on potential changes in the research on this issue.

Nonessential Elements

Aluminum, arsenic, and sodium are generally considered nonessential elements for turfgrass growth and development. They become toxic when levels are excessive and should not normally be applied in supplemental fertilizers.

STARTING A FERTILIZER PROGRAM

Fertilization programs for golf course grasses require ample nutrients for optimum growth and performance quality but must also protect Minnesota's fragile environment. Trying to improvise one fertilization schedule that encompasses all courses within the state is unrealistic. Players' expectations, budget constraints, the soils used in construction, and location all influence the inputs each course must use when determining a sound fertility program. Many times this is intensified by the high, and often excessive, standards demanded by professional players. Club members often place undue pressure on their superintendents to provide lush conditions that drive up costs and waste or harm natural resources.

The state is very concerned about nitrate-nitrogen leaching into ground water and the phosphorus and nitrogen impacts on surface waters in many areas. Both local and state agencies have been examining the fertilization practices of golf courses. Excessive and unnecessary fertilization should be avoided to prevent water contamination and the possible penalties faced by those deemed to be the source of water pollution.

The following provides an overview of fertility recommendations for most courses and special situations in the state. Each course, however, should follow the fertility program that best suits its situation.

SOIL ACIDITY AND LIMING

Liming acidic soils to a pH of 6.5 has numerous positive effects on the soil and on turfgrass growth and quality. The beneficial effects of liming acidic soils include the following:

- Increased turfgrass growth and quality
- Decreased thatch buildup
- Increased retention and reduced leaching of fertilizer elements
- Increased rooting density and depth
- Optimum availability of nutrients
- Increased activity of beneficial soil organisms
- Amelioration of toxic elements in the soil
- Better soil structure and tilth

Soil pH should be monitored by annual soil testing. Intensively managed and artificially constructed areas such as putting greens may require more frequent testing. Whenever soil pH drops below 6.0, lime should be applied in sufficient quantity to raise the pH to 6.5. A general rule of thumb for liming sandy soils with low buffering capacity, is to apply 1 ton of lime per acre to raise the pH 1 unit. However, liming based on laboratory recommendations is more precise and should be used whenever possible.

Pulverized calcitic or dolomitic limestone with a calcium carbonate equivalent (CCE), or neutralizing power, of 90 or greater is recommended for liming golf turf. Dolomitic limestone is the preferred product for soils that are low in magnesium. Pelletized products reduce the dust associated with the application of liming materials and flow more easily.

FERTILIZATION PROGRAM FOR GOLF GREENS

Determining how much and how often fertilizer should be applied depends on several factors. Each golf course superintendent should consider the quantity and scheduling of fertilizer to be applied during the year. Fertilization programs should provide adequate levels of essential nutrients to sustain growth and acceptable turf quality and color. Improper timing and/or rates of fertilizer application influence the stress tolerance and recuperative ability of turfgrasses. In addition, disease occurrence and severity often are closely linked to the amounts and timing of fertilization programs. For example, dollar spot (*Moellerodiscus* and *Lanzia* spp.) disease often is associated with low nitrogen levels. A fertilizer application containing quick-release nitrogen often allows the turfgrass to outgrow these disease symptoms, thus eliminating the need for fungicide applications. In contrast, the excessive fertilization often promotes the occurrence of brown patch (*Rhizoctonia* spp.) and pythium (*Pythium* spp.) diseases.

Proper fertilization not only provides disease- and stress-free turf, but also an acceptable playing surface. Excessive fertilization with nitrogen is not only agronomically detrimental but drastically slows ball roll and draws complaints from players. Exceptions, such as certain high-traffic greens and tees (e.g., Par 3) or newly constructed greens, require more nitrogen fertilization to promote turf recovery from ball marks and concentrated traffic, and to facilitate more rapid grow-in.

Timing

The timing of fertilization may be based on the minimum and optimum temperatures necessary for turfgrass growth. Minimum temperatures for cool season shoot growth are about 40° F; cool season roots may grow at temperatures as low 33° F. Optimum temperatures for cool season shoot growth are about 60° to 75° F, while optimum temperatures for cool season roots are 50° to 65° F. If temperatures are outside the growth range of the grass, slow-growing plants use fertilizer applications inefficiently, which creates a potential for loss into the environment.

Nitrogen Rates

Quality putting surfaces can be maintained without excessive N rates. Courses with high traffic and elevated demands from serious amateur and tournament players use more N than public courses with modest traffic. The most important factor in the environmental fate of N application to turfgrass is not the total amount applied annually, but rather the amount applied in any single application and therefore available to leach or run off to surface waters before being used by the plants. Frequent “spoon-feeding” of greens is the most effective method of avoiding accidental N losses to the environment. The nitrogen content in reclaimed water used for irrigation should be included in these calculations.

Frequency

To maintain optimum color and density during periods of active growth, sand-based bentgrass golf greens need approximately 0.1 lb. soluble N per 1,000 ft^2 every 7 to 10 days. High fertilizer application rates can lead to problems. Excessive thatch can quickly accumulate, causing slower putting speeds because more leaf area is produced, and a decrease in turfgrass rooting may result.

Prescription Fertilization

Whenever practicable, fertilization should be based on the specific needs of each green at a given time. Soil and tissue testing can help devise a prescriptive approach to each area.

Nitrogen Sources

The source of N used to fertilize golf greens affects the amount applied. Usually, a combination of soluble and insoluble sources is recommended to provide uniform grass growth and reduce N leaching. Ureaformaldehyde (Nitroform), IBDU, and SCU often are used to provide slow-release, residual N, while a soluble source is used for rapid response. During cold temperatures, IBDU or soluble sources provide the fastest turf response, because they are less dependent on microorganisms for N conversion and release. Other considerations involving N sources include higher costs for slow release and natural organic sources compared with soluble ones, the salinity hazard of ammonium nitrate and ammonium sulfate, and the acidifying effects of ammonium sulfate and ammonium phosphate.

Except for slow release (water-insoluble) materials, actual N should never be applied in excess of 1 lb. per 1,000 ft^2 in any one application, and then only when appropriate soils and healthy turf preclude leaching. Small amounts (0.5 lb. soluble N per 1,000 ft^2) frequently applied are preferred, since this produces a higher-quality turf, reduces growth flushes, and minimizes leaching potential. In most cases, a high-quality turfgrass can be maintained for a 90-day period without flushes of growth or drastic changes in color when slow release sources are used. Additionally, slow release N sources leach less than soluble ones.

Other Elements

Potassium (K) often is called the “health” element. Without a readily available supply of K, turfgrasses may be more susceptible to environmental and pest stresses. Root growth also is related to K availability. Unfortunately, K does not readily remain in the turfgrass root zone, especially in greens constructed predominately with sandy soils. Therefore, it should be applied to golf greens nearly as frequently as N, at between one-half to equal the N rate.

Soil phosphorus (P) levels tend not to fluctuate as readily as N or K. Soil test results should be used to determine the amount needed for a particular golf course. Golf greens constructed of uncoated sands, and sand greens that have a pH less than 5.0, may leach P readily. In such situations, soil P levels should be monitored frequently and P source fertilizers applied only when soil P levels become deficient.

Micronutrients

Regular soil and tissue testing is the best preventive approach to avoiding many of the micronutrient deficiency problems. Iron and manganese are two of the most common micronutrient deficiencies that Minnesota turf managers experience.

TEES

Tees, like greens, should be fertilized sufficiently to sustain vigorous recuperative growth, but not to the point that wear tolerance is sacrificed. Tees, in general, are maintained almost as intensively as golf greens. This is especially true for tees constructed with a sand-based profile and for Par 3 tees that receive excessive traffic and damage from club divots. For most Par 4 and Par 5 tees, the fertilization program can be reduced to approximately one-half that for golf greens. For Par 3 tees, the fertilization program should range between three-fourths of or equal to that for greens. K applications should be approximately one-half of N applications, except where clippings are removed or when sand-based tees are constructed. In such cases, K application rates may need to equal those of N.

FAIRWAYS AND ROUGHS

Fairways generally are maintained with lower fertilizer inputs than golf greens. Clippings are not removed during mowing, resulting in the recycling of more nutrients, and heavier soils are usually used for fairways. In addition, higher mowing heights promote deeper rooting, and less irrigation is applied that may leach soil nutrients. N fertilization rates should range between three and four pounds per 1000 m^2 per year. P and K needs should be based on yearly soil tests.

Applications should begin in mid-May during the flush of new turf growth, or when soil temperatures are about 55° F. In general, one application of a complete fertilizer during this period and another around Labor Day are needed. These are supplemented throughout the year with N and K, as needed, to maintain desirable color, leaf texture, density, and recuperative ability. In general, applications are made every 5 to 8 weeks on high-maintenance courses and every 10 to 12 weeks on low-maintenance courses through the spring and summer. The last fertilization should be made approximately one month before anticipated frost and should consist of a 2-to-1 N-to-K ratio to encourage desirable carbohydrate formation.

Because roughs are mowed higher than fairways, may have less traffic, have lower expectations, and clippings are returned, fertilization requirements for roughs are much lower than for fairways and greens. Roughs should usually be fertilized once each year to provide color and recuperation from pest or traffic damage.

GROW-IN

Grow-in, or the establishment of turfgrass, is one of the most intensive phases in turfgrass management. Typically, to promote rapid establishment, large amounts of N and water are applied during the 10-to-12-week grow-in period, when the largest amount of environmental impairment may take place. Research has shown that this does not have to be the case. By regulating the rate of N applied according to the level of establishment of the turfgrass, i.e., applying less when the turfgrass coverage is less and gradually increasing the rate of N application as more of the ground is covered, one can reduce N leaching losses by as much as

25%. Also, by properly selecting the N source, i.e., including some slow release or organic N sources in the fertilizer mixture, the rate of N loss through leaching can also be reduced.

These practices delay the full establishment of the turfgrass by as much as 14 days, but through the proper selection of application rates and N fertilizer sources, N leaching losses can be reduced to less than 10% of the applied N during the entire 12-week grow-in period, even with the high rates of irrigation that are normally applied. Combinations of soluble, organic, and slow release N sources produce high quality turfgrass during grow-in. The incorporation of fertilizer nutrients in the grow-in root-zone sand/peat mixture does not result in more rapid establishment of turfgrass but does result in more total N, P, and K leached. Recently, some golf course construction firms have used sand only as a root-zone mix. Sand-only greens have a higher propensity to leach N and P, and are slower to become established. Great care should be exercised when establishing turfgrasses on sand-only greens.

P and K fertilization are also very important during grow-in. In general, turfgrasses respond better to P fertilization during grow-in than at any other time during their growth cycle. If the root-zone mix does not contain adequate levels of P for root development, the turfgrass establishes slowly and has a poor root system. Extreme care should be exercised when fertilizing with P during grow-in, because the turfgrass coverage area may be small and the roots poorly developed. When establishing turfgrass on sands containing low levels of P and sesquioxide/clay coatings, P may leach. Apply P when dictated by a soil test and at the recommended rates for good turfgrass growth.

K is also very important during turfgrass establishment for good root growth and healthy turfgrass growth. Sandy soils are typically low in K and require K fertilization. Fortunately, K is not considered an element of environmental impairment; thus, K fertilization may not have an environmental impact, but salt buildup in the root-zone mix and the depletion of a natural resource are two reasons to monitor the soil test K level and apply only the amount required for optimum turfgrass growth. Maintaining an optimum soil pH for turfgrass growth through proper liming results in maximum K retention by media cation exchange sites in the root zone.

SOIL SAMPLING

Soil testing is an applied science and can be used as a tool in maintaining healthy turfgrass and landscapes. For the effective management of nutrients, soil testing should be used in conjunction with tissue testing. Soil test recommendations are based on a correlation between the level of a given nutrient extracted from the soil and the anticipated plant response. The amount of nutrients extracted by a particular extractant is only an index relative to crop response. It is not a direct measure of actual plant nutrient availability.

The levels of extracted P, K, and Mg are divided into five categories: very low, low, medium, high, and very high.

Methodology

The soil test and resulting recommendations are only as representative as the sample itself. Therefore, it is imperative that the soil sample be taken and handled properly. The sample should be obtained by taking 15 to 20 small plugs at random over the entire area where information is desired. Avoid any unusual areas or areas with specific, identifiable characteristics; these should be sampled separately. For turfgrass, since most of the roots are in the top three inches of soil, limit the sampling depth to three inches. For landscape plants, the sampling depth should be no more than six inches.

Place the plugs that have been collected into a plastic container, mix them thoroughly, and send approximately one pint of the mixed sample to the University of Minnesota Soil Testing Laboratory for chemical analysis. Several commercial laboratories also offer the same service in Minnesota. You should use the same laboratory on a continued basis to establish a historical log of your soil properties. Laboratories do not use the same extractant, and so if you change labs often, you may be comparing results obtained by different methods.

Soil Test Interpretation

A soil analysis supplies a wealth of information on a soil's nutritional status and can detect potential problems that limit plant growth. A routine soil analysis supplies information on soil pH and the extractable phosphorus, potassium, calcium, and manganese status of the soil.

TISSUE TESTING

Because of the mobility of most essential nutrients for landscape plant and turfgrass growth in Minnesota soils, one of the best indicators of appropriate fertilization and plant health is tissue analysis. Since turfgrass is a perennial crop, historical logs of tissue composition can be used to fine tune a turfgrass fertilization program for optimum plant growth and minimum environmental impact. Leaf analysis, along with appearance and soil analysis, can be used to diagnose the problems and the effectiveness of a fertilization program, especially for micronutrient deficiencies. Soil analysis for some nutrients, because it is a snapshot of what is present at the time of sampling, does not always indicate their availability to plants. Potential nutrient deficiencies can be detected with leaf analysis before visual symptoms appear. Leaf analysis may provide information on induced deficiencies and inferences on plant uptake.

Methodology

Samples can be collected for tissue analysis during regular mowing. It is essential that the clippings be free of sand and fertilizer contamination. Do not harvest clippings immediately after fertilization, topdressing, or any other cultural practice that results in significant mower pickup. Place approximately a handful of well-mixed clippings in a paper bag. Do not place the clippings in a plastic bag because the clippings may begin fermenting prior to drying.

If facilities exist at your location, dry the collected clippings at approximately 70° C (158° F) for 24 hours, and then mail them to an analytical laboratory for analysis. If you do not have drying facilities, ship the samples, preferably overnight, to the analytical laboratory. Even if placed in a paper bag, if a sample is allowed to sit for more than a couple of days the tissue begins to ferment and the value of the sample for analytical purposes is lost.

Sample Contamination

Turfgrass clippings that have been recently sprayed with micronutrients for fungicidal or nutritional purposes should not be used for micronutrient analysis. Washing recently unsprayed clippings to remove soil and dust particles is recommended prior to sending the samples to the lab for analysis. If you wash one collection of clippings and not all, the nutritional analyses may not be comparable because the concentration of some nutrients, such as K, in tissue is highly mobile and a portion of the K may be removed during washing. Unwashed samples may appear to have a much higher concentration than the washed samples, and you may suspect a deficiency in the washed samples when in fact an adequate supply of K exists.

Interpretation of Results

Sufficiency levels of essential nutrients, except for N, do not vary much among the various turfgrass species. The concentration of other macronutrients and micronutrients in tissue does not vary greatly among the various species of turfgrasses. If analytical test results are in the deficiency range or below the sufficiency range, an increase in fertilization for that nutrient may be appropriate. Alternatively, if test results fall outside the sufficiency range, the fertilization program may need adjustment. However, other causes may need to be considered. If a change in fertilization is indicated, the adjustment should be reasonable. The intent is to find the correct nutrient management level that maintains nutrient concentrations in turfgrass tissue within the optimum range, but does not lead to overfertilization and possible adverse environmental and economic results.

FERTILIZER LOADING

Load fertilizer into application equipment away from wells or surface waterbodies. A concrete or asphalt pad with rainfall protection is ideal, as it permits the easy recovery of spilled material. If this is not feasible, spread a tarp to collect spillage. Where dedicated facilities are not available, loading at random locations can prevent a buildup of nutrients in one location. It is not recommended to load fertilizers on a pesticide CMC because of the potential for cross-contamination. Fertilizers contaminated with pesticides may cause turf damage or generate hazardous wastes. Many pesticide carriers are hydrocarbon-based and they may react with oxidizers in spilled fertilizer materials.

Clean up spilled material immediately. Collected material may be applied as fertilizer. The area can be cleaned by sweeping or vacuuming (or by using a shovel or loader, if a large spill), or by washing down the loading area to a containment basin specially designed to permit recovery and reuse of the washwater. Washwater generated should be collected and applied to the turf. **Discharging this washwater to waterbodies, wetlands, storm drains, or septic systems is illegal.**

FERTILIZER APPLICATION

The only way to accurately know how much fertilizer is actually being applied is to calibrate your application equipment. Calibration should be done in accordance with the manufacturer’s recommendations, or whenever wear or damage is suspected to have changed the delivery rate. For granular materials, it may be necessary to recalibrate whenever using a new material with different flow characteristics. Sprayers and metering pumps on liquid systems also need to be calibrated regularly.

GRANULAR APPLICATION

Granular fertilizer is usually applied with a rotary spreader. When applying it near waterways, cart paths, or other nontarget areas, always use a deflector shield to prevent inappropriate fertilizer distribution. If fertilizer is deposited on cart paths, parking lots, or other impervious surfaces, sweep the material into the turf where it can be properly absorbed and will not run off into storm drains or waterbodies. Drop spreaders may be used occasionally, but they may cause mechanical damage to the coatings of slow release fertilizers.

FOLIAR FEEDING

Foliar feeding and liquid fertilization involve the use of a soluble nutrient form for plants. Nutrients are used more rapidly and deficiencies corrected in less time than conventional soil treatments. However, the response is often temporary. Due to the small amounts required, micronutrient applications have traditionally been the most prominent use for foliar sprays.

Foliar feeding involves using low fertilizer rates (e.g., 0.125 lb. nitrogen or iron per 1,000 ft^2) at low spray volumes (e.g., 0.5 gal. per 1,000 ft^2). Low nutrient and spray volumes minimize costs and supplement the normal fertilization program with nutrients absorbed directly by turfgrass leaves. At higher spray volumes, (e.g., 3 to 5 gals. per 1,000 ft^2), the fertilizer is washed off the leaves. This is called liquid fertilization. With liquid fertilization, fertilizers and pesticides often are applied together. Although the initial spray equipment for liquid application costs more, it usually is less expensive to apply in the long run than granular fertilizer.

The application of micronutrients, iron being a notable example, is commonly employed with foliar fertilization. All micronutrients are metals except boron and chloride. With the exception of molybdenum, the availability of most micronutrients declines with increasing soil pH. Chloride is unaffected by soil pH. Micronutrient fertilizers are generally more expensive than macronutrient materials. The application rates for micronutrients usually are low enough so that foliar applications are feasible. One potential problem when zinc, iron, manganese, and copper are added to clear liquid fertilizers is that precipitation often occurs as a reaction with phosphates. Chelates of the metal micronutrients can be mixed with liquids without causing precipitation.

Nitrogen also is added to many micronutrient products to stabilize the solution. Micronutrient solutions can retain elements at higher temperatures and become supersaturated. Upon cooling, micronutrients in the solution may precipitate out, forming insoluble compounds. Urea has been shown to help prevent precipitation, and it also gives the turf a small color boost.

Advantages of foliar fertilization:

- There is no segregation of particles, as is common with granular fertilizers.
- The process provides nutrients directly to plants and is not influenced by soil properties.
- Fertilization provides water-soluble forms of nutrients.
- Coapplication with pesticides is possible.
- The fertilizer is generally easier to handle and quicker to apply.

Disadvantages of foliar fertilization:

- There are problems with sufficient application without severe leaf burn.
- Some solutions may salt out at lower temperatures.
- Frequent applications at low rates may be necessary because turf response is temporary and low rates prevent leaf burn.

PRECISION APPLICATION

Precision application refers to the use of automated application equipment using global positioning system (GPS) data and detailed mapping to apply just the right amount of a chemical to a specific area. This may reduce overall fertilizer (or pesticide) use by customizing the application to the particular characteristics at a given location, and may be accurate to within one or two feet. Typically, standard spreading equipment applies the same amount everywhere. To ensure that enough is applied to troublesome spots, overapplication may occur in many other areas.

FERTIGATION

Fertilizer application through an irrigation system is termed *fertigation*. This ideally combines the two operations to use resources and labor more efficiently.

Frequent light applications (e.g., spoon-feeding) of fertilizer are metered into irrigation lines and distributed along with irrigation water through sprinkler heads. Since most of the applied irrigation water and fertilizer enters the soil and is not retained on the foliage, fertigation is not synonymous with foliar fertilization. Nitrogen, potassium, and micronutrients are often applied in this manner. Fertigation helps maintain even color and growth, minimizes color surges that result after heavy granular applications, and reduces the labor costs associated with frequent applications of granular forms.

Application through a simple irrigation delivery system is probably the best. This consists of a fiberglass or plastic storage tank with a visual volume gauge, a filter, and an adjustable, corrosion-resistant pump to inject fertilizer into the main irrigation line. If a centrifugal pump is used for irrigation, drawing fertilizer into the suction side of the irrigation pump can eliminate the injector pump, so that some fertilizer is applied at each irrigation event.

If the injection pump supplies fertilizer at a constant rate, it is important that the irrigation system is well balanced, with each zone covering approximately the same amount of land area so the fertilization rate is also constant— except for areas where it is desirable to fertilize at a heavier rate. Proportioning systems have been developed that keep a constant ratio between the volume of liquid fertilizer injected and the volume of irrigation water applied.

To operate the system, the amount of N and other nutrients that are desired per unit of turf area per unit of time (e.g., lbs. N per 1,000 ft^2 or per acre applied per month) must be determined. Then, by knowing the concentration of the fertilizer solution, the rate at which the injection pump must operate can be determined. This rate can be adjusted if necessary to compensate for unusually high or low amounts of rainfall that affect irrigation needs. The visual gauge on the fertilizer tank helps determine how well the fertilization schedule is being maintained, since the period needed to empty the tank (e.g., a week or a month) can be determined in advance. Heavily-used areas such as tees and greens often require higher N rates than fairways. Various methods can be devised to increase the rate of fertilizer applied by irrigation systems on these areas. Such complications, however, may cause excessive work and problems. In most cases, it seems best to use fertigation to supply a uniform rate of N to the entire golf course and traditional granular means to augment fertilization on the relatively small, heavily-used green and tee areas.

WATER FEATURES AND AQUATIC PLANT MANGEMENT

Golf course lakes and water features are present for many reasons. They may be natural or man-made. They may have been sited as water hazards for the game, for aesthetic pleasure, to provide irrigation, or because of regulatory requirements for stormwater treatment. Most fill many purposes at the same time.

In its natural state, a lakeshore supports a variety of herbaceous and woody vegetation, has emergent and submergent shoreline plants, and experiences fluctuations in algae populations. Traditional Minnesota golf courses favor pond banks with open views of sparkling clear water, distinguished by neat edges of closely-cropped sod or hardscape-retaining structures. Maintaining such a highly artificial edge requires intensive management. Understanding natural lake processes and accommodating them in the design and management of a pond can create significant aesthetic value and reduce operational costs.

Lakes and ponds have several distinct defining characteristics. Their size, shape, and depth may all affect how they respond to various environmental inputs. Most lakes on a golf course are relatively small and somewhat shallow. This can lead to rapid changes in temperature and a lack of oxygen in the water, resulting in dying plants and fish and bad odors. In shallow or nutrient-impacted ponds, aeration may be required to maintain acceptable dissolved oxygen (DO) levels in the water.

No matter what their purpose, golf course ponds can still provide sustainable aquatic ecosystems for aquatic insects, fish, frogs, turtles, birds, and other wildlife. It is, therefore, important to develop a comprehensive lake management plan that not only allows a pond to continue to function as it was originally designed, but also protects water quality and prevents undesirable changes that could lead to significant restoration costs.

Successful pond management must include a clear statement of goals and priorities to guide the development of the BMPs necessary to meet those goals. Some of the challenges facing superintendents in maintaining the quality of golf course ponds are as follows:

- Low DO
- Sedimentation
- Changes in plant populations
- Nuisance vegetation
- Maintenance of littoral shelves and vegetation on the lakeshore

LAKE MANAGEMENT

Each pond has regions or zones that significantly influence water quality and are crucial in maintaining the ecological balance of the system. It is important to understand their function and how good water quality can be maintained if these zones are properly managed. The four zones of a lake are the riparian zone, littoral zone, limnetic zone, and benthic zone.

Riparian zones (buffers) are strips of grass, shrubs, and/or trees surrounding a pond and separating it from upland areas. They filter pollutants and trap sediment from stormwater runoff and also slow the velocity of the water, allowing it to filter into the soil and recharge the ground water aquifer. They also offer valuable wildlife habitat. These upland areas are above the high-water mark and should be unfertilized and left in a natural state if possible; otherwise they should mowed to two to three inches to act as a filter and buffer to nutrients moving toward the water. A slight swale and berm system also helps by requiring most of the water to infiltrate through the root zone rather than running overland to reach the lake.

The *littoral zone* is the transitional area between the upland and the open water where sunlight penetrates to the bottom of the lake and emergent plants thrive. Ideally, it should have a slope of about 1 foot vertical to 6 to10 feet horizontal, but this may vary with the size, shape, and morphology of the pond. This zone is crucial to a pond's health, because the macrophytes in this area not only take up nutrients themselves but provide a habitat for other nutrient-removing organisms.

The *limnetic zone*, or open water, is usually the largest volume of water. In this area, light can penetrate several feet if the water is clear, allowing submergent plants and algae to photosynthesize oxygen during the day and respire carbon dioxide at night. Aerobic bacteria in the water use the oxygen to decompose organic matter and keep nutrients at a low level. This zone is typically easier to manage.

The *benthic zone*, the area at the bottom of the pond, comprises sediment and soil. It is typically nutrient enriched and has a high demand for DO. The benthic zone functions as habitat for epifaunal organisms that live on the sediment surface and infaunal organisms that spend all or part of their live cycle within the sediments. These organisms are important because they consume plankton and are the basis of the food web, as they are a source of food for bottom-feeding fish and aquatic organisms.

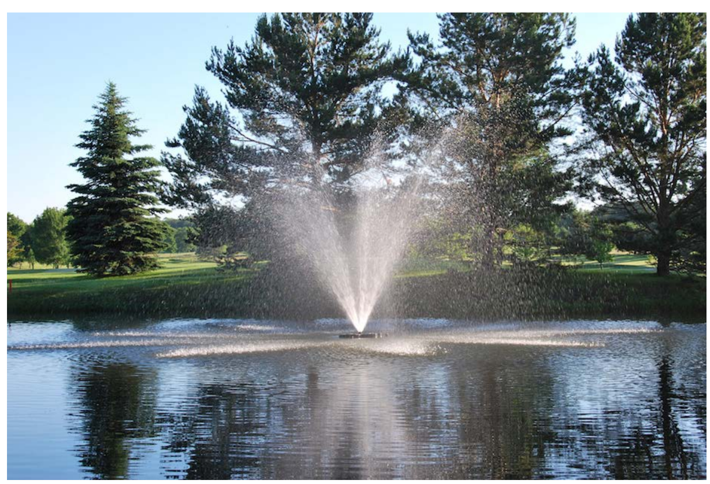
DISSOLVED OXYGEN

As stated previously, maintaining levels of DO that are adequate to sustain a healthy lake ecosystem is a challenge to a lake manager, but may be the single most important water quality factor to understand. The air over a pond is roughly 20% or 200,000 ppm oxygen, but rarely does a pond contain more than 20 ppm oxygen. Most fish show stress if levels reach 3 ppm, with fish kills occurring at levels of 2 ppm. The maximum amount of DO in the water (saturation) primarily depends on water temperature, with warm water able to hold less oxygen than colder water.

DO enters the water from two sources: as an exchange from the atmosphere and as a result of photosynthesis from green plants in the water. It is consumed most significantly by the respiration of plants and decomposition of decaying organic matter. Levels naturally rise during the day as sunlight drives the photosynthesis process and decline at night as plants consume oxygen through respiration. Excessive oxygen depletion and resulting fish kills, bad odors, and generally unpleasant conditions are usually caused by one or more of the following factors:

- Blooms of algae and other phytoplankton, characterized by very green water, usually result from increased loadings of nutrients coming from excessive fertilization or runoff from human activities. Heavy blooms consume large amounts of oxygen at night, and when the wind is low (minimizing atmospheric exchange) and there are cloudy days (minimizing photosynthesis), the risk of serious oxygen depletion is high. When phytoplankton levels are high enough to limit visibility to a foot or less, there is a danger of oxygen depletion. See the discussion of phytoplankton below.
- Being fairly simple plants, phytoplankton populations can expand rapidly and also die rapidly. Such die-offs cause rapid oxygen depletions as oxygen production from the loss of these plants ends and as anaerobic bacteria and fungi working to degrade the now-dead plankton consume the water's remaining oxygen. Die-offs can be caused by sudden drops in temperature and other natural factors, and by heavy herbicide applications to a pond.
- A pond *turnover* can result in low oxygen levels. Turnovers occur most frequently in the spring, when the sun starts warming the surface water while the lower depths remain cool from winter conditions. This stratification causes the bottom water to lose its oxygen to decomposition, and the oxygen is not replaced by surface exchange or photosynthesis. A sudden cooling of the surface, perhaps by a cold wind or rain, can break down this stratification and bring the oxygen-poor water to the surface, where fish become starved for air. Such turnovers occur most frequently in deeper (over eight feet) ponds.

In Minnesota, lakes less than six feet in depth can be difficult to keep oxygenated. Because they are shallow, light penetrates the entire water column and promotes plant and algae growth. They also heat up quickly, often reaching more than 85° F, limiting the maximum amount of oxygen they can hold during the day. Hot and humid summer weather provides a worst-case situation. Artificial aeration, particularly at night, for as long as the depleting factors are at work can help to control oxygen depletion in any pond. Encouraging the establishment of desirable plants in an effort to establish a natural balance also buffers a pond from wide swings in oxygen levels.



SEDIMENTATION

Excess sedimentation usually results from upstream erosion or the buildup of decaying organic matter. Excessive nutrients can result in excessive floating plant growth, algal growth, and other problems. As aquatic plants and algae die, they sink to the bottom and form an organic sludge. If this occurs faster than bacteria can degrade the material, the sludge can build up over time, leading to odors and clumps of floating sludge buoyed by gases.

The sludge may be sucked into irrigation systems. These sediments can build up to the point where a pond’s capacity is significantly reduced, and dredging may be necessary. If used on a golf course, this “black layer” may seal the soil pores and cause considerable harm to the turf. Excess sediments also smother benthic organisms, inhibiting nutrient reduction and reducing food resources available to other aquatic species. In addition, sediments often build up high levels of cadmium, lead, nickel, and or toxic substances, including herbicides and other pesticides. The disposal of these sediments may be subject to regulation, and application to turf may cause damage from residual herbicides.

AQUATIC PLANT CONTROL

Soon after a pond is constructed, unforeseen problems may arise, e.g., it becomes clogged with floating or submersed aquatic plants. The degree to which an aquatic plant becomes a weed problem depends on a pond's intended use. For example, shoreline grasses can help stabilize and prevent bank erosion, but out-of-control grasses may encroach into the water, restricting access and usability.

Plants are vital to the functioning of lakes and wetlands and serve various roles, such as producing oxygen and providing wildlife habitat. Ponds may be constructed on golf courses simply as water hazards but usually have additional purposes such as stormwater management (wet detention ponds) and irrigation. Stormwater management is often a pond’s primary purpose. Wet detention ponds may be constructed with shallow sloping areas, called littoral shelves, which provide habitat for rooted plants. Plants in ponds need to be managed, and management goals depend on a pond’s intended purposes.

When developing an aquatic plant management strategy, it is important to know the intended uses of a waterbody, the site’s physical attributes and location, the invasive or weedy species present, aesthetics, and other environmental considerations. Preventing the introduction and spread of non-native plants in Minnesota's waterways is the best and least expensive means of restoring natural freshwater habitats. In addition, preventive measures such as properly locating and constructing a pond help to reduce the risk of a takeover by invasive aquatic weeds.

As with other pest problems, the principles of IPM should be used. Prevention is better than cure, and the first steps in prevention are the use of proper fertilization practices, along with proper mowing, unfertilized buffer strips, and good pond design and littoral shelf plantings. The use of lake colorants and dyes, aeration, mechanical removal, and biological controls also has a place in a lake IPM system.

Chemical maintenance control may be necessary to reduce invasive or noxious plant or algae populations, overall herbicide use, and management and environmental costs.

In a maintenance control program, even though herbicide applications occur more frequently, the overall amount of herbicide used is much lower than what would be used to treat an out-of-control infestation and the stress on the pond is much less. Maintenance control also reduces sediment deposition. Plant managers choose the aquatic herbicide for each job according to the target plant, waterbody type and uses, wind, temperature, water depth, and other factors such as efficiency and cost-effectiveness.

It is important to consider the types of chemicals used in an aquatic environment. Copper products are a concern to environmental agencies because copper is persistent in the environment and highly toxic to many fish and other aquatic animals at exposure levels near those used to control algae, especially in water with low alkalinity. In general, chelated copper compounds are safer to use than copper sulfate. The Virginia Cooperative Extension Service has published an excellent reference for pesticide use in aquatic environments: *Pesticides and Aquatic Animals: A Guide to Reducing Impacts on Aquatic Systems* (available: https://ext.vt.edu/)

ROLES OF PLANT LIFE IN URBAN PONDS

Phytoplankton, which give water its green appearance, provide the base for the food chain in ponds. Tiny animals called zooplankton use phytoplankton as a food source. Larger animals, including small fish, use the zooplankton for food, and other, larger animals such as fish and birds feed on these to make up the higher levels of the food chain. Phytoplankton also produce oxygen, needed by fish and other animals in pond water, through the process of photosynthesis.

Large aquatic plants (aquatic macrophytes) can grow rooted to the bottom and supported by the water (submersed plants), rooted to the bottom or shoreline and extended above the water surface (emersed plants), rooted to the bottom with their leaves floating on the water surface (floating-leaved plants), or free-floating on the water surface (floating plants). Different types of aquatic macrophytes have different functions in ponds. Plant life growing on littoral shelves may help to protect receiving waters from the pollutants present in surface water runoff, and a littoral shelf is often required in permitted surface water retention ponds. Floating plants suppress phytoplankton because they absorb nutrients from the pond water and cause shading.

All types of aquatic macrophytes harbor insects. These may feed directly on plants (phytophagous), or they may be predatory insects that prey on other insects or small fish. In turn, these insects provide food for fish and birds. The presence or absence of plants, and the types of plants, may affect the bird life that frequents ponds. Birds use large aquatic plants, including adjacent shrubs and trees, willows, river birch, and red maples for nesting, feeding, and refuge sites. They also use macrophytes as food, and the plants provide habitat for other species eaten by birds. For example, bulrush (*Scirpus* spp.) is a primary habitat for red-winged blackbirds, and boat-tailed grackles. Trees such as oak (*Quercus* spp.) and poplar (*Populus* spp.) provide perches and resting places for cormorants, herons, osprey, and a variety of other birds that hunt for food in ponds. Establishing a broad littoral shelf of rush or other grasslike plants can provide space for sandhill cranes, a frequenter of fairways, to build nests. Dead trees that do not create a safety hazard provide insect populations for woodpeckers, whose holes offer nesting opportunities for a number of birds.

Certain plants have ornamental or aesthetic value in ponds. Plants such as pond lilies have showy flowers. Plants such as bulrush have bright green stems and foliage. All plants provide interesting shapes and screens that add aesthetic variety to a pond. For the butterfly enthusiast, butterfly gardens can be created on pond margins and littoral shelves, with the proper selection of planting material. The use of aquatic plants to improve the appearance of a pond (aquascaping) can be included as part of the overall landscape design.

MANAGEMENT OF PLANT LIFE

Aquatic plants growing in and around a pond provide many benefits. They help maintain good water quality by reducing shore erosion and absorbing nutrients. Plants provide cover for fish and a substrate for the colonization of minute organisms used by small fish. Wildlife use shoreline vegetation for concealment and as areas to search for food. Properly-designed ponds with a narrow fringe of vegetation along the edge are much more resistant to problems than those with highly-maintained sod. Still, plant life needs to be managed to ensure that a pond functions as it was intended. Ponds may be constructed on golf courses strictly as water hazards or for landscape purposes, but they often have the primary purpose of drainage and stormwater management, and are also often a source of irrigation water. Wildlife habitat is an ancillary benefit, and aesthetic value can also be derived from a pond whose primary purpose is stormwater detention.

Vegetation is managed differently for different purposes. Special practices may be required in stormwater management ponds. In ponds with littoral plantings, problem plants should be selectively controlled without damaging littoral shelves. If water from the pond contains herbicide and is used for irrigation, delay using the water for irrigation as directed by the herbicide label. The herbicide label must be consulted as the legal guideline. The management of vegetation for certain combinations of benefits may be mutually exclusive, and certain compromises may have to be made.

Practices commonly used to manage plant life in ponds include the modification of cultural practices surrounding the pond (e.g., fertilization practices), the introduction of desirable plants, the hand removal of plants or mechanical harvesting, biological controls, aeration, and chemical controls.

Herbicides (and algicides) registered by the EPA and the Minnesota Department of Agriculture for use in water are also an option. A commercial aquatic plant pesticide applicator license is required to use products with restricted use labels. Another option is to contract a reputable pond management company. As mentioned earlier, many surface waters are impaired due to high levels of copper in the water. Superintendents should be aware of any such designated waters in their area.

The method or combination of methods to be used depends on the management objectives for a pond. Selectivity (the ability of a practice to control certain plants and not others), secondary environmental effects on the pond, irrigation considerations, and permit restrictions are important considerations when determining the vegetation management practices to be used.

Types of Plant Life

A comprehensive lake management plan should include strategies to control the growth of nuisance vegetation that can negatively affect a pond's water quality and treatment capacity. These plants fall into two categories: phytoplankton (suspended algae) and filamentous algae, and plants (floating, submersed, and emersed).

Phytoplankton – Green and turbid water caused by abundant phytoplankton results from high levels of nutrients, particularly nitrogen and phosphorus, in pond water. Fertilizers and reclaimed water are common sources of nutrients on golf courses. The reduction of nutrient inputs to pond water is the best long-term solution to chronic phytoplankton problems. Irrigation should not directly strike or run off to waterbodies, and no-fertilization buffers should be maintained along the edges.

A dense and active littoral zone may reduce nutrient inputs before they reach open water. EPA-approved lake dyes that reduce light infiltration and algal photosynthesis may be helpful. Bacteria-containing pond clarifiers are available that reportedly reduce algae in water. These must be continually added to a pond, and the water must be aerated. Aeration alone may help correct certain problems associated with phytoplankton.

If other methods are not feasible, an algicide containing endothall, copper, or hydrogen peroxide can be used to temporarily reduce phytoplankton blooms. Fish mortality is likely to occur after algaecide application, because the decay of treated phytoplankton consumes oxygen, and oxygen is no longer being produced by phytoplankton, which are the primary source of oxygen in pond water. There is a greater potential for fish mortality when water temperatures are high. Oxygen depletion is less likely to be a problem with an algaecide containing hydrogen peroxide than one with copper or endothall. Phytoplankton are very resilient and will quickly reoccur if suitable conditions for growth prevail.

Filamentous Algae – Filamentous algae are one of the most common and difficult problems in ponds. Like phytoplankton, filamentous algae obtain nutrients from pond water. Therefore, these algae may be reduced if nutrient inputs to pond water can be reduced, and problems may be fewer if the pond is heavily vegetated with macrophytes. As with phytoplankton, dyes and aeration may help. However, some problems with filamentous algae may still occur. It is best to keep filamentous algae to a minimum by frequent hand removal and/or the frequent application of algicide to small areas of algae (spot treatment). Treating an entire pond with an algicide is likely to cause fish mortality due to the lowering of oxygen in the water.

Floating Plants – The most common floating plants that can become problems include duckweed (*Lemna* sp., *Spirodela* sp., *Landoltia* spp.). Floating plants, like algae, are the greatest problem under high nutrient conditions. Therefore, limiting nutrient runoff from artificial sources may reduce the problem. Small amounts of invasive, non-native plants such as water hyacinth and water lettuce can be hand removed or spot treated with herbicide.

Submersed Plants – While submersed plants provide certain wildlife benefits, they can become objectionable in small urban ponds if allowed to grow out of control. Because they can derive nutrients from both the water and hydrosoil, rooted submersed plants can proliferate under all but very low-nutrient conditions. Most submersed plants can be selectively controlled with herbicides without permanently damaging littoral shelves. Desirable vegetation may be damaged, or acceptable control may not be achieved.

Nuisance Plants – A newly-created pond offers a welcome mat for colonizing plants. Unfortunately, many are not native to Minnesota, and without natural enemies, find conditions ideal for rapid expansion to the detriment of native species. Some plants that are considered native, such as cattails, also find an open pond bank a great place to become established and expand, reducing the plant diversity that a healthy system requires. Even in established ponds, a drawdown of water levels can expose the pond bottom and create the kind of disturbed habitat that these colonizers love. Maintaining a pond with a diversity of desirable plants requires the selective removal of weedy plants. In ponds containing dense emergent vegetation, the appearance of the pond improves and the rate of detrital accumulation decreases if dead vegetation is removed in the fall or spring.

If cattails are allowed to become the dominant vegetation on a littoral shelf, reducing their population to a manageable level is very labor intensive and damaging to littoral shelf plantings. If possible, any regrowth from the rhizome fragments that are left after pulling or cutting should be treated when the shoots are no more than 1 foot tall.

Turfgrass Basic Pest Management

To grow healthy turfgrass in Minnesota, it is important for golf course superintendents to know what IPM is and how to implement it for each pest group (arthropods, diseases, and weeds). They must be well versed in pest identification, understand pest life cycles and/or conditions that favor pests, and know about all possible methods of controlling pests.

INTEGRATED PEST MANAGEMENT

IPM is a method of combining proper plant selection, correct cultural practices, the monitoring of pest and environmental conditions, the use of biological controls, and the judicious use of pesticides to manage pest problems. IPM is the selection, integration, and implementation of multiple pest control techniques based on predictable economic, ecological, and sociological consequences, making maximum use of naturally-occurring pest controls, such as weather, disease agents, and parasitoids, using various biological, physical, chemical, and habitat modification methods of control, and using artificial controls only as required to keep particular pests from surpassing intolerable population levels predetermined from an accurate assessment of the pest damage potential and the ecological, sociological, and economic cost of other control measures.

The philosophy of IPM was developed in the 1950s because of concerns over increased pesticide use, environmental contamination, and the development of pesticide resistance. The objectives of IPM include reducing pest management expenses, conserving energy, and reducing the risk of exposure to people, animals, and the environment. Its main goal, however, is to reduce pesticide use by using a combination of tactics to control pests, including cultural, biological, genetic, and chemical controls, as follows:

- **Cultural controls** consist of the proper selection, establishment, and maintenance (such as mowing/pruning, fertilization, and irrigation) of turf and landscape plants. Keeping turf healthy reduces its susceptibility to diseases and insects, thus reducing the need for chemical treatment.
- **Biological controls** involve the release and/or conservation of natural enemies (such as parasites, predators, and pathogens) and other beneficial organisms (such as pollinators). Natural enemies (including ladybird beetles and green lacewings) may be purchased and released near pest infestations. However, the golf course landscape can also be modified to attract natural enemies, provide habitat for them, and protect them from pesticide applications. For example, in nonplay areas, flowering plants may provide parasitoids with nectar, or sucking insects (aphids, mealybugs, or soft scales) growing on less valuable plants may provide a honeydew source for natural enemies.
- **Genetic controls** rely on the breeding or genetic engineering of turfgrasses and landscape plants that are resistant to key pests. Such resistance may increase a plant's tolerance of damage, or weaken or kill the pests. Pests may also develop more slowly on partially resistant plants, thus increasing their susceptibility to natural enemies or “softer” pesticides. Selecting resistant cultivars or plant species when designing a golf course is a very important part of IPM. Although superintendents often work with established plant material, they can still recommend changes. Every opportunity should be taken to educate builders, developers, landscape architects, plant producers, and others on which plants are best suited to golf courses.

Chemical controls include a wide assortment of conventional, broad-spectrum pesticides and more selective, newer chemicals, such as microbial insecticides and insect growth regulators. IPM is not antipesticide, but it does promote the use of the least toxic and most selective alternatives when chemicals are necessary. Pesticides are only one weapon against pests and should be used responsibly and in combination with other, less toxic control tactics.

The basic steps of an IPM program are as follows:

- Identify key pests on key plants.
- Determine the pest's life cycle, and know which life stage to target (for an insect pest, whether it is an egg, larva/nymph, pupa, or adult).
- Use cultural, mechanical, or physical methods to prevent problems from occurring (for example, prepare the site and select resistant plant cultivars), reduce pest habitat (for example, practice good sanitation and carry out pruning and dethatching), or promote biological control (for example, provide nectar or honeydew sources for natural enemies).
- Decide which pest management practice is appropriate and carry out corrective actions. Direct control to where the pest lives or feeds. Use properly-timed preventive chemical applications only when your professional judgment indicates that they are likely to control the target pest effectively, while minimizing the economic and environmental costs.
- Determine if the corrective actions actually reduced or prevented pest populations, were economical, and minimized risks. Record and use this information when making similar decisions in the future.

MONITORING/SCOUTING

Monitoring, or scouting, is the most important element of a successful IPM program. It enables you to monitor for the presence and development of pests throughout the year. By observing turf conditions regularly (daily, weekly, or monthly, depending on the pest) and noting which pests are present, intelligent decisions can be made regarding how damaging they are and what control strategies are necessary. Keep in mind that pests may be present for some time before damage occurs or is noticed. It is essential to record the results of scouting to develop historical information, document patterns of pest activity, and document successes and failures.

Look for the following when monitoring:

- **What are the signs?** These may include mushrooms, animal damage, insect frass, or webbing.
- **What are the symptoms?** Look for symptoms such as chlorosis, dieback, growth reduction, defoliation, mounds, or tunnels.
- **Where does the damage occur?** Problem areas might include the edges of fairways, shady areas, or poorly-drained areas.
- **When does the damage occur?** Note the time of day and the year, and the flowering stages of nearby plants.
- **What environmental conditions are present at the time of damage?** These include air temperature and humidity, soil moisture, soil fertility, air circulation, and amount of sunlight.

PESTS

Several fine-bladed turfgrasses are managed at the edge of their adaptations to create suitable surfaces for playing golf in Minnesota. Various groups of plant pathogens can disrupt play by marring and destroying all species and cultivars of this intensely-managed turf, if conditions are conducive to disease. As some superintendents note, the tolerance of golfers for disease damage is generally inversely proportional to what they pay to use the course. In other words, the more they pay, the better they expect the turf to look.

No measure can completely eliminate the threat of turfgrass disease on a golf course. However, turfgrass managers have several tactics and tools that can reduce the likelihood of disease. A superintendent's budget, turfgrass species and cultivars, and membership expectations dictate what options are available.

The first rule is to minimize plant stress by optimizing cultural management programs. Cultural factors that can influence turfgrass stress and the likelihood of disease problems include organic layer management, fertility programs, water management, and mowing height selection. Healthy, well-managed turfgrass is less likely to develop disease problems. Diseases that do occur are less likely to be severe because healthy turf has better recuperative potential than stressed, unhealthy turf. Successful superintendents find a balance between membership expectations and the edge of their turf's adaptation.

Many excellent fungicide products are labeled for use on golf courses and marketed to superintendents. Fungicide use should be integrated into an overall management strategy for a golf course. In general, plant diseases are difficult to manage once symptoms are severe in an area, and fungicides are most effective when used in preventive programs. The appropriate (most effective) preventive fungicide should be applied to susceptible turfgrasses when unacceptable levels of disease are likely to occur.

Determining when and where diseases are likely to occur requires an understanding of the potential disease problems for a particular turfgrass cultivar and knowledge of the impact that environmental variables such as temperature, relative humidity, and leaf wetness have on disease outbreaks. Because this type of prediction is difficult, and even veteran superintendents and plant pathologists cannot predict all disease outbreaks, curative treatments are sometimes necessary. Fungicide labels generally call for higher rates and shorter intervals when treating diseased turfgrass curatively. Selecting the appropriate fungicide product is very important for efficient and effective curative treatment and depends on a correct disease diagnosis.

No one fungicide product is effective against all common turfgrass pathogens. Also, for some turfgrass injuries and disorders (not caused by a pathogen), the symptoms are identical to those of disease. Some turfgrass diseases are fairly obvious, and others can cause a range of overlapping symptoms that makes correctly diagnosing the problem difficult. Diagnostic services are available from the University of Wisconsin Turf Diagnostic Lab and private laboratories. To avoid using the wrong product, ask your fungicide company sales representative, turfgrass consultant, or county agent for diagnostic lab confirmation to make sure the best fungicide product for your situation is applied.

ARTHROPODS

Many arthropods (especially insects and mites) occur in the turfgrasses and ornamental plant beds located on golf courses. Some are beneficial (e.g., pollinators, decomposers, and natural enemies) or aesthetically attractive (e.g., butterflies), while others may be nuisance pests or negatively affect plant health. Arthropods can cause various types of damage to turfgrass, depending on where they attack the plant. Major root-feeding pests in Minnesota are white grubs. Arthropods that commonly feed on leaves or stems include cutworms, billbugs and greenbugs. Nuisance pests may not directly damage turfgrass but can be abundant during short periods, make mounds or castings (e.g., earthworms), nest in sand traps or electrical equipment, or affect human or animal health (e.g., stinging wasps, fleas, and ticks).

Pest management decisions should be made with more localized information on pest life cycles and susceptible life stages. Early pest detection and identification are vital to any IPM program. Turf should be inspected as often as practical, especially in areas that tend to become reinfested each year. All employees should be trained to spot potential problems while performing their assigned duties. Specimens can be sent to the Extension Service at the University of Minnesota and private identification labs.

IPM is useful against most arthropod pests of turfgrass. It is both a practice and strategy to keep pest populations below damaging levels with minimal nontarget effects. When possible, it is important to identify which factors might predispose areas to unwanted arthropod pests and then modify those factors before using pesticides. For example, some golf course practices that enhance playability or plant growth (e.g., fertilization during grow-in or in late summer) can attract flying beetles or moths that lay eggs on grass blades or in the soil.

Cultural practices, such as mowing, dethatching, and aerating may help to mechanically kill some pests or reduce their habitats. Leaving roughs and driving ranges as untreated refuges for natural enemies, providing flower or nectar sources for parasitic flies or wasps, or applying insect-parasitic nematodes or pathogens to infested turfgrass may provide more sustainable pest suppression than a pesticide program.

Insecticides are effective tools if they are accurately selected, timed, and targeted against a pest's appropriate life stage. Products within several chemical classes are available to superintendents, and product manufacturers continue to create new chemical classes for use in turf and ornamentals. However, the potential for a pest to develop resistance to a pesticide is real and needs to be considered. Resistance is likely to develop if products in the same chemical class are repeatedly used without rotation, the insect has several generations a year, it has limited dispersal, and it can reproduce and develop quickly. For these reasons, aphids or mites are more likely to become resistant than white grubs.

WEEDS

A weed is any plant out of place or growing where it is not wanted. In addition to being unsightly, weeds compete with turfgrasses for light, soil nutrients, soil moisture, and physical space. Weeds also are hosts for other pests such as plant pathogens, nematodes, and insects, and certain weeds can cause allergic reactions in humans.

The most undesirable characteristic of weeds in turf is the disruption of visual turf uniformity that occurs when weeds with a different leaf width or shape, growth habit, or colors are present.

Broadleaf weeds such as dandelions, creeping charlie and spurge, have leaves with a different size and shape than the desirable turf species. Annual grasses, such as crabgrass, grow in clumps or patches that also disrupt turf uniformity. In addition, large clumps are difficult to mow effectively and increase maintenance problems. The lighter-green color typically associated with certain weeds, such as annual bluegrass, in a golf green often distracts from the playing surface.

Weed management is an integrated process where good cultural practices are employed to encourage desirable turfgrass ground cover, and where herbicides are intelligently selected and judiciously used. A successful weed management program consists of: 1) preventing weeds from being introduced into an area, 2) using proper turfgrass management and cultural practices to promote vigorous competitive turf, 3) properly identifying weeds, and 4) properly selecting and using the appropriate herbicide, if necessary.

Weeds often are the result, but never the cause, of a weakened turf. The major reasons for weed encroachment are reduced turfgrass quality and low density. Weakened turf or bare areas results from:

- Selection of turf species or cultivars not adapted to the prevalent environmental conditions
- Damage from turfgrass pests such as diseases, insects, nematodes, and animals
- Environmental stresses such as shade, drought, heat, and cold
- Improper turf management practices, such as the misuse of fertilizer and chemicals, improper mowing height or mowing frequency, and improper soil aeration
- Physical damage and compaction from excessive traffic.

Unless the factors that contribute to the turf decline are corrected, continued problems with weed encroachment can be expected.

Proper weed identification is essential for effective management and control. Turf managers should be able to correctly identify at least the most common species for their geographic area. Because weeds often indicate fertilizer, drainage, traffic, or irrigation problems, correct weed identification can help turf managers to determine the underlying causes of certain infestations and correct them.

Identification begins with classifying the weed type. Broadleaves, or dicotyledonous plants, have two seed cotyledons (young leaves) at emergence and have netlike veins in their true leaves. They often have colorful flowers. Examples include clover, spurges, plantain, and dandelion.

Grasses, or monocots, have only one seed cotyledon present when seedlings emerge from the soil. They also have hollow, rounded stems with nodes (joints) and parallel veins in their true leaves. Examples include crabgrass and annual bluegrass. Sedges and rushes generally favor a moist habitat and have stems that are either triangular-shaped and solid (sedges), or round and solid (rushes).

Weeds complete their life cycles in either one growing season (annuals), two growing seasons (biennials), or three or more years (perennials). Annuals that complete their life cycles from spring to fall are referred to as summer annuals. Those that complete their life cycles from fall to spring are winter annuals.

Pesticide Interactions

Golf courses are typically dependent on pesticides for turfgrass management. In Minnesota, concern about the presence of pesticides in the environment and the threat they pose to surface water and ground water quality is significant. The careful use of pesticides to avoid environmental contamination is an important aspect of course management and is desired by both superintendents and the general public. This section discusses factors affecting the behavior of pesticides in soil and water, and how pesticides should be selected and used to prevent environmental contamination.

SURFACE WATER AND GROUND WATER RESOURCES Surface waters are those we can see on the surface of the earth, including lakes, rivers, streams, wetlands, estuaries, and even the oceans. They are replenished by rain, runoff, the upwelling of ground water, and the lateral discharge of ground water. Ground water, the source of water for wells and springs, is found underground, within cracks in bedrock or filling the spaces between particles of soil and rocks. The ground water layer in which all available spaces are filled with water is called the saturated zone.

The dividing line between the saturated zone and overlying unsaturated rock or sediments is called the water table.

Water entering the soil gradually percolates downward to become ground water if it is not first taken up by plants, evaporated into the atmosphere, or held within soil pores. This percolating water, called recharge, passes downward through the root zone and unsaturated zone until it reaches the water table. Effective programs for ground water protection focus primarily on the recharge process, because this controls both the quantity and the quality of water reaching the saturated zone.

The quantity of recharge in any particular location depends on the amount of precipitation or irrigation, runoff soil storage, evapotranspiration, the type of soil, and the site's topography and geology. Seasonal fluctuations occur in the quantity of recharge, leading also to fluctuations in the depth of the water table. During the dry season, shallow wells can run dry and also cause some springs, wetlands, and small streams to dry up due to a falling water table. Recharge is the only natural means of replenishing ground water supplies, and the water table drops if the amount of water lost exceeds the amount of recharge.

BEHAVIOR OF PESTICIDES IN SOIL AND WATER Once a pesticide is applied to turfgrass, a number of things may happen. The pesticide may be taken up by plants, or ingested by animals such as insects and earthworms or by microorganisms in the soil. It may move downward in the soil and either adhere to particles or dissolve. The pesticide may volatilize and enter the atmosphere, or break down via microbial and chemical pathways into other, less toxic compounds. Pesticides may be leached out of the root zone or washed off the land surface by rain or irrigation water. Although the evaporation of water at the ground surface can lead to the upward flow of water and pesticides, in most Minnesota soils this process is likely not to be as important as downward leaching from irrigation and/or rainfall.

Nontarget Effects

Although pesticides can effectively control pests, they can also be dangerous when misused. Fish kills, reproductive failure in birds, and acute illnesses in people have all been attributed to exposure to or the ingestion of pesticides—usually as a result of misapplication, spray drift or the careless disposal of unused pesticides and containers. In addition to obvious nontarget organisms such as people, pets, birds, and wildlife, other important organisms that can be affected by pesticides include earthworms, honeybees and other beneficial arthropods, and fungi or other microorganisms that might degrade thatch or control pathogens, or are important to nutrient dynamics and overall soil health.

There are three principal ways in which pesticides can leave their application site: runoff, leaching, and spray drift during application. Runoff is the physical transport of pesticides over the surface of the ground with rainwater or irrigation water that does not penetrate the soil. Leaching is a process where pesticides are flushed through the soil by rain or irrigation water as it moves downward. Many of Minnesota's soils are sandy, making them more susceptible to leaching of dissolved nutrients and pesticides.

Drift is the airborne movement of pesticide particles into nontarget areas during application. Droplet size, which is affected by nozzle type and spray pressure, wind speed, and application height are the most important factors influencing spray drift. Drift is one of the most likely causes of neighborhood complaints and may result in injury to greens or neighboring properties, pets, or people. It may also contaminate surface water if the pesticide settles on a waterbody. In addition, secondary drift may occur when a pesticide volatilizes from the soil or leaf blade and moves with the air.

Due to Minnesota's soils and geology, there are also significant surface water–ground water interactions, which allow pollutants to move from one to the other. Sinkholes and springs are the most obvious, but equally important are the coarse soils, shallow water tables, and drainage ditches and canals.

Persistence and Sorption

The fate of a pesticide applied to soil depends largely on two of its properties: persistence and sorption. Persistence defines the stability of a pesticide. Most modern pesticides are designed to break down or degrade relatively rapidly over time as a result of chemical and microbiological reactions in soils. Sunlight breaks down some pesticides, and soil microorganisms can break down others. Some pesticides are degraded or metabolized to intermediate substances, called *degradates*, as they break down. Degradation time is expressed as half-life (T1/2), the amount of time it takes for the concentration of a pesticide in soil to be reduced by one-half. For example, if the half-life of a pesticide is 10 days in the topsoil, then theoretically, the concentration would decrease from 100% to 50% over 10 days. It would take an additional 10 days for the concentration to be further reduced from 50% to 25%. In the soil, a pesticide's half-life may be affected by soil type, soil horizons, sediments, temperature, and pH.

As a pesticide moves through soil, some of it sticks to soil particles, particularly organic matter or clay particles, through a process called sorption, and some dissolves in soil water. As more water enters the soil through rain or irrigation, the sorbed pesticide molecules may be from soil particles through a process called *desorption*. The solubility of a pesticide and its sorption to soil are two critical factors affecting the fate of a pesticide.

A useful index for quantifying pesticide sorption on soils is the partition coefficient (Koc) which is defined as the ratio of pesticide concentration in the sorbed state (i.e., bound to soil particles) and the solution phase (i.e., dissolved in the soil water). Thus, for a given amount of pesticide applied, the smaller the Koc value, the greater the tendency to move into solution. Pesticides with small Koc values are more likely to leach, compared with those having large Koc values, which are more likely to bind with soil and organic matter. For example, glyphosate, which has a Koc value of 24,000, does not leach because it binds very tightly to soil. In contrast, dicamba, which has a Koc value of 2, can readily leach. This explains why dicamba should never be sprayed under the drip line of a tree, because it can readily move into the roots. Glyphosate, on the other hand, is frequently sprayed as an edging material around the trunk of a tree without causing damage. Dicamba is not bound to the soil, and glyphosate is strongly bound.

An added complexity in turf is thatch. When washed off turfgrass leaves, a pesticide encounters the thatch layer that accumulates on top of the soil. This layer of living and dead leaves, stems, and other organic matter provides sites for pesticides to attach and become immobilized. This process often explains the poor efficacy of certain pesticides on their target organisms (e.g., insecticides on controlling grub worms).

Turf also supports an abundant population of microorganisms. Once in the soil, a pesticide may be metabolized and rendered ineffective by these microorganisms. The role and impact that thatch sorption and degradation have on pesticide mobility is an important area of ongoing research.

Estimating Pesticide Losses

When estimating pesticide losses from soils and their potential to contaminate ground water or surface water, it is essential to consider both persistence and sorption. In general, strongly sorbed pesticides (that is, compounds with large Koc) are likely to remain near the ground surface, reducing the likelihood of leaching but increasing the chances of being carried to surface water via runoff or erosion. In contrast, weakly sorbed pesticides are more likely to leach through the soil and reach ground water.

For nonpersistent pesticides with a short half-life, the possibility of surface water or ground water contamination depends primarily on whether heavy rains (or irrigation) occur soon after pesticide application. Without water for movement these pesticides are more likely to remain within the biologically-active turf root zone where they may be degraded. In addition, the depth to the water table and the type of subsoil and surficial geology may also affect a pesticide’s ability to reach ground water. Therefore, pesticides with intermediate Koc values and short T1/2 values may be considered lower risk with respect to water quality, because they are not readily leached and degrade fairly rapidly, reducing their potential impact on nearby waterbodies. Soils with hard pans (i.e., spodic horizons) or finer-textured horizons in the subsoil may have a greater ability to adsorb a pesticide as it leaches through the surface horizons. The worst-case scenario with respect to ground water vulnerability is where sandy soil overlies porous limestone with a shallow water table.

PESTICIDE SELECTION AND USE

The use of pesticides should be part of an overall pest management strategy that includes biological controls, cultural methods, pest monitoring, and other applicable practices, referred to altogether as IPM. When a pesticide application is deemed necessary, its selection should be based on effectiveness, toxicity to nontarget species, cost, and site characteristics, as well as its solubility and persistence. Half-lives are particularly important when the application site of a pesticide is near surface water or underlain with permeable subsoil and a shallow aquifer. Short half-lives and intermediate to large Koc are best in this situation. Many areas of Minnesota have impermeable subsoils that impede the deep leaching of pesticides. On such land, pesticides with low Koc and moderate-to-long half-lives should be used cautiously to prevent rapid transport in drainage water to a nearby waterbody. Non-erosive soils are common to much of Minnesota, and pesticides with large Koc remain on the application site for a long time. However, the user should be cautious of pesticides with long half-lives, as they are more likely to build up in the soil.

Environmental characteristics of a pesticide can often be ascertained (without any additional information on environmental fate and/or non-target effects) by the environmental hazards statement found on pesticide product labels. The environmental hazards statement (referred to as “Environmental Hazards” on the label and found under the general heading “Precautionary Statements”) provides the precautionary language advising the user of the potential hazards to the environment from the use of the product. The environmental hazards generally fall into three categories: 1) general environmental hazards, 2) non-target toxicity, and 3) endangered species protection. Advisories specific to these general categories include:

- General Environmental Hazards

  Generic water advisory (for terrestrial pesticides) – “Do not apply directly to water”

  Ground water advisory – for pesticides (or major degradates) that are mobile and persistent in the environment

  Surface water advisory – for pesticides with the potential to contaminate surfaces water via spray drift and/or potential for runoff for several months after application (i.e., persistent in soil)

- Non-Target Toxicity

  High toxicity to aquatic organisms (i.e., fish and/or aquatic invertebrates)

  High toxicity to wildlife (i.e., birds and mammals)

  High toxicity to beneficial insects (i.e., honey bees)

- Endangered Species Protection

  Product may have effects on endangered species – instructions are provided to users on mitigating potential effects (i.e., on the label or Endangered Species Protection Bulletin)

Several factors should be considered when applying pesticides with potential environmental impacts specified on the label (Environmental Hazards statement) including:

- Groundwater Hazards

  Proximity to sinkholes, wells, and other areas of direct access to ground water, such as karst topograph

  Highly permeable soils

Soils with poor adsorptive capacity

Shallow aquifers

Wellhead protection areas

- Surface Water Hazards

  Proximity to surface water

  Runoff potential

  Rainfall forecast

  Prevailing wind direction and speed (drift)

  Wind erosion

- Non-Target Hazards

  Proximity to surface water

  Proximity to wildlife

  Potential for the presence of foraging bees and beneficial insects

- Endangered Species Protection

  Proximity to federally listed species and/or habitat

Pesticide Risk and Applicator Safety

Pesticides belong to numerous chemical classes that vary greatly in their toxicity. The human health risk associated with pesticide use is related to both pesticide toxicity and the level of exposure. The risk of a very highly toxic pesticide may be very low if the exposure is sufficiently small. Conversely, pesticides having low toxicity may present a potential health risk if the exposure is sufficiently high. Toxicity is measured using an LD50 value, which is the dose that is lethal to 50% of the test animal population. Therefore, the lower the LD50 value, the more toxic the pesticide.

Pesticide exposures are classified as acute or chronic. **Acute** refers to a single exposure or repeated exposures over a short time, such as an accident during mixing or applying pesticides. **Chronic** effects are associated with long-term exposure to lower levels of a toxic substance, such as the ingestion of pesticides in the diet or ground water.

Pesticide labels contain signal words that are displayed in large letters on the front of the label to indicate approximately how acutely toxic the pesticide is to humans. The signal word is based on the entire contents of the product, not the active ingredient alone, and therefore reflects the acute toxicity of the inert ingredients. The signal word does not indicate the risk of chronic effects. Pesticide products having the greatest potential to cause acute effects through oral, dermal, or inhalation exposure have DANGER as their signal word, and their labels carry the word POISON printed in red with the skull-and-crossbones symbol. Products that have the DANGER signal word due to their potential for skin and eye irritation only do not carry the word POISON or the skull-and-crossbones symbol. Other signal words include WARNING for moderately toxic pesticides and CAUTION for slightly to relatively nontoxic pesticides.

PESTICIDE HANDLING AND STORAGE

The proper handling and storage of pesticides is important. Failure to do so correctly may lead to the serious injury or death of an operator or bystander, fires, environmental contamination that may result in large fines and cleanup costs, civil lawsuits, the destruction of the turf you are trying to protect, and wasted pesticide product.

PERSONAL PROTECTIVE EQUIPMENT

Personal protective equipment (PPE) statements on pesticide labels provide the applicator with important information on protecting himself/herself. PPE provides a barrier between the applicator and a pesticide. PPE statements on pesticide labels dictate the minimum level of protection that an applicator must wear; additional protection is encouraged but is up to the discretion of the applicator. Some pesticides require additional garments during high-risk tasks such as mixing, loading, and cleaning. Note also that PPE may not provide adequate protection in an emergency situation.

Store PPE where it is easily accessible but not in the pesticide storage area (where it may become damaged or contaminated). Check the label and the Material Safety Data Sheet (MSDS) for each pesticide for the safety equipment requirements.

PESTICIDE STORAGE

The storage and handling of pesticides and fertilizers in their concentrated forms pose the highest potential risk to ground water or surface water from agricultural chemicals. For this reason, it is essential that facilities for storing and handling these products be properly sited, designed, constructed, and operated.

Before you site a pesticide storage facility, check to see if your local government has a zoning ordinance that influences the locations of these types of facilities. If so, it must be obeyed. Similarly, depending on the kinds of products stored and their quantity, you may need to register the facility with the MDA and your local emergency response agency. Check with your dealer about community right-to-know laws for the materials that you purchase.

Minnesota law indicates every golf management facility must have an emergency response plan in place, and golf course personnel should be familiar with the plan before an emergency occurs, such as a lightning strike, fire, or tornado. Individuals conducting emergency pesticide cleanups should be properly trained under the requirements of the federal Occupational Safety and Health Administration (OSHA).

Storage Facilities

Pesticides should be stored in a lockable concrete or metal building. The secure storage of pesticides benefits everybody. It both helps to protect Minnesota’s environment and reduces the risk of pesticide theft. It also reduces the chance of pesticides getting into the hands of vandals and terrorists. Secure storage is equally important for all pesticides—not just those that are highly toxic.

The pesticide storage area should be separate from other buildings, or at least separate from areas used to store other materials, especially fertilizers. These facilities should be located at least 50 feet from other types of structures to allow fire department access.

Floors should be impervious and sealed with a chemical-resistant paint. They should have a continuous sill to retain spilled materials and no drains, although a sump may be included. Sloped ramps should be provided at the entrance to allow the use of wheeled handcarts for moving material in and out of the storage area safely. Shelving should be made of sturdy plastic or reinforced metal. Metal shelving should be kept painted to avoid corrosion. Wood shelving should never be used, because it may absorb spilled pesticides. Automatic exhaust fans and an emergency wash area should be provided. Explosion-proof lighting may be required. Light and fan switches should be located outside the building, so that both can be turned on before staff enter the building and turned off after they leave the building. PPE should be easily accessible and stored immediately outside the pesticide storage area. An inventory of the pesticides kept in the storage building and the MSDSs for the chemicals used in the operation should be accessible on the premises but not kept in the pesticide storage room itself (as that would make them unavailable in an emergency).

Maintaining a Pesticide Inventory

Do not store large quantities of pesticides for long periods. Adopt the “first in–first out” principle, using the oldest products first to ensure that the product shelf life does not expire.

Store pesticides in their original containers. Never put pesticides in containers that might cause children and others to mistake them for food or drink. Keep the containers securely closed and inspect them regularly for splits, tears, breaks, or leaks. All pesticide containers should retain their original labels. Arrange the containers so that the labels are clearly visible, and make sure the labels are legible. Refasten all loose labels, using nonwater-soluble glue or sturdy, transparent packaging tape. Do not refasten labels with rubber bands (these quickly rot and break) or nontransparent tape, such as duct tape or masking tape (these may obscure important product caution statements or label directions for product use). If a label is damaged, immediately request a replacement from the pesticide dealer or formulator. As a temporary substitute for disfigured or badly damaged labels, fasten a baggage tag to the container handle. On the tag write the product name, formulation, concentration of active ingredient(s), and date of purchase. If there is any question about the contents of a container, set it aside for proper disposal.

Flammable pesticides should be separated from those that are nonflammable. Dry bags should be raised on pallets to ensure that they do not get wet. Liquid materials should always be stored below dry materials, never above them. Labels should be clearly legible. Herbicides, insecticides, and fungicides should be separated to prevent cross-contamination and minimize the potential for misapplication.

Storage building plans are available from several sources, including the Midwest Plan Service and the USDA–NRCS.

Your county offers provides a free, disposal service for pesticide end users—specifically, in agricultural, nursery, golf course, and pest control operations—to eliminate potential public health and environmental hazards from cancelled, suspended, and unusable pesticides that are being stored. The program offers an opportunity to avoid the formidable regulatory barriers to legal disposition of these materials and to promote safe and environmentally sound pesticide use, handling and disposal.

CHEMICAL MIXING AND LOADING

Pesticide leaks or spills, if contained, will not percolate down through the soil into ground water or run off the surface to contaminate streams, ditches, ponds, and other waterbodies. One of the best containment methods is the use of a properly designed and constructed chemical mixing center (CMC). The Midwest Plan Service book, Designing Facilities for Pesticide and Fertilizer Containment (revised 1995), the Tennessee Valley Authority (TVA) publication, Coating Concrete Secondary Containment Structures Exposed to Agrichemicals (Broder and Nguyen, 1995), and USDA–NRCS Code 703 contain valuable information about constructing CMC facilities. One point to remember is that the sump is only a point of collection and pump suction; the containment volume is the entire volume of the bermed and sealed pad. The sump should be small enough to provide for rapid and easy cleaning.

Although the use of a CMC is not mandatory, adherence to the practices in the publications listed above is strongly encouraged. A CMC provides a place for performing all operations where pesticides are likely to be spilled in concentrated form—or where even dilute formulations may be repeatedly spilled in the same area—over an impermeable surface.

Loading pesticides and mixing them with water or oil diluents should be done over an impermeable surface (such as lined or sealed concrete), so that spills can be collected and managed. This surface should provide for easy cleaning and the recovery of spilled materials. In its most basic form, a CMC is merely a concrete pad treated with a sealant and sloped to a liquid-tight sump where all of the spilled liquids can be recovered. Pump the sump dry and clean it at the end of each day. Liquids and sediments should also be removed from the sump and the pad whenever pesticide materials are changed to an incompatible product (i.e., one that cannot be legally applied to the same site). Liquids and sediments can then be applied as a pesticide, provided the label instructions are followed, instead of requiring disposal as a (possibly hazardous) waste.

Absorbents such as cat litter or sand may be used to clean up small spills and then applied as a topdressing in accordance with the label rates, or disposed of as a waste. Solid materials, of course, can be swept up and reused.

Washwater from pesticide application equipment must be managed properly, as it contains pesticide residues. The BMP for this material is to collect it and use it as a pesticide in accordance with the label instructions. This applies to washwater from both inside and outside the application equipment. Rinsate may be applied as a pesticide (preferred) or stored for use as makeup water for the next compatible application. Otherwise, it must be treated as a (potentially hazardous) waste. After the equipment is washed and before an incompatible product is handled, the sump should be cleaned of any liquid and sediment.

PESTICIDE CONTAINER MANAGEMENT

The containers of some commonly-used pesticides are classified as hazardous wastes if not properly rinsed, and as such, are subject to the many rules and regulations governing hazardous waste. The improper disposal of a hazardous waste can result in very high fines and/or criminal penalties. However, pesticide containers that have been properly rinsed can be handled and disposed of as nonhazardous solid waste. Federal law (FIFRA) requires pesticide applicators to rinse all empty pesticide containers before taking other container disposal steps. **Under federal law (the Resource Conservation and Recovery Act, or RCRA), A PESTICIDE CONTAINER IS NOT EMPTY UNTIL IT HAS BEEN PROPERLY RINSED.**

Immediate and proper rinsing removes more than 99% of the container residues typically left by most liquid pesticide formulations. Properly-rinsed pesticide containers pose a minimal risk for the contamination of soil and water resources, and preventing contamination is an important part of pesticide management. Containers holding liquid pesticides should be rinsed as soon as they are empty; thus, the time to rinse is during the mixing and loading process. Immediate rinsing has several advantages. A freshly-emptied container is easier to clean because the formulation residues have not had time to dry and cake on the inside of the container. Also, rinsing containers during the mixing and loading process solves the problem of what to do with the container rinse water, as it is added to the water used to prepare the finished spray mix. Newly-emptied pesticide containers can be properly rinsed by either triple rinsing or pressure rinsing—both methods work. The steps for triple rinsing and pressure rinsing a container are as follows:

Triple Rinsing a Container

1. Put on the PPE listed on the product's label.
2. Allow the formulation to drip drain from its container into the sprayer tank for at least 30 seconds.
3. Partially fill the container with clean diluent, usually water (about 20% of its capacity).
4. With the container cap placed back on, swirl the water so that all sides are rinsed.
5. Pour the rinse water back into the sprayer tank and allow the container to drip drain for at least 30 seconds.
6. Repeat Steps 2 through 5 twice more.

Pressure Rinsing a Container

1. Put on the PPE listed on the product's label.
2. Install a pressure-rinse nozzle on a hose connected to a water supply capable of delivering 35 to 60 pounds per square inch (psi) of water pressure.
3. Allow the formulation to drip drain from its container into the sprayer tank for at least 30 seconds.
4. Firmly press the pressure-rinse nozzle tip into the side of the pesticide container until the probe is inserted and seated, and then turn on and rinse the container for at least 30 seconds with it draining into the sprayer tank. For containers that are larger than 5 gallons, insert the pressure-rinse nozzle into the tank’s bottom.
5. Allow the container to drip drain for at least 30 seconds.

Recycle rinsed containers in counties where a program is available.

PESTICIDE SPILL MANAGEMENT

Clean up spills as soon as possible. The sooner you can contain, absorb, and dispose of a spill, the less chance there is that it will cause harm. Always use the appropriate PPE as indicated on the MSDS and the label. In addition, follow the following four steps:

1. CONTROL actively spilling or leaking materials by setting the container upright, plugging leak(s), or shutting the valve.
2. CONTAIN the spilled material using barriers and absorbent material.
3. COLLECT spilled material, absorbents, and leaking containers and place them in a secure and properly labeled container.
4. STORE the containers of spilled material until they can be applied as a pesticide or appropriately disposed of.

Small liquid spills may be cleaned up by using an absorbent such as cat litter, diluting with soil, and then applying the absorbent to the crop as a pesticide in accordance with the label instructions.

Golf course managers and landowners must comply with all applicable federal, state, and local regulations on spill response training for employees, spill-reporting requirements, spill containment, and cleanup. Keep spill cleanup equipment available when handling pesticides or their containers. If a spill occurs of a pesticide covered by certain state and federal laws, you may need to report any accidental release if the spill quantity exceeds the reportable quantity of active ingredient specified in the law. Large spills or uncontained spills involving hazardous materials may best be remediated by hazardous material cleanup professionals.

Maintenance and Operation

FUELING AREAS

The first line of management is to minimize the possibility of a discharge and the need for disposal of water captured in the containment system. Critical levels at which discharge is considered should be established for each facility and the levels marked on the containment wall. This prevents the frequent and unnecessary discharge of small volumes.

The water to be discharged must always be checked for contamination, by looking for an oil sheen, observing any smell of fuel or oil, or by using commercially available test kits. Never discharge to the environment any water that is contaminated.

Treat contaminated water on site by using commercially available treatment systems, discharging it to an Minnesota Pollution Control-permitted off-site industrial wastewater treatment system, or transporting it by tanker truck to a treatment facility. Never discharge to a sanitary sewer system without written permission from the utility. Never discharge to a septic tank. For more information on disposal options, contact the appropriate MPCA district office.

If the water is not contaminated, it can be reused or discharged to a permitted stormwater treatment system, such as a retention area, grassed swale, or wet detention pond, although this practice is not encouraged. Do not discharge it during or immediately after a rainstorm, since the added flow may cause the permitted storage volume of the stormwater system to be exceeded.

EQUIPMENT-WASHING FACILITY

An equipment-washing facility can be a source of both surface water and ground water pollution, if the washwater generated is not properly handled. All equipment used in the maintenance of golf courses and associated developments should be designed, used, maintained, and stored in a way that eliminates or minimizes the potential for pollution. Washwater generated from the general washing of equipment, other than pesticide application equipment, may not have to be collected. Always check with local authorities to determine which BMPs are accepted in your jurisdiction.

BMPs for the disposal of washwater (from other than pesticide application equipment, and with no degreasers or solvents) depend on several factors, such as the volume of washwater generated, the nature of the surrounding area, and the frequency of the operations. For limited washdown of ordinary field equipment, it may be legal to allow the washwater to flow to a grassed retention area or swale. Do not allow any washwater to flow directly into surface waters. Always check with local authorities to determine whether other requirements may apply. Discharge to a septic system is illegal.

Other options include the following:

- Use a closed-loop washwater recycling system and follow MDA BMPs
- Discharge to a treatment system that is permitted under MPCA industrial wastewater rules
- Use the washwater for field irrigation

Grass-covered equipment should be brushed or blown with compressed air before being washed. Dry material is much easier to handle and store or dispose of than wet clippings. It is best to wash equipment with a bucket of water and a rag, using only a minimal amount of water to rinse the machine. Spring-operated shutoff nozzles should be used. Freely-running hoses waste vast amounts of water, and water can harm the hydraulic seals on many machines. Where formal washing areas are not available, a “dog leash” system using a short, portable hose to wash off the grass at random locations with syringing valves may be an option. Again, do not allow any washwater to flow directly into surface waters or storm drains.

While there are no state requirements to have a closed recycling system for washwater, the use of a well-designed system is considered one of the available BMPs to deal with this issue. Be cautious in operating a system where maintenance activities are involved, because the filters can concentrate traces of oils and metals that are washed off the engines and worn moving parts. In some cases, the concentrations of these substances can become high enough that the filters must be treated and disposed of as hazardous waste. Ask the recycling systems manufacturer or sales representative for information on filter disposal. The contractor who handles oil filters, waste oil, and solvents can probably handle these filters, too.

Oil/water separators can be used but must be managed properly to avoid problems. Do not wash equipment used to apply pesticides on pads with oil/water separators, because the pesticide residues will contaminate the oil that is salvaged. Be aware that the oil collected in these systems may be classified as a hazardous waste (due to the high concentrations of heavy metals from engine wear), making disposal expensive. Usually, filters from these systems may be disposed of at an approved landfill. Keep all records on the disposal of these materials to prove that you disposed of them properly.

Oil/water separators are generally not necessary, unless the water from the system is to be reclaimed for some particular end use, or large volumes of water are generated and the industrial wastewater permit, local government, or receiving utility requires such a system.

PESTICIDE APPLICATION EQUIPMENT

Washwater from pesticide application equipment must be managed properly, as it contains pesticide residues.

The BMP for this material is to collect it and use it as a pesticide in accordance with the label instructions for pesticide. This applies to washwater from both the inside and the outside of the application equipment. Often, the easiest way to do this is to wash the equipment in the pesticide fill area. The pad should be flushed with clean water after the equipment is washed, and the captured washwater should be applied to the labeled site as a dilute pesticide, or it may be pumped into a rinsate storage tank for use in the next application. The sump should then be cleaned of any sediment before another type of pesticide is handled.

Clean the tires and particularly dirty areas of the equipment's exterior with plain water before bringing it into the pad area. This practice prevents unwanted dirt from getting on the mix/load pad and sump, or from being recycled into the sprayer. Avoid conducting such washing in the vicinity of wells or surface waterbodies.

EQUIPMENT MAINTENANCE AREAS

Equipment used to apply pesticides and fertilizers should be stored in areas protected from rainfall. Rain can wash pesticide and fertilizer residues from the exterior of the equipment, and these residues can contaminate soil or water. Pesticide application equipment can be stored in the pesticide fill area, but fertilizer application equipment should be stored separately. Blow or wash loose debris off the equipment to prevent dirt from getting on the pesticide fill pad, where it could become contaminated with pesticides.

Other equipment should be stored in a clean, safe and protected area when not in use. One BMP is to use paint to delineate parking areas for each piece of equipment. This makes it easy to notice fluid leaks and take corrective action.

WASTE HANDLING

HAZARDOUS MATERIALS

Ensure that all containers are sealed, secured, and properly labeled. Use only state approved, licensed contractors for disposal.

PESTICIDES

Remember, pesticides that have been mixed so they cannot be legally applied to a site in accordance with the label must be disposed of as a waste. Depending on the materials involved, they may be classified as hazardous waste.

PESTICIDE CONTAINERS

Rinse pesticide containers as soon as they are empty. Pressure rinse or triple rinse containers, and add the rinse water to the sprayer. Shake or tap nonrinseable containers, such as bags or boxes, so that all dust and material into the application equipment. Always wear the proper PPE when conducting rinse operations. See the section on pesticide container management for more details.

After cleaning them, puncture the pesticide containers to prevent reuse (except glass and refillable minibulk containers). Keep the rinsed containers in a clean area, out of the weather, for disposal or recycling. Storing the containers in large plastic bags is one popular option to protect the containers from collecting rainwater. Recycle rinsed containers in counties where an applicable program is available, or take them to a landfill for disposal. Check with your local landfill before taking containers for disposal, as not all landfills will accept them.

USED OIL, ANTIFREEZE, AND LEAD-ACID BATTERIES

Collect used oil, oil filters, and antifreeze in separate marked containers and recycle them. Recycling is the only legal option for handling used oil. Oil filters should be drained (puncturing and crushing helps) and taken to the place that recycles your used oil, or to a hazardous waste collection site. Many gas stations or auto lube shops accept small amounts (including oil filters) from individuals.

Antifreeze must be recycled or disposed of as a hazardous waste. Commercial services are available to collect this material.

Lead-acid storage batteries are classified as hazardous wastes unless they are recycled. All lead-acid battery retailers in Minnesota are required by law to accept returned batteries for recycling. Used acid from these batteries contains high levels of lead and must be disposed of as a hazardous waste, unless the acid is contained within a battery being recycled. Make sure that all caps are in place to contain the acid. Store batteries on an impervious surface and preferably under cover. Remember, spent lead-acid batteries must be recycled if they are to be exempt from strict hazardous waste regulations.

Do not mix used oil with used antifreeze or sludge from used solvents.

SOLVENTS AND DEGREASERS

One of the key principles of pollution prevention is to reduce the unnecessary use of potential pollutants. Over time, the routine discharge of even small amounts of solvents can result in serious environmental and liability consequences, due to the accumulation of contaminants in soil or ground water. As little as 25 gallons per month of used solvents to be disposed of can qualify you as a “small quantity generator” of hazardous waste, triggering EPA reporting requirements.

Whenever practical, replace solvent baths with recirculating aqueous washing units (which resemble heavy-duty dishwashers). Soap and water or other aqueous cleaners are often as effective as solvent-based ones. Blowing off equipment with compressed air instead of washing with water is often easier on hydraulic seals and can lead to fewer oil leaks.

Storage

Store solvents and degreasers in lockable metal cabinets in an area away from ignition sources (e.g., welding areas or grinders), and provide adequate ventilation.

They are generally toxic and highly flammable. Never store them with pesticides or fertilizers, or in areas where smoking is allowed. Keep basins or cans of solvent covered to reduce the emissions of volatile organic compounds (VOCs) and fire hazards. Keep an inventory of the solvents stored and the MSDSs for these materials on the premises, but not in the solvent storage area. Keep any emergency response equipment recommended by the manufacturer of the solvent in a place that is easily accessible and near the storage area, but not inside the area itself. Follow OSHA signage requirements.

Use

Always wear the appropriate PPE, especially eye protection, when working with solvents. Never allow solvents to drain onto pavement or soil, or discharge into water-bodies, wetlands, storm drains, sewers, or septic systems, even in small amounts. Solvents and degreasers should be used over a collection basin or pad that collects all used material. Most solvents can be filtered and reused many times. Store the collected material in marked containers until it can be recycled or legally disposed of.

Solvent disposal

Many firms provide solvent washbasins that drain into recovery drums and a pickup service to recycle or properly dispose of the drum contents. Collect used solvents and degreasers, place them into containers marked with the contents and the date, and then have them picked up by a service that properly recycles or disposes of them. Never mix used oil or other liquid material with the used solvents.

COMPOSTING

Grass clippings and routine, healthy landscape trimmings should be composted and used to improve the soil. Do not compost diseased material, as this may spread disease.

PAPER, PLASTIC, GLASS, AND ALUMINUM RECYCLING

Office paper, recyclable plastics, glass, and aluminum should be recycled. Place containers for recycling aluminum cans and glass or plastic drink bottles at convenient locations on the course.

GLOSSARY

annual grasses Grasses that normally complete their life cycles in one year.

apron The fairway area close to and in front of the putting green, adjoining the putting green collar. This area is normally mowed at fairway height but sometimes is mowed slightly closer.

bentgrass Generally speaking, bentgrasses are tolerant of cold weather, extremely fine-bladed and very popular among golfers, especially for greens. Bentgrasses are even in demand in the South, but it is difficult and costly to maintain them in warm climates.

biennial A term applied to plants that normally complete their life cycles in two years.

biological control Control of turfgrass pests by the use of living organisms.

blend A combination of two or more varieties of the same grass species.

blight A general term used to describe symptoms of plant disease that may include sudden wilting or the death of leaves, flowers, stems or entire plants. The most common blight of golf course turfs is Pythium.

broadleaved Any of the dicotyledonous plants that grow in a turfgrass stand (e.g., dandelion, plantain, clover, chickweed, or knotweed).

brushing The practice of lifting excessive leaf and stem growth off grasses before mowing. Usually accomplished with brushes affixed to mowers ahead of the cutting reel.

calibrate To determine or mark the graduation of, or to determine and control the amount of material delivered by a sprayer or spreader on a given area or in a given time.

chlorosis As commonly used, the condition in plants relating to the loss or lack of green color. May be caused by disease activity, albinism or nutritional deficiency.

collar An area of turf adjoining the putting green that is mowed at an intermediate height between the fairway and the green.

compaction The reduction in the number and size of airspaces caused by compression, most often the result of traffic. Compaction prevents adequate water and air penetration, and reduces turfgrass root growth.

complete fertilizer A fertilizer that contains nitrogen, phosphorus and potassium.

contour mowing To shape the border between the fairway and rough to add interest, direction or strategy to the golf hole.

cool-season grasses Among the best known are colonial bentgrass, creeping bentgrass, Kentucky bluegrass, perennial ryegrass, fine fescue and tall fescue. They grow best between 55° F and 85° F.

coring The removal of a core from a turfgrass area with a soil probe or hollow metal tines, usually to provide aeration.

cultivar A term used to distinguish cultivated varieties of plants from the naturally occurring varieties e.g., Penncross creeping bentgrass.

cultivation A mechanical procedure such as spiking, grooving or core removal on established turf without destroying its sod characteristics.

cutting height The distance above the soil line that grasses are clipped. **bench setting** - The height at which the bedknife is set above a firm, level surface. This is generally the accepted measure for determining cutting height. **effective cutting height** - The actual height at which grasses are cut. It varies from the bench setting, depending on the degree of thatch and flotation of the cutting unit.

damping off A disease of seeds or young seedlings caused by fungi, usually occurring under wet conditions.

desiccation Drying up. A type of winter injury that exposed turf areas suffer when subject to high winds and inadequate moisture or snow cover.

dethatching The procedure of removing an excessive thatch accumulation either mechanically, by practices such as vertical mowing, or biologically, such as by topdressing with soil.

disease A disturbance in normal functioning and growth, usually caused by pathogenic fungi, bacteria, or viruses.

dormant In a resting, or nonvegetative, state.

drainage The rapid removal of water by surface contouring (swales or ditches) or the installation of subsurface tile.

erosion The wearing away of the land by running water, wind or other geological agents.

evapotranspiration The combination of soil evaporation and transpiration from a plant; total water loss from plant and soil.

facing The slope or incline of a bunker constructed in the direction of the putting green, intended to create an added obstacle for a player to negotiate.

fairway No precise definition exists in the Rules of Golf for fairway. It is deemed to be an area between the tee and putting green included in the term “through the green.” In terms of maintenance, fairways are those areas of the course that are mowed at heights between 0.5 and 1.25 inches, depending on the grass species and the cultural intensity desired. Fairways normally are about 50 yards wide but vary from about 33 yards to more than 60 yards, depending on the caliber of the golf course and the limitations imposed by architecture or terrain.

fertigation The application of fertilizer through an irrigation system.

fertilizer A nutrient applied to plants to assist growth.

foliar fertilizers Soluble plant nutrients applied to the leaf and capable of being absorbed through leaves.

foot printing Temporary foot impressions left on a turf because the flaccid leaves of grass plants have insufficient water to spring back.

friable Easily crumbled in the fingers. Most often used when describing soils.

fumigant A liquid or solid substance that forms vapors that destroy pathogens, insects, or other pests. Fumigants are usually used in soils or closed structures.

fungicide A chemical that kills or inhibits the growth of fungi.

fungus A form of life distinct from plants that, lacking chlorophyll and being incapable of manufacturing its own food, lives off dead or living plant and animal matter.

germination The beginning of growth in a seed, plant bud or joint.

grain As applied to putting greens, the tendency for grass leaves to lie down in one direction and interfere with the natural roll of the ball.

ground covers Plants used to provide a low-maintenance, vegetative cover that is not necessarily turf.

herbaceous Nonwoody plants.

herbicide A chemical used to kill weeds or herbaceous growth.

humus A dark, well-decomposed material formed from decayed vegetable or animal matter in the soil.

hydroseeding A technique for applying seed, mulch and fertilizer in a water slurry over a seedbed.

infiltrate To filter into; the penetration of water through soils.

inorganic fertilizer Plant nutrients derived from mineral rather than organic sources.

insecticide A chemical used to destroy insects.

internode The portion of a stem between the nodes or joints.

lip An abutment of sod raised 3 to 4 inches above the sand level of a bunker. It faces the putting green and prevents a player from putting out.

lime Materials containing calcium and magnesium used to neutralize soil acidity and to supply calcium and magnesium as plant nutrients. Lime materials include limestone, shell, marl, slag and gypsum.

localized dry spot A dry area of sod and soil that resists water as normally applied; caused by various factors such as heavy thatch, soil or fungal organisms.

mat In turf, an undecomposed mass of roots and stems hidden underneath green vegetation. Associated with sponginess or fluffiness in turf.

matting The process of working topdressing, fertilizers or other materials into a turfgrass area with drag mats.

microenvironment The area in the immediate vicinity of the turfgrass plant from the surface to the depth of root penetration into the soil.

micronutrient An element needed in small amounts for turfgrass growth.

mildew A disease in which the causal fungus forms a coating over the surface of plant parts. The coating, which is a mycelial growth, is usually thin and whitish. There are two types of mildew: downy and powdery.

mulch A material such as wood chips, straw, netting, or burlap spread over seeded or stolonized areas to protect them from erosion, moisture loss, and temperature extremes and to enhance germination and growth.

native grasses Grasses that are indigenous or that occur naturally in a particular region.

nematicide A substance used to destroy nematodes.

nematode A small, round worm, usually microscopic and colorless, that lives free in moist soil, water or decaying or living organic matter. Parasitic forms puncture plant tissues and live by sucking the juice of the plant.

node The joint of a grass stem from which leaves and buds arise.

nutrients, plant The elements taken in by the plant, essential to its growth and function.

organic matter Decomposed material derived from plant or animal sources. An important component of topsoil often added to topdressing soil mixtures to give added water-holding capacity and exchange capacity to the soil.

organic soil A general term used in reference to any soil that is at least 20% organic matter.

overseed To sow seed over an area that is sparsely covered or to plant cool-season grasses into dormant warm-season turfgrass swards for a temporary, green winter cover.

pathogen An organism causing disease.

peat Unconsolidated soil material consisting largely of undecomposed or only slightly decomposed organic matter accumulated under conditions of excess moisture.

permeability A measure of the ease with which air, roots and water penetrate the soil.

perennial grasses Lasting or continuing from year to year in areas where adapted.

pH A measure of the acidity or alkalinity of a material or solution. pH ranges from 0 to 14. Values below 7 are increasingly acid; above 7, increasingly alkaline.

phytotoxic Harmful to plants.

plant growth regulator In turfgrass, a chemical used to slow vegetative growth.

plugging The vegetative propagation of turfgrass by means of plugs or small sod pieces. A method of establishing vegetatively-propagated turfgrasses, and repairing damaged areas.

Poa The genus of all bluegrasses.

pore space The space between solid soil particles or aggregates that is normally filled with water, air or grass roots.

postemergence A term used to refer to herbicide treatment made after weed seedlings have emerged from the soil.

preemergence A term used to refer to herbicide treatments made before weed seedlings emerge from the soil.

profile, soil A cross-section of soil that shows the layers or horizons lying above the unweathered parent material.

Pythium blight A highly destructive turfgrass disease that can totally destroy a turfgrass stand in less than 24 hours. Pythium blight most commonly occurs under conditions of high temperature and humidity.

rebuilding A term that refers to practices involving complete changes in the total turf area, i.e., the reconstruction of a green, tee, fairway, rough or any other area of the golf course.

renovation Turf improvement carried out by replanting into existing live and/or dead vegetation.

resiliency The capability of the turf to spring back when balls, shoes or other objects strike the surface, thus providing a cushioning effect.

rhizome An underground, root-like stem; underground creeping stem.

saline soils Soils in which there is a heavy accumulation of salts.

scald Turf damage occurring under conditions of excessive water, high temperatures and intense light.

scalping Cutting into or below the crown of the grass plant while mowing. Continued scalping will weaken or kill the turf.

seed bed An area of soil prepared for seeding.

seedling A plant grown from seed; usually refers to a young plant.

selective herbicide One that can be applied to a mixed stand of turfgrass and weeds that will selectively kill certain weeds without injuring the turfgrasses.

soil modification The alteration of soil characteristics by adding soil amendments such as sand, peat, lime, or other material; commonly used to improve physical and chemical conditions.

soil texture The coarseness or fineness of the soil. Sand is coarse-textured; clay is fine-textured.

species An established classification into which similar individuals in the plant or animal kingdom are placed. A species is described as a morphologically distinctive and genetically isolated natural population.

spray drift The movement of small spray particles away from the target area.

sprigging The planting of stolons (runners), rhizomes or vegetative segments of plants.

sterilize To treat soil chemically or by heat to kill disease organisms, weed seeds and insects.

stolons Creeping stems or runners aboveground that may produce roots and new stems and become independent plants.

striping A pattern left on turfgrass, usually a fairway or green, using lightweight mowing equipment. Its main purpose is a pleasing appearance. Patterns are the result of light reflected from blades of grass lying in different directions because they have been mowed in different directions.

subsoil That part of the soil profile below plow depth, usually considered unsatisfactory for plant growth.

surfactant An agent that reduces the surface tension of liquids on plant materials or in the soil. Wetting agents are common examples.

susceptible Lacking an inherent ability to resist. Turf may be susceptible to diseases, insect damage or weed encroachment.

synergistic The action of one chemical upon another causing an accelerated action or a result that neither one alone could produce.

syringing The light sprinkling of water on turf, usually done during the hot part of the day to prevent wilting. Only enough water is applied to wet the leaves, not the soil.

texture, grass The width of individual leaves. A narrow-leaved grass, such as creeping bentgrass, is considered fine-textured. A wide-leaved grass, such as some tall fescues, is considered coarse-textured.

thatch A tightly intermingled layer of dead and decaying roots, stolons, shoots and stems that develops between the green vegetation and soil surface.

tolerance The ability of a plant to withstand the effects of adverse conditions, chemicals or parasites.

topdressing A prepared mixture usually containing sand and organic matter used for leveling and smoothing the playing surface. It aids in controlling thatch and in maintaining biological balance. Topdressing is also used to cover stolons or sprigs in vegetative planting.

topsoil A general term applied to the top natural layer of soil.

toxicity Quality, state or degree of being toxic; poisonous.

transpiration The movement of water vapor out of a plant through leaf openings.

variety In classification, a subdivision of species. Differing from the remainder of the species in one or more recognizable and heritable characteristics.

vegetative propagation Propagation by means of pieces of vegetation, i.e., sprigs or sod pieces.

verdure The green, living plant material remaining after mowing.

warm-season grasses Among the best known are bermudagrass, St. Augustine grass, zoysiagrass, bahiagrass, carpetgrass and centipedegrass. Bermudagrass is the most popular for greens. Warm-season grasses grow at their optimal rate between 75° F and 95° F.

weeds Plants out of place; undesirable or unwanted plants.

wettable powder A dry powdered formulation of a pesticide that is applied as a suspension in water.

winterkill (injury) The general term applied to injuries of turf from a variety of causes that occur during the winter and become evident in spring.

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