GCSAA

Golf Course Superintendents Association of America

BEST MANAGEMENT PRACTICES FOR KENTUCKY GOLF COURSES

BMP Best Management Practices

Best Management Practices Planning Guide & Template

GCSAA USGA

In partnership with the PGA TOUR

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EIFG *Funded through the Environmental Institute for Golf*

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Who We Are/ Acknowledgments

Golf Course Superintendents Association of America

The Golf Course Superintendents Association of America (GCSAA) is the professional association for the men and women who manage and maintain the game's most valuable resource — the golf course. Today, GCSAA and its members are recognized by the golf industry as one of the key contributors in elevating the game and business to its current state.

Since 1926, GCSAA has been the top professional association for the men and women who manage golf courses in the United States and worldwide. From its headquarters in Lawrence, Kansas, the association provides education, information and representation to more than 17,000 members in more than 72 countries. GCSAA's mission is to serve its members, advance their profession and enhance the enjoyment, growth and vitality of the game of golf.

Environmental Institute for Golf

The Environmental Institute for Golf (EIFG) fosters sustainability by providing funding for research grants, education programs, scholarships and awareness of golf's environmental efforts. Founded in 1955 as the GCSAA Scholarship & Research Fund for the Golf Course Superintendents Association of America, the EIFG serves as the association's philanthropic organization. The EIFG relies on the support of many individuals and organizations to fund programs to advance stewardship on golf courses in the areas of research, scholarships, education, and advocacy. The results from these activities, conducted by GCSAA, are used to position golf courses as properly managed landscapes that contribute to the greater good of their communities. Supporters of the EIFG know they are fostering programs and initiatives that will benefit the game and its environment for years to come.

United States Golf Association

The United States Golf Association (USGA) provides governance for the game of golf, conducts the U.S. Open, U.S. Women's Open and U.S. Senior Open as well as 10 national amateur championships, two state team championships and international matches, and celebrates the history of the game of golf. The USGA establishes equipment standards, administers the Rules of Golf and Rules of Amateur Status, maintains the USGA Handicap System and Course Rating System, and is one of the world's foremost authorities on research, development and support of sustainable golf course management practices.

Acknowledgments

The GCSAA and EIFG wish to thank the **University of Florida**, Institute of Food and Agricultural Sciences, faculty, Dr. J. Bryan Unruh, Dr. Travis Shaddox, Dr. Jason Kruse, and Mr. Don Rainey, who worked on this project, providing their knowledge and expertise to help the golf course industry; the **USGA** for their grant to fund this important project; the **volunteers who served on the task group** to review BMP and provide technical assistance; and the **Florida Department of Environmental Protection** for permission to copy its publication, "Best Management Practices for the Enhancement of Environmental Quality on Florida Golf Courses

Additional Acknowledgement

The development of the Best Management Practices for Kentucky Golf Courses was made possible by superintendents in the Commonwealth of Kentucky, as well as the GCSAA affiliated chapters including the Bluegrass Golf Course Superintendents Association, the Kentuckiana Golf Course Superintendents Association, the Quad-State Turfgrass Association, and the Tri-State Golf Course Superintendents Association.

A special thank you to Stephen Babcock, Kraig Binder, Jacob Blair, Brent Downs, Kevin Glover, Mike Harrell, David Hawes, Damon Hitti, Paul Hoarston, Nick Krysinski, Mike Mason, Sam Montgomery, Brad Nevitt, Brad Reynolds, Andy Short, Jason Vaughn, Shannon Watson, Andrew Wolfe, and Bryce Yates for their tireless effort and expertise in review and preparation of this document.

Additional thanks go to the university turfgrass scientists and researchers for donating their time and expertise in preparing this document; including Carla Hagan of Eastern Kentucky University, as well as Steven Evans, and Dr. Travis Shaddox of the University of Kentucky and researchers from Western Kentucky University. .

Thank you to Kentucky's regulatory agencies for reviewing the draft version of this document and providing comments.

Finally, thank you to John Ballard, CGCS for providing leadership and inspiration in preparation of this document.

Introduction

Introduction

The game of golf has long since provided an environment for recreation and competition. Golf courses serve as the setting where this takes place. Stretched across the landscape of Kentucky you will find over 270 courses. And while our great state may be best known for horses, agriculture and Kentucky bourbon, you would be hard pressed to engage someone who doesn't have a story to share about golf. Perhaps it is their first time playing, a favorite course, the specific shot that brings them back, the place where they exchanged their vows, a family reunion destination or the elusive hole-in-one they found one summer afternoon. Golf course superintendents across the Commonwealth work tirelessly to create environments for these moments to take place. They do it in a responsible manner creating safe work spaces for their staff, adhering to local, state and federal guidelines and have a keen eye for protecting the land upon which they work. The Best Management Practices for Kentucky Golf Courses manual was developed as a resource for golf course superintendents to enhance existing efforts. It is designed as a living document that can be tailored to specific facility needs. It is my sincere hope that this manual serves as a guide for your facility not only for today but for future generations to come.

John G. Ballard, CGCS

BMP Index

Planning, Design and Construction

Regulatory Issues

The construction phase of any industry's infrastructure poses the greatest risk of ecosystem alteration. With proper planning and design, golf facilities can be constructed and maintained with minimal impact to existing wildlife and their habitat. Furthermore, facilities should be designed and constructed to maximize energy efficiency.

Local and state regulations may be in place in your location. Early engagement among developers, designers, local community groups, and permitting agencies is essential to designing and constructing a golf facility that minimizes environmental impact and meets the approval process.

Planning

Principles

Proper planning will minimize expenses resulting from unforeseen construction requirements. Good planning provides opportunities to maximize/integrate environmentally favorable characteristics into the property. This often requires the involvement of golf course architects, golf course superintendents, civil engineers, soil scientists, agronomists, irrigation designers, ecologists, etc.

Best Management Practices

- Assemble a qualified team
    - Golf course architect
    - Golf course superintendent
    - Clubhouse architect
    - Irrigation engineer
    - Environmental engineer
    - Energy analyst
    - Economic consultant
    - Civil engineer
    - Soil scientist

- Geologist
- Golf course builder
- Legal team

- Determine objectives
- Complete a feasibility study

  - Are needs feasible given existing resources?
  - Financial
  - Environmental
  - Water
  - Energy
  - Labor
  - Materials
  - Governmental regulatory requirements/restrictions

- Select an appropriate site that is capable of achieving the needs of stakeholders.
- Identify strengths and weakness of the selected site.
- Identify any rare, protected, endangered, or threatened plant or animal species on the site.

Design

Principles

Proper design will meet the needs of the stakeholders, protect the locations environmental resources, and be economically sustainable.

Best Management Practices

- Retain a qualified golf course superintendent/project manager at the beginning of the design and construction process to integrate sustainable maintenance practices in the development, maintenance, and operation of the course.
- Design the course to minimize the need to alter or remove existing native landscapes. The routing should identify the areas that provide opportunities for restoration.
- Design the course to retain as much natural vegetation as possible. Where appropriate, consider enhancing existing vegetation through the supplemental planting of native vegetation/materials next to long fairways, out-of-play areas, and along water sources supporting fish and other water-dependent species.
- Design out-of-play areas to retain or restore existing native vegetation where possible. Nuisance, invasive, and exotic plants should be removed and replaced with native species that are adapted to that particular site.
- Greens
  - Select a location that has adequate sunlight to meet plant specific needs and provides sufficient drainage.

    - Choose a green size and sufficient number of hole locations that is large enough to accommodate traffic and play damage, but not so large that it is not sustainable with your resources.
    - Select an appropriate root-zone material as designated by the USGA.
    - Consider the number of bunkers as it relates to resources available for daily maintenance.
    - Greens should be irrigated separately from surrounding turf.
    - Select a turf species/variety that meets the needs of the stakeholders while adhering to the principle of "right plant, right place."
- Plant only certified turfgrass.
- Decide what type of drainage bunkers will require to handle rain events.
- Consider bunker entry and exit points. Consider wear patterns and create adequate space for ingress/egress points on greens, tees, fairways, and bunkers.
- Select the proper color, size, and shape of bunker sand that meets your needs.
- Define play and non-play maintenance boundaries.

Construction

Principles

Construction should be completed with care to minimize environmental impact and financial ramifications caused by poor construction techniques.

Best Management Practices

- Conduct a pre-construction conference with stakeholders.
- Construction should be scheduled to maximize turfgrass establishment and site drainage.
- Use environmentally sound construction techniques.
- Use soil stabilization techniques to minimize soil erosion and maximize sediment containment.
- Maintain a construction progress report and communicate the report to the proper permitting agencies.
- Use only qualified contractors who are experienced in the special requirements of golf course construction.
- Schedule construction and turf establishment to allow for the most efficient progress of the work, while optimizing environmental conservation and resource management.
- Temporary construction compounds should be built in a way that minimizes environmental impacts.

Grow-in

Principles

Turfgrass establishment is a unique phase in turfgrass growth, which can require greater quantities of water and nutrients than established turfgrasses. To this end, the establishment phase should be considered carefully to minimize environmental risk.

Best Management Practices

- The area to be established should be properly prepared and cleared of pests (weeds, pathogens, etc.).
- Ensure erosion and sediment control devices are in place and properly maintained.
- Sprigs should be “knifed-in” and rolled to hasten root establishment.
- Sod should be topdressed to fill in the gaps between sod pieces. This hastens establishment and provides a smoother surface.
- Use appropriate seeding methods for your conditions. When using sod, nutrient applications should be delayed until sod has sufficiently rooted.
- When using sprigs, application rates for nitrogen, phosphorous, and potassium should correspond to percent ground cover (i.e., increasing rate as ground coverage increases.)
- Slow-release nitrogen or light, frequent soluble-nitrogen sources should be used during grow-in.
- Nutrients should be applied — in either foliar or granular formulations — to the turf surface. Incorporating nutrients into the root zone does not result in more rapid establishment and increases environmental risk.
- Mow as soon as the sod has knitted-down, when sprigs have rooted at the second to third internode, and seedlings have reached a height of one-third greater than intended height-of-cut. This will hasten establishment.

Erosion and Sediment Control

Principles

- Soil carried by wind and water erosion transports contaminants with it. Contaminants can dislodge, especially on entering water bodies, where they can cause pollution.
- Erosion and sediment control is a critical component of construction and grow-in of a golf course.

Best Management Practices

- Develop a working knowledge of erosion and sediment control management. Each state has its own specifications including types of acceptable structures, materials, and design features.
- Develop and implement strategies to effectively control sediment, minimize the loss of topsoil, protect water resources, and reduce disruption to wildlife, plant species, and designed environmental resource areas.
- Hydro-seeding or hydro-mulching offer soil stabilization.

Figure 1. Erosion and sediment control is a critical component of construction and grow-in of a golf course. Photo credit: Damon Hitti.

Wetlands

Principles

- Most states consider wetlands as “waters of the state,” a designation that carries significant legal ramifications. Furthermore, permitting requirements for wetlands can have multiple overlapping jurisdictions of federal, state, and local agencies. At the federal level alone, the U.S. Army Corps of Engineers (USACOE), EPA, U.S Fish and Wildlife Service (FWS), National Oceanic and Atmospheric Administration (NOAA), and maritime agencies may all be involved.
- Wetlands act both as filters for pollutant removal and as nurseries for many species of birds, insects, fish, and other aquatic organisms. 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.
- 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 need to be permitted to be an integral part of the stormwater management system.

Best Management Practices

- Ensure that proper permitting has been obtained before working on any wetlands.

- Ensure that wetlands have been properly delineated before working in and around any wetlands.

Drainage

Principles

- Adequate drainage is necessary for growing healthy grass.
- A high-quality BMP plan for drainage addresses the containment of runoff, adequate buffer zones, and filtration techniques in the design and construction process to achieve acceptable water quality.
- Drainage of the golf course features is only as good as the system's integrity. Damaged, improperly installed, or poorly maintained drainage systems will result in inferior performance that negatively impacts play and increases risks to water quality.

Best Management Practices

- When constructing drainage systems, pay close attention to engineering details such as subsoil preparation, the placement of gravel, slopes, and backfilling.
- Internal golf course drains should not drain directly into an open waterbody, but should discharge through pretreatment zones and/or vegetative buffers to help remove nutrients and sediments.
- Drainage should discharge through proper drainage and stormwater management devices, for example, vegetative buffers, swales, etc.
- The drainage system should be routinely inspected to ensure proper function.

Figure 2. When constructing drainage systems, pay close attention to engineering details such as subsoil preparation, the placement of gravel, slopes, and backfilling. Photo Credit: John Ballard, CGCS.

Surface Water: Stormwater, Ponds, Lakes

Principles

- Stormwater is the conveying force behind nonpoint source pollution.
- Controlling stormwater on a golf course is more than preventing the flooding of facilities and play areas. In addition to controlling the amount and rate of water leaving the course, stormwater control also involves storing irrigation water, controlling erosion and sediment, enhancing wildlife habitat, removing waterborne 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.

Best Management Practices

- 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.
- Eliminate or minimize as much directly connected impervious area (DCIA) as possible.
- Use vegetated swales to slow and infiltrate water and trap pollutants in the soil, where they can be naturally destroyed by soil organisms.
- Use depressed landscape islands in parking lots to 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 treatment volume and settle out sediments, while allowing the overflow to drain away.
- Maximize the use of pervious pavements, such as brick or concrete pavers separated by sand and planted with grass. Special high-permeability concrete is available for cart paths or parking lots.
- Disconnect runoff from gutters and roof drains from impervious areas, so that it flows onto permeable areas that allow the water to infiltrate near the point of generation.

Maintenance Facilities

Principles

The maintenance facilities must incorporate BMP to minimize the potential for contamination of soil and water resources. The pesticide mixing and storage facility, the equipment wash pad, and the fuel center are focal points.

Best Management Practices

- 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.
- Construct floors of seamless metal or concrete sealed with a chemical-resistant paint.
- Ensure that flow from floor drains does not discharge directly to the ground and that drains are not connected to the sanitary sewer line or septic system.
- Equip the floor with a continuous curb to retain spilled materials.
- Do not store pesticides near burning materials or hot work (welding, grinding), or in shop areas.
- Provide storage for personal protective equipment (PPE) where it is easily accessible in the event of an emergency, but do not store in the pesticide storage area.
- Provide adequate space and shelving to segregate herbicides, insecticides, and fungicides.
- Use shelving made of plastic or reinforced metal. Keep metal shelving painted.
- Provide appropriate exhaust ventilation and an emergency wash area.
- Always place dry materials above liquids, never liquids above dry materials.
- Never place liquids above eye level.
- Locate operations well away from groundwater wells and areas where runoff may carry spilled pesticides into surface waterbodies.
- Do not build new facilities on potentially contaminated sites.
- An open building must have a roof with a substantial overhang (minimum 30° from vertical, 45° recommended) on all sides.
- In constructing a concrete mixing and loading pad, it is critical that the concrete have a water-to-cement ratio no higher than 0.45:1 by weight.
- The sump should be small and easily accessible for cleaning.
- Ensure that workers always use all personal protection equipment as required by the pesticide label and are provided appropriate training.
- Assess the level of training and supervision required by staff.
- Any material that collects on the pad must be applied as a pesticide according to the label or disposed of as a (potentially hazardous) waste according to state laws and regulations.
- Clean up spills immediately!
- Always store nitrogen-based fertilizers separately from solvents, fuels, and pesticides, since many fertilizers are oxidants and can accelerate a fire. Ideally, fertilizer should be stored in a concrete building with a metal or other type of flame-resistant roof.
- Always store fertilizers in an area that is protected from rainfall. The storage of dry bulk materials on a concrete or asphalt pad may be acceptable if the pad is adequately protected from rainfall and from water flowing across the pad.
- Sweep up any spilled fertilizer immediately.
- Do not wash equipment unnecessarily.
- Clean equipment over an impervious area, and keep it swept clean.
- Brush or blow equipment with compressed air before, or instead of, washing.

- Use spring shutoff nozzles.
- Use a closed-loop recycling system for wash water.
- Recycle system filters and sludge should be treated and disposed appropriately.
- Each piece of equipment should have an assigned parking area. This allows oil or other fluid leaks to be easily spotted and attributed to a specific machine so that it can be repaired.
- Use solvent-recycling machines or water-based cleaning machines to cut down on the use of flammable and/or toxic solvents.
- Use a service to remove the old solvents and dispose of them properly.
- Design pesticide storage to keep pesticides secure and isolated from the environment.

External Certification Programs

Principles

- Golf-centric environmental management programs or environmental management systems can help golf courses protect the environment and preserve the natural heritage of the game.
- These programs help people enhance the natural areas and wildlife habitats that golf courses provide, improve efficiency, and minimize potentially harmful impacts of golf course operations.
- Golf courses can gain valuable recognition for their environmental education and certification efforts.

Best Management Practices

- Obtain and review materials to ascertain whether the facility should seek certification.
- Work with staff to establish facility goals that lead to certification.
- Establish goals to educate members about the certification program.

Wildlife Considerations

Principles

- Golf courses occupy large land areas, generally in urban areas, providing critical links between urban and rural/natural environments.
- Maintaining wildlife habitat on golf courses better maintains biological diversity, which is especially important in the urban environment.
- Most golfers enjoy observing non-threatening wildlife as they play the game.

Figure 3. Maintaining wildlife habitat on golf courses better maintains biological diversity, which is especially important in the urban environment. Photo Credit: John Ballard, CGCS.

Best Management Practices

- Identify the different types of habitat specific to the site.
- Identify the habitat requirements (food, water, cover, space) for identified wildlife species.
- Identify species on the site that are considered threatened or endangered by the federal or state government, including species the state deems “of special concern.”
- Preserve critical habitat.
- Identify and preserve regional wildlife and migration corridors.

- Design and locate cart paths to minimize environmental impacts. Construct the paths of permeable materials, if possible.
- Avoid or minimize crossings of wildlife corridors. Design unavoidable crossings to accommodate wildlife movement.
- Remove nuisance and exotic/invasive plants and replace them with native species that are adapted to a particular site.
- Maintain clearance between the ground and the lowest portion of a fence or wall to allow wildlife to pass, except in areas where feral animals need to be excluded.
- Retain dead tree snags for nesting and feeding sites, provided they pose no danger to people or property.
- Construct and place birdhouses, bat houses, and nesting sites in out-of-play areas.
- Plant butterfly gardens around the clubhouse and out-of-play areas.
- Retain riparian buffers along waterways to protect water quality and provide food, nesting sites, and cover for wildlife.
- Minimize stream or river crossings to protect water quality and preserve stream banks.
- Retain riparian buffers along waterways to protect water quality, provide food, nesting sites, and cover for wildlife.

Irrigation

Water Management Approaches

The supplemental use of water for course play and non-play areas is essential to supporting healthy turfgrass and landscape plant health. It is also necessary to sustaining optimal course playability, aesthetics, marketability, and club membership participation.

The purpose of this section is to identify best management practices related to water use that conserve and protect water resources. It is important to keep in mind that, while new technology makes many tasks easier or less labor-intensive, the principles discussed in this section are important to understand and apply to protect water quality and quantity and surrounding natural resources.

Additionally, irrigation BMP may provide an economic, regulatory compliance, and environmental stewardship advantage to those who consider them part of their irrigation management plan. BMP are not intended to increase labor or place an undue burden on the owner/superintendent. If applied appropriately, BMP can help stabilize labor cost, extend equipment life, and limit repair and overall personal and public liability.

The monetary investment in non-structural, BMP costs little to nothing to implement in a daily course water-use plan. Other advantages to using BMP include: reduced administrative management stress, improved employee communication and direction, and effective facilities training procedures.

Several benefits of adopting BMP are:

- Conserving the water supply
- Protecting existing water quality
- Maintaining optimal ball roll and playing conditions
- Saving water and electricity
- Increasing pump and equipment life longevity
- Demonstrating responsible environmental stewardship
- Retaining knowledgeable and effective employees

Conservation and Efficiency

Conservation and efficiency considers the strategic use of appropriate course and irrigation design, plant selection, computerized and data-integrated scheduling, and alternative water quality/supply options that maximize plant health benefits and reduce the potential for negative impacts on natural resources.

Resource Protection

Resource protection is an integrated approach that includes irrigation practices as part of the course design, pesticide and nutrient practices, and regulatory compliance measures and structural measures as they concern environmental stewardship and policy.

Regulatory Considerations

Principles

- Golf course owners are responsible for contacting federal, state, and local water use authorities at the pre-and post-construction phase to determine annual or specific water consumption (water rights), permitting guidelines, and other requirements allowed by regulators.
- Superintendents have a responsibility to adhere to water-quality standard rules regarding groundwater and surface water flows resulting from the removal of water for irrigation use.

Best Management Practices

- Design and/or maintain a system to meet site’s peak water requirements under normal conditions and also be flexible enough to adapt to various water demands and local restrictions.
- Develop an annual water budget for the golf course.
- Look for ways to increase efficiency and reduce energy use associated with irrigation systems and practices.
- Demonstrate good stewardship practices by supplementing watering only for the establishment of new planting and new sod, hand watering of critical hot spots, and watering-in of chemicals and fertilizers (if permissible).
- Protect aquatic life and impairment of water systems by adhering to state and local water withdrawal allocations (gallons/day).
- Design an irrigation system that delivers water with maximum efficiency.

Irrigation Water Suitability

Principles

- Golf course designers and managers should endeavor to identify and use alternative supply sources to conserve freshwater drinking supplies, promote plant health, and protect the environment.
- The routine use of potable water supply is not a preferred practice; therefore, municipal drinking water should be considered only when there is no alternative.
- Studies of water supplies are recommended for irrigation systems, as are studies of waterbodies or flows on, near, and under the property. These maybe helpful to properly design a course's stormwater systems, water features, and to protect water resources.
- When necessary, sodic water system treatment options should be included in the budget to address water quality and equipment maintenance.

Best Management Practices

- Use alternative water supplies/sources that are appropriate and sufficiently available to supplement water needs.
- Use salt-tolerant varieties of turf and plants to mitigate saline conditions resulting from an alternative water supply or source, if necessary.
- Amend sodic water systems appropriately (with gypsum or an appropriate ion) to minimize sodium buildup in soil.
- Flush with freshwater or use amending materials regularly to move salts out of the root zone and/or pump brackish water to keep salts moving out of the root zone.
- Monitor sodium and bicarbonate buildup in the soil using salinity sensors.
- Routinely monitor shallow groundwater table of freshwater for saltwater intrusion or contamination of heavy metals and nutrients.
- Reclaimed, effluent, and other non-potable water supply mains must have a thorough cross-connection and backflow prevention device in place and operating correctly.
- Post signage in accordance with local utility and state requirements when reclaimed water is in use.
- Account for the nutrients in effluent (reuse/reclaimed) water when making fertilizer calculations.
- Monitor reclaimed water tests regularly for dissolved salt content.
- Where practical, use reverse-osmosis filtration systems to reduce chlorides (salts) from saline groundwater.
- Monitor the quantity of water withdrawn to avoid aquatic life impairment.
- Identify appropriate water supply sources that meet seasonal and bulk water allocations for grow-in and routine maintenance needs.

Water Conservation and Efficient Use Planning

Principles

- Document actual watering practices, especially to show savings in water use over averages. Communication should be maintained with water managers, golf course members, and the public to explain what you are doing and why.
- Potable water supplies in many areas of the United States are limited, and demand continues to grow. Our challenge is to find solutions to maintain the quality of golf while using less water.
- BMP and educational programs are necessary to change the public's mind-set toward the inevitable changes in water-related issues.
- Some 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 turf to naturally adapted native plants, grasses, or ground covers to reduce water use and augment the site's aesthetic appeal.

Best Management Practices

- Selecting drought-tolerant varieties of turfgrasses can help maintain an attractive and high-quality playing surface, while minimizing water use.
- Non-play 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.
- 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.
- If properly designed, rain and runoff captured in water hazards and stormwater ponds may provide supplemental water under normal conditions, though backup sources may be needed during severe drought.
- During a drought, closely monitor soil moisture levels. Whenever practicable, irrigate at times when the least amount of evaporative loss will occur.
- Control invasive plants or plants that use excessive water.

Irrigation System Design

Principles

- A well-designed irrigation system should operate at peak efficiency to reduce energy, labor and natural resources.
- Irrigation systems should be properly designed and installed to improve water use efficiency.
- An efficient irrigation system maximizes water use, reduces operational cost, conserves supply and protects water resources.

Best Management Practices

- Design should account for optimal distribution efficiency and effective root-zone moisture coverage. Target 80% or better Distribution Uniformity (DU).
- Design should allow the putting surface and slopes and surrounds to be watered independently.
- The design package should include a general irrigation schedule with recommendations and instructions on modifying the schedule for local climatic soil and growing conditions. It should include the base ET rate for the particular location.
- The application rate must not exceed the infiltration rate, ability of the soil to absorb and retain the water applied during any one application. Conduct saturated hydraulic conductivity tests periodically.
- The design operating pressure must not be greater than the available source pressure.
- The design operating pressure must account for peak-use times and supply line pressures at final buildout for the entire system.
- The system should be flexible enough to meet a site's peak water requirements and allow for operating modifications to meet seasonal irrigation changes or local restrictions.
- Turf and landscape areas should be zoned separately. Specific use areas zoned separately; greens, tees, primary roughs, secondary roughs, fairways, native, trees, shrubs, etc.
- Design should account for the need to leach out salt buildup from poor-quality water sources by providing access to freshwater.
- Permanent irrigation sprinklers and other distribution devices should be spaced according to the manufacturer's recommendations.
- Space should be based on average wind conditions during irrigation.
- For variable wind directions, triangular spacing is more uniform than square spacing.
- Distribution devices and pipe sizes should be designed for optimal uniform coverage.
- The first and last distribution device should have no more than a 10% difference in flow rate. This usually corresponds to about a 20% difference in pressure.
- Distribution equipment (such as sprinklers, rotors, and micro-irrigation devices) in a given zone must have the same precipitation rate.
- Heads for turf areas should be spaced for head-to-head coverage.
- Water supply systems (for example, wells, and pipelines) should be designed for varying control devices, rain shutoff devices, and backflow prevention.
- Water conveyance systems should be designed with thrust blocks and air-release valves.
- Flow velocity must be 5 feet per second or less.
- Pipelines should be designed to provide the system with the appropriate pressure required for maximum irrigation uniformity.
- Pressure-regulating or compensating equipment must be used where the system pressure exceeds the manufacturer's recommendations.

- Equipment with check valves must be used in low areas to prevent low head drainage.
- Isolation valves should be installed in a manner that allows critical areas to remain functional.
- Manual quick-coupler valves should be installed near greens, tees, and bunkers so these can be hand-watered during severe droughts.
- Install part-circle heads along lakes, ponds, and wetlands margins.
- Use part-circle or adjustable heads to avoid overspray of impervious areas such as roadways and sidewalks.
- Update multi-row sprinklers with single head control to conserve water and to enhance efficiency.
- Incorporate multiple nozzle configurations to add flexibility and enhance efficiency/distribution.
- Ensure heads are set at level ground and not on slopes.

Irrigation System Installation

Principles

- A professionally installed irrigation system can provide many years of service with minimal downtime and repairs.
- Choosing the right professional to install your project (large or small) is the most critical piece to obtaining many years of service from your irrigation system.
- The team concept on a project is the best approach.

Best Management Practices

- Only qualified specialists should install the irrigation system.
- Construction must be consistent with the design.
- The designer must approve any design changes before construction.
- Construction and materials must meet existing standards and criteria, as spelled out in the specifications.
- Prior to construction, all underground cables, pipes, and other obstacles must be identified and their locations flagged.
- Prior to construction, a pre-construction meeting should be scheduled with the designer, contractor and representatives of the golf course. This assures that everyone is, "on the same page" and understands the overall process of the project and the responsibilities of all involved.
- Taking the approach of a team working together during a project provides the best overall experience and installation upon completion. Remember, this is now your system once installed and the contractor has vacated the property.
- Record Drawing – Be sure that the specifications provide for the facility to receive a final record drawing (GPS mapped) that shows the location of everything that was installed.

Figure 4. Irrigation systems should be properly designed and installed to improve water use efficiency. Photo credit: Shannon Watson.

Irrigation Pumping System

Principles

- 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 necessitated by line breaks, and allow maximum system scheduling flexibility.
- Variable frequency drive (VFD) 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.
- Design pumping systems for energy conservation.

Best Management Practices

- The design operating pressure must not be greater than the available source pressure.
- The design operating pressure must account for peak-use times and supply-line pressures at final buildout for the entire system.
- Maintain the air-relief and vacuum-breaker valves by using hydraulic-pressure-sustaining values.
- Install VFD systems to lengthen the life of older pipes and fittings until the golf course can afford a new irrigation system.
- An irrigation system should also have high- and low-pressure sensors that shut down the system in case of breaks and malfunctions.
- Pumps should be sized to provide adequate flow and pressure.
- Pumps should be equipped with control systems to protect distribution piping.
- System checks and routine maintenance on pumps, valves, programs, fittings, and sprinklers should follow the manufacturer's recommendations.
- Monitor pumping station power consumption.
- Monthly bills should be monitored over time to detect a possible increase in power usage.
- Compare the power used with the amount of water pumped. Requiring more power to pump the same amount of water may indicate a problem with the pump motor(s), control valves, or distribution system.
- Quarterly checks of amperage by qualified pump personnel may more accurately indicate increased power usage and thus potential problems.

Irrigation System Program and Scheduling

Principles

- 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 (ET) rates, recent rainfall, recent temperature extremes and soil moisture.
- Irrigation should not occur on a calendar-based schedule, but should be based on ET rates and soil moisture replacement.
- An irrigation system should be operated based only on the moisture needs of the turfgrass, or to water-in a fertilizer or chemical application as directed by the label.
- Responsible irrigation management conserves water, reduces nutrient and pesticide movement.
- 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. Frequent adjustment is necessary to compensate for the needs of individual turfgrass areas.

Best Management Practices

- The reliability of older clock-control station timing depends on the calibration of the timing devices; this should be done periodically, but at least seasonally.
- An irrigation system should have rain sensors to shut off the system after 0.25 to 0.5 inch of rain is received. Computerized systems allow a superintendent to call in and cancel the program if it is determined that the course has received adequate rainfall.
- Install control devices to allow for maximum system scheduling flexibility.
- Generally, granular fertilizer applications should receive 0.25 inch of irrigation to move the particles off the leaves while minimizing runoff.
- Irrigation quantities should not exceed the available moisture storage in the root zone.
- Irrigation rates should not exceed the maximum ability of the soil to absorb and hold the water applied at any one time.
- Irrigation schedule should coincide with other cultural practices (for example, the application of nutrients, herbicides, or other chemicals).
- Account for nutrients in effluent supply when making fertilizer calculations.
- Irrigation should occur in the early morning hours before air temperatures rise and relative humidity drops.
- Base plant water needs should be determined by ET rates, recent rainfall, recent temperature extremes, and soil moisture.
- Use mowing, verticutting, aeration, nutrition, and other cultural practices to control water loss and to encourage conservation and efficiency.
- Visually monitor for localized dry conditions or hot spots to identify poor irrigation efficiency or a failed system device.
- Use predictive models to estimate soil moisture and the best time to irrigate.
- Avoid use of a global setting; make adjustments to watering times per head.
- Base water times on actual site conditions for each head and zone.
- Adjust irrigation run times based on current local meteorological data.
- Use computed daily ET rate to adjust run times to meet the turf's moisture needs.
- Manually adjust automated ET data to reflect wet and dry areas on the course.
- Use soil moisture sensors to assist in scheduling or to create on-demand irrigation schedules.
- Use multiple soil moisture sensors to reflect soil moisture levels.
- Install soil moisture sensors in the root zone for each irrigation zone to enhance scheduled timer-based run times.
- Place soil moisture sensors in a representative location within the irrigation zone. Install a soil moisture sensor in the driest irrigation zone of the irrigation system.
- Wired soil moisture systems should be installed to prevent damage from aerification.
- Periodically perform catch-can uniformity tests.
- Reducing dry spots and soil compaction improves water infiltration, which in turn reduces water use and runoff in other areas.
- Install emergency shutdown devices to address line breaks.

Turf Drought Response

Principles

- The presence of visual symptoms of moisture stress is a simple way to determine when irrigation is needed.
- Use a soil moisture meter to determine moisture needs of greens and tees.
- Managers of golf greens cannot afford to wait until symptoms occur, because unacceptable turf quality may result.
- Be prepared for extended drought/restrictions by developing a written drought management plan.

Best Management Practices

- Waiting until visual symptoms appear before irrigating is a method best used for low-maintenance areas, such as golf course roughs and, possibly, fairways.
- Use soil moisture meters to determine moisture thresholds and plant needs.
- 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 several inches of soil.
- For fairways and roughs, use infrequent, deep irrigation to supply sufficient water for plants and to encourage deep rooting.
- Proper cultural practices such as mowing height, irrigation frequency, and irrigation amounts should be employed to promote healthy, deep root development and reduce irrigation requirements.
- Create a drought management plan for the facility that identifies steps to be taken to reduce irrigation/water use and protects critical areas, etc.
- Use appropriate turfgrass species adapted to the location of the golf course being managed.

Irrigation System Quality

Principles

- Irrigation system maintenance on a golf course involves four major efforts: (1) Calibration or Auditing, (2) Preventive maintenance (PM), (3) Corrective maintenance, and (4) Record keeping.
- 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.

- 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.
- As maintenance costs increase, the question of whether to renovate arises. Renovating a golf course irrigation system can improve system efficiencies, conserve water, improve playability, and lower operating costs.

Best Management Practices

1) Calibration or Auditing

- Conduct a periodic professional irrigation audit at least once every five years.
- Irrigation audits should be performed by trained technicians
- Catch-can tests should be run to determine the uniformity of coverage and to accurately determine irrigation run times.

2) Preventative Maintenance

- System checks and routine maintenance on pumps, valves, programs, fittings, and sprinklers should follow the manufacturer's recommendations.
- The system should be inspected daily for proper operation by checking computer logs and visually inspecting the pump station, remote controllers, and irrigation heads. A visual inspection should be carried out for leaks, misaligned or inoperable heads, and chronic wet or dry spots, so that adjustments can be made.
- Systems need to be observed in operation at least weekly. This can be done during maintenance programs such as fertilizer or chemical applications where irrigation is required, or the heads can be brought on-line for a few seconds and observed for proper operation. This process detects controller or communications failures, stuck or misaligned heads, and clogged or broken nozzles.
- Check filter operations frequently. An unusual increase in the amount of debris may indicate problems with the water source.
- Even under routine conditions, keeping filters operating properly prolongs the life of an existing system and reduces pumping costs.

3) Corrective Maintenance

- Respond to day-to-day failures in a timely manner, maintain the integrity of the system as designed, and keep good records.
- Application/distribution efficiencies should be checked annually. Implement a PM program to replace worn components before they waste fertilizer, chemicals, and water.
- Replace or repair all broken or worn components before the next scheduled irrigation.
- Replacement parts should have the same characteristics as the original components.

- Record keeping is an essential practice; document all corrective actions.

4) Record Keeping

- Keep records of filter changes, as this could be an early sign of system corrosion, well problems, or declining irrigation water quality.
- Document equipment run-time hours. Ensure that all lubrication, overhauls, and other preventive maintenance are completed according to the manufacturer's schedule.
- Gather together all the documentation collected as part of the PM program, along with corrective maintenance records for analysis.
- Correctly identifying problems and their costs helps to determine what renovations are appropriate.
- Collecting information on the cost of maintaining the system as part of system overall evaluation, allows for planning necessary upgrades, replacement etc. and to compare after changes are made.

Irrigation Leak Detection

Principle

- Irrigation systems are complex systems that should be closely monitored to ensure leaks are quickly detected and corrected.
- Golf courses without hydraulic pressure-sustaining valves are much more prone to irrigation pipe and fitting breaks because of surges in the system, creating more downtime for older systems. A good preventive maintenance program is very important.

Best Management Practices

- Monitor water meters or other measuring devices for unusually high or low readings to detect possible leaks or other problems in the system. Make any needed repairs.
- An irrigation system should also have high- and low-pressure sensors that shut down the system in case of breaks and malfunctions.
- The system should be monitored daily for malfunctions and breaks. It is also a good practice to log the amount of water pumped each day.
- Document and periodically review the condition of infrastructure (such as pipes, wires, and fittings). If the system requires frequent repairs, determine why these failures are occurring. Pipe failures may be caused not only by material failure, but also by problems with the pump station.
- Ensure that control systems provide for emergency shutdowns caused by line breaks, and allow maximum system scheduling flexibility.

Sprinkler Maintenance

Principles

- Good system management starts with good preventive maintenance (PM) procedures and record keeping. This can be done during maintenance programs such as fertilizer or chemical applications where irrigation is required, or the heads can be brought on-line for a few seconds and observed for proper operation.
- 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.

Best Management Practices

- Routinely check sprinkler operation assuring rotation and that part circle rotors are in proper alignment. (Ex. – 2 to 3 golf holes per week)
- Ensure that all lubrication, overhauls, and other preventive maintenance are completed according to the manufacturer's schedule for sprinkler maintenance.
- Inspect sprinkler heads for levelness. Assure that they are level and flush to the finish grade. Re-level and raise sprinkler heads to finish grade as needed. This assures the highest efficiency possible with each sprinkler head.
- Replace worn sprinkler head components as needed.

Figure 5. Replace worn components as needed. Photo Credit: Shannon Watson.

System Maintenance

Principles

- Course owners/superintendents do routine maintenance to ensure water quality and responsible use of the water supply.
- System checks and routine maintenance include: pumps, valves, programs, fittings, and sprinklers.
- To ensure that it is performing as intended, an irrigation system should be calibrated regularly by conducting periodic irrigation audits to check actual water delivery and nozzle efficiency.
- Be proactive; if the system requires frequent repairs, it is necessary to determine why these failures are occurring.
  - Pipe failures may be caused not only by material failure, but also by problems with the pump station.
  - Wiring problems could be caused by corrosion, rodent damage, or frequent lightning or power surges.
  - Control tubing problems could result from poor filtration.

Best Management Practices

- A visual inspection should first be conducted to identify necessary repairs or corrective actions. It is essential to make repairs before carrying out other levels of evaluation.
- 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 to determine the average application rate in an area.
- Catch-can testing should be conducted on the entire golf course to ensure that the system is operating at its highest efficiency.
- Conduct an irrigation audit annually to facilitate a high-quality maintenance and scheduling program for the irrigation system.
- Inspect for interference with water distribution.
- Inspect for broken and misaligned heads.
- Check that the rain sensor is present and functioning.
- Inspect the backflow device to determine that it is in place and in good repair.
- Examine turf quality and plant health for indications of irrigation malfunction or needs for scheduling adjustments.
- Schedule documentation; make adjustments and repairs on items diagnosed during the visual inspection before conducting pressure and flow procedures.

Preventive Maintenance

- In older systems, inspect irrigation pipe and look for fitting breaks caused by surges in the system.
- Install thrust blocks to support conveyances.

- The system should be inspected daily for proper operation by checking computer logs and visually inspecting the pump station, remote controllers, and irrigation heads.
- A visual inspection should be carried out for leaks, misaligned or inoperable heads, and chronic wet or dry spots so that adjustments can be made.
- Maintain air-relief and vacuum-breaker valves.
- Systems need to be observed in operation at least weekly to detect controller or communication failures, stuck or misaligned heads, and clogged or broken nozzles.
- Flush irrigation lines regularly to minimize emitter clogging. To reduce sediment buildup, make flushing part of a regular maintenance schedule. If fertigating, prevent microbial growth by flushing all fertilizer from the lateral lines before shutting down the irrigation system.
- Clean and maintain filtration equipment.
- Check filter operations frequently; keeping filters operating properly prolongs the life of an existing system and reduces pumping costs.
- Even under routine conditions, keeping filters operating properly prolongs the life of an existing system and reduces pumping costs.
- Keep records of filter changes, as this could be an early sign of system corrosion, well problems, or declining irrigation water quality.
- Application/distribution efficiencies should be checked annually.
- Conduct a periodic professional irrigation audit at least once every five years.
- Document equipment run-time hours. Ensure that all lubrication, overhauls, and other preventive maintenance are completed according to the manufacturer's schedule.
- Monitor the power consumption of pump stations. Monthly bills should be monitored over time to detect a possible increase in power usage. Compare the power used with the amount of water pumped. Requiring more power to pump the same amount of water may indicate a problem with the pump motor(s), control valves, or distribution system. Quarterly checks of amperage by qualified pump personnel may more accurately indicate increased power usage and thus potential problems.
- Qualified pump personnel should perform quarterly checks of amperage to accurately identify increased power usage that indicates potential problems.
- Qualified pump station personnel should perform an annual PM (preventative maintenance) on the pump station. This routine maintenance will help provide a longer life of this piece of equipment.
- Monitor and record the amount of water being applied, including system usage and rainfall. By tracking this information, you can identify areas where minor adjustments can improve performance. Not only is this information essential in identifying places that would benefit from a renovation, but it is also needed to compute current operating costs and compare possible future costs after a renovation.

- Document and periodically review the condition of infrastructure (such as pipes, wires, and fittings). If the system requires frequent repairs, it is necessary to determine why these failures are occurring.
- Increase frequency of routine inspection/calibration of soil moisture sensors that may be operating in high-salinity soils.
- Operate manual isolation valves at least 2 times per year. Take them to fully open and fully close each time. This will keep them from ceasing up which can cause them not to operate properly when needed.
- After opening a gate valve fully, turn it back down at least a half turn. This will help to keep it from locking or ceasing up.
- Open and close isolation valves slowly to avoid water hammer or air hammer (spring start-up). A valve that is only 20% open, allows 50% of it's full flow capacity past the gate. A valve that is 50% open allows 80% of it's full flow past the gate. The last 1-2 turns of closing a gate valve are the most critical to avoiding water hammer damage to pipes and fittings. The first 1-2 turns of opening a gate valve are the most critical to avoiding air hammer damage to pipes and fittings
- Winterize irrigation system to prevent damage.

System Renovation

- Appropriate golf course renovations can improve system efficiencies, conserve water, improve playability, and lower operating costs.
- Correctly identify problems and their cost to determine which renovations are appropriate.
- Determine the age of the system to establish a starting point for renovation.
- Identify ways to improve system performance by maximizing the efficient use of the current system.
- Routinely document system performance to maximize the effectiveness of the renovation.
- Evaluate cost of renovation and its return on benefits both financial and management.

Winterization and Spring Startup

Principle

Winterization of the irrigation system is important to protect the system and reduce equipment failures resulting from freezing.

Best Management Practices

- Conduct a visual inspection of the irrigation system: inspect for mainline breaks, low pressure at the pump, and head-to-head spacing.
- Conduct a catch-can test to audit the system.

- Flush and drain above-ground irrigation system components that could hold water.
- Remove water from all conveyances and supply and distribution devices that may freeze with compressed air or open drain plugs at the lowest point on the system.
- Clean filters, screens, and housing; remove drain plug and empty water out of the system.
- Secure systems and close and lock covers/compartment doors to protect the system from potential acts of vandalism and from animals seeking refuge.
- Remove drain plug and drain above-ground pump casings.
- Record metering data before closing the system.
- Secure or lock irrigation components and electrical boxes.
- Perform pump and engine servicing/repair before winterizing.
- Recharge irrigation in the spring with water and inspect for corrective maintenance issues.
- Ensure proper irrigation system drainage design.

Sensor Technology

Principles

- To prevent excess water use, irrigation scheduling should take into account plant water requirements, recent rainfall, recent temperature extremes, and soil characteristics.
- Irrigation management and control devices need to be installed correctly for proper irrigation management.
- Soil moisture sensors and other irrigation management tools should be installed in representative locations and maintained to to provide the information necessary for making good irrigation management decisions.
- Rain gauges are necessary measurement tools to track how much rain has fallen at a specific site on the golf course. On some courses, more than one station may be necessary to get a complete measure of rainfall or evaporation loss. The use of soil moisture probes and 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.
- 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 annual turf water requirements.
- Weather data such as rainfall, air and soil temperature, relative humidity, and wind speed are incorporated into certain model formulas, and soil moisture content is estimated. Models, however, are only as effective as the amount of data collected and the number of assumptions made.
- It is best to have an on-site weather station to daily access weather information and ET to determine site specific water needs.

Best Management Practices

- Irrigation controllers/timers should be reset as often as practically possible to account for plant growth requirements and local climatic conditions.
- Properly calibrated flow meters, soil moisture sensors, rain shut-off devices, and/or other automated methods should be used to manage irrigation.
- Irrigation rates should not exceed the maximum ability of the soil to absorb and hold the water applied in any one application.
- Irrigation should not occur on a calendar-based schedule, but should be based on ET rates and soil moisture replacement.
- 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.
- Rain shut-off devices and rain gauges should be placed in open areas to prevent erroneous readings.
- Use multiple soil moisture sensors/meters for accuracy and to reflect soil moisture levels.

Maintained Turf Areas

Principle

Courses should use 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 in order to maximize efficient watering.

Best Management Practices

- The irrigation system should be designed and installed so that the putting surface, slopes, and surrounding areas can be watered independently.
- Account for nutrients in effluent supply when making fertilizer calculations.
- Install part-circle heads that conserve water and reduce unnecessary stress to greens and surrounds.
- Avoid use of a global setting; make adjustments to watering times per head.
- Base water times on actual site conditions for each head and zone.
- Adjust irrigation run times based on current local meteorological data.
- Use computed daily ET rate to adjust run times to meet the turf's moisture needs.
- Manually adjust automated ET data to reflect wet and dry areas on the course.
- Install rain switches to shut down the irrigation system if enough rain falls in a zone.
- Use soil moisture sensors to bypass preset or to create on-demand irrigation schedules.
- Permanent irrigation sprinklers and other distribution devices should be spaced according to the manufacturer's recommendations.

- Spacing should be based on average wind conditions during irrigation.
- Triangular spacing is more uniform than square spacing.
- Periodically perform catch-can uniformity tests.
- Reducing dry spots and soil compaction improves water infiltration, which in turn reduces water use and runoff in other areas.
- Irrigation should occur in the early morning hours before air temperatures rise and relative humidity drops.
- Base plant water needs on evapotranspiration rates, recent rainfall, recent temperature extremes and soil moisture.
- Use mowing, verticutting, aeriation, wetting agents, nutrition, and other cultural practices to control water loss and to encourage conservation and efficiency.
- Depending on physical soil characteristics and turf type, using solid-tine aeration equipment in place of verticutting is an option.
- Slicing and spiking help relieve surface compaction and promote better water penetration and aeration.
- Visually monitor for localized dry conditions or hot spots to identify poor irrigation efficiency or a failed system device.
- Use predictive models to estimate soil moisture and the best time to irrigate.
- Install in-ground (wireless) soil moisture sensors or use hand-held moisture meters in the root zone for each irrigation zone to enhance scheduled timer-based run times.
- An irrigation system should also have high- and low-pressure sensors that shut down the system in case of breaks and malfunctions.
- Place soil moisture sensors in a representative location of the irrigation zone.
- Install soil moisture sensors in the driest irrigation zone of the irrigation system.
- Wireless soil moisture systems should be installed to prevent damage from aeration.

Non-Play and Landscape Areas

Principles

- Map any environmentally sensitive areas such as sinkholes, wetlands, or flood-prone areas, and identify species classified as endangered or threatened by federal and state governments, and state species of special concern.
- Natural vegetation should be retained and enhanced for non-play areas to conserve water.
- The most efficient and effective watering method for non-turf landscape is micro-irrigation.
- Older golf courses may 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 and transitioned into non-play areas.

Best Management Practices

- Designate 50% to 70% of the non-play area to remain in natural cover according to “right-plant, right-place,” a principle of plant selection that favors limited supplemental irrigation and on-site cultural practices.
- Incorporate natural vegetation in non-play areas.
- Use micro-irrigation and low-pressure emitters in non-play areas to supplement irrigation.
- Routinely inspect non-play irrigation systems for problems related to emitter clogging, filter defects, and overall system functionality.

Wellhead Protection

Principles

- Wellhead protection is the establishment of protection zones and safe land-use practices around water supply wells in order to protect aquifers from accidental contamination. It also includes protecting wellheads from physical impacts, keeping them secure, and sampling wells according to the monitoring schedule required by the regulating authority, which is often a local health department or state department of environmental quality.
- When installing new wells, contact the regulating authority to determine the permitting and construction requirements and the required isolation distances from potential sources of contamination.
- Locate new wells up-gradient as far as possible from likely pollutant sources, such as petroleum storage tanks, septic tanks, chemical mixing areas, or fertilizer storage facilities.
- Licensed water-well contractors may be needed to drill new wells to meet state requirements, local government code, and water management districts’ well-construction permit requirements.

Best Management Practices

- Use backflow-prevention devices at the wellhead, on hoses, and at the pesticide mix/load station to prevent contamination of the water source.
- Properly plug abandoned or flowing wells.
- Surround new wells with bollards or a physical barrier to prevent impacts to the wellhead.
- Inspect wellheads and the well casing at least annually for leaks or cracks; make repairs as needed.
- Maintain records of new well construction and modifications to existing wells.
- Obtain a copy of the well log for each well to determine the local geology and how deep the well is; these factors will have a bearing on how vulnerable the well is to contamination.
- Sample wells for contaminants according to the schedule and protocol required by the regulating authority.
- Never apply a fertilizer or pesticide next to a wellhead.

- Never mix and load pesticides next to a wellhead if not on a pesticide mix/load pad.

Pond Location and Design

Principles

- 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 golf courses plan their lakes and water hazards to be a part of the stormwater control and treatment system. This usually works well for all concerned. However, natural waters may not be considered treatment systems and must be protected.
- Lakes and ponds may be used as a source of irrigation water. It is important to consider these functions when designing and constructing the ponds.
- Careful design may significantly reduce future operating expenses for lake and aquatic plant management.

Best Management Practices

- Consult with a qualified golf course architect, working in conjunction with a stormwater engineer, to develop an effective stormwater management system that complies with the requirements of the water management district/department or other permitting agency.
- When constructing drainage systems, pay close attention to engineering details such as subsoil preparation, the placement of gravel, slopes, and backfilling.
- Where practical, internal golf course drains should discharge through pretreatment zones and/or vegetative buffers to help remove nutrients and sediments.
- Studies of water supplies are needed for irrigation systems, and studies of waterbodies or flows on, near, and under the property are needed to properly design a course's stormwater systems and water features, and to protect water resources.
- Peninsular projections and long, narrow fingers into ponds may prevent water mixing. Ponds that are too shallow may reach high temperatures, leading to low oxygen levels and promoting algal growth and excess sedimentation.
- In shallow or nutrient-impacted ponds, the use of aeration equipment may be required to maintain acceptable dissolved oxygen (DO) levels in the water.

Pond Use and Maintenance

Principles

- Successful pond management should include a clear statement of goals and priorities to guide the development of the BMP 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
    - Vegetation on the lakeshore
- 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 for the manager to understand their function and how good water quality can be maintained if these zones (riparian zone, littoral zone, limnetic zone, and benthic zone) are properly managed.
- Surface water sources can present problems with algal and bacteria growth. Algal cells and organic residues of algae can pass through irrigation system filters and form aggregates that may plug emitters.
- Pond leaks should be controlled and managed properly.
- Use an expert in aquatic management to help develop and monitor pond management programs.

Best Management Practices

- Use leak controls in the form of dike compaction, natural-soil liners, soil additives, commercial liners, drain tile, or other approved methods.
- Maintain a riparian buffer to filter the nutrients and sediment in runoff.
- Reduce the frequency of mowing at the lake edge and collect or direct clippings to upland areas.
- Prevent overthrowing fertilizer into ponds. Practice good fertilizer management to reduce nutrient runoff into ponds, which causes algae blooms and ultimately reduces DO levels.
- Establish a special management zone around pond edges.
- Dispose of grass clippings where runoff will not carry them back to the lake.
- Encourage clumps of native emergent vegetation at the shoreline.
- Maintain water flow through lakes, if they are interconnected.
- Establish wetlands where water enters lakes to slow water flow and trap sediments.
- Maintain appropriate silt fencing and BMP on projects upstream to reduce erosion and the resulting sedimentation.
- Manipulate water levels to prevent low levels that result in warmer temperatures and lowered DO levels.
- Aerate ponds and dredge or remove sediment before it becomes a problem.

Pond Water-Level Monitor

Principle

Evaporation losses are higher in some regions than others and vary from year to year and within the year. However, evaporative losses could approach 6 inches per month during the summer. Aquatic plants are more difficult to control in shallow water.

Best Management Practices

- A pond should hold surplus storage of at least 10 percent of full storage.
- Provide an alternative source for ponds that may require supplemental recharge from another water source such as a well during high-demand periods.
- Estimated losses from evaporation and seepage should be added to the recommended depth of the pond.

Metering

Principles

- Rainfall may vary from location to location on a course; the proper use of rain gauges, rain shut-off devices, flow meters, soil moisture sensors, and/or other irrigation management devices should be incorporated into the site's irrigation schedule.
- It is also important to measure the amount of water that is actually delivered through the irrigation system, via a water meter or a calibrated flow-measurement device.
- Knowing the flow or volume will help determine how well the irrigation system and irrigation schedule are working.

Best Management Practices

- Calibrate equipment periodically to compensate for wear in pumps, nozzles, and metering systems.
- Properly calibrated flow meters, soil moisture sensors, rain shut-off devices, and/or other automated methods should be used to manage irrigation.
- Flow meters should have a run of pipe that is straight enough — both downstream and upstream — to prevent turbulence and bad readings.
- Flow meters can be used to determine how much water is applied.

Surface Water Management

Stormwater Capture

Although golf courses are typically large properties ranging in size from 60 to 200 acres, they are just one link in a stormwater management chain. Generally, a quantity of stormwater enters the golf course area, supplemented by what falls on the golf course proper, and then the stormwater leaves the golf course. Therefore, golf courses are realistically capable of having only a small impact on major stormwater flow. That impact should be to add only small increments of water over a given period of time. Engineers call this function "detention."

When golf courses are designed and built, their drainage capability concept is guided by an average rainfall event of a given frequency. For example, typically, a golf course drainage system is designed to detain a two- or five-year rain event. In other words, when that rain event happens, the golf course will be able to be reasonably drained in a matter of hours, as excess water not absorbed by the soil flows through the drainage system, is temporarily held, and finally leaves the property. In some instances, golf courses and other recreational facilities are mandated to be designed to handle a 20-, 50- or 100-year rain event, which means the golf course must detain more water for perhaps a longer period of time. This ability to detain large amounts of water requires accurate engineering and extensive construction to prevent physical or financial damage to the facility.

Best Management Practices are intended to prolong the detention process as long as practical, harvest as much of the stormwater in surface or underground storage as reasonable, and to improve the quality of water leaving the property when possible.

Principles

- When the golf course is properly designed, rain and runoff captured in water hazards and stormwater ponds may provide most or all of the supplemental water necessary under normal conditions, though backup sources may be needed during drought conditions.
- Capture systems should be considered part of the overall treatment.

- Stormwater capture is desirable where the lowest quality of water is needed to conserve potable water, maintain hydrologic balance, and improve water treatment.
- This practice uses natural systems to cleanse and improve water treatment.

Best Management Practices

- Install berms and swells to capture pollutants and sediments from runoff before it enters the irrigation storage pond.
- Monitor pond water level for water loss (seepage) to underground systems. If seepage is occurring, it may be necessary to line or seal the pond or install pumps to relocate water.
- Install water-intake systems that use horizontal wells placed in the subsoil below the storage basin; use a post pump to filter particulate matter.
- A backup source of water should be incorporated into the management plan.
- Inspect irrigation pumps, filtration systems, conveyances and control devices to prevent/correct system issues.

Regulatory Considerations

Principle

Course owners and superintendents should investigate regulatory requirements that apply to the golf facility to protect surface and groundwater quality.

Best Management Practices

- Consult with federal, state, and local water management agencies, and/or consult an approved management plan before performing cultural practices: fertilization, installation of plants, hand removal of plants, or mechanical harvesting. Any fertilization practices would need to be in compliance with the Water Quality Standards found in the Kentucky Administrative Regulations, Title 401 Energy and Environment Cabinet – Department for Environmental Protection 401 KAR Chapter 10 regulations or the Chapter 5 regulations pertaining to groundwater protection.
- The introduction of aquatic triploid grass carp, biological controls, aeration, and chemical controls (herbicide/algaecide) must be approved and monitored according to permit and licensing protocols and compliance. The discharge from impoundments would be permitted through 401 KAR Chapter 5.
- The disposal of sediments from surface water ponds (stormwater detention) are subject to 401 KAR Chapter 5 Regulations.
- Golf course management may be affected by Total Maximum Daily Loading (TMDL), mitigation, and watershed basin management action plans (BMAP). 401 KAR Chapter 10 Regulations pertain to water quality standards associated with TMDL. The permitting of the discharge to the TMDL would be handled through401 KAR Chapter 5 Regulations.

- Wetlands are protected areas; consult with federal and state agencies before altering natural aquatic areas. 401 KAR Chapter 4 Regulations apply to construction in and around streams.
- Constructed wetlands should have an impervious bottom to prevent groundwater contamination and should be in compliance with 401 KAR Chapter 4 and 5 Regulations.
- Studies of water supplies are needed for irrigation systems, including studies of waterbodies or flows on, near, and under the property to properly design a course's stormwater system and water features to protect water resources. Must be in compliance with 401 KAR Chapter 4 Regulations for water supply requirements and 401 KAR Chapter 5 Regulations for groundwater protection requirements.

Water Quality Protection

Principle

- An aquatic plant management strategy should address the intended uses of the waterbody to maintain water quality. Proper documentation of the site's physical attributes and location, the presence of invasive or weedy species, aesthetics, watershed and groundwater assessments, and other environmental considerations.
- Only licensed individuals or contractors should be allowed to select and apply aquatic pesticides.

Best Management Practices

- Accommodate natural lake processes in the construction of lakes and ponds; include herbaceous and woody vegetation and emergent and submergent shoreline plants to reduce operational costs.
- Use integrated pest management (IPM) strategies and native or naturalized vegetation wherever practical.
- Apply appropriate herbicides to minimize damage to non-target littoral plantings.
- Maintain a narrow band of open water at the pond edge to control the expansion of plants into more desirable littoral plantings.
- Use appropriate aquatic herbicides to prevent turfgrass injury and to protect water quality and wildlife habitat.
- Irrigation should not directly strike or run off to waterbodies, and no-fertilization buffers should be maintained along water edges.
- Outline goals and priorities to guide the development of the BMP necessary to support the lake/aquatic management plan.
- Superintendents should monitor designated waters in their area for the persistence of toxic herbicides and algaecides in the environment.
- Secondary environmental effects on surface water and groundwater from the chemical control of vegetation should be monitored and recorded.

- Apply fertilizer and reclaimed (reuse) irrigation/fertigation appropriately to avoid surface water and groundwater contamination.
- Apply copper products per label instructions to reduce the risk of impairing water quality and causing negative biological impacts.
- Identify position of property in relation to its watershed.
- Identify overall goals and validate concerns of the local watershed.
- Identify surface water and flow patterns.
- Indicate stormwater flow as well as existing and potential holding capacity.
- Indicate impervious surfaces, such as buildings, parking lots, or pathways.
- Indicate major drainages and catch basins that connect to local surface water bodies.
- Identify and understand depth to water tables and soil types.
- Locate and protect wellheads.

Dissolved Oxygen

Principles

- Every golf course should have a plan to monitor the state of the environment and the effects the golf course may be having on the environment.
- Monitoring is used to determine whether outside events are changing the water quality entering the golf course, or whether the golf course is having a positive, neutral, or negative effect on water quality. It also provides a body of evidence on the golf course's environmental impact.
- A water-quality monitoring plan should be prepared to ensure the ongoing protection of groundwater and surface-water quality after construction has been completed. The same sites should be monitored during the preconstruction phase, although the monitoring plan can be modified based on site-specific conditions.
- Sampling parameters are determined based on golf course operation and basin-specific parameters of concern (these may be identified by local/state Total Maximum Daily Load (TMDL) Programs). Typically, samples should be analyzed for nutrients, pH and alkalinity, sediments, and suspended solids, dissolved oxygen (DO), heavy metals, and any pesticides expected to be used on the golf course.
- Ongoing, routine water sampling provides meaningful trends over time. A single sample is rarely meaningful in isolation.
- Post-construction sampling of surface-water quality should begin with the installation and maintenance of golf course turf and landscaping. Samples should be collected a minimum of three times per year.
- If there is no discharge on the scheduled sample date, samples should be taken during the next discharge event.
- Post-construction surface-water quality sampling should continue through the first three years of operation and during the wet and dry seasons every third year thereafter, provided that all required water-quality monitoring has been

completed and the development continues to implement all current management plans. It may also be wise to sample if a significant change has been made in course operation or design that could affect nearby water quality.

- Sampling parameters should be determined based on golf course operation and any basin-specific parameters of concern (identified by the TMDL program or local regulators).
- The purpose of quality assurance/quality control (QA/QC) is to ensure that chemical, physical, biological, microbiological, and toxicological data are appropriate and reliable. Data should be collected and analyzed using scientifically sound procedures.
- However, even if the data are only for proprietary use and are not reported to any regulatory agency, it is strongly recommended that a certified laboratory be used and all QA/QC procedures followed.
- Golf course management must have good data to make good decisions. If a golf course should ever want to produce data for an agency or go to court to defend the facility from unwarranted charges, those data must meet QA/QC standards to be defensible as evidence.

Best Management Practices

- Establish DO thresholds to prevent fish kills (occur at levels of 2 ppm), for example, use artificial aeration (diffusers).
- Reduce stress on fish; keep DO levels above 3 ppm.
- Select algaecides containing hydrogen peroxide instead of copper or endothall to treat high populations of phytoplankton.
- Use IPM principles to limit excess use of pesticides.
- Spot-treat filamentous algae or frequently remove algae by hand to prevent lowering oxygen concentrations in water.
- Use dyes and aeration to maintain appropriate light and DO levels.
- Apply algaecides to small areas to prevent fish mortality; do not treat the entire pond at once.
- Coordinate construction/renovation activities to minimize the amount of disturbed area and possible risk of contamination via runoff.
- Plan construction/renovation activities in phases to limit soil disruption and movement.
- Sod, spring, or reseed bare or thinning turf areas.
- Mulch areas under tree canopies to cover bare soil.
- Avoid the use of trimmers along the edge of the water body.
- Mow lake and pond collars at a higher height to slow and filter overland flow to waterbodies.
- Remove excess sediments to reduce irrigation system failures.
- Treat dredged materials as a toxic substance. Avoid contact with turf.
- Locate littoral shelves at the pond’s inlets and outlets to reduce problems with the playability and maintainability of a water hazard.

- Seek professional assistance from an environmental specialist to design an appropriate water sample collection strategy.
- Determine which sites will be analyzed, and use reputable equipment and qualified technicians.
- Demonstrate responsible land and water use practices based on water data.
- Define data values appropriately based on the associated BMP used to protect water quality.
- Record observations of fish, wildlife, and general pond conditions.

Aquatic Plants

Principles

- 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.
- Address areas where standing water may provide habitat for nuisance organisms.

Best Management Practices

- Use IPM principles to address insects that may pose a hazard to human health.
- Drain areas of standing water during wet seasons to reduce insect populations.
- Use *Bacillus thuringiensis* (*Bt*) products according to label directions to manage waterborne insect larvae.

Human Health Concerns

Principles

- 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.
- Address areas where standing water may provide habitat for nuisance organisms.

Best Management Practices

- Use IPM principles to address insects that may pose a hazard to human health.
- Drain areas of standing water during wet seasons to reduce insect populations.
- Use *Bacillus thuringiensis* (*Bt*) products according to label directions to manage waterborne insect larvae.

Floodplain Restoration

Principles

- Reestablishment of natural water systems helps mitigate flooding and control stormwater.
- Address high sediment and nutrient loads and vertical and lateral stream migration causing unstable banks, flooding, and reductions in groundwater recharge.
- Land use decisions and engineering standards must be based on the latest research science available.

Best Management Practices

- Install stream buffers to restore natural water flows and flooding controls.
- Install buffers in play areas to stabilize and restore natural areas that will attract wildlife species.
- Install detention basins to store water and reduce flooding at peak flows.

Stormwater, Ponds, and Lakes

Stormwater is the conveying force behind what is called nonpoint source pollution. Nonpoint pollution, which is both natural and caused by humans, comes not from a pipe from a factory or sewage treatment plant, but from daily activity. Pollutants commonly found in stormwater include the microscopic wear products of brake linings and tires; oil; shingle particles washed off roofs; soap, dirt, and worn paint particles from car washing; leaves and grass clippings; pet and wildlife wastes; lawn, commercial, and agricultural fertilizers; and pesticides.

Principles

- 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 involves storing irrigation water, controlling erosion and sediment, enhancing wildlife habitat, removing waterborne pollutants, and addressing aesthetic and playability concerns.
- Most golf courses plan their lakes and water hazards to be a part of the stormwater control and treatment system. 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.
- 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.
- 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.

Best Management Practices

- Install swales and slight berms where appropriate around the water's edge, along with buffer strips, to reduce nutrients and contamination.
- Design stormwater treatment trains to direct stormwater across vegetated filter strips (such as turfgrass), through a swale into a wet detention pond, and then out through another swale to a constructed wetland system.
- Ensure that no discharges from pipes go directly to water.
- Eliminate or minimize directly connected impervious areas.
- Use vegetated swales to slow and infiltrate water and trap pollutants in the soil, where they can be naturally destroyed by soil organisms.
- Use depressed landscape islands in parking lots to 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 treatment volume and settle out sediments, while allowing the overflow to drain away.
- Maximize the use of pervious pavements, such as brick or concrete pavers separated by sand and planted with grass. Special high-permeability concrete is available for cart paths or parking lots.
- Disconnect runoff from gutters and roof drains from impervious areas, so that it flows onto permeable areas that allow the water to infiltrate near the point of generation.
- Golf course stormwater management should include "natural systems engineering" or "soft engineering" approaches that maximize the use of natural systems to treat water.
- Ensure that no discharges from pipes go directly to water.
- Use a treatment train approach.
- Institute buffers and special management zones.

Water Quality Monitoring and Management

Site Analysis

Design an aquatic plant management strategy that addresses the intended uses of the waterbody to maintain water quality. Identify the site's physical attributes and location, the invasive or weedy species present, aesthetics, watershed and groundwater assessments, and other environmental considerations.

Best Management Practices

- Accommodate natural lake processes in the construction of lakes and ponds; include herbaceous and woody vegetation and emergent and submergent shoreline plants to reduce operational costs.
- Use Integrated Pest Management (IPM) and native or naturalized vegetation wherever practical.
- Apply appropriate herbicides to minimize damage to non-target littoral plantings.
- Maintain a narrow band of open water at the pond edge to control the expansion of plants into more desirable littoral plantings.
- Use appropriate aquatic herbicides to avoid turfgrass injury.
- Irrigation should not directly strike or runoff to waterbodies and no-fertilization buffers should be maintained along edges.
- Outline goals and priorities to guide the development of the BMP necessary to support the lake/aquatic management plan.
- Superintendents should monitor designated waters in their area for the persistence of highly toxic herbicides and algaecides in the environment.
- Secondary environmental effects on surface water and groundwater from the chemical control of vegetation should be monitored and recorded.
- Apply fertilizer and reclaimed (reuse) irrigation/fertigation appropriately to avoid surface and groundwater contamination.
- Apply copper products per label instructions to reduce the risk of negative biological impacts and impairing water quality.
- Identify position of property in relation to its watershed.
- Identify overall goals and qualify concerns of the local watershed.
- Indicate surface water and flow patterns.
- Indicate stormwater flow as well as existing and potential holding capacity.

- Indicate impervious surfaces, such as buildings, parking lots, or pathways.
- Indicate major drainages and catch basins that connect to local surface water bodies.
- Identify and understand depth to water tables and soil types.
- Locate and protect wellheads.

Regulatory Considerations

Golf course owners and superintendents should investigate regulatory requirements that may exist in their location to protect surface and groundwater quality.

Best Management Practices

- Aquatic management of plants may be regulated under construction permitting and regulatory licensing requirements. Consult with federal, state, and local water management agencies before managing golf course lakes and wetland areas.
- Consult with federal, state, and local water management agencies, and/or consult an approved management plan before performing cultural practices: fertilization; installation of plants; hand removal of plants or mechanical harvesting.
- The introduction of aquatic triploid grass carp, biological controls, aeration, and chemical controls (herbicide/algaecide) must be approved and monitored according to permit and licensing protocols and compliance.
- The disposal of sediments from surface-water ponds (stormwater detention) may be subject to regulation.
- Golf course owners are responsible for Total Maximum Daily Loading (TMDLs), mitigation, and watershed basin management action plans (BMAP).
- Wetlands are protected areas; consult with federal and state agencies before altering natural aquatic areas.
- Constructed wetlands should have an impervious bottom to prevent groundwater contamination.
- Studies of water supplies are needed for irrigation systems, including studies of waterbodies or flows on, near, and under the property are needed to properly design a course's stormwater system and water features to protect water resources.

Sampling Parameters, Collection, and Analysis

Principles

- A water quality monitoring program must include monitoring of surface water, groundwater, and pond sediments. It should be implemented in three phases: background, construction, and long-term management.

- Sampling of all watershed ingress and egress points is important to know what is coming into the property to identify potential impacts and baseline of water quality data.
- The purpose of quality assurance/quality control (QA/QC) is to ensure that chemical, physical, biological, microbiological, and toxicological data are appropriate and reliable, and are collected and analyzed using scientifically sound procedures.
- It is strongly recommended that a certified laboratory be used even if the data are only for proprietary use and are not reported to any regulatory agency
- QA/QC procedures should be followed. Golf course management must have good data to make good decisions, and if a golf course should ever want to produce data for an agency or in court to defend the facility from unwarranted charges, those data must meet QA/QC standards to be defensible as evidence.

Best Management Practices

- Seek professional assistance from an environmental specialist to design an appropriate water sample collection strategy.
- Determine what sites will be analyzed and use reputable equipment and qualified technicians.
- Demonstrate responsible land and water use practices based on water data.
- Define data values appropriately based on the associated BMP used to protect water quality.
- Record observations of fish, wildlife, and general pond conditions.

Figure 6. Sampling of all watershed ingress and egress points is important to know what is coming into the property to identify potential impacts and baseline of water quality data. Photo credit: C. Santilli

Water Quality Sampling Program

Principles

- Every golf course should have a plan to monitor the state of the environment and the effects the golf course may be having on the environment.
- Monitoring is the method used to determine whether outside events are impacting the water quality entering the golf course, or whether the golf course is having a positive, neutral, or negative effect on water quality. It also provides a body of evidence on the golf course's environmental impact.
- A water quality monitoring plan should be prepared to ensure the ongoing protection of groundwater and surface-water quality after construction is completed. The same sites should be monitored during the preconstruction phase, although the monitoring plan can be modified based on site-specific conditions.

- Sampling parameters are determined based on golf course operation and basin-specific parameters of concern (these may be identified by local/state Total Maximum Daily Load [TMDL] Programs). Typically, samples should be analyzed for nutrients, pH and alkalinity, sediments, suspended solids, dissolved oxygen (DO), heavy metals, and any pesticides expected to be used on the golf course.
- Ongoing, routine water sampling provides meaningful trends over time. A single sample is rarely meaningful in isolation.
- Post-construction surface-water quality sampling should begin with the installation and maintenance of golf course turf and landscaping. Samples should be collected a minimum of three times per year.
- Should there be no discharge on the scheduled sample date, samples should be taken during the next discharge event.
- Post-construction surface-water quality sampling should continue through the first three years of operation and during the wet and dry seasons every third year thereafter, provided that all required water quality monitoring has been completed and the development continues to implement all current management plans. It may also be wise to sample if a significant change has been made in course operation or design that could affect nearby water quality.
- Sampling parameters should be determined based on golf course operation and any basin-specific parameters of concern (identified by the TMDL program or local regulators).
- Golf courses should also sample for macroinvertebrates as determined useful by water quality specialists.

Best Management Practices

- Establish dissolved oxygen (DO) thresholds to prevent fish kills (occur at levels of 2 ppm), for example, use artificial aeration (diffusers).
- Reduce stress on fish; keep DO levels above 3 ppm.
- Select algaecides containing hydrogen peroxide instead of one containing copper or endothall to treat high populations of phytoplankton.
- Use IPM principles to limit excess use of pesticides.
- Spot-treat filamentous algae or frequently remove algae by hand to prevent lowering oxygen concentrations in water.
- Use dyes and aeration to maintain appropriate light and DO levels.
- Apply algaecides to small areas to prevent fish mortality; do not treat the entire pond at once.
- Coordinate construction/renovation activities to minimize the amount of disturbed area and possible risk of contamination via runoff.
- Plan construction/renovation activities in phases to limit soil disruption and movement.
- Sod, sprig, or reseed bare or thinning turf areas.
- Mulch areas under tree canopies to cover bare soil.
- Avoid the use of trimmers along the edge of the water body.

- Mow lake and pond collars at 2 inches or higher to slow and filter overland flow to water bodies.
- Remove excess sediments to reduce irrigation system failures.
- Treat dredged materials as a toxic substance. Avoid contact with turf.
- Locate littoral shelves at the pond’s inlets and outlets to reduce problems with the playability and maintainability of a water hazard.

Surface Water Quality Standards can be found at: 401 KAR 10:031

Wetland Protection

Principles

- Several states protect wetlands as waters of the state by rule of law. Wetlands act both as filters for pollutant removal and as nurseries for many species. Many people do not realize the vital role they play in purifying surface waters.
- 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 golf holes have been threaded through sensitive areas, and with proper design and management golf 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.

Best Management Practices

- Establish wetlands where water enters lakes to slow water flow and trap sediments.
- Maintain appropriate silt fencing and BMP on projects upstream to prevent erosion and sedimentation.
- Natural waters cannot be considered treatment systems and must be protected. (Natural waters do not include treatment wetlands.)
- Establish a low- to no-maintenance level within a 75-foot buffer along non-tidal and tidal wetlands.
- Establish and maintain a 100-foot riparian buffer around wetlands, springs, and spring runs.

You can find more information on Cooperative Extension Service Publication: ENRI - 109

Figure 7. Wetlands act both as filters for pollutant removal and as nurseries for many species. Many people do not realize the vital role they play in purifying surface waters. Photo credit: Kraig Binder.

Buffer Zones

Principles

- Buffers around the shore of a waterbody 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/food sources for wildlife. As discussed above, 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 BMP in these areas include filter and trap sediment, site-specific natural/organic fertilization, and limits on pesticide use, primarily focusing on the control of invasive species.
- Golf course stormwater management should include “natural systems engineering” or “soft engineering” approaches that maximize the use of natural systems to treat water.

Best Management Practices

- Riparian buffer areas are above the high-water mark and should be unfertilized and left in a natural state.
- Reduce the frequency of mowing at the lake edge and collect or direct clippings to upland areas.
- Institute buffers and special management zones.
- The placement of bunkers and the shaping of contours surrounding a green should allow proper drainage and provide for the treatment and absorption of runoff from the green.
- Use turf and native plantings to enhance buffer areas. Increase height of cut in the riparian zone to filter and buffer nutrient movement to the water.
- Use a deflector shield to prevent fertilizer and pesticide prills from contacting surface waters.
- Apply fertilizer and pesticides based on the effective swath; keep application on target and away from buffers or channel swales.
- Use a swale and berm system to allow for resident time (ponding) for water to infiltrate through the root zone to reduce lateral water movement to the surface water body.
- Maintain a riparian buffer to filter the nutrients in stormwater runoff.
- An appropriate-sized buffer (steeper slope requires great buffer width) of turf mowed at a higher height of cut and minimally fertilized with enhanced-efficiency fertilizers can provide an effective buffer.
- Use plant buffers with native species to provide pleasing aesthetics, habitat, and food sources for wildlife.
- Ideally, littoral zones should have a slope of about 1 foot vertical to 6-10 foot horizontal.
- Encourage clumps of native emergent vegetation at the shoreline.
- Establish special management zones around pond edges.
- Reverse-grade around the perimeter to control surface water runoff into ponds and reduce nutrient loads.
- Planting on slopes with less than a 6-foot horizontal to a 1-foot vertical may not be as successful over the long term.
- Construct random small dips and ridges of a few inches to a foot to promote diversity within the plant community and provide a healthier and more productive littoral zone.
- 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.
- Practice good fertilizer management to reduce the nutrient runoff into ponds that causes algae blooms and ultimately reduces DO levels.
- Manipulate water levels to prevent low levels that result in warmer temperatures and lowered DO levels.
- Aerate shallow lakes less than 6 feet in depth to maintain acceptable DO levels.
- Where applicable, aerate at night to control oxygen depletion in any pond.
- Install desirable plants to naturally buffer DO loss and fluctuation.

- Dispose of grass clippings where runoff and wind will not carry them back to the lake.
- Nutrient rich runoff encourages alga blooms and other phytoplankton; apply appropriate fertilizer rates and application setbacks.
- Dredge or remove sediment to protect beneficial organisms that contribute to the lakes food web and overall lake health.

You can find more information in University of Kentucky Cooperative Extension Service Publication: ENRI - 109 http://water.ca.uky.edu/files/enri109.pdf

Stormwater Management

Controlling 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, stormwater involves storing irrigation water, controlling erosion and sedimentation, enhancing wildlife habitat, removing waterborne 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.

Best Management Practices

- Use vegetated swales to slow and infiltrate water and trap pollutants in the soil, where they can be naturally destroyed by soil organisms.
- Maximize the use of pervious pavements, such as brick or concrete pavers separated by sand and planted with grass.
- Special high-permeability concrete is available for cart paths or parking lots.
- Design stormwater control structures to hold stormwater for appropriate residence times in order to remove total suspended solids.
- Use a stormwater treatment train to convey water from one treatment structure to another.
- Eliminate or minimize directly connected impervious areas as much as possible.
- Disconnect runoff from gutters and roof drains from impervious areas, so that it flows onto permeable areas that allow the water to infiltrate near the point of generation.
- Use depressed landscape islands in parking lots to 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 treatment volume and settle out sediments, while allowing the overflow to drain away.
- Ensure that no discharges from pipes go directly to water.

You can find more information in University of Kentucky Cooperative Extension Service Publication: HENV-203

Sediment

Principle

During construction and/or renovation, 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.

Best Management Practices

- Use shoreline grasses to prevent bank erosion.
- Use dry detention basins/catchments to buffer flooding and excessive runoff that may contain sediment.
- When constructing drainage systems, pay close attention to engineering details such as subsoil preparation, the placement of gravel, slopes, and backfilling.
- Internal golf course drains should not drain directly into an open water body, but should discharge through pretreatment zones and/or vegetative buffers to help remove nutrients and sediments.
- Maintain a vegetative cover on construction sites until it is actually ready for construction.

Figure 8. Use dry detention basins/catchments to buffer flooding and excessive runoff that may contain sediment. Photo credit: Kraig Binder.

Sodic/Saline Conditions

Principles

- All natural waters contain soluble salts; however, the amount and type of salts they contain vary greatly.
- Irrigation water can degrade when wells are pumped at high rates or for prolonged periods. Sometimes “up-coning” can occur from pumping, whereby saline water, rather than freshwater, is drawn into the well.
- Saline water typically is unsuitable for irrigation because of its high content of TDS.
- Saltwater intrusion from groundwater pumping near coastal areas can create a problem with some irrigation wells.

Best Management Practices

- Use surface water to mix (blend) affected groundwater to lower the total salt concentration.
- Routinely monitor water quality to ensure that salt concentrations are at the acceptable levels.
- Consider fertilizer that uses soluble nitrogen forms with a relatively low concentration of salts in frequent applications.
- Consider a controlled-release fertilizer to reduce salt injury.
- Identify salt additions and saline sources that contribute to the total salt concentration.
- Base management plan on routine soil tests to determine sodium adsorption ration (SAR), exchangeable sodium ercentage (ESP), electrical conductivity saturated paste method/unit (ECe), and free calcium carbonate content.
- Select alternative turfgrass and landscape plants that are more salt-tolerant.
- Reduce salt accumulations in the soil by flushing soils as needed with a higher-quality water source.
- Design irrigation systems to account for flushing of salt accumulation from soil.
- Amend soil and water to remove salt ions from affected areas.
- Evaluate BMP to determine effectiveness toward managing sodic/saline conditions.

Nutrients Management

Regulatory Considerations

Proper nutrient management plays a key role in the reduction of environmental risk and increases course profitability. Among other benefits, applied nutrients inflate the available pool of nutrients and allow turfgrass to recover from damage, increase its resistance to stress, and increase its playability. However, the increase in available nutrients also increases the potential risk of environmental impact. Nutrients may move beyond the turfgrass via leaching or runoff, which may directly impact our environment. Other organisms also respond to increases in nutrients and, in some cases, these organisms may deleteriously alter our ecosystem. The goal of a proper nutrient management plan should be to apply the minimum necessary nutrients to achieve an acceptable playing surface and apply these nutrients in a manner that maximizes their plant uptake.

Principles

Local and state regulations are in place to better manage nutrient risks based on the unique conditions that exist in your location. Designing a nutrient management plan within these regulations addresses local concerns and minimizes risk within your unique ecosystem. Depending on your location, regulatory agencies may include federal, state, or local policies. In general, if your location is regulated by nutrient policies (such as nutrient management plans), all of your nutrient BMPs will be designed according to these policies.

Best Management Practices

- Anyone spreading fertilizer must have a pesticide license and category N18
- 3 specific + 6 general hours are required every three years.

Label

- A line-by-line explanation of the Kentucky fertilizer label can be found at http://www.rs.uky.edu under 'Kentucky Fertilizer Law'.
- The fertilizer label may contain:
    - Brand

- Grade
- Manufacturer’s name and address
- Guaranteed analysis
- “Derived from” statement
- Net weight

Soil Testing

Principles

Through proper sampling, laboratory analysis, interpretation of results, recommendations, and record keeping, soil testing can be used to manage nutrients more efficiently.

Best Management Practices

- Accurate and consistent sampling is essential to providing useful soil test information over time.
- Divide the course into logical components such as greens, fairways, tees, roughs, etc., for each hole.
- Ten to 15 soil samples should be randomly taken from each section and blended together to provide a representative, uniform soil sample.
- Each soil sample should be taken from the same depth. Placing a stopper on the outside of your soil sampler will ensure the sampler penetrates the soil to the same depth each time. A small piece of metal welded to the outside of the sampler works well.
- The Mehlich (Mā lik) III extractant should be the preferred extractant. If another extractant is used, the nutrient critical levels detailed below are not useful.
- The same extractant must be used for each test in order to compare soil test results over time.
- Soil tests can be used to determine if lime, P, K, or Mg should or should not be applied.
- Soil tests can be used to determine specific application rates of lime.
- Soil tests cannot be used to determine specific application rates of P, K, or Mg. Correlation data between the soil test value and applied P, K, or Mg are necessary to provide application recommendations. These correlation data do not exist for either warm-season or cool-season turfgrasses in Kentucky.
- Keeping soil tests from prior years will allow you to observe changes over time.
- This practice can provide good evidence of the impact of your nutrient management plan.

Table 1. Suggested soil test nutrient levels for cool and warm-season turfgrasses.

pH	Salinity	P	K	Mg
	(ds/m)	--- Mehlich III (ppm) ---		

6.5	< 4	≥ 10	≥ 40	≥ 20

Soil pH

Principles

Identifying pH levels may be the most important soil test result for turfgrass managers. In most cases, a pH of 6.3 is ideal because it provides the greatest probability of micronutrient availability. Soil pH adjustments may occur slowly and are temporary.

Best Management Practices

- To increase soil pH, apply a liming material (calcium carbonate, calcium oxide, dolomitic limestone) that contains Ca^{2+} and neutralizes acidity.
- To lower soil pH, products containing elemental sulfur or ammonium sulfate should be applied.
- In some cases, utilizing injection pumps into irrigation water to address pH can be beneficial.

Plant Tissue Analysis

Principles

- Tissue testing provides a precise measurement of nutrients within the plant.
- Tissue test sufficiency ranges vary by season and are not universally accepted by scientists.
- Through proper sampling, consistent intervals, and record keeping, historical tissue concentrations may be used to help diagnose existing turfgrass issues.

Best Management Practices

- Tissue samples may be collected during regular mowing.
- Do not collect tissue after any event that may alter the nutrient analysis. Events may include fertilization, topdressing, pesticide applications, etc.
- Place tissue in paper bags, not plastic.
- If possible, allow tissue samples to air-dry at your facility before mailing them.
- Poor-quality turfgrass that is of concern should be sampled separately from higher-quality turfgrass.
- When turfgrass begins to show signs of nutrient stress, a sample should be collected immediately.
- More frequent tissue sampling allows a more accurate assessment of your turfgrass nutrient status changes over time.
- The quantity of tissue analysis you choose to use is entirely up to you and your needs. However, two to four tests per year are common on greens and one to two tests per year are common on tees and fairways.

- Keeping tissue tests from prior years will allow you to observe changes over time.
- Tissue testing can provide good evidence of the impact of your nutrient management plan.
- Do not apply a specific amount of nutrient based upon a tissue test because little to no evidence exists supporting this practice. Instead, determine your baseline nutrient levels by sampling your minimum acceptable turfgrass several times over several years. When your baseline minimum level has been estimated, then adjust your nutrient applications in small increments relative to your baseline.

Nutrients

Principles

Understanding the components of fertilizers, the fertilizer label, and the function of each element within the plant are all essential in the development of an efficient nutrient management program.

Nitrogen

- Do not apply N based upon soil tests.
- Do not apply N based upon tissue tests.
- Based N applications upon turfgrass response research.
- Apply no more than 1 lb. of N per 1,000 sq. ft. per application when using granular soluble N.
- Apply no more than 2 lb. of N per 1,000 sq. ft. per application when using 100% slow-release N.
- Do not apply N to dormant turfgrass.
- Slow-release N sources reduces environmental risk.
- Foliar N may be derived from any soluble N source.

Nitrogen (N) is required by turfgrass in larger quantities than any other mineral nutrient because the plant demand for N is high and the supply of N from the natural environment is normal low. In instances where N is not applied according to the University of Kentucky recommendations, applied N can increase the risk of surface and ground water contamination. The fate of N applied to Kentucky turfgrass and detailed descriptions of the conversion processes can be found in AGR****. The objective of this document is to describe the function of N in turfgrass, explain how soil and tissue tests can be used to manage N applications, and to describe the various N sources available for application to turfgrass.

Function of Nitrogen in Turfgrasses

Numerous biochemical compounds inside turfgrass cells contain N including amino acids, proteins, chlorophyll, and hormones. Because N is a component of numerous compounds, N deficiency results in a rapid reduction in growth and will eventually result in severe yellowing of leaf tissue. Turfgrasses subject to intense traffic stress, such as turfgrass grown for sport turf, sod production, and golf courses may exhibit slow recovery in the absence of N. On the contrary, when N is over applied, turfgrass may also respond negatively by exhibiting reduced root growth, reduced stress tolerance, and increased thatch production.

Tissue Testing for Nitrogen

Using tissue testing to manage N applications to turfgrass can be problematic for several reasons. First, N concentrations in healthy turfgrass tissue can vary dramatically from season to season and most laboratories do not have sufficient data to separate these differences. For example, in Kentucky, warm season turfgrasses emerge from dormancy in the spring, grow during the summer, and enter dormancy in the fall. Healthy turfgrass may have 3% N in the spring, 2.5% N in the summer, and 3% N in the fall. Therefore, if the 'healthy N concentration' were 3%, than a tissue test in the summer would result in a recommendation to apply N when none was needed. The inverse of this seasonal effect is true for cool-season grasses, such as tall fescue and bentgrass. Second, N is mobile in turfgrass tissue, which results in N being translocated from older leaves to newer leaves. This movement of N results in N deficiency occurring first in older leaves. However, older leaves are rarely sampled because the mower removes tissue from the upper turf canopy rather than the lower leaves. Therefore, a true N deficiency in turfgrass may be easily overlooked by tissue testing. The last reason tissue tests are of little value is that tissue test calibrations have not been determined on Kentucky turfgrasses. In order to provide a meaningful recommendation, the concentration of N in the turfgrass must be correlated and calibrated to a response from the application of N. This research has not been conducted.

If tissue tests are collected from the same turfgrass, at the same time of year for several years, then historical values may be a useful diagnostic tool. However, please be aware that a sudden change in tissue N may be the symptom rather than the cause of the observed problem.

Soil Testing for Nitrogen

A soil test cannot be used to manage N applications to turfgrasses. However, some newer soil N tests are showing promising results in row-crop agriculture. These tests measure CO_2 flux and report values as 'CO_2 Burst' in parts per million, which provide an estimation of microbial activity. An additional test may provide an estimation of labile amino N extracted from soil organic matter. While these tests may eventually prove to be useful, they have not been correlated or calibrated to turfgrass response in Kentucky. In the absence of calibration data, it is not possible to interpret the reported value for turfgrasses. Therefore, using these tests to manage N applications to Kentucky turfgrasses is not recommended.

Applying Nitrogen

In general, apply no more than 1 pound of N per 1,000 ft^2 per application from granular soluble N sources and no more than 2 pounds of N per 1,000 ft^2 when the N source is

100% slow-release. The higher application rate for slow-release N sources is necessary because at lower rates, the amount of N released on a day-to-day basis may be insufficient to meet turfgrass demands. On highly manicure turfgrass, soluble N may be sprayed on the turfgrass foliage. As a foliar spray, the rate of soluble N may vary greatly depending upon the desired result. Nitrogen rates of 0.1 pounds of N per 1,000 ft^2 are usually necessary to induce a turfgrass response whereas, rates exceeding 1 pound of N per 1,000 ft^2 increase the risk of foliar burn.

Nitrogen Sources

Nitrogen sources are commonly categorized by the rate at which they release the N: soluble or slow-release (Table 1). Soluble N sources may also be referred to as readily available or quick release N and are defined as any N sources that contains water soluble N in either ammoniacal, nitrate, or urea form. Slow-release N may also be referred to as controlled-release N and is defined as any N source that delays the release of N into water soluble form relative to a reference soluble product (such as urea). A third, more ambiguous category, has been deemed ‘Enhanced-Efficiency’. Enhanced efficiency N sources are any N source that results in an increase in plant uptake and reduces the potential for environmental risk when compared to a reference material. Thus, essentially all slow-release N sources are also enhanced efficiency N sources, but only a few soluble N sources may be categorized as enhanced efficiency, as we will discuss.

Which type of N should you choose? Acceptable turfgrass quality can be achieved for extended periods with either soluble or slow-release N sources. The value of slow-release N sources is primarily environmental. Slow-release N sources greatly reduce the risk of off-site movement of N when compared with soluble N sources. This does not imply that soluble N sources result in environmental contamination. If applied according to UK recommendations, both soluble and slow-release N sources pose very little environmental risk, but both N sources must be applied appropriately based upon their release characteristics.

Table 2. Nutrient content of common soluble and slow-release N sources.

N Source	Guaranteed Analysis	Other Elements
Quick-Release		
Ammonium Nitrate	34-0-0	
Ammonium Sulfate	21-0-0	24% S
Diammonium phosphate (DAP)	18-46-0	
Monoammonium phosphate (MAP)	10-50-0	
Calcium Nitrate	15-0-0	20% Ca
Potassium Nitrate	13-0-44	
Sodium Nitrate	16-0-0	
Urea	46-0-0	
Slow-Release		

Sulfur-coated Urea	Variable	5-20% S
Polymer-coated Urea	Variable	
Ureaformaldehyde	38-0-0	
Methylene Urea	40-0-0	
Isobutylidene diurea (IBDU)	31-0-0	
Biosolids	Variable	Various

Soluble N Sources

Urea

Urea has a guaranteed analysis of 46-0-0 and may be the most common N source applied to turfgrass. Urea may be applied in granular or liquid forms, and is the least expensive N source based upon pounds of N and based upon cost per day of acceptable turf. Upon contact with water, urea immediately solubilizes into the soil solution. Once in the soil solution, urea must be converted to ammonium, which is mediated by the enzyme urease. Many factors may influence this enzymatic reaction. Soil moisture, temperature, and pH each influence the conversion of urea to ammonium and for this reason, urea is best utilized when moisture and temperature are adequate for plant growth.

Ammonium Sulfate

Ammonium sulfate is the ammonium salt of sulfuric acid and contains 21% N. Ammonium sulfate is a popular N source for turfgrasses especially on high pH soils. Ammonium sulfate normally results in a decrease in soil pH and is the most acidifying N source available (Table 2). Its ability to reduce pH is approximately 1/3 that of elemental sulfur. Thus, in situations where high soil pH is limiting turf quality, switching N sources to ammonium sulfate is a cost effective option, but will require time and regular applications. Be aware, soil pH changes are slow and temporary. Ammonium sulfate often results in a noticeable increase in growth and greening compared with urea. This is likely a result of N from ammonium sulfate being immediately plant available in the form of ammonium whereas N from urea must undergo conversion to ammonium prior to being plant available. Ammonium sulfate should be watered in immediately to reduce the probability of leaf burn. Leaf burn is a result of the ammonium sulfate salt remaining on the leaf surface, which lowers the water potential outside the leaf and ‘pulls’ water out of the plant.

Table 3. Acidifying effect of N sources based upon 1 pound of N (modified from Meister 1999; Pierre 1933; and Tisdale, et al. 1985)

N Source	Calcium Carbonate Equivalent*
Ammonium Sulfate	5.4
Monoammonium phosphate (MAP)	5.1
Diammonium phosphate (DAP)	3.6

Sulfur-coated Urea (40%N)	3.2
Polymer-coated Urea (44%N)	1.8
Urea	1.8
Ammonium Nitrate	1.8
Ureaform	1.8
Isobutylidene diurea (IBDU)	1.8
Biosolids	1.7
Calcium Nitrate	-1.3
Sodium Nitrate	-1.8
Potassium Nitrate	-2.0
* Negative numbers indicate a decrease in acidity (increase in pH).	

Ammonium Nitrate

Ammonium nitrate was a common N source for many years but its use has been reduced because it has been the oxidizing agent in various explosives. It has a guaranteed analysis of 34-0-0 with both the ammoniacal and nitrate forms of N being immediately plant available. Ammonium nitrate must immediately be watered in to avoid leaf burn.

Monoammonium and Diammonium Phosphates

Both monoammonium (MAP) and diammonium phosphate (DAP) are manufactured by reacting ammonia with phosphoric acid. MAP and DAP have guaranteed analyses of 11-48-0 and 18-46-0, respectively. MAP is a good choice for high pH soils because the soil pH immediately adjacent to the fertilizer particle may be reduced to 3.5, which can result in more of the N and P being available for plant uptake.

DAP is the most used fertilizer in the world and is a good choice for acidic soils because the application of DAP results in a pH of 8.5 immediately around the fertilizer granule. When DAP is applied to high pH, calcareous soils, the P may be bound by calcium to form dicalcium phosphate and the N easily volatilize because ammonium is highly soluble and easily converted to ammonia gas. Over time, the soil pH will return to the initial soil pH due to the conversion of ammonium to nitrate (nitrification). However, in the time required to reduce the soil pH back to its initial level, much of the P will have been lost to precipitation and N will have been lost to volatilization. When soil pH exceeds 6.5, volatilization of N from DAP can exceed 30% of applied N and can be 5x greater than that of MAP and 2x greater than that of urea and ammonium sulfate. Thus, DAP should not be used on high pH, calcareous soils.

Calcium Nitrate

Calcium nitrate has a guaranteed analysis of 15-0-0 and contains 20% calcium. The application of calcium nitrate may lead to an increase of soil pH (Table 2). Similar to urea and ammonium nitrate, calcium nitrate absorbs water readily and thus, has a short storage life. Blended fertilizers containing calcium nitrate that have been sparged with pesticides should be applied as soon as possible to prevent the fertilizer from hardening.

Potassium Nitrate

Potassium nitrate may be referred to as ‘Pot-Nit’ and has a guaranteed analysis of 13-0-44. It has the added benefit of containing K as well as N. The application of potassium nitrate results in an increase in soil pH and, thus, can be a good option where a low soil pH is limiting turfgrass quality. On native Kentucky soils, the application of K is normally unnecessary because Kentucky soils are naturally high in K. Your soil test results will determine if K is warranted. See AGR-***.

Sodium Nitrate

Sodium nitrate has a guaranteed analysis of 16-0-0. Sodium nitrate was commonly used prior to World War II because it could be mined from natural deposits and the process of harvesting N from the atmosphere was not yet invented. However, today the application of sodium nitrate is uncommon due to its cost and burn potential (Table 3). Sodium nitrate contains Na, which is not a plant essential element and may contribute to sodic soils.

Table 4. Relative burn potential from N sources based upon pounds of N (modified from Rader et al., 1943)

N Source	%
Sodium Nitrate	100
Potassium Nitrate	88
Ammonium Sulfate	53
Ammonium Nitrate	49
Monoammonium phosphate (MAP)	40
Urea	26
Diammonium phosphate (DAP)	26
Natural Organics	11

* For example, natural organics are 10x less likely to burn than sodium nitrate.

Slow-Release N Sources

Sulfur-coated Urea

Sulfur-coated ureas may be manufactured in several ways, but each has a urea substrate and a component of sulfur in the coating. Some manufactures use a polymer on the urea whereas other use a polymer on the outside of the sulfur. Regardless, SCU is perhaps the most common slow-release N source in turfgrass management. SCUs released almost entirely by catastrophic eruption, which describes the process in which the sulfur shell breaks open as a result of the internal force of water. University research has shown that the newer SCUs have a portion of prills that release without erupting. Regardless, the turfgrass response to SCU is comparable with other synthetic N sources. SCUs are the least expensive slow-release N source based upon price per pound of N and price per day of response.

Polymer-coated Urea

Polymer-coated ureas (PCUs) are manufactured in a variety of ways, but the finished products all contain a urea substrate coated with a polymer or resin. The guaranteed analysis of PCUs vary between 38-44% N. The manner in which N releases from PCUs is called osmotic diffusion. This simply means that water from outside the fertilizer prill enters the urea substrate by crossing through the semi-permeable polymer shell. After the urea inside the shell has dissolved, the water/urea solution moves out of the polymer shell by diffusion. This process is almost entirely mediated by temperature and the thickness and/or density of the polymer shell. Because temperature is the only environmental variable influencing the release of N from PCUs, PCUs have been documented to provide a more predictable and consistent N release than other slow-release N sources. University research has shown that the initial release of N from PCUs can be slower than other slow-release N sources. This initial delay is a result of the time required for the fertilizer to absorb water and dissolve the urea. However after this initial delay, the turfgrass response to PCUs is comparable to other N sources.

Methylene urea and Ureaformaldehyde

Methylene urea and ureaformaldehyde are reacted slow-release N sources that have a guaranteed analysis of 38-0-0 and 40-0-0, respectively. Because they are reaction products, they do not require a coating to maintain their slow-release characteristics. The release of N is microbially mediated and thus, any environmental factor that influences microbial activity will influence the release of N from methylene ureas. The cost of methylene ureas is comparable to other synthetic slow-release N sources based upon price per ton and price per pound of N.

Isobutylidene diurea

Isobutulidene diurea (IBDU) is the only slow-release N source that release N entirely by hydrolysis and is largely unaffected by environmental variables other than rainfall. IBDU has a guaranteed analysis of 31-0-0. The popularity of IBDU has waned over the last two decades because it is more expensive than other synthetic slow-release N sources. However, turfgrass response to IBDU is commonly as good as or better than many other N sources, especially during cool months.

Natural Organics

Natural organics are any N sources that originated from a plant or animal. Examples of natural organic fertilizers are municipal biosolids, bone meal, and feather meal. The N is bound into organic molecules and requires microbial activity to be liberated for turfgrass consumption. Generally, natural organics have low N analyses (<11%) unless blended with synthetic N sources. Turfgrass response to natural organics is normally equal to or better than equivalent amounts of N from urea and some other slow-release N sources. The increased response is likely a result of other nutrients also found in natural organics (phosphorus, magnesium, etc.). Natural organics are commonly the least expensive N source based upon price per ton and are the most expensive based upon price per pound of N. Natural organics that contain phosphorus should be applied based upon pounds of phosphorus to be applied, not based upon the pounds of N. When phosphorus-containing natural organics are applied based upon pounds of N, the amount of P that is also applied may be excessive. See AGR-*** for more information.

Liquid Slow-Release

Liquid slow-release N sources may be solutions or suspensions and primarily include methylene ureas. Examples of solutions include Coron and triazones whereas suspension include Blue Chip and Powder Blue. Suspension products are derived from the same granular methylene urea as describe above. The only difference is the particle size of the suspension is small enough to pass through nozzle screens. While these products contain a portion of slow-release N, the turfgrass response to these products is similar to urea. The actual benefit of liquid slow-release N sources is their document reduction of foliar burn.

Enhanced-Efficiency Fertilizers

All slow-release N sources are also enhanced-efficiency fertilizers (EEF) because they deliver their N to the plant more efficiently than their soluble N counterpart (i.e. urea, ammonium sulfate, etc.).

Urea may be treated with stabilizing compounds that reduces gaseous losses of N via denitrification and/or volatilization. Stabilized urea is considered an EEF but is not considered a slow-release N source. Stabilized urea contains either a nitrification inhibitor [nitrapyrin or dicyandiamide (DCD)] and/or a urease inhibitor [N-(n-butyl) thiophosphoric triamide (NBPT) or phenyl phosphorodiamidate (PPD)]. Many other urea stabilizing products claim to reduce gaseous N loss but only nitrapyrin, DCD, NBPT, and PPD have been confirmed in university testing.

When using stabilized urea, it is important to consider the turfgrass response relative to the cost. Stabilized urea should be used when conditions favor gaseous N loss, otherwise, the additional expense may not be warranted. In some cases, stabilized urea does not increase the color, quality, or the longevity of turfgrass response relative to urea, but the cost of stabilized urea is nearly double that of urea. When stabilized urea is ineffective, the conditions were likely not conducive to losses of gaseous N. Examples of conditions conducive to gaseous N loses are soils with pH > 7.0 or saturated soils. Therefore, if you do not have these conditions, stabilized urea may be unnecessary.

Fate of Nitrogen

The quality of Kentucky's surface and ground waters are of utmost importance to flora and fauna living in these waters. The growth of flora and fauna is directly related to the amount of available nutrients in these waters. Additionally, we use these waters as the primary source of drinking water for ourselves and our families. A wide range of compounds may be found in these waters, the most common of which may be nitrate (NO_3^-). The sources of nitrogen (N) may include, but are not limited to, atmospheric deposition, septic tanks, effluent water disposal, agricultural fertilization, or landscape fertilization. The objective of this publication is to identify and describe the sources and potential fates of N applied to Kentucky turfgrass.

This discussion will include five paths N may take after being applied to turfgrass: conversion to atmospheric gas, turfgrass uptake, soil storage, leaching, and runoff. However, it is first important to understand turfgrass' contribution to Kentucky's fertilizer consumption. When discussing Kentucky's water quality, in particular N contamination, we must consider all the potential sources of N and their relative contributions to groundwater contamination. When all the N fertilizer applied in Kentucky is considered, the amount applied to turfgrass is comparatively low, contributing < 7% to the total N applied in Kentucky. Although that percentage is low relative to other markets, it is still crucial that we understand the paths that it may take in a turfgrass system. Understanding these fates will help to protect Kentucky's ecosystem and enhance decisions regarding best management practices.

Atmospheric Nitrogen

More than 99% of all N on planet earth exists in the atmosphere and is chemically and biologically unavailable to plants, except those which are capable of biological N fixation. Approximately 78% of the air we breathe is N_2 gas, which can be converted into a useable form (i.e. fertilizer) via the Haber-Bosch process or by biological N fixation. Approximately 80% of the N manufactured via the Haber-Bosch process is used for agricultural fertilizers, and it is estimated that the Haber-Bosch process is responsible for supplying the dietary needs of 50% of the human population or 3 billion people. Thus, second to photosynthesis, the Haber-Bosch process may be the most important process influencing human development over the past century. Once harvested from the atmosphere, N applied to turfgrass easily coverts back to a gas either via volatilization or denitrification (Figure 1).

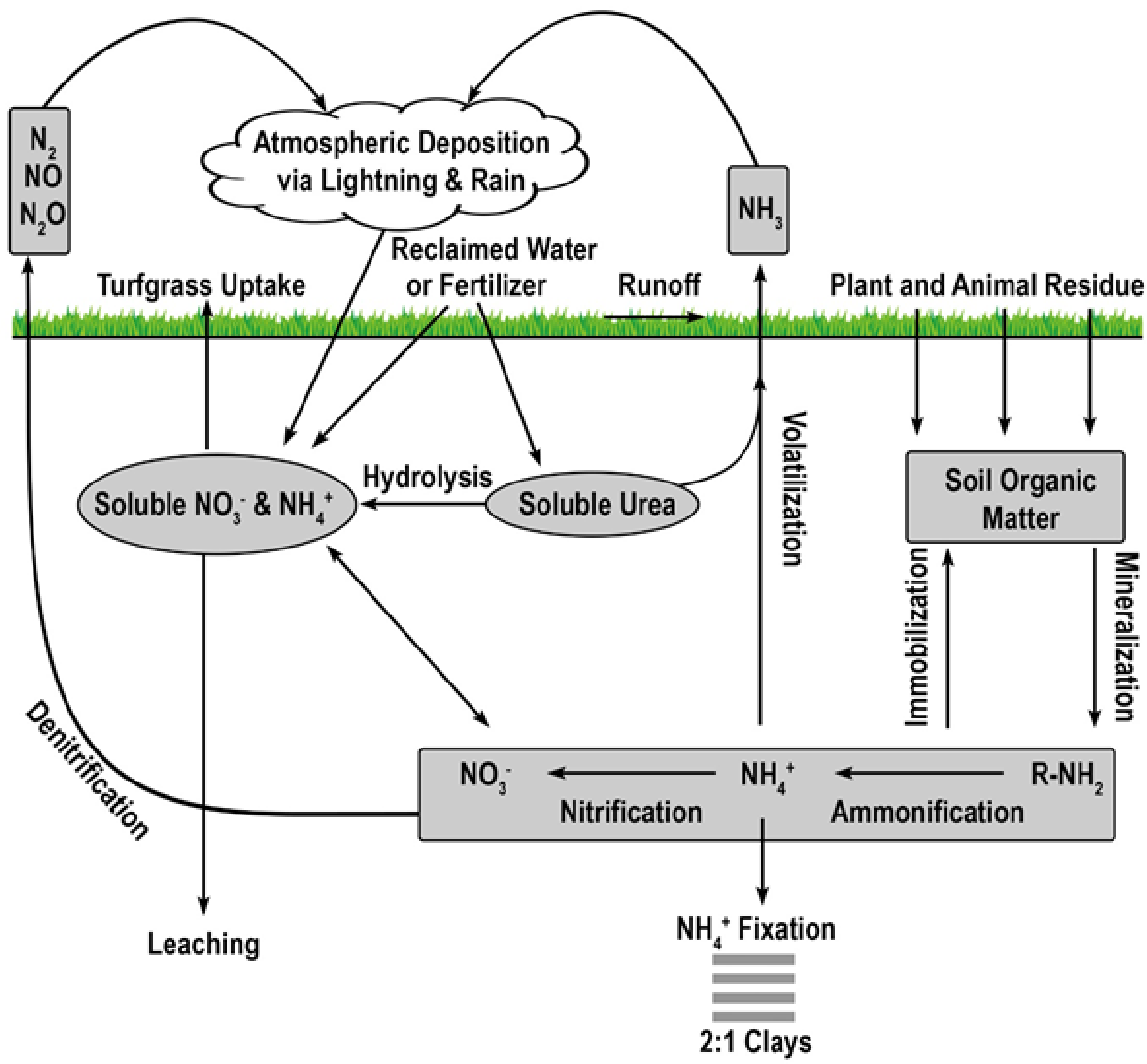


Figure 9. The nitrogen cycle in turfgrass

Volatilization is the conversion of N to ammonia (Figure 2). The factors influencing conversion of N to a gas include quantity of soluble N as urea or ammonium, temperature, high soil pH, low soil moisture, and low cation exchange capacity. Nitrogen converted to ammonia is lost to the atmosphere and is no longer available for turfgrass uptake. While volatilization is a distinct disadvantage to the turfgrass, the loss of N as ammonia decreases the amount of N available to move into nearby water bodies via leaching or runoff. However, N volatilization may increase the amount of N returned to the earth via rainfall and atmospheric deposition. Because N is commonly applied to turfgrass as urea, volatilization can be a major contributor to N lost from turfgrass systems, with losses ranging from <1% to as high as 60% of applied N. This percentage can be reduced by using slow-release urea, urease inhibitors, or by irrigating the turf immediately after fertilization. Slow-release N sources are defined as any N source that releases its N at a slower rate compared with a reference soluble N source. Urease inhibitors slow the conversion of urea to NH_4^+ by inhibiting urease, the enzyme necessary for urea hydrolysis to occur. In so doing, the rate of volatilization can be reduced by as much as half. Urease inhibitors may be marketed as ‘nitrogen stabilizers’. Numerous products marketed as urease inhibitors have been tested by land-grant institutions. Only the ‘nitrogen stabilizers’ containing N-(n-butyl) thiophosphoric acid triamide (NBPT) or N-(n-propyl) thiophosphoric acid triamide (NPPT) have consistently reduced volatilization compared with urea alone. Slow-release N fertilizer also reduced volatilization not through urease inhibition, but by delaying the release of urea into the N cycle.

$$\underset{\textit{Urea}}{CO(NH_2)_2} + H_2O \xrightarrow{\textit{urease}} 2NH_3 + CO_2$$

Figure 10. Nitrogen volatilization converts urea into ammonia gas.

Denitrification is the microbial conversion of NO_3^- to N2 gas (Figure 3). The conditions that favor denitrification are wet, organic soils containing NO_3^-. Similar to volatilization, denitrification converts N into one of several N species: nitrite (NO_2^-), nitric oxide (NO), nitrous oxide (N_2O), or gaseous N (N_2), reducing the amount of plant-available N and the amount of N available to move to non-target locations. Denitrification requires N to be in the NO_3^- form, which is then reduced as oxygen is removed. Denitrification is greatly influenced by increased soil moisture, which results in an oxygen-deprived soil and hastens the removal of oxygen from NO_3^- by denitrifying bacteria. When soil oxygen levels drop below 2%, denitrification is increased. However, denitrification may still occur in aerated soils due to the saturation of internal soil microsites. Turfgrass studies designed to determine denitrification rates in Kentucky are limited. However, soils with appreciable quantities of clay tend to poorly drain resulting in substantial N loss via denitrification. On sandy soils such as those on sand-based putting greens, denitrification is normally low and accounts for <1% to 5% of applied N, but could approach 94% when temperature exceeds 30°C. Because denitrification in Kentucky soils can be high, nitrification inhibitors and/or slow-release N sources can be useful. Nitrification inhibitors should contain either 2-chloro-6 (trichloromethyl) pyridine (Nitrapyrin) or dicyandiamide (DCD), as these are the only two compounds that have reduced denitrification in field and laboratory studies. Similar to their effect on volatilization, slow-release N fertilizers may reduce denitrification by delaying the release of their N into the N cycle.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

Figure 11. Denitrification - NO_3-N is subject to reduction by soil microbes leading to N_2.

Turfgrass Uptake

The objective of all N applications to turfgrass is sustainable plant uptake and the resulting increase in turfgrass growth or quality. Numerous factors may influence turfgrass uptake of N, including (but not limited to) turfgrass species, season, N type, N rate, and moisture management.

The percent of applied N recovered in turfgrass varies depending upon turfgrass species. Species that possess a greater density of roots deeper in the soil profile tend to take up greater amounts of applied N compared with turfgrasses with less dense root systems. Clearly, greater uptake occurs because a turfgrass with a greater quantity of roots has an increased chance for its roots to intercept and uptake N.

Like most plants, the change in climatic seasons can have a dramatic influence on plant growth and nutrient uptake. During the winter, warm-season turfgrasses enter dormancy (a natural turfgrass phase in which the plant is alive, but no cell division or elongation occurs). As turfgrass growth declines, the amount of N needed by the turfgrass also declines. Thus, consumption of applied N by warm-season turfgrass is lower in the winter than in the summer. Inversely, cool-season grass grow best in autumn and spring and exhibit reduced growth in winter and summer. N applications to dormant or semi-dormant turfgrass has not resulted in N leaching unless excessive rainfall occurs, thus the applied N will remain in the soil until the plant consumes it or until rainfall/irrigation moves the N beyond the rootzone. However, the agronomic advantages to applying N to dormant turfgrasses are low relative to the environmental risk. Thus, N applications to dormant turfgrasses in Kentucky is not recommended.

Nitrogen fertilizers differ in their form of N and their release characteristics. These differences can lead to different quantities of N absorbed by turfgrass. Nitrogen applied as NH_4^+ may result in less N uptake than N applied as NO_3^- due to the tendencies of NH_4^+ to volatilize and be lost from the soil/turfgrass system. A larger percentage of N from slow-release N fertilizers may be taken up by the turfgrass compared with soluble N sources. Soluble N is immediately available to follow any of the potential paths in the soil/turfgrass system, including leaching and volatilization, whereas only small portions of N from slow-release N fertilizers become soluble at any given time. To this end, slow-release N fertilizers can increase N uptake by as much as 300% compared with soluble N sources.

A driving factor behind the University of Kentucky nutrient recommendations to turfgrass is to apply the amount of N necessary to achieve a desired turfgrass response without applying more N than the turfgrass can consume at any given time. When the University of Kentucky recommended N rates are followed, turfgrass uptake of applied N ranges from 40–68% and may approach 80% under certain conditions. When small quantities of N are applied, very little N has an opportunity to escape turfgrass assimilation. As rates of soluble N increase, the percentage of applied N recovered in turfgrass tissues decreases. However, slow-release N sources often require higher application rates compared with soluble N sources in order to achieve the same desired turfgrass response because only a small portion of the slow-release N will become soluble on a daily basis. Consequently, higher rates of slow-release N sources may result in greater percent uptake of applied N than lower rates. Additionally, a single application of slow-release N at a high rate may result in the same N uptake as soluble N applied as a split application. Therefore, slow-release N sources may be applied at higher rates than soluble N sources so long as the single application rate and total annual N applied do not exceed the University of Kentucky recommendations.

Moisture management greatly influences plant uptake of applied N. Most N is taken up by the plant via the soil solution. Thus, when the soil water content exceeds the soil water holding capacity, N in the soil solution may be moved below the rootzone, which results in reduced plant uptake. On the other hand, when insufficient water is applied, the turfgrass may enter a state of drought-induced dormancy in which the turfgrass reduces water and N uptake in order to survive. Thus, careful consideration should be given to applying sufficient water to maintain acceptable turfgrass, but not applying more water than can be retained by the soil. Generally, rain sensor, soil water sensor, and evapotranspiration controllers apply water more effectively than automatically timed controllers.

Soil Retention, Immobilization, and NH_4^+ Fixation

The amount of N stored in the soil is dependent upon many factors, particularly fertilizer type, fertilizer rate, time of year, soil moisture, soil pH, and rainfall. The majority of soil N exists as organic N in the form of organic matter or as N that has not been released from slow-release fertilizer granules. Technically, fertilizer granules are not a component of soil-stored N. However, the process of measuring soil N (combustion or digestion) will also measure N from any fertilizer granules that have not yet been released. The type and amount of slow-release fertilizer will directly influence this value. Once released from the slow-release form, N may remain in the soil via anion or cation exchange. The cation exchange capacity of most Kentucky soils is normally high (~15 cmol (+) per kilogram of soil), and the anion exchange capacity is normally too low to measure. In Kentucky soils, mineralized N, N applied as urea, or N applied as NH_4^+ can rapidly convert to NO_3^- and, because NO_3^- is an anion, it is not retained by the soil. Thus, soil storage of N via cation exchange is commonly less than 10% of applied N and can be less than 2%.

Nitrogen immobilization occurs when inorganic N is converted to organic N via microbial activity. An organic form of N is simply any form of N that is bound with carbon. Like plants, microbes require N to survive and some portion of applied N will be consumed by microbes and converted into amino acids, proteins, or some other organic form used for growth by the microbes. While in an organic form, N is not soluble and therefore is unavailable for plant uptake or loss to a water body. Organic N will remain unavailable for plant uptake until the environmental conditions change to favor N mineralization. The percentage of applied N that becomes microbially immobilized in turfgrass systems will vary according to numerous factors including soil moisture, pH, and soil temperature. Little, if any, research has been conducted to determine immobilization of applied N in Kentucky turfgrass systems. Thus, providing an estimation is difficult. However, research conducted on turfgrass in cooler climates (Connecticut) reports that N immobilization may range from 15 to 26% of applied N.

Ammonium fixation occurs when NH_4^+ enters the layer (lattice) of a 2:1 clay (Figure 4), becoming unavailable for plant uptake. Ammonium fixation in Kentucky soils may be significant because the content of 2:1 clays in Kentucky soils can be high. The exact percentage of applied N to Kentucky turfgrasses that eventually is fixed by 2:1 clay minerals is unknown.

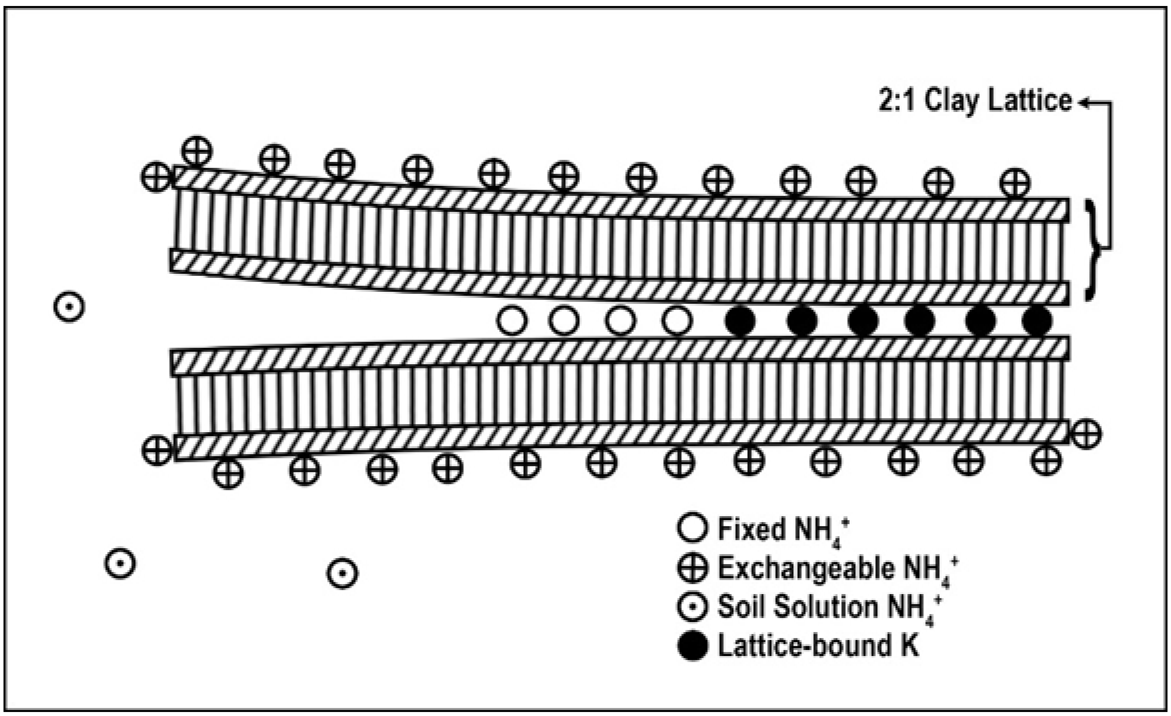


Figure 12. Ammonium may become fixed within the lattice of 2:1 clays and be rendered unavailable for turfgrass uptake [Figure modified from Strand, (1998)].

Leaching

Leaching is the process that moves soluble N below the rooting zone. Nitrogen leaching in turfgrass systems occurs at the moment soluble N moves below the deepest root. When turfgrass is fertilized according to the University of Kentucky recommendations, N leaching is normally low. As with other fates of applied N, the exact amount of N that will leach is difficult to determine. However, it is possible that 0 to 55% of applied N could be leached, with the higher percentages occurring when the University of Kentucky recommendations are not followed. When N leaching does occur, it is usually a factor of the turfgrass species, irrigation management, N source, N rate, or stressed turfgrass.

The influence of turfgrass species on N leaching losses is largely a factor of the turfgrass root system. Deeper rooted turfgrasses tend to reduce N leaching losses compared with shallow-rooted turfgrasses. Management practices that encourage deep rooting, such as deep, infrequent irrigation, are factors that shape the University of Kentucky recommendations. Increased N leaching has been documented when N is applied within the first 60 days of planting sod. After the sod has been planted for 60 days, N leaching is reduced and is a result of increased root growth. Therefore, it is suggested that N applications to newly sodded turf commence 60 days after the sod has been planted. This suggestion allows the sod to develop a root system prior to fertilization and thus minimizes the risk of N leaching.

The movement of water through the soil has a profound influence on N leaching. Once any nutrient becomes soluble in the soil solution, that nutrient is subject to the movement of water. Therefore, it is crucial to minimize any movement of water beyond the turfgrass rootzone. Increased water movement may be a result of excessive irrigation or fluctuations in rainfall due to changing seasons, which may result in more water being applied to the soil than the soil can retain.

When applied according to the University of Kentucky recommendations, soluble N may not leach more N compared with N lost naturally from unfertilized turfgrass or from fallow soil. Additionally, slow-release N sources further reduce N leaching losses compared with soluble N sources. Essentially, slow-release N sources delay the release of N into the N cycle (Figure 1). Over time, small portions of N are released, which increases the likelihood of plant uptake of applied N and decreases potential for N leaching losses. Blending soluble N sources with slow-release N sources also results in reduced N leaching losses. Generally, differences in N leaching losses among slow-release N sources are negligible assuming they are applied at the same time and rate. However, differences in N release rates within polymer-coated ureas can be substantial with the faster release PCUs resulting in greater N leaching than the slower release PCUs. Enhanced efficiency fertilizers, such as nitrification and urease inhibitors, do not delay the release of N into the N cycle and thus result in similar N leaching losses as other soluble N sources.

Increasing the rate of applied N beyond the rate recommended by the University of Kentucky can increase the risk of N leaching losses. The University of Kentucky turfgrass nutrient recommendations take into account the turfgrass need for N and the potential impact on the environment. These recommendations are often 50–75% less than the amount of N necessary to increase N leaching losses above the natural environment. Thus, current rates are considered conservative, and exceeding these rates is unnecessary because any further increase in turfgrass growth or quality is minimal and could come at a cost to the environment.

As previously mentioned, N applied according to the University of Kentucky recommendations to healthy, growing turfgrass has a low probability of leaching. However, when turfgrass is stressed, N leaching can increase. Normally, stresses manifest themselves as reductions in turfgrass density and growth, which correspond to a reduction in N uptake. These stresses are largely environmental caused by pests, late-season frosts, and changes in season. However, stresses can also be anthropogenic caused by misapplications of nutrients or pest control products. When stresses occur, further applications of N may not cure the problem and may, in fact, exacerbate the problem and increase N leaching.

Runoff

Runoff is defined as the lateral movement of N beyond the target location. Runoff may occur above or below the soil surface but always occurs above the deepest root. At the moment that N moves below the deepest root, further movement of N is defined as leaching. Leached N may then runoff if the leached N encounters a subsurface barrier, but the N lost from the turfgrass system is considered leached if the N moved vertically beyond the rootzone. Nitrogen lost via runoff may be influenced by topography, soil type, soil compaction, soil moisture, rainfall, and fertilizer type. Because Kentucky soils contain large quantities of clay and have a relatively low water infiltration capacity, the movement of water across the soil surface can be more common than the movement of water into the soil. However, runoff studies conducted on Kentucky turfgrasses are few. However on topographies and environments similar to Kentucky, studies indicate that N runoff from turfgrass may range from 0 - 7%.

Summary

Nitrogen is normally the most beneficial element applied to turfgrass because the plant's demand is high and the supply is low. A greater understanding of the numerous N sources available will enhance your nutrient management program. The fate of N applied to Kentucky turfgrass may vary greatly depending upon numerous factors. Essentially all N used in turfgrass management originated from the atmosphere and will eventually return to the atmosphere. During this cycle, ranges of the potential fates of applied N to Kentucky turfgrasses are:

Volatilization - <1%–60%
Denitrification - <1%–5%
Plant uptake – 40%–68%
Soil Storage – 7%–15%
Leaching – <1%–55%
Runoff – <1%–7

Phosphorus

- Apply P when soil Mehlich III P concentrations are < 10 ppm or 20 lbs. per acre.
- Do not apply P based upon tissue tests.

- Use granular diammonium phosphate or concentrated superphosphate when soil pH is < 7.0.
- Use granular monoammonium phosphate or concentrated superphosphate when soil pH is > 7.0.
- Foliar P may be derived from any soluble P source.
- For best results on cool-season grasses, apply P in September, October, November, or May.
- For best results on warm-season grasses, apply P in June, July, August, or September.
- pH adjustments towards 6.5 will help solubilize existing soil P.
- Do not apply P to dormant turfgrass.

Phosphorus (P) is a common component of many turfgrass nutrition programs. P is required for many functions within the plant including energy transfer, but applying P to turfgrass is not always necessary because many Kentucky soils contain an adequate supply of plant available P. However, in some circumstance applying P is necessary to increase turfgrass quality. What is the function of P within the plant, and how much P is required to sustain acceptable turfgrass in Kentucky? Also, if P applications are necessary, when and how should P be applied?

Function of Phosphorus in Turfgrasses

Phosphorus has many plant functions but the most essential function is energy transfer. During photosynthesis, energy is stored in the high-energy compounds adenosine diphosphate or adenosine triphosphate (ADP and ATP). ADP and ATP may be transferred to other parts of the plant and then split, which releases a relatively large quantity of energy used for various metabolic processes. Essentially every metabolic process in turfgrass development requires P.

Phosphorus is absorbed by the plant as either H_2PO^{4-} or HPO_4^{2-} (often referred to as orthophosphate or ortho-P) with the former more prevalent at low soil pH and the latter more prevalent at high soil pH. Small amounts of organic P may be absorbed by the plant but the quantity and importance of organic P for turfgrasses is limited due to the instability of organic P compounds in the presence of active microbes. Phosphorus is highly mobile within the plant and P deficiencies normally appear on the most mature leaves first.

Phosphorus is associated with increased root growth, particularly during the early stages of development. During these early stages, the turfgrass has a high demand for energy and very little ability to supplying P due to insufficient root growth. Thus, applications of P during turfgrass establishment increase root production and subsequently turfgrass establishment. Special care should be given to the N:P ratio during putting green establishment. A ratio of 5:2 has been shown to increase establishment compared to a 1:0 N:P, whereas further increases of P above a 5:2 N:P may actually decrease establishment.

Phosphorus deficiency in turfgrasses is uncommon in Kentucky, but can occur in turfgrasses grown on some western Kentucky soils or on golf course putting greens. Western Kentucky from Nelson to Livingston counties has soils that naturally contain low concentrations of plant available P (Figure 1). Turfgrass grown on sand-based putting greens may also exhibit P deficiency because P is poorly retained in sand-based rootzones. Phosphorus deficient turfgrass can appear different from other nutrient deficiencies and may actually appear darker green, particularly on the older leaves. When darker green leaves are observed in conjunction with reduced growth, P deficiency may be the cause. The darker green leaves are a result of an increased concentration of chlorophyll partly due to the reduction in growth. If P deficiency progresses, older leaves may appear purple, which is a result of excess anthocyanins, a pigment normally associated with ripening of some fruits including blueberries.

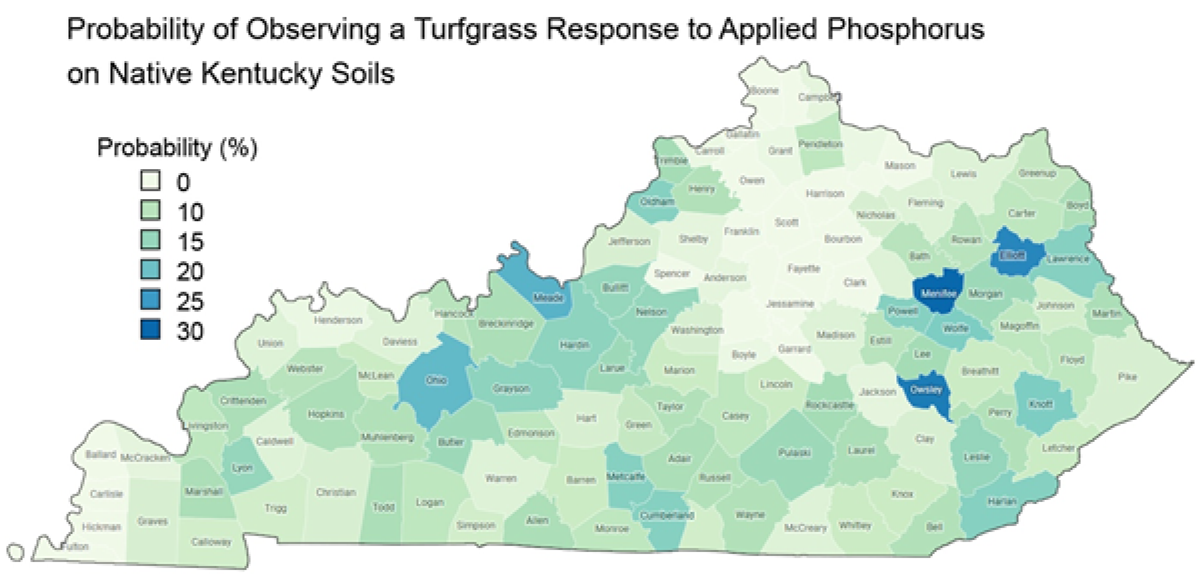


Figure 13. Probability of turfgrass responding to applied phosphorus on Kentucky soils.

Tissue Testing for Phosphorus

Turfgrass tissue testing is not a dependable method of managing applied P because baseline P concentrations in turfgrass fluctuate and are not well understood. Current research indicates that the P concentration in healthy turfgrass naturally fluctuates based upon turfgrass species, location, and even season. Tissue tests may be useful if tissue is collected from the same location at the same time of year and records are collected for several years. To this end, fluctuations in tissue P above or below historical norms may provide useful information when diagnosing potential problems. But, the decision to apply or not apply P based upon a single turfgrass tissue test is not a best management practice (BMP).

Soil Phosphorus

Most Kentucky soils contain an adequate supply of P to sustain acceptable turfgrass quality. Soluble P is highest in the soil solution when the pH is between 5.0 and 7.2 with maximum P solubility occurring at a soil pH of 6.5 (Figure 2). Below 5.0, P precipitates with iron (Fe) or aluminum (Al) and falls out of the soil solution. Above 7.2, P may bind with Ca and become unavailable for plant uptake. Phosphorus in these secondary minerals of Fe, Al, and Ca may again become plant available through dissolution if the soil pH remains between 5.0 and 7.2. Plant available P is one reason why soil pH is a critical part of soil testing for turfgrasses.

Soil organic matter contains between 1% and 3% P. The majority of P in organic matter is organic P although a small fraction is already in the ortho-P (plant available) form. Organic P must be mineralized into ortho-P by soil microbes in order for the P to become plant available. After mineralization, the P is in an inorganic form and may be taken up by the turfgrass or returned to its original organic form via immobilization by other soil microbes. Mineralization and immobilization are soil process mediated by soil microbes and, thus, environmental variables (such as pH, soil moisture, soil temperature, etc.) that influences soil microbial activity will influence P mineralization and immobilization.

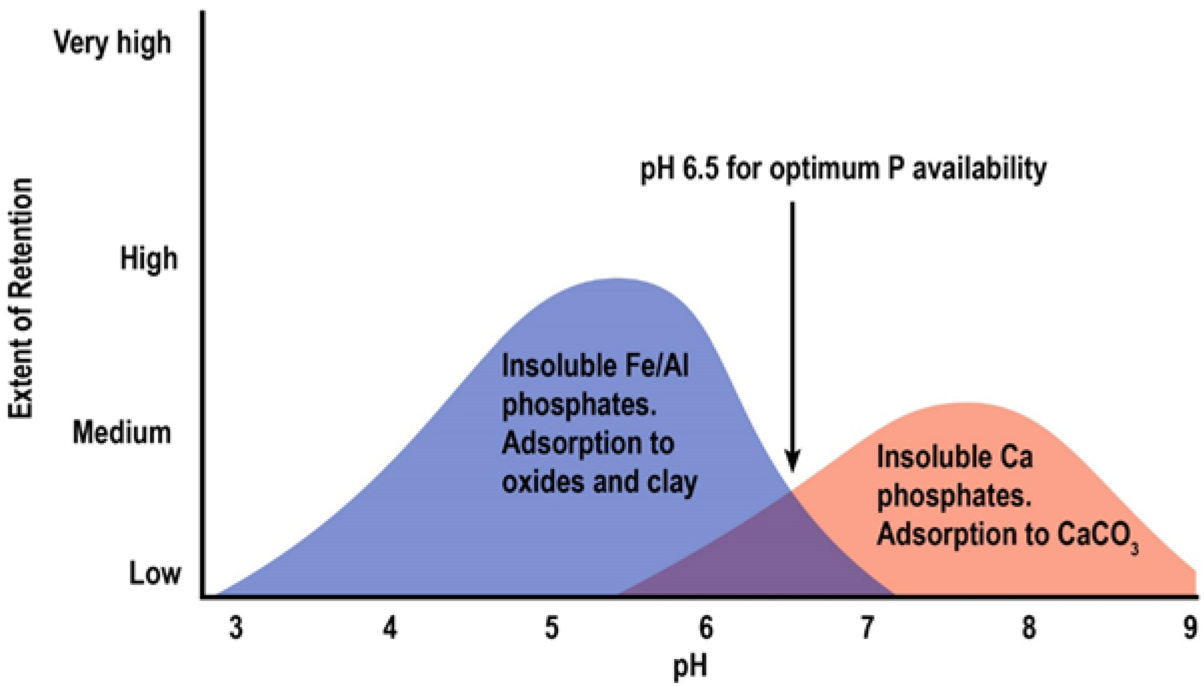


Figure 14. Soil pH influences P solubility. Adapted from Stevenson, Cycles of Soil, 1986.

Soil Testing for Phosphorus

Phosphorus soil tests are very important for agricultural crops. However, for Kentucky turfgrasses, soil testing for phosphorus has limited use because P levels have not been calibrated to a turfgrass response. Thus, applying specific amounts of P to turfgrasses based upon soil P concentration has been proven unreliable. For turfgrasses, P soil tests are best used to indicate when P should *not* be applied. Current research on both warm-season and cool-season turfgrasses indicates that turfgrasses grown on soils with a Mehlich III P concentration ≥ 10 ppm will not likely respond to applied P. Approximately 80% of Kentucky turfgrass soil tests report soil P concentrations ≥ 10 ppm, indicating that the majority of Kentucky soils do not require additional P to sustain acceptable turfgrass. Determining soil P concentrations by county provides a more precise indication whether P is necessary in your location (Figure 2). At best, turfgrass grown in Menifee and Owsley counties have a 30% probability of responding to applied P, whereas the majority of counties have less than a 20% probability, and many counties have less than a 1% probability of responding to applied P. To save money and reduce environmental risk, P can be omitted from nutrient applications to turfgrass until a soil test indicates the Mehlich III P concentration is less than 10 ppm *and* the turfgrass appears unacceptable.

Applying Phosphorus

If your turfgrass appears acceptable to you, then additional P is normally not necessary regardless of soil test P values. However, if your turfgrass is not acceptable *and* a soil test confirms the soil concentration is less than 10 ppm Mehlich III P, then additional P may be warranted.

When applying P to turfgrass, perhaps the easiest and most common method is to use a fertilizer that contains both N and P and apply the fertilizer during your next scheduled N application. Once the turfgrass grows out of the P deficiency, P may be lowered or eliminated from future applications. Simply applying P 'just in case it needs it' is not a BMP for turfgrasses grown on native Kentucky soils.

Professional turfgrass managers (such as sport turf managers, golf course superintendents, sod producers, or landscape managers) may choose to apply sole-P fertilizers. Sole-P fertilizers should be applied with caution because misapplications of sole-P fertilizers can lead to significant environmental risk. Benefits of sole-P fertilizers include lower cost than NPK fertilizers and the ability to apply P more precisely to smaller areas such as golf course putting greens.

Regardless of your level of expertise, P should be applied at a time when the turfgrass has the greatest opportunity to use it. For cool-season turfgrasses such as tall fescue and bentgrass, an efficient time to apply would be during late spring and again in the autumn months (Table 1). If you have warm-season turfgrasses such as bermudagrass or zoysiagrass, the suggested time to apply P is during summer months. Applying P to either cool or warm-season turfgrasses during winter months is not a BMP because both species are normally dormant and have little to no ability to absorb applied nutrients. Applying slow-release P during winter months has not been shown to be any more beneficial than waiting until spring or early summer when the turfgrass begins to grow out of dormancy.

Table 5. Suggested timing and amounts of phosphorus to apply to turfgrasses grown in Kentucky when soil Mehlich III phosphorus levels are less than 10 ppm *and* turfgrass appears unacceptable.

	May	June	July	August	September	October	November
	Pounds of P_2O_5/1,000 ft^2						
Cool-season grasses	0.25	-	-	-	0.25	0.25	0.25
Warm-season grasses	-	0.25	0.25	0.25	0.25	-	-
* For home lawns, the total annual amount of P applied should not exceed 1 pound/1,000 ft^2 unless an additional soil test indicates Mehlich III P levels remain less than 10 ppm.							
† During turfgrass establishment, annual P amounts may exceed 1 pound/1,000 ft^2 if the initial soil test P level is less than 10 ppm Mehlich III P.							

Golf, sport turf, and sod production represent unique turfgrass systems. Turfgrass grown under these conditions may be subject to excessive stresses requiring the turf to constantly reestablish itself. Under these conditions, additional P may be warranted. Be mindful that applying P to turfgrass grown on soils with Mehlich III P concentrations ≥ 10 ppm does not normally result in appreciable increases in turfgrass growth and quality.

Phosphorus Sources

When naturally available soil P is too low to meet the turfgrass needs, P may be applied as one of numerous P fertilizers. Nearly all P sources used in turfgrass management originated from mined P, usually apatite (a form of calcium phosphate). Once applied, P sources will have vastly different reactions in the soil. In most soils, P is immobile and the solution concentration of P is highly dependent upon pH and P source, thus, an understanding of P source reactions is essential to maximize the efficient use of applied P.

Ordinary and Triple Superphosphate

Mined apatite is reacted with either sulfuric or phosphoric acid to form ordinary or triple superphosphate (OSP and TSP, respectively). OSP and TSP have a guaranteed analysis of 0-20-0 and 0-46-0, respectively. OSP and TSP are highly water soluble and considered neutral fertilizers because they have little influence on soil pH.

Monoammonium and Diammonium Phosphates

Both monoammonium (MAP) and diammonium phosphate (DAP) are manufactured by reacting ammonia with phosphoric acid. MAP and DAP have guaranteed analyses of 11-48-0 and 18-46-0, respectively. MAP is a good choice for high pH soils because the soil pH immediately adjacent to the fertilizer particle may be reduced to 3.5, which can result in more of the nitrogen (N) and P being available for plant uptake.

DAP is the most used fertilizer in the world and is a good choice for acidic soils because the application of DAP results in a pH of 8.5 immediately around the fertilizer granule.

When DAP is applied to high pH, calcareous soils, the P is immediately bound by calcium to form dicalcium phosphate and the N will volatilize because ammonium is highly soluble and easily converted to ammonia gas. Over time, the soil pH will return to the initial soil pH due to the conversion of ammonium to nitrate (nitrification). However, in the time required to reduce the soil pH back to its initial level, much of the P will have been lost to precipitation and N will have been lost to volatilization. When soil pH exceeds 6.5, volatilization of N from DAP can exceed 30% of applied N and can be 5x greater than that of MAP and 2x greater than that of urea and ammonium sulfate. Thus, DAP should not be used on high pH, calcareous soils.

Liquid Phosphorus

Phosphorus may be applied as a liquid or as a foliar spray. Liquids are applied in water at 80 gallons per acre or greater, whereas foliar sprays are designed to remain on the leaf surface and are applied at lower rates near 40 gallons per acre. In either case, P in liquid form is usually as phosphoric acid. The ammoniated P sources previously mentioned may also be used as a liquid, but phosphoric acid is more common because it only contains P and it tends to be the least expensive liquid source. The P concentration of liquid P fertilizers vary greatly because the phosphoric acid must be diluted in water and may be blended with other components, particularly N and K.

Organic Phosphorus

Most, if not all, natural organic fertilizers are manufactured from plant or animal wastes and contain a component of P. Typical P concentrations of organic fertilizers range between 1% and 7%. Organic P fertilizers contain both inorganic and organic P with the ratio of inorganic P:organic P varying widely depending upon the source. However, on average, P in organic fertilizers is roughly 50% organic and 50% inorganic. Thus, half of the total applied P would immediately contribute to soil solution P whereas, the remaining organic P would require mineralization to be converted to a plant-available form.

Natural organic fertilizers are often viewed more favorably than synthetic fertilizers due to a perceived reduction in environmental risk. However, evidence indicates that natural organic fertilizers may increase environmental risk compared to synthetic fertilizers with respect to P. Caution should be taken when using natural organic fertilizers to minimize the risk of P leaching and/or runoff. When natural organic fertilizers are applied at rates sufficient to meet N needs, more P may be applied than the turfgrass can utilize leading to excess P lost to the environment. Thus, natural organic fertilizers should be applied as a supplemental N source or applied based upon the rate of P, without exceeding UK P recommendations for turfgrass.

Summary

P is a plant essential element and most Kentucky soils provide sufficient P to sustain acceptable turfgrass without additional P applications. In rare circumstances where P is required, an understanding of the plant and soil reactions with P will help you build a more efficient nutrient program. Be mindful that unless soil test P concentrations are less than 10 ppm Mehlich III P, the application of P to turfgrasses will increase costs and environmental risk and may provide little to no benefit to the turfgrass

Potassium

- Apply K when soil Mehlich III K concentrations are < 40 ppm or 80 lbs. per acre.
- Do not apply K based upon tissue tests.
- Muriate of potash (KCl) is the least expensive K source but also possesses a high burn potential.
- Sulfate of potash (SOP) is more expensive than KCl but its burn potential is 55% lower.
- Foliar K may be derived from any soluble K source.
- For cool-season grasses, apply K in September, October, November, or May.
- For warm-season grasses, apply K in June, July, August, or September.
- Do not apply K to dormant turfgrass.

Potassium (K) is an essential plant element and is the most abundant mineral, macro-nutrient in turfgrass behind nitrogen (N). Sufficient concentrations of K are important to maximizes turfgrass tolerance to stresses caused by temperature, drought, traffic, and salinity. Understanding the function, soil content, and fertilizer forms of K are essential to creating an efficient nutrient management program.

Function of Potassium in Turfgrasses

Potassium has many functions in turfgrass tissue. Perhaps the most important function of K is the activation of at least 80 enzymes. Enzymes are compounds that reduce the activation energy of biochemical reactions within the plant. Therefore, in the absence of K, plant activities such as sugar translocation and energy transfer either do not occur efficiently or cease all together. Secondary to enzyme activation, K is also the primary element responsible for maintaining cell turgor pressure and electroneutrality. Potassium does not enter into any organic compound inside the plant tissue. Instead, K is actively transported throughout the plant to locations such as cell vacuoles. The presence of K in the vacuole lowers the water potential, which results in the movement of water into the vacuole. In this manner, K controls the movement of water into and out of cells as needed. When K is deficient, the ability of the plant to move water is reduced. This reduction in water movement is an important variable influencing various turfgrass stresses. For example, when K is limited, the ability of the plant to close their stomata is limited. This results in increased water loss and high temperature stress and a reduction in cell turgor pressure. If turfgrass is exhibiting these symptoms and is then exposed to traffic, the ability to resist and recover from damage may be reduced.

Nutrient Management

Principles

- Within each state, environmental conditions vary greatly including differences among soils, topography, rainfall, and temperature. These differences require that a nutrient management plan be flexible enough to allow turfgrass managers to address their unique needs.
- Understand the importance of application timing for effective use of applied nutrients.

Best Management Practices

- The objective of all nutrient applications is plant uptake and the corresponding desirable response.
- Apply nutrients when turfgrass is actively growing.
- Apply slow-release N fertilizers at the appropriate time of year to maximize the products' release characteristics. For example, an application of slow-release N to warm-season turfgrasses in fall may not be as effective as the same application applied in early summer because of the prolonged release time in fall.
- Follow N application rate recommendations from your local land-grant university.
- N application rates from slow-release materials should take into consideration the release rate of the chosen material. If insufficient material is applied, the desired response may not be observed.
- Consult your local land-grant university for efficient N:K in your location.
- The reduced height of cut and excessive traffic damage on putting greens results in an increased need for growth leading to an increase in nutrition.
- Tees and landing areas often have higher fertility requirements than fairways and roughs because they suffer constant divot damage.
- Fairways and roughs often require less nutrient inputs than other locations because of their increased height of cut, less damage, and clipping return.
- Exercise caution when applying nutrient applications during turfgrass establishment as these applications are particularly susceptible to loss via leaching and runoff.
- Provide appropriate rates and products to minimize N loss without reducing turfgrass establishment.
    - Increased water applications
    - Increased nutrients to hasten establishment
    - Reduced root mass
- Be aware of the different types of spreaders and understand the advantages and disadvantages of each.
- Not all fertilizers can be spread with every spreader. For example, if sulfur-coated urea was spread through a drop spreader, the sulfur coating could be damaged, essentially leading to an application of soluble urea.
- Choose the appropriate spreader for a given fertilizer material.

    - Walk-behind rotary
    - Drop spreader
    - Bulk rotary
    - Spray

- Calibration reduces environmental risk and increases profitability.
- Proper fertilizer storage, loading, and clean-up reduce environmental risk.
- Avoid applying fertilizer to soils that are at, or near, field capacity or following rain events that leave the soils wet.
- Do not apply fertilizer when the National Weather Service has issued a flood, tropical storm, or hurricane water or warning, or if heavy rains are likely.

Cultural Practices

Overview

Cultivation practices are an important part of golf course turf management. Certain cultural practices such as mowing, verticutting, and rolling are necessary to provide a high-quality playing surface, while others such as aerification are required to enhance plant health.

Heavily used areas such as putting greens often deteriorate because of compacted soil, thatch accumulation, and excessive use. Soil problems from active use are usually limited to the top 3 inches of the soil profile and should be actively managed to enhance turf health and improve nutrient and water uptake.

Unlike annual crops, which offer the opportunity for periodic tilling of the soil profile to correct problems like soil compaction that might develop over time, turfgrass does not offer opportunities for significant physical disturbance of the soil without destroying the playing surface.

Mowing

Principles

- Mowing is the most basic yet most important cultural practice to consider when developing a management plan.
- The mowing practices implemented on a facility will have an impact on turf density, texture, color, root development, and wear tolerance.
- Mowing practices affect turfgrass growth. Frequent mowing will increase shoot density and tillering. It will also decrease root and rhizome growth as a result of plant stress associated with removal of leaf tissue.
- Infrequent mowing results in alternating cycles of vegetative growth followed by scalping, which further depletes food reserves of the plants.
- Proper mowing height is a function of the species/cultivar being managed and the intended use of the site. Other factors influencing mowing height include mowing frequency, shade, mowing equipment, time of year, root growth, and abiotic and biotic stress.

- Maintaining an optimal root-to-shoot ratio is critical. Turfgrass plants that are mowed too low will require a substantial amount of time to provide the food needed to produce shoot tissue for future photosynthesis. If turf is mowed too low in one event, an imbalance occurs between the remaining vegetative tissue and the root system, resulting in more roots being present than the plant needs physiologically. As a result, the plants will slough off the unneeded roots. Root growth is least affected when no more than 30% to 40% of leaf area is removed in a single mowing.
- Failure to mow properly will result in weakened turf with poor density and quality.

Best Management Practices

- Mowing frequency should increase during periods of rapid growth and decrease during dry, stressful periods.
- If turf becomes too tall, it should not be mowed down to the desired height all at once. Such severe scalping reduces turf density and can result in a dramatic reduction in root growth. Tall grass should be mowed frequently and height gradually decreased until desired height of cut is achieved.
- Shade affects turfgrass growth by filtering out photosynthetically active radiation. As a result, turfgrass plants respond by growing upright in an effort to capture more light to meet their photosynthetic needs. As a result, mowing height should be increased by at least 30% to improve the health of turf grown in a shaded environment.
- The use of the plant growth regulator trinexapac-ethyl has been shown to improve overall turf health when used as a regular management tool for grasses growing in shaded environments.
- Environmental stresses such as prolonged cloudy weather or drought can have a significant impact on turf health. Increase mowing heights as much as use will allow in order to increase photosynthetic capacity and rooting depth of plants.
- Use proper mowing equipment.
- Reel mowers are ideally suited for maintaining turfgrass stands that require a height of cut below 1.5 inches. They produce the best quality when compared to other types of mowers.
- Rotary mowers, when sharp and properly adjusted, deliver acceptable cutting quality for turf that is to be cut above 1 inch in height. Dull blades will result in shredding of leaf tissue, increasing water loss and the potential for disease development.
- Flail mowers are most often used to maintain utility turf areas that are mowed infrequently and do not have a high aesthetic requirement.
- Mowing patterns influence both the aesthetic and functional characteristics of a turf surface.
- Turfgrass clippings are a source of nutrients, containing 2% to 4% nitrogen on a dry-weight basis, as well as significant amounts of phosphorus and potassium.
- Nutrients contained in clippings can be sources of pollution and should be handled properly.

- Clippings should be returned to the site during the mowing process unless the presence of grass clippings will have a detrimental impact on play. Cases when clippings should be removed include times when the amount of clippings is so large that it could smother the underlying grass or on golf greens where clippings might affect ball roll.
- Collected clippings should be disposed of properly to prevent undesirable odors near play areas and to prevent fire hazards that can occur when clippings accumulate. Consider composting clippings or dispersing them evenly in natural areas where they can decompose naturally without accumulating in piles.

Figure 15. The mowing practices implemented on a facility will have an impact on turf density, texture, color, root development, and wear tolerance. Photo credit: John Ballard, CGCS.

Cultivation

Principles

- Cultivation involves disturbing the soil or thatch through the use of various implements to achieve important agronomic goals that include relief of soil compaction, thatch/organic matter reduction, and improved water and air exchange.
- Cultivation techniques will result in disturbance of the playing surface that can require significant time for recovery.
- Frequency of cultivation should be based on traffic intensity and level of soil compaction.
- Core aerification is effective at managing soil compaction and aiding in improvement of soil drainage.
- Accumulation of excessive thatch and organic matter will reduce root growth, encourage disease, and create undesirable playing conditions.
- Light and frequent applications of sand will smooth the playing surface, control thatch, and potentially change the physical characteristics of the underlying soil when done in conjunction with core aerification.

Best Management Practices

- Core aerification involves removal of small cores or plugs from the soil profile. Cores are usually 0.25 to 0.75 inch in diameter. Annual core aerification programs should be designed to remove 15%-20% of the surface area. High-traffic areas may require a minimum of two to four core aerifications annually.
- Core aerification should be conducted only when grasses are actively growing to aid in quick recovery of surface density.
- Vary depth of aerification events by incorporating varying length tines to prevent development of compacted layers in the soil profile as a result of cultivation.
- Solid tines cause less disturbance to the turf surface and can be used to temporarily reduce compaction and soften surface hardness during months when the growth rate of grasses has been reduced. Benefits of solid-tine aerification are temporary because no soil is removed from the profile.
- Deep-drill aerification creates deep holes in the soil profile through use of drill bits. Soil is brought to the surface and distributed into the canopy. Holes can be backfilled with new root-zone materials if a drill-and-fill machine is used. These machines allow replacement of heavier soils with sand or other materials in an effort to improve water infiltration into the soil profile.
- Slicing and spiking reduce surface compaction and promote water infiltration with minimal surface damage.
- Slicing is faster than core aerification but is less effective. Slicing is best accomplished on moist soils.
- A spiker can break up crusts on the soil surface, disrupt algae layers, and improve water infiltration.

- Vertical mowing (verticutting) can be incorporated into a cultural management program to achieve a number of different goals. The grain of a putting green can be reduced by setting a verticutter to a depth that just nicks the surface of the turf. Deeper penetration of knives will stimulate new growth by cutting through stolons and rhizomes while removing accumulated thatch.
- Verticutting depth for thatch removal should reach the bottom of the thatch layer and extend into the surface of the soil beneath the thatch.
- Dethatching with a verticutter is an aggressive practice that is not recommended on golf putting greens because of the damage that occurs and the extensive recovery time required.
- Initiate vertical mowing when thatch level reaches 0.25 to 0.5 inch in depth. Shallow vertical mowing should be completed at least monthly on putting greens to prevent excessive thatch accumulation.
- Groomers, or miniature vertical mowers attached to the front of reels, are effective at improving management of grain and improving plant density through cutting of stolons.
- Topdress the playing surface with sand following core aerification and heavy vertical mowing to aid in recovery of turf. Rates will vary from 0.125 to 0.25 inch in depth and will depend on the capacity of the turf canopy to absorb the material without burying the plants.
- Light, frequent applications of topdressing sand on putting greens can smooth out minor surface irregularities, aiding in the management of thatch accumulation.
- Use only weed-free topdressing materials with a particle size similar to that of the underlying root zone.
- Use of finer materials can result in layering and can have a negative impact on water infiltration.
- Daily rolling of putting surfaces following mowing can increase putting speeds by roughly 10%, allowing for improved ball roll without lowering height of cut.
- To minimize potential for compaction caused by rolling, use light weight rollers.

Figure 16. Core aerification should be conducted only when grasses are actively growing to aid in quick recovery of surface density. Photo credit: Shannon Watson.

Overseeding Warm-Season Turfgrass

Principles

- The fundamental purpose of overseeding is to establish a temporary cool-season grass into the warm-season base for improved color and playability during the fall and winter when the warm-season grass enters dormancy.

- Overseeding increases the need for irrigation and routine mowing and may result in significant thinning of the base grass during spring transition.
- Successful overseeding programs require year-long planning and incorporate all aspects of root-zone cultivation and weed control in an effort to maintain health of the warm-season turfgrass while allowing successful establishment of the overseeded cool-season grass species.

Best Management Practices

- Thatch depth greater than 0.5 inch in the warm-season turfgrass base will prevent good seed-to-soil contact and will result in sporadic germination and establishment. Remove thatch as part of an active cultivation program before overseeding.
- Reduce or eliminate fertilization of the base grass three to four weeks before the planned seeding date to minimize growth and competition.
- Core-aerify the soil four to six weeks before the planned overseeding date to open turf canopy and aid in uniform establishment of overseeded grass.
- Select grass species/cultivars that are adapted to the desired use, taking note of disease resistance and spring transition traits. Cultivars with improved heat tolerance can delay spring transition and create increased competition for water, nutrients, and light with the warm-season turfgrass base.
- Irrigate newly planted overseed to maintain constant moisture levels, not allowing the soil surface to dry out. Gradually reduce irrigation once the seedlings have been mowed.
- Do not fertilize with nitrogen immediately before or during establishment of overseed as the N may encourage warm-season turfgrass competition and increase disease potential.
- Move hole locations on putting greens daily during the establishment period to minimize damage to seedlings from foot traffic.
- Reduce fertilizer rates in spring to slow growth of overseeded grass. Once warm-season turfgrass regrowth is apparent, restore fertilizer applications to stimulate growth of the warm-season turfgrass.
- Colorants (dyes and pigments) can be used to provide winter color to dormant grasses.
- Overseeding practices can generate significant dust that may require dust control measures.

Shade and Tree Management

Principles

- In general, most turfgrasses perform best in full sun.
- Excessive shade reduces photosynthesis and air circulation, thus increasing the susceptibility of the turf to pest and disease problems.

Best Management Practices

- Prune tree limbs and roots as needed to reduce competition for sunlight, water, and nutrients.
- When possible, trees located near closely mowed areas such as tees and greens should be removed or their canopy should be thinned to promote good turf growth.
- Understand the variability in sun angles at different times of the year and how this affects turf health.
- Conduct a shade audit to identify problem areas.
- Conduct a tree survey that identifies each tree’s location, species, health, life expectancy, safety concerns, value and special maintenance requirements.

Figure 17. Prune tree limbs and roots as needed to reduce competition for sunlight, water, and nutrients. Photo credit: Shannon Watson.

Integrated Pest Management

Regulatory Considerations

The philosophy of integrated pest management (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 pesticide 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.

Pest management on golf courses results in significant inputs of time, labor, and financial resources. To grow healthy turfgrass, it is important for golf course superintendents to know what IPM is and how to implement it for each pest group (arthropods, nematodes, 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.

Principles

- Some federal or state regulations cover practically anyone who manufactures, formulates, markets, and uses pesticides.
- Record keeping of pesticide use may be required by law. IPM principles suggest that you keep records of all pest control activity so that you may refer to information on past infestations or other problems to select the best course of action in the future.

Best Management Practices

- Proper records of all pesticide applications should be kept according to local, state, or federal requirements.
- Use records to establish proof of use and follow-up investigation of standard protocols regarding:
    - Date and time of application
    - Name of applicator
    - Person directing or authorizing the application

- Weather conditions at the time of application
- Target pest
- Pesticide used (trade name, active ingredient, amount of formulation, amount of water)
- Adjuvant/surfactant and amount applied, if used
- Area treated (acres or square feet) and location
- Total amount of pesticide used
- Application equipment
- Additional remarks, such as the severity of the infestation or life stage of the pest
- Follow-up to check the effectiveness of the application

IPM Overview

Principles

- The fundamental basis of an environmentally sound pest control program is a process called IPM.
- IPM 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 less toxic alternatives to chemical pesticides whenever possible.
- Chemical controls should have minimal effect on beneficial organisms and the environment and minimize the development of pesticide resistance.

Best Management Practices

- Chemical pesticide applications should be carefully chosen for effective and site-specific pest control with minimal environmental impact.
- 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, select resistant cultivars), reduce pest habitat (for example, practice good sanitation, carry out pruning and dethatching), or to help promote biological control (for example, provide nectar or honeydew sources).
- Decide which pest management practice is appropriate and carry out corrective actions. Direct control where the pest lives or feeds.
- Use preventive chemical applications only when your professional judgment indicates that properly timed preventive applications are likely to control the target pest effectively while minimizing the economic and environmental costs.
- Determine whether 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.

Written Plan

Principles

- IPM is an overall pest management strategy that includes biological controls, cultural methods, pest monitoring, other applicable practices, and is a last measure when threshold levels are exceeded.
- A pest-control strategy should be used only when the pest is causing or is expected to cause more damage than what can be reasonably and economically tolerated. A control strategy should be implemented that reduces the pest numbers to an acceptable level while minimizing harm to non-targeted organisms.
- When a pesticide application is deemed necessary, its selection should be based on effectiveness, toxicity to non-target species, cost, and site characteristics, as well as its solubility and persistence.

Best Management Practices

- Decide which pest management practice(s) are appropriate and carry out corrective actions. Direct control where the pest lives or feeds. Use properly timed preventive chemical applications only when your professional judgment indicates they are likely to control the target pest effectively, while minimizing the economic and environmental costs.
- Determine whether 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.
- Observe and document turf conditions regularly (daily, weekly, or monthly, depending on the pest), noting which pests are present, so intelligent decisions can be made regarding how damaging the pests are and what control strategies are necessary.

Pest Thresholds

Principles

- IPM is commonly used in agricultural crop production, where the economic thresholds for key pests have been determined. Pest levels exceeding the site's threshold warrant treatment.
- Using IPM is more challenging on golf courses than in an agricultural setting. The golf industry is sensitive to aesthetic damage, and golfers are often intolerant of anything that could affect the appearance of turfgrass and ornamental plants. Increased education of golfers and maintenance personnel could raise their tolerance of minor aesthetic damage without compromising plant health, play, and aesthetics.

Best Management Practices

- Use available pest thresholds to guide pesticide application decisions (see IPM Guide).
- Use preventive chemical applications only when professional judgment indicates that properly timed preventive applications are likely to control the target pest effectively while minimizing the economic and environmental costs.
- Record and use this information when making similar decisions in the future.

Monitoring

Principles

- Monitoring, or scouting, is the most important element of a successful IPM program. Monitoring documents the presence and development of pests, or the conditions that are conducive for pest outbreak throughout the year.
- It is essential to record the results of scouting in order to develop historical information, document patterns of pest activity, and document successes and failures.

Best Management Practices

- Train personnel to observe and document turf conditions regularly (daily, weekly, or monthly, depending on the pest), noting which pests are present, so intelligent decisions can be made regarding how damaging they are and what control strategies are necessary.
- Train personnel to 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).
- Train personnel to determine whether 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.
- Train personnel to document, identify, and record key pest activities on key plants.
- Look for signs of the pest. These may include mushrooms, animal damage, insect frass, or webbing.
- Identify the symptoms of the pest. Look for symptoms such as chlorosis, dieback, growth reduction, defoliation, mounds, or tunnels.
- Determine the damage. Problem areas might include the edges of fairways, shady areas, or poorly drained areas.
- Document when the damage occurred. Note the time of day, year, and flowering stages of nearby plants.
- Map pest outbreaks locations to identify patterns and susceptible areas for future target applications and ultimate pesticide reductions.

Record Keeping

Principles

- It is essential to record the results of scouting in order to develop historical information, document patterns of pest activity, and document successes and failures.
- Record keeping is required to comply with the federal Superfund Amendments and Reauthorization Act (SARA, Title III), which contains emergency planning and community right-to-know legislation
- Certain pesticides are classified as restricted-use pesticides (RUPs). Very few pesticides in this category are routinely used in turf maintenance, but if you happen to use one of them, certain record-keeping requirements apply.

Best Management Practices

- Document, identify, and record key pest activities on key plants and locations.
- 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).
- Determine whether 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.
- Observe and document turf conditions regularly (daily, weekly, or monthly, depending on the pest), noting which pests are present, so intelligent decisions can be made regarding how damaging they are and what control strategies are necessary.

Turfgrass Selection

Principles

- Selecting pest-resistant cultivars or plant species is a very important part of IPM, and it leads to reduced pesticide usage. Species grown outside of their zone of adaptation are more prone to pest problems.
- Species and cultivars should be managed under conditions similar to their intended use (for example, not exceeding mowing height limitations that a grass was bred for or selected for).
- Educate builders, developers, golf course and landscape architects, sod producers, golfers and others on which plants are best suited to their areas.
- Turfgrasses must be scientifically selected for the eco-region of the golf course, resulting in minimized irrigation requirements, fertilization needs, and pesticide use.

Figure 18. Selecting pest-resistant cultivars or plant species is a very important part of IPM, and it leads to reduced pesticide usage. Photo credit: Andrew Wolfe.

Best Management Practices

- Select the most suitable turfgrass for existing conditions and one that adheres to design specifications.
- Avoid use of turfgrass in heavy shade.
- Select shade-adapted grasses for areas receiving partial sun or shaded areas.
- Reduce pest and disease pressures by correcting dead spots and air-circulation issues by pruning understory and adjusting irrigation scheduling.
- Reduce fertilizer applications in shaded areas.
- Reduce traffic in shaded areas to protect turfgrasses and trees from injury and soil compaction, if practical.

Biological Controls

Principles

- The biological component of IPM involves the release and/or conservation of natural predators, such as parasites and pathogens, and other beneficial organisms (pollinators).
- Natural enemies (including ladybird beetles, green lacewings, and mantids) may be purchased and released near pest infestations.
- Areas on the golf course can also be modified to better support natural predators and beneficial organisms.

Best Management Practices

- Identify areas on the golf course that can be modified to attract natural predators, provide habitat for them, and protect them from pesticide applications.
- Install flowering plants that can provide parasitoids with nectar, or sucking insects (aphids, mealybugs, or soft scales) with a honeydew source.
- Avoid applying pesticides to roughs, driving ranges, or other low-use areas to provide a refuge for beneficial organisms.
- Release insect-parasitic nematodes to naturally suppress mole crickets and white grubs.

Pollinators

Principles

- It is important to minimize the impacts on bees and beneficial arthropods. Pesticide applicators must use appropriate tools to help manage pests while safeguarding pollinators, the environment, and humans.
- Pollinator-protection language is a label requirement found on pesticide labels.
- Be mindful of pollinators; when applying pesticides, focus on minimizing exposure to non-target pollinators in play and non-play course areas.
- Pollinators may be negatively impacted when pesticide applications are made based on insufficient information and/or made without regard to the safety of pollinators.

Best Management Practices

- When using pesticides, minimize injury and damage by following label directions.
- Follow label information concerning the application of pesticides when plants may be in bloom. Avoid applying pesticides during bloom season.
- Stay on target by using coarse-droplet nozzles and monitor wind to reduce drift.
- Do not apply pesticides when pollinators are active.
- Before applying a pesticide, scout/inspect area for both harmful and beneficial insect populations, and apply only when the indicated threshold of damage has been reached.
- Mow flowering plants (weeds) before insecticide application.
- If flowering weeds are prevalent, control them before applying insecticides.

- Use insecticides that have a lower impact on pollinators.
- Use the latest spray technologies, such as drift-reduction nozzles to prevent off-site (target) translocation of pesticide.
- Avoid applications during unusually low temperatures or when dew is forecasted.
- Use granular formulations of pesticides that are known to be less hazardous to bees.
- Consider lures, baits, and pheromones as alternatives to insecticides for pest management.

Conventional Pesticides

Principles

- IPM does not preclude the use of pesticides. However, pesticides should be viewed as one of the many tools used to minimize pest problems.
- IPM involves both prevention — keeping the pest from becoming a problem — and suppression — reducing the pest numbers or damage to an acceptable level.
- A pest-control strategy using pesticides should be used only when the pest is causing or is expected to cause more damage than what can be reasonably and economically tolerated.
- Pesticides are designed to control or alter the behavior of pests. When, where, and how they can be used safely and effectively is a matter of considerable public interest.
- Pesticides should be evaluated on effectiveness against the pest, mode of action, life stage of the pest, personnel hazards, non-target effects, potential off-site movement, and cost.
- A control strategy should be implemented that reduces the pest numbers to an acceptable level while minimizing harm to non-targeted organisms.
- Always follow the directions on the label. These directions have been developed after extensive research and field studies on the chemistry, biological effects, and environmental fate of the pesticide. The label is the single most important document in the use of a pesticide. State and federal pesticide laws require following label directions!

Best Management Practices

- Train employees in proper pest identification and pesticide selection techniques.
- Choose the product most appropriate for the problem or pest.
- Mix only the quantity of pesticide needed in order to avoid disposal problems, protect non-target organisms, and save money.
- Spot-treat pests whenever appropriate.
- Make note of any environmental hazards and groundwater advisories included on the label.
- Rotate pesticide modes-of-action to reduce the likelihood of resistance.

- Follow guidelines and advice provided by the Fungicide Resistance Action Committee (FRAC), Herbicide Resistance Action Committee (HRAC),and Insecticide Resistance Action Committee (IRAC).

Disease

Principles

- In the presence of a susceptible host and a conducive environment, plant pathogens can disrupt play by damaging and destroying intensely managed turf.
- No measure can completely eliminate the threat of turfgrass disease on a golf course. However, turfgrass managers have multiple tactics and tools that can reduce the likelihood of disease.
- 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.
- Disease outbreaks that do occur are less likely to be severe on turf that is healthy because it has better recuperative potential than stressed, unhealthy turf.

Best Management Practices

- Correctly identify the disease pathogen. This often involves sending samples to diagnostic clinics.
- Ensure that proper cultural practices that reduce turfgrass stress are used.
- Correct conditions that produce stressful environments for the turf (for example, improve airflow and drainage, reduce or eliminate shade.)
- Fungicide use should be integrated into an overall management strategy for a golf course.
- The appropriate (most effective) preventive fungicide should be applied to susceptible turfgrasses when unacceptable levels of disease are likely to occur.
- Preventively apply appropriate fungicides where diseases are likely to occur and when conditions favor disease outbreaks.
- Record and map disease outbreaks and identify trends that can help guide future treatments and focus on changing conditions in susceptible areas to reduce disease outbreaks.

Weeds

Principles

- Weeds compete with desired plants for space, water, light, and nutrients and can harbor insect pests and diseases.
- 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:
    - preventing weeds from being introduced into an area
    - using proper turfgrass management and cultural practices to promote vigorous, competitive turf
    - properly identifying weeds
    - properly selecting and using the appropriate herbicide, if necessary
- Weeds are hosts for other pests such as plant pathogens, nematodes, and insects, and certain weeds can cause allergic reactions in humans.
- Weeds reproduce from seed, root pieces, and special vegetative reproductive organs such as tubers, corms, rhizomes, stolons, or bulbs. People, animals, birds, wind, and water can distribute seeds.
- 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.

Best Management Practices

- Proper weed identification is essential for effective management and control.
- Select appropriate turf species or cultivars that are adapted to the prevalent environmental conditions to reduce weed encroachment that may lead to bare soils.
- To prevent weed encroachment, adopt or maintain cultural practices that protect turfgrass from environmental stresses such as shade, drought, and extreme temperatures.
- To reduce weed infestation, address improper turf management practices, such as the misuse of fertilizers and chemicals, improper mowing height or mowing frequency, and improper soil aeration, and physical damage and compaction from excessive traffic.
- Proper fertilization is essential for turfgrasses to sustain desirable color, growth density, and vigor and to better resist diseases, weeds, and insects.
- Avoid scalping; it reduces turf density, increasing weed establishment.
- Weed-free materials should be used for topdressing.
- Address damage from turfgrass pests such as diseases, insects, nematodes, and animals to prevent density/canopy loss to broadleaf weeds.
- Record and map weed infestations to help identify site specific issues for preventative actions.

Nematodes

Principles

- Plant-parasitic nematodes adversely affect turfgrass health.

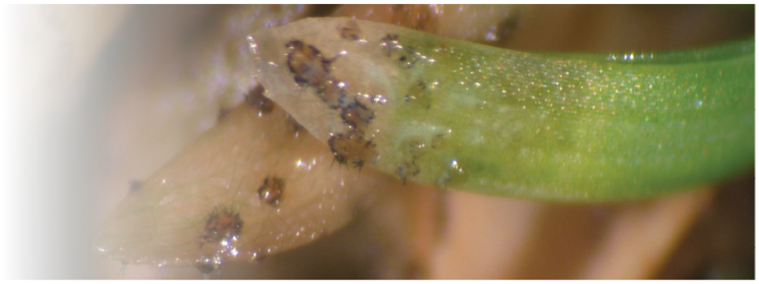
- Plant-parasitic nematodes are microscopic roundworms (unsegmented), usually between 0.0156 and 0.125 inch (0.25 and 3 mm) in length, and are difficult to control.
- Nematodes debilitate the root system of susceptible turfgrasses; plant-parasitic nematodes cause turf to be less efficient at water and nutrient uptake from the soil and make it much more susceptible to environmental stresses. Additionally, weakened turf favors pest infestation, especially troublesome weeds that necessitate herbicide applications.
- Over time, turf in the affected areas thins out and, with severe infestations, may die. The roots of turfgrasses under nematode attack may be very short, with few, if any, root hairs, or they may appear dark and rotten.
- Turfgrasses usually begin showing signs of nematode injury as they experience additional stresses, including drought, high temperatures, low temperatures, and wear.

Best Management Practices

- When nematode activity is suspected, an assay of soil and turfgrass roots is recommended to determine the extent of the problem.
- The application of a nematicide on golf course turf should always be based on assay results.
- Divert traffic away from areas that are stressed by insects, nematodes, diseases, or weeds.
- Increase mowing height to reduce plant stress associated with nematodes, root-feeding insects, disease outbreaks, or peak weed-seed germination.
- Reduce/eliminate other biotic/abiotic stresses when nematodes are compromising the root system and plant health.

Pesticide Management

Overview



Pesticide use should be part of an overall pest management strategy that includes biological controls, cultural methods, pest monitoring, and other applicable practices, referred altogether as IPM. When a pesticide application is deemed necessary, its selection should be based on effectiveness, toxicity to non-target species, cost, site characteristics, and its solubility and persistence in the environment.

Regulatory Considerations

What Is a Pesticide? A pesticide, as defined by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA), is “. . . any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any insect, rodent, nematode, fungus, weed, or any other forms of life declared to be pests; and any substance or mixture of substances intended for use as a plant regulator, defoliant, or desiccant.”

Pesticides contain active ingredients and inert ingredients. In any pesticide product, the component that kills or otherwise controls the target pest is called an active ingredient. The rest of the pesticide is made up of inert ingredients such as solvents, surfactants, and carriers. Both active and inert ingredients may be controlled or regulated by federal, state, and local laws because of environmental and health concerns.

The Division of Environmental Services of the Kentucky Department of Agriculture (KDA) regulates federal and state pesticide laws and regulations, including the Kentucky Fertilizer and Pesticides Storage, Pesticide Use and Application Act of 1996 (KRS 217b). It is responsible for regulating the registration, sale, distribution, proper use, storage, disposal, and application of pesticides in the Commonwealth. The Division strives to educate the pest control industry and consumers about the proper use of pesticides through education and training programs. All golf applications fall under Category 18 - Golf course. This category shall include persons who apply pesticides or fertilizer to land on which turf and ornamental care is done for the purpose of preparing the land for use in the game of golf.

KDA personnel give exams to certify and license qualified citizens who wish to apply or to sell pesticides. Field inspectors from the Agricultural Branch inspect facilities of the businesses which sell and/or apply pesticide and review their records. They can impose fines on businesses and/or individuals who neglect to follow federal and state laws concerning the proper storage, containment, sale, distribution, application, record keeping, or disposal of federally registered pesticides. They also investigate potential pesticide application complaints and violations. You are responsible for learning about and complying with pesticide laws and regulations before making any applications. In addition, you are responsible for any consequences of actions that result from an application. *Ignorance of the law is never an excuse for noncompliance or violations.*

Important Definitions for Golf Courses (Category 18)

Application - the spreading of plant-regulating materials in liquid or dry form on a golf course.

Golf course - land on which turf and ornamental care, including application of pesticides or fertilizer and storage of pesticides or fertilizer, is done for the purpose of preparing the land for use in the game of golf.

Plant-regulating materials - fertilizers, pesticides, or defoliants applied or intended for application to a golf course.

Best Management Practices

- Only apply pesticides that are legally registered at all levels of jurisdiction.
- Only apply pesticides that are legally registered for use on the facility (for example, do not apply pesticides labeled for agricultural even though they may have the same active ingredient).
- Follow the pesticide label.
- Handle pesticides safely.
- Keep accurate records.
- Pesticides must be applied by licensed pesticide applicator with a license in good standing.

Laws and Regulations for Turf and Ornamentals

Human Health Risks

Principles

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. To manage toxicity, pesticide usage should be minimized as part of an IPM strategy and the least toxic, but effective pesticide selected. Exposure can be limited through good work habits, and protective clothing (PPE). The risk of a very highly toxic pesticide may be very low if the exposure is sufficiently small. Each pesticide label will provide information on personal protective equipment needed (PPE), first aid, as well as include a precautionary statement and pesticide signal word. The label is the law, and each applicator should read the label in its entirety prior to mixing, loading or applying a pesticide. Safety Data Sheets (SDS) also contain relevant information such as precautionary and first aid treatment. SDS should be used in conjunction with the pesticide label.

Signal words are found on pesticide product labels, and they describe the acute (short-term) toxicity of the formulated pesticide product. The signal words: **DANGER, WARNING or CAUTION**. Products with the DANGER signal word are the most toxic. Products with the signal word CAUTION are lower in toxicity

Best Management Practices

- Select the least toxic pesticide with the lowest exposure potential.
- Read the label completely before loading, mixing or applying a pesticide.
- Know and understand the hazard warning symbols on each label.
- Know and understand pesticide toxicity - LD50 values can be found on SDS.
- Follow the label's PPE requirements
- In case of exposure, refer to the label for additional information and treatment recommendations.
- Know the emergency response procedure in case excessive exposure occurs.

Shelf Life

Principles

Pesticides degrade over time. Do not store large quantities of pesticides for long periods. Utilize computer software systems to record inventory and use.

Best Management Practices

- Avoid purchasing large quantities of pesticides that require storage for greater than six months.
- Mark containers with the date of purchase
- Adopt the “first in–first out” principle, using the oldest products first.
- Ensure labels are on every package and container.
- Consult inventory when planning and before making purchases.
- Conduct routine inspections of the storage area for containers that may be damaged.
- Kentucky has a program to dispose of unwanted pesticides - Contact your KY Department of Agriculture (KDA) field representative.

Environmental Fate and Transport

Principles

Environmental characteristics of a pesticide can often be determined 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.

Best Management Practices

- Select pesticides that have a low runoff and leaching potential.
- Before applying a pesticide, evaluate the impact of site-specific characteristics (for example, proximity to surface water, water table, and well-heads; soil type; prevailing wind; etc.) and pesticide-specific characteristics (for example, half-lives and partition coefficients)
- Select pesticides with reduced impact on pollinators. *see pollinator chapter
- Select pesticides that, when applied according to the label, have no known effect on endangered species present on the facility.
- Do not make pesticide applications during adverse weather conditions.

Pesticide Transportation, Storage, and Handling

Principles

Storage and handling of pesticides in their concentrated form poses the highest potential risk to ground or surface waters. For this reason, it is essential that facilities for storing and handling these products be properly sited, designed, constructed, secured, and operated. Although existing buildings are often used for pesticide storage, it is best to have a separate storage facility for pesticides, fertilizers and other similar products. Storing pesticides separately gives emergency response crews more options in dealing with fires and spills. Keeping equipment, employees, and records away from pesticides is always recommended where possible.

Transport vehicles should be in good mechanical condition. Make sure brakes, tires, and steering work properly. Repair all fluid leaks before putting a truck on the road. Always transport pesticides in their original box, carry SDS, and have a spill kit in the vehicle.

Best Management Practices

- Store, mix, and load pesticides away from sites that directly link to surface water or groundwater.

- Store pesticides in a lockable concrete or metal building that is separate from other buildings.
- Locate pesticide storage facilities from other types of structure to allow fire department access.
- Storage facility floors should be impervious and sealed with a chemical-resistant paint.
- Floors 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.
- Avoid temperature extremes inside the pesticide storage facility and during transport.
- Personal protective equipment (PPE) should be easily accessible and stored immediately outside the pesticide storage area.
- Place a spill containment kit in the storage area, in the mix/load area, and on the spray rig
- Keep your inventory list and SDS sheets close in case of an emergency; multiple copies in separate locations on site
- Have the proper "Pesticide Storage" signs on storage facility.
- Never leave pesticides unattended during transport.
- Do not transport pesticides in the passenger section of a vehicle.
- Place pesticides where they will not come in contact with food, clothing, or other things that people or animals might eat or touch.
- Transport highly volatile pesticides separately from other chemicals.

Transporting and Storing Pesticides Safely

Figure 19. Wood shelving should never be used, because it may absorb spilled pesticides. Metal should be painted to stop corrosion. Photo credit: Kevin Glover.

Emergency Preparedness and Spill Response

Principles

Accidents happen. Advance preparation on what to do when an accident occurs is essential to mitigate the human health effects and the impact on the environment. Be prepare for a pesticide emergency. Make sure the plan includes designating an emergency response coordinator, maintaining a list of emergency response agencies, preparing a map of the facility, and keeping a product inventory. Be sure all employees at the facility are familiar with the emergency response plan and know what to do in a crisis. Take precautions to reduce the chance of pesticide fires.The best way to manage pesticide spills is to prevent them from happening. It is your responsibility as a pesticide applicator to do everything possible to avoid spills and adhere to a few basic guidelines when handling spills and leaks. Accidents happen. Be prepared so that they will not become catastrophes.

IMPORTANT NUMBERS: Emergency Response Branch KY HOTLINE 1-800-928-2380 or 502-564-2380 Report an Environmental Emergency 24 hours a day, 7 days a week.

Best Management Practices

- Develop a golf course facility emergency response plan which includes procedures to control, contain, collect, and store spilled materials.
- Prominently post "Important Telephone Numbers" including CHEMTREC, for emergency information on hazards or actions to take in the event of a spill
- Ensure an adequately sized spill containment kit is readily available.
- Designate a spokesperson who will speak on behalf of the facility should an emergency occur.
- Host a tour for local emergency response teams (for example, fire fighters, etc.) to show them the facilities and to discuss the emergency response plan. Seek advice on ways to improve the plan.

Disposal

Principle

Wash water from pesticide application equipment must be managed properly, since it contains pesticide residues.

Best Management Practices

- Collect wash water (from both inside and outside the application equipment) and use it as a pesticide in accordance with the label instructions.
- The rinsate may be applied as a pesticide (preferred) or stored for use as makeup water for the next compatible application.

Pesticide Record Keeping

Principles

Maintaining accurate records of pesticide-related activities is required by law. KRS 217b requires that applicator keep records of applications of general and restricted use pesticides. Maintain the records for 3 years. USDA and/or KDA representatives have legal access to the records.

Benefits of Keeping Records: Records help you evaluate how well a pesticide worked, particularly if you have used reduced rates or alternative application techniques. Allows you to compare effectiveness of different application rates, techniques, equipment or adjuvants. Records help you determine how much pesticide you will need in the future so you can manage your inventory more effectively. Records may help to protect you from legal action if you are accused of improper pesticide use. Records can help determine the most economical pesticide management program. Keeping records is part of a successful Integrated Pest Management (IPM) program.

At the time of application of plant-regulating materials, an applicator shall record the following information for each regulating material used:

- Brand name or common name of the pesticide applied
- Pesticide type
- EPA registration number
- Fertilize rate and analysis
- Reason for use
- Concentration of end use product applied to the golf course, the rate of application, and the total gallons of end use product applied to the golf course
- The location of area treated
- Any special instruction appearing on the label of the plant-regulating material applicable to the golf course use following application and any other precautionary or hazard information appearing on the label as applicable to the end use concentration
- The name and the state applicator license or certification number of the individual actually making the application

Notification and Information Requirements

Immediately following the application of plant-regulating materials on a golf course, the applicator shall place a golf course marker on the number-one (1) and number-ten (10) tees.

The golf course marker consists of, at a minimum, a four (4) inch by five (5) inch white sign attached to the upper portion of a dowel or other supporting device of not less than twelve (12) inches in length. Lettering on the golf course marker shall be in a contrasting color and shall read on one side "PLANT-REGULATING MATERIALS HAVE BEEN APPLIED. IF DESIRED, YOU MAY CONTACT THE GOLF COURSE SUPERINTENDENT FOR FURTHER INFORMATION" in letters easily readable and not less than three-eighths (3/8) inches in height. The golf course marker may also display a symbol depicting the required message and the name, logo, and service mark of the applicator. The golf course marker may be removed by the applicator or other personnel authorized by the golf course management the day following application.

Best Management Practices

- Keep and maintain records of all pesticides used to meet legal (federal, state, and local) reporting requirements.
- Use records to monitor pest control efforts and to plan future management actions.
- Use electronic or hard-copy forms and software tools to properly track pesticide inventory and use.

- Develop and implement a pesticide drift management plan.
- Keep a backup set of records in a safe, but separate of pesticide storage area.

Sprayer Calibration

Principle

Properly calibrated application equipment is paramount to mitigating environmental and human health concerns.

Best Management Practices

- Clean your sprayer before calibrating your sprayer, make sure it is in good working condition.
- Replace or carefully clean nozzles and screens with a soft brush or compressed air before calibration.
- Personally ensure spray technician is experienced, licensed, and properly trained.
- Minimize off-target movement by using properly configured application equipment.
- Properly calibrate all application equipment at the beginning of each season (at a minimum) or after equipment modifications.
- Check equipment daily when in use.
- Use recommended spray volumes for the targeted pest to maximize efficacy.
- Calibration of walk-behind applicators should be conducted for each person making the application to take into consideration their walking speed, etc.

More information can be found in the Kentucky Extension Publication PAT-3.

Personal Protective Equipment

Principles

Exposure to pesticides can be mitigated by practicing good work habits and adopting modern pesticide mix/load equipment (for example, closed-loading) that reduce potential exposure. Personal Protective Equipment (PPE) statements on pesticide labels provide the applicator with important information on protecting himself/herself.

Best Management Practices

- Provide adequate PPE for all employees who work with pesticides (including equipment technicians who service pesticide application equipment).
- Ensure that PPE is sized appropriately for each person using it.
- Make certain that PPE is appropriate for the chemicals used.
- Ensure that PPE meets rigorous testing standards and is not just the least expensive.

- Store PPE where it is easily accessible but not in the pesticide storage area.
- Forbid employees who apply pesticides from wearing facility uniforms home where they may come into contact with children.
- Provide laundering facilities or uniform service for employee uniforms.
- The federal Occupational Safety and Health Administration (OSHA) requires employers to fit test workers who must wear tight-fitting respirators.
- Meet requirements for OSHA 1910.134 Respiratory Protection Program.
- Do not store PPE in the pesticide storage area.

Mixing/Washing Station

Principles

Pesticide leaks or spills, if contained, will not percolate down through the soil into groundwater 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).

Best Management Practices

- 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.
- Mixing station surface should provide for easy cleaning and the recovery of spilled materials.
- 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 (that is, one that cannot be legally applied to the same site).
- Apply liquids and sediments as you would a pesticide, strictly following label instructions.
- 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.
- Sweep up solid materials and use as intended.

Pesticide Container Management

Principles

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) and some state laws require 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.

Best Management Practices

- Rinse pesticide containers immediately in order to remove the most residue.
- Rinse containers during the mixing and loading process and add rinsate water to the finished spray mix.
- Rinse emptied pesticide containers by either triple rinsing or pressure rinsing.
- Puncture empty and rinsed pesticide containers and dispose of according to the label.

Types of Sprayers

Principles

Various types and sizes of application equipment are readily available. The size of the equipment (tank size, boom width, etc.) should be matched to the scale of the facility.

Best Management Practices

- Use an appropriately sized applicator for the size of area being treated.
- Equipment too large in size requires greater volumes to prime the system. This can result in significant waste that must be properly handled.

Leaching Potentials

Principles

Weakly sorbed pesticides (compounds with small Koc values) are more likely to leach through the soil and reach groundwater. Conversely, strongly sorbed pesticides (compounds with large Koc values) are likely to remain near the soil surface, reducing the likelihood of leaching, but increasing the chances of being carried to surface water via runoff or soil erosion.

Best Management Practices

- Understand pesticide sorption principles so that appropriate decisions can be made.
- Understand site characteristics that are prone to leaching losses (for example, sand-based putting greens, coarse-textured soils, shallow water tables).
- Identify label restrictions that may pertain to your facility.
- Avoid using highly water-soluble pesticides.
- Exercise caution when using spray adjuvants that may facilitate off-target movement.

Inventory

Principles

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. Use computer software systems to record inventory and use.

Best Management Practices

- An inventory of the pesticides kept in the storage building and the Safety Data Sheets (SDS) for the chemicals used in the operation should be accessible on the premises, but not kept in the pesticide storage room itself.
- Avoid purchasing large quantities of pesticides that require storage for greater than six months.
- Mark containers with the date of purchase
- Consult inventory when planning and before making purchases.

Pollinator Protection

Overview

Most flowering plants need pollination to reproduce and grow fruit. While some plants are pollinated by wind, many require assistance from insects and other animals. In the absence of pollinators, many plant species, including the fruits and vegetables we eat, would fail to survive.

The western honey bee (*Apis mellifera*) is one of the most important pollinators in the United States. Hundreds of other bee species, including the bumble bee (*Bombus* spp.), also serve as important pollinator species. Protecting bees and other pollinators is important to the sustainability of agriculture.

Pesticides are products designed to control pests (for example, insects, diseases, weeds, nematodes, etc.). Pesticides and other plant growth products, including plant growth regulators, surfactants, biostimulants, etc., are used in golf course management. The non-target effect of products used in golf course management is of increasing concern; therefore, pesticide applicators, including those on golf courses, need to be mindful of the impact that pesticides have on pollinator species and their habitat.

Regulatory Considerations

Principles

- Pollinator-protection language is a label requirement found on pesticide labels; follow the label, it is the law.
- Pesticide applicators must be aware of honey bee toxicity groups and able to understand precautionary statements.
- Recordkeeping may be required by law in order to use some products. IPM principles suggest that you keep records of all pest control activity so that you may refer to information on past infestations or other problems to select the best course of action in the future.

Best Management Practices

- Proper records of all pesticide applications should be kept according to local, state, or federal requirements.
- Use records to establish proof of use and follow-up investigation of standard protocols regarding:
    - Date and time of application
    - Name of applicator
    - Person directing or authorizing the application
    - Weather conditions at the time of application
    - Target pest
    - Pesticide used (trade name, active ingredient, amount of formulation, amount of water)
    - Adjuvant/surfactant and amount applied, if used
    - Area treated (acres or square feet) and location
    - Total amount of pesticide used
    - Application equipment
    - Additional remarks, such as the severity of the infestation or life stage of the pest
    - Follow-up to check the effectiveness of the application
- Those applying pesticides, and who make decisions regarding their applications should be able to interpret pollinator protection label statements.
- Those applying pesticides should be aware of honey bee biology.
- Those applying pesticides should understand the various routes of exposure (outside the hive and inside the hive).
- Those applying pesticides should understand the effects of pesticides on bees.

Figure 20. While some plants are pollinated by wind, many require assistance from insects and other animals. Photo credit: GCSAA.

Pollinator Habitat Protection

Principles

- It is important to minimize the impacts of pesticides on bees and beneficial arthropods. Pesticide applicators must use appropriate tools to help manage pests while safeguarding pollinators, the environment, and humans.
- Be mindful of pollinators; when applying pesticides, focus on minimizing exposure to non-target pollinators in play and non-play course areas.
- Pollinators require a diversity of flowering species to complete their life cycle. Pollinator habitat contains a diversity of wildflower species of different colors and heights, with blossoms throughout the entire growing season

Best Management Practices

- Follow label information directing the application of pesticide when the plant may be in bloom. Avoid applying pesticides during bloom season.
- Stay on target by using coarse-droplet nozzles, and monitoring wind to reduce drift.
- Do not apply pesticides when pollinators are active.
- Before applying a pesticide, scout/inspect the area for both harmful and beneficial insect populations, and use pesticides only when a threshold of damage has been indicated.
- Mow flowering plants (weeds) before insecticide application.
- If flowering weeds are prevalent, control them before applying insecticides.
- Use insecticides that have a lower impact on pollinators.
- Use the latest spray technologies, such as drift-reduction nozzles to prevent off-site (target) translocation of pesticide.
- Avoid applications during unusually low temperatures or when dew is forecast.
- Use granular formulations of pesticides that are known to be less hazardous to bees.
- Consider lures, baits, and pheromones as alternatives to insecticides for pest management.
- Develop new pollinator habitat and/or enhance existing habitat.

Figure 21. Pollinator habitat contains a diversity of wildflower species of different colors and heights, with blossoms throughout the entire growing season. Photo credit: Brian Curtis.

Maintenance Operations

Regulatory Considerations

Equipment maintenance, fueling, and chemical storage can have an impact on water quality on-site and off-site both during construction and during the maintenance of existing golf courses.

Local and state regulations may be in place in your location. Early engagement among developers, designers, local community groups and permitting agencies is essential to designing and constructing a golf maintenance and storage facility that minimizes environmental impact and meets the needs for the approval process.

Storage and Handling of Chemicals

Principles

- Proper handling and storage of pesticides and petroleum-based products is important to reduce risk of serious injury or death of an operator or bystander. Fires or environmental contamination may result in large fines, cleanup costs, and civil lawsuits if these chemicals are not managed properly.
- Check federal, state, and local regulations for specific requirements related to storage of pesticides.

Best Management Practices

- Storage buildings should have appropriate warning signs and placards.
- Follow all personal protective equipment (PPE) statements on pesticide labels.
- Store PPE away from pesticide storage areas in an area that is easily accessible.
- Develop an emergency response plan and educate all golf course personnel regarding emergency procedures on a regular basis.
- Individuals conducting emergency chemical cleanups should be properly trained under requirements of federal Occupational Safety and Health Administration (OSHA).
- Store pesticides in a lockable concrete or metal building.
- Locate pesticide storage away from other buildings, especially fertilizer storage facilities.

- Floors of chemical storage buildings should be impervious and sealed with chemical-resistant paint.
- Floors of chemical storage buildings should have a continuous sill to contain spills and should not have a drain. A sump is acceptable.
- Shelving should be fabricated from plastic or reinforced metal. Metal shelving should be painted to avoid corrosion. Wood shelving should never be used because of its ability to absorb spilled pesticides.
- Automatic exhaust fans and an emergency wash area should be provided
- Explosion-proof lighting may be required. Locate fan and light switches outside the entrance to the building to facilitate ventilation of building before entrance of staff.
- Maintain detailed records of current pesticide inventory in the storage facility. Safety Data Sheets (SDS) for the chemicals stored on-site should be stored separate from the storage room, but readily accessible on-site.
- Do not store large quantities of pesticides or chemicals for long periods of time. Follow a “first in, first out” principle to rotate products into use to ensure products do not expire.
- Store chemicals in original containers. Never store them in containers that might be mistaken as packaging for food or drink.
- Arrange containers so the labels are clearly visible. Securely fasten loose labels to ensure containers and associated labels are kept together.
- Damaged labels should be replaced immediately.
- Store flammable pesticides separate from those that are nonflammable.
- Store liquid materials below dry materials to prevent leaks from contaminating dry products.
- Ensure that oil containers and small fuel containers (service containers) are properly labeled and stored within the facility.

Equipment Storage and Maintenance

Principle

Storing and maintaining equipment properly will extend useful life and reduce repairs.

Best Management Practices

- Store and maintain equipment in a covered area complete with a sealed impervious surface to limit risk of fluid leaks contaminating the environment and to facilitate the early detection of small leaks that may require repair before causing significant damage to the turf or the environment.
- Seal floor drains unless they are connected to a holding tank or sanitary sewer with permission from the local wastewater treatment plant.
- Store pesticide and fertilizer application equipment in areas protected from rainfall. Rain can wash pesticide and fertilizer residues from the exterior of the equipment and possibly contaminate soil or water.

- Store solvents and degreasers in lockable metal cabinets away from ignition sources in a well-ventilated area. These products are generally toxic and highly flammable. Never store them with fertilizers or in areas where smoking is permitted.
- Keep an inventory of solvents and SDS for those materials on-site but in a different location where they will be easily accessible in case of an emergency.
- Keep basins of solvent baths covered to reduce emissions of volatile organic compounds (VOC).
- When possible, replace solvent baths with recirculating aqueous washing units. Soap and water or other aqueous cleaners are often as effective as solvent-based products and present a lower risk to the environment.
- Always use appropriate PPE when working with solvents.
- Never allow solvents or degreasers to drain onto pavement or soil, or discharge into waterbodies, wetlands, storm drains, sewers, or septic systems.
- Collect used solvents and degreasers in containers clearly marked with contents and date; schedule collection by a commercial service.
- Blow off all equipment with compressed air to reduce damage to hydraulic seals.

Waste Handling

Principles

- Proper disposal of waste materials is critical for protection of water and natural resources. State or local laws and regulations related to disposal of hazardous waste products may vary. Be sure to familiarize yourself with all state and local laws related to disposal/recycling of these waste materials.
- Identify and implement waste-reduction practices.
- Look for ways to increase recycling efforts and programs.
- Purchase environmentally preferred products in bulk packaging when possible.

Best Management Practices

- Pesticides that have been mixed for application must be disposed of as waste and may be classified as hazardous waste depending on the materials involved. Contact local authorities for guidance regarding proper disposal.
- Collect used oil, oil filters, and antifreeze in separate marked containers and recycle them as directed by local and state authorities.
- Antifreeze may be considered hazardous waste by state or local laws and should be handled accordingly. Commercial services are available to collect and recycle antifreeze.
- Lead-acid batteries are classified as hazardous waste unless they are properly recycled.
- Store old batteries on impervious services where they are protected from rainfall and recycle as soon as possible.
- Recycle used tires.

- Recycle or dispose of fluorescent tubes and other lights according to state requirements.

Equipment Washing

Principle

Wash water generated from equipment-washing facilities can be a source of both surface-water and groundwater pollution. Steps should be taken to prevent pollution.

Best Management Practices

- Equipment washing areas should drain to an oil/water separator before draining to a sanitary sewer or holding tank.
- Consider the use of a closed-loop wash-water recycling system.
- Grass-covered equipment should be brushed or blown off with compressed air before being washed.
- Wash equipment with a bucket of water and a rag to minimize the amount of water used and use only the minimal amount of water required to rinse the machine.
- Spring-operated shut-off nozzles should be used.
- Do not allow any wastewater to flow directly into surface waters or storm drains.

Fueling Facilities

Principle

Safe storage of fuel, including use of above-ground tanks and containment facilities, is critical to the protection of the environment. State or local laws and regulations related to storage of fuel may vary.

Best Management Practices

- Locate fueling facilities on roofed areas with a concrete (not asphalt) pavement. Areas should be equipped with spill-containment and recovery facilities.
- Use of above ground fuel tanks is preferred.

Pollution Prevention

Principles

- Plan appropriately to minimize the possibility of an elicit discharge and need for disposal. Monitor the water to be discharged for contamination; never discharge to the environment any contaminated water. If the water is not contaminated, it can be reused or discharged to a permitted stormwater treatment system.

- Pesticide leaks or spills, if contained, will not percolate down through the soil into groundwater or run off the surface to contaminate streams, ditches, ponds, and other water bodies.
- Wash water from pesticide application equipment must be managed properly, since it contains pesticide residues. This applies to wash water from both the inside and the outside of the application equipment. Material should be collected and used as a pesticide in accordance with the label instructions for that pesticide.
- An equipment-washing facility can be a source of both surface water and groundwater pollution, if the wash water 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.
- 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, because of the accumulation of contaminants in soil or groundwater.
- 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.
- Generating as little as 25 gallons per month of used solvents for disposal can qualify you as a “small-quantity generator” of hazardous waste, triggering EPA and state reporting requirements.
- 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.
- Provide adequate protection from the weather. Rain can wash pesticide and fertilizer residues from the exterior of the equipment, and these residues can contaminate soil or water.
- 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.
- Office paper, recyclable plastics, glass, and aluminum should be recycled. Place containers for recycling aluminum cans and glass or plastic soft drink bottles at convenient locations on the golf course.

Best Management Practices

- Pesticides should be stored in a lockable concrete or metal building.
- Pesticide storage and mixing facility floors should be impervious and sealed with a chemical-resistant paint. Floors should have a continuous sill to retain spilled materials and no drains, although a sump may be included.

- For valuable information about constructing chemical mixing facilities, reference 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.
- Use a chemical mixing center (CMC) as 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. (A CMC is a concrete pad treated with a sealant and sloped to a liquid-tight sump where all of the spilled liquids can be recovered.)
- Flush wash pad with clean water after the equipment is washed. Captured wash water can be used as a dilute pesticide per labeled site, or it may be pumped into a rinsate storage tank for use in the next application.
- FIFRA, Section 2(ee), allows the applicator to apply a pesticide at less than the labeled rate.
- The sump should then be cleaned of any sediment before another type of pesticide is handled.
- Discharge to a treatment system that is permitted under industrial wastewater rules.
- Never discharge to a sanitary sewer system without written permission from the utility.
- Never discharge to a septic tank.
- Use a closed-loop wash-water recycling system and follow appropriate BMP.
- Use non-containment wash water for field irrigation.
- Do not discharge non-contaminated wastewater during or immediately after a rainstorm, since the added flow may cause the permitted storage volume of the stormwater system to be exceeded.
- Whenever practical, replace solvent baths with recirculating aqueous washing units (which resemble heavy-duty dishwashers).
- Use soap and water or other aqueous cleaners; these products 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.
- 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.
- Clean up spills as soon as possible.
- 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.
- For emergency (only) information on hazards or actions to take in the event of a spill, call CHEMTREC, at (800)424–9300. CHEMTREC is a service of the Chemical Manufacturers Association. For information on whether a spilled chemical requires reporting, call the CERCLA/RCRA help line at (800) 424–9346.
- Do not allow any wash water to flow directly into surface waters or storm drains.
- Avoid washing equipment in the vicinity of wells or surface water bodies.
- Wash equipment over a concrete or asphalt pad that allows the water to be collected. After the residue dries on the pad, collect, compost, or spread in the field.
- If applicable, allow runoff onto a grassed area to soak into the ground, but never into a surface water body or canal.
- Use compressed air to blow off equipment. This is less harmful to the equipment's hydraulic seals, eliminates wastewater, and produces dry material that is easier to handle.
- Handle clippings and dust separately. After the residue dries on the pad, it can be collected and composted or spread in the field.
- Minimize the use of detergents. Use only biodegradable non-phosphate detergents.
- Minimize the amount of water used to clean equipment. This can be done by using spray nozzles that generate high-pressure streams of water at low volumes.
- Do not discharge wash water to surface water or groundwater either directly or indirectly through ditches, storm drains, or canals.
- Do not conduct equipment wash operations on a pesticide mixing and loading pad. (This keeps grass clippings and other debris from becoming contaminated with pesticide).
- Solvents and degreasers should be used over a collection basin or pad that collects all used material.
- 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
- 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 tha properly recycles or disposes of them. Never mix used oil or other liquid material with the used solvents.
- Collect used oil, oil filters, and antifreeze in separate marked containers and recycle them. Arrange pickup of used oil, or deliver to a hazardous waste collection site.
- Do not mix used oil with used antifreeze or sludge from used solvents. Antifreeze must be recycled or disposed of as a hazardous waste.
- 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.

- Lead-acid storage batteries are classified as hazardous wastes unless they are recycled. All lead-acid battery retailers in Florida are required by law to accept returned batteries for recycling.
- Spent lead-acid batteries must be recycled if they are to be exempt from strict hazardous waste regulations.
- Equipment used to apply pesticides and fertilizers should be stored in areas protected from rainfall.
- Pesticide application equipment can be stored in the chemical mixing center (CMC), but fertilizer application equipment should be stored separately.
- Blow or wash loose debris off equipment to prevent dirt from getting on the CMC pad, where it could become contaminated with pesticides.
- Ensure that all containers are sealed, secured, and properly labeled. Use only regulatory agency-approved, licensed contractors for disposal.
- 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 non-rinseable containers, such as bags or boxes, so that all dust and material fall into the application equipment.
- After cleaning them, puncture the pesticide containers to prevent reuse (except glass and refillable mini-bulk containers).
- Keep the rinsed containers in a clean area, out of the weather, for disposal or recycling.
- Storing the containers in large plastic bags/tubs 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.

Landscape

Overview

Landscape (non-play) areas are an essential part of the overall course design, providing enhanced course aesthetics, wildlife habitat, external sound/noise abatement, and natural cooling and freeze protection.

An environmental landscape design approach addresses environmentally safe and energy-saving practices; therefore, environmentally sound landscape management is also economically important. Non-play areas require a mix of sun and shade, optimal soil conditions and adequate canopy air movement to sustain growth and function.

Species Selection and Size Considerations

Principles

- 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.
- 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.
- The addition of proper soil amendments can improve 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.
- The goal of species-selection BMP is to maintain as close to a natural ecosystem as practical, while meeting the needs of a golf course.
- Landscape areas should be fundamentally designed to facilitate rapid plant establishment to conserve water and lower nutritional input requirements once mature. Plants within 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. Additionally, 50% to 70% of the non-

play areas should remain in natural cover. 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 non-play areas, along water sources 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 native grasses, the amount of work needed to prepare a course is reduced while habitat for wildlife survival is maintained.

Best Management Practices

- Base plant selection as close to a natural ecosystem as practical, while meeting the needs of the golf course. It has adapted specifically to the soil, microclimate, rainfall, light patterns, insects and other pests, and endemic nutrient levels over many years.
- Select trees, plants, and grass species to attract birds seeking wild fruits, herbs, seeds, and insects.
- Know the ultimate sizes and growth rates of trees, shrubs, and ground covers.
- Use plants that are adapted for the site based on the United States Department of Agriculture (USDA) cold-hardiness map.
- Select stress-tolerant species or cultivars to manage periodic dry/wet conditions.
- Choose the most stress-tolerant species or cultivar for a particular area.

Figure 22. The fundamental principle for the environmentally sound management of landscapes is “right plant, right place.” Photo credit: John Ballard, CGCS.

Design and Function

Principles

- Aesthetic gardens, window boxes, and container gardens should include a variety of plants of different heights that provide nectar for hummingbirds and butterflies. Again, “right plant, right place” is the key to success.
- When integrating turf areas into the landscape around the clubhouse, entries, and other areas, design them for ease of maintenance and keep in mind that

turfgrasses grow best in sunny areas. Consider the effect that tree canopy and other design features may have on the health and function of the turf.
- Garden plants, shrubbery, ground covers, or native plants may provide a pleasing a view and also provide useful food, cover, or other environmental benefits to wildlife; they may also require reduced maintenance.
- Trees and shrubs along streams provide temperature moderation through shade, which lowers water temperature in summer and increases it in winter.

Best Management Practices

- 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.
- Use forested buffers to trap and remove upland sources of sediments, nutrients, and chemicals.
- Use forested buffers to protect fish and wildlife by supplying food, cover, and shade.
- Use forested buffers to maintain a healthy riparian ecosystem and stable stream channel.
- Leave dead tree snags whenever possible for nesting and food source to wildlife. However, make sure that these snags are a safe distance away from playing surfaces should they get blown over.
- Use turf as a landscape element where needed.

Planting Methods

Principles

- 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, light patterns, insects, and other pests, and endemic nutrient levels over hundreds or thousands of generations. Where these factors have changed, the challenge is finding 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.
- 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.
- Keep mulch 2 to 3 inches away from plants, to prevent fungal growth from excess dampness.
- Excess mulch or compacted mulch may be detrimental, causing water to shed away from the root zone and encourage overwatering. Compaction or excessive mulch buildup should be avoided, especially when annual re-mulching is performed.

Best Management Practices

- The plant palette and irrigation system should be appropriate for site conditions, taking into account that, in some cases, soil improvement can enhance water-use efficiency.
- Plants should be grouped together based on irrigation demand.
- The percentage of landscaped area in irrigated high-water-use hydrozones should be minimized. Local government ordinances should address the percentage of irrigated landscaped area that may be included in high-water-use hydrozones. These high water-use limits should not apply to landscaped areas requiring large amounts of turf for their primary functions (for example, ball fields and playgrounds).
- In most instances, established, drought-tolerant landscape plants have a root system substantial enough to keep them alive with little or no supplemental irrigation.
- Pruning and fertilizing will also benefit landscape plants while they are becoming established.
- Add proper soil amendments in garden areas to improve the soil’s physical and chemical properties, increase its water-holding capacity, and reduce the leaching of fertilizers.

Energy

Energy Conservation

According to the GCSAA Golf Course Environmental Profile, Vol. IV (GCSAA 2012), six major energy sources were identified for golf course use: electricity, gasoline, diesel, natural gas, propane and heating oil. In addition, operational uses were segmented to meet irrigation, turf maintenance, buildings, clubhouse operations, swimming pools and various amenity needs.

The overall conclusion of the study suggests that golf facility managers must take steps toward identifying options for conservation, efficiency, and cost savings.

To address current needs and future energy reduction opportunities, managers should evaluate current energy conservation performance practices based on the following categories:

- General energy conservation position statements on policy and planning
- Buildings and amenities statements –buildings, infrastructure and facility amenities such as the clubhouse, swimming pool, restaurant, parking lot, kitchen, offices, maintenance building(s), tennis courts, etc.
- Golf course statements – the golf course and surrounding landscapes, pump station, irrigation system and related agronomic operations (playing surfaces, equipment, turfgrass maintenance etc.)

Principles

- Determine goals and establish an energy policy that is part of the facility's overall environmental plan.
- Establish an energy management plan for the facility based on current energy use baselines to optimize efficiency.
- Communicate policy to all staff regarding use patterns and management practices to effect change.
- Relate the policy to the entire facility, including the services the facility provides to its customers and community.
- Incorporate quality management elements for continual improvement (plan, do, check, and act) to reduce environmental and economic impacts.
- Understand that the irrigation pump is the largest user of energy. A well-engineered pump station is critical to reducing energy consumption.

Best Management Practices

- Conduct an energy audit.
- Conduct a lighting audit.
- Conduct a carbon footprint analysis.
- Add insulation where needed.
- Use non-demand electrical hour rates: charge golf carts, and use pumps to acquire water, charge maintenance equipment, and other items later in the day or early in the morning.
- Limit high-consumption activities during periods when demand is high.
- Use alternative energy from natural sources, such as solar, geothermal and wind energy generation.
- Upgrade or install National Electrical Manufacturers Association's (NEMA) premium efficiency-rated pump motors.
- Seek output reduction by watering less area, apply target golf goals.
- Install LED lighting and/or retrofit devices.
- Install motion sensors for lights where appropriate.
- Install a programmable thermostat.
- Install solar/Geo Thermal pumps for pools and spa.

Evaluation

Principles

- Continually track and measure energy use at the facility based on energy assessment units, for example, kilowatt hour.
- Benchmark practices to evaluate existing facility consumption with other local golf facilities of similar size.

Best Management Practices

- Monitor energy use: track data, evaluate billing meters.
- Install adequate meters, gauges, etc.
- Develop an equipment inventory incorporating individual equipment's energy use, use / traffic patterns, etc. (maintenance records, operation hours, etc.).
- Establish a baseline for performance parameters to optimize irrigation pumps.
- Consider benchmarking performance against similar-sized facilities.

Efficiency

Principles

- Evaluate energy efficiency performance.
- Evaluate electric equipment/operations and ensure proper selection, operation, charging, and maintenance.

Best Management Practices

- Evaluate all energy providers (electricity, natural gas and liquid petroleum fuels) for costs, efficiency/assistance programs, and incentives.
- Identify and categorize operations for energy efficiency opportunity and conservation analysis.
- Perform assessments of all the facility's infrastructure and operations.
- Perform appropriate audits throughout the facility depending on operation, infrastructure, and planning stage.
- Identify efficiency and conservation elements of infrastructure/hard items and behavioral/process-oriented items.
- Consider alternative equipment, products, and practices.

Design and Renovation

Principles

- Incorporate an analysis of the assessments, audits, and data.
- Incorporate first cost consideration (initial investment and long-term gain).
- Redesign – evaluate future projects with a priority for energy conservation.
- According to system and compliance standards, communicate with utility provider, insurance company, and any state or local regulatory officials.

Best Management Practices

- Identify buildings, amenities, and operations including existing, new construction, or renovation activities where energy efficiency enhancements are needed.
- Identify the golf course, course infrastructure, and related agronomic operations including existing and future developments or renovations that would benefit from energy efficiency improvements.

Implementation Plan

Principles

- Set goals for buildings/amenities and the golf course operation; develop an implementation plan.
- Set energy-use goals according to efficiency/conservation of the building, infrastructure and equipment efficiency.

Best Management Practices

- Evaluate effectiveness of upgrades according to efficiency/conservation goals for energy use.
- Continue to identify future energy needs and maintain good record keeping.
- Prioritize energy consumption as part of purchase/decision-making process for HVAC, food service, laundry, swimming pools, etc.

- Consider other devices as part of the plan; do research on building, pumps, and power generation.

Infrastructure

Principles

- Ensure efficient building/facility/amenities and related infrastructure.
- Consider the materials: used insulation and color selection.
- Ensure efficient lighting in both interior and exterior areas.

Best Management Practices

- Maximize use of space.
- Inspect and repair leaks/maintenance.
- Monitor temperature/environmental settings (heat loss, etc.).
- Evaluate building automation systems, monitoring systems, etc.
- Incorporate technology and up-to-date equipment (lights, controls, switches, etc.).
- Implement schedules/controlled use.
- Evaluate off-grid pole lighting and similar technology.

Alternative products, operations, and practices

Principles

- Educate and motivate employees, guests, etc.
- Educate, train, and motivate employees on energy efficiency practices pertaining to golf course operations.
- Identify incentives and programs from energy providers.
- Identify state/local programs and certification.
- Consider U.S. Green Building Council's LEED program.
- Consider EPA's EnergyStar, Portfolio Manager, etc.
- Consider energy management software, services, etc.
- Consider national and local programs and programs like the EPA's WaterSense program as it relates to buildings (see Water Conservation BMP).

Best Management Practices

- Evaluate alternative transportation.
- Evaluate cleaning practices (dry vs. wet).
- Consider local vs. distant purchases, product selection, etc.
- Evaluate energy acquisition and energy coming into the facility.
- Evaluate golf car equipment/operations and ensure proper selection, operation, charging, and maintenance.
- Incorporate training for employees.
- Incorporate the use of incentives.

Course Management Plan

Principles

- Set energy-use goals for efficiency/conservation including infrastructure, equipment, behavior and agronomic practices.
- Ensure proper selection (type, size, etc.), operation, and equipment maintenance.
- Ensure efficient design, selection, operation, and maintenance of irrigation pumps, irrigation controls and other irrigation components.
- Implement energy source selection, management, and efficiency/conservation practices.

Best Management Practices

- Work with energy providers and evaluate existing programs, resources, etc.
- Consider long-term costs in addition to acquisitions.
- Schedule reviews to evaluate future technology and fuel types.
- Evaluate upgrades.
- Evaluate use of alternative energy/fuels.
- Identify future energy needs.
- Prioritize energy consumption as part of selection.
- Optimize equipment use data including hours operated, use patterns, etc.
- Incorporate new technology and upgrades when feasible.
- Consider alternative equipment, products, and practices.

Irrigation

Principles

- Ensure efficient design, selection, operation, and maintenance of irrigation pumps, irrigation controls, and other irrigation components.
- Assess irrigation pump efficiency; consider alternative equipment, products, and practices; use energy efficiently to maximize the output of the pump station.

Best Management Practices

- Audit irrigation system (see Water Conservation BMP).
- Schedule and operate pumps and irrigation in an efficient manner.
- Identify and implement infrastructure and behavioral changes.
- Evaluate technology and upgrades; implement when feasible.

References

Selected References

(Note: URLs are as of September 2016)

Aerts, M.O., N. Nesheim, and F. M. Fishel. April 1998; revised September 2015. *Pesticide recordkeeping.* PI-20. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/PI012.

Aquatic Ecosystem Restoration Foundation. 2014. Biology and Control of Aquatic Plants: A Best Management Practices Handbook: 3rd Ed. Gettys, L.A., W. T. Haller, and D. G. Petty, editors.http://www.aquatics.org/bmp%203rd%20edition.pdf

ASCE, January 2005. *The ASCE standardized reference evapotranspiration equation.* Final report of the Task Committee on Standardization of Reference Evapotranspiration, Environmental and Water Resourses Institute of the American Society of Civil Engineers. 1801 Alexander Bell Drive, Reston, VA 20191 Available: http://www.kimberly.uidaho.edu/water/asceewri/ascestzdetmain2005.pdf

Bohmont, B. 1981. *The new pesticide users guide.* Fort Collins, Colorado: B & K Enterprises.

Brecke, B.J., and J.B. Unruh. May 1991; revised February 25, 2003. *Spray additives and pesticide formulations.* Fact Sheet ENH-82. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/LH061.

Broder, M.F., and D.T. Nguyen. 1995. *Coating concrete secondary containment structures exposed to agrichemicals.* Circular Z-361. Muscle Shoals, Alabama: Tennessee Valley Authority, Environmental Research Center. Tel. (205) 386–2714.

Broder, M.F., and T. Samples. 2002. *Tennessee handbook for golf course environmental management.* Tennessee Department of Agriculture.

Buss, E.A. January 2002; revised July 2003. *Insect pest management on golf courses.* ENY-351. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/IN410.

Butler, T., W. Martinkovic, and O.N. Nesheim. June 1993; revised April 1998. *Factors influencing pesticide movement to groundwater.* PI2. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/PI002.

California Fertilizer Association. 1985. *Western fertilizer handbook*, 7th ed. Sacramento, California.

Carrow, R.N., R. Duncan, and C. Waltz. 2007. Best Management Practices (BMPs) Water-Use Efficiency/Conservation Plan for Golf Courses. Available: https://www.gcsaa.org/uploadedfiles/Environment/Get-Started/BMPs/Water-use-efficiency-and-conservation-best-management-practices-(Georgia).pdf

Carrow, R.N., R.R. Duncan, and D. Wienecke. 2005. BMPs: Critical for the golf industry. *Golf Course Management*. 73(6):81-84.

Center for Resource Management. 1996. *Environmental principles for golf courses in the United States.* 1104 East Ashton Avenue, Suite 210, Salt Lake City, Utah 84106. Tel: (801) 466-3600, Fax: (801) 466-3600.

Clark, G.A. July 1994. *Microirrigation in the landscape.* Fact Sheet AE254. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/AE076.

Clark, Mark and Acomb, Glenn; Florida Field Guide to Low Impact Development: Stormwater Reuse. Univ. Florida 2008. http://buildgreen.ufl.edu/Fact_sheet_Stormwater_Reuse.pdf

Colorado Nonpoint Source Task Force. 1996. Guideslines for Water Quality Enahncement at Golf Courses Through the Use of Best Management Practices. Available: http://www.wrightwater.com/assets/7-golf-course-bmps.pdf

Connecticut Department of Environmental Protection. 2006. Best Management Practices for Golf Course Water Use. Available: http://www.ct.gov/deep/lib/deep/water_inland/diversions/golfcoursewaterusebmp.pdf

Cromwell, R.P. June 1993; reviewed December 2005. *Agricultural chemical drift and its control.* CIR1105. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/AE043.

Crow, W.T. February 2001; revised November 2005. *Nematode management for golf courses in Florida.* ENY-008 (IN124). Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/IN124.

Daum, D.R., and T.F. Reed. n.d. *Sprayer nozzles.* Ithaca, New York: Cornell Cooperative Extension. Available http://psep.cce.cornell.edu/facts-slides-self/facts/gen-peapp-spray-nozz.aspx.

Dean, T.W. February 2003. *Pesticide applicator update: Choosing suitable personal protective equipment.* PI-28. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/PI061.

———. April 2004; revised November 2004. *Secure pesticide storage: Facility size and location.* Fact Sheet PI-29. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/PI064.

———. April 2004; revised November 2004. *Secure pesticide storage: Essential structural features of a storage building.* Fact Sheet PI-30. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/PI065.

Dean, T.W., O.N. Nesheim, and F. Fishel. Revised May 2005. *Pesticide container rinsing.* PI-3. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/PI003.

Delaware Nutrient Management Commission. 2006. Water Quality Best Management Practices: Nutrients, Irrigation and Pesticides for Golf Course, Athletic Turf, Lawn Care and Landscape Industries. Available: http://dda.delaware.gov/nutrients/forms/BMPnonagforprinter.pdf

Dodson, R.G. 2000. Managing wildlife habitat on golf courses. Sleeping Bear Press. Chelsea, MI.

Elliott, M.L., and G.W. Simone. July 1991; revised April 2001. *Turfgrass disease management.* SS-PLP-14. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/LH040.

Fishel, F.M. March 2005. *Interpreting pesticide label wording.* Gainesville, Florida: Institute of Food and Agricultural Sciences. Available: http://edis.ifas.ufl.edu/PI071.

Fishel, F.M., and Nesheim, O.N. November 2006. *Pesticide safety.* FS11. Gainesville, Florida: Institute of Food and Agricultural Sciences. Available: http://edis.ifas.ufl.edu/pdffiles/CV/CV10800.pdf.

Florida Department of Agriculture and Consumer Services. n.d. *Pesticide recordkeeping—benefits and requirements.* Available: http://www.flaes.org/pdf/Pesticide%20Recordkeeping%20Pamphlet%205-05.pdf.

Florida Department of Agriculture and Consumer Services. Division of Agricultural Environmental Services. *Suggested pesticide recordkeeping form.* Available: https://www.freshfromflorida.com/content/download/2990/18861/Suggested%20Pesticide%20Recordkeeping%20Form.pdf

———. Division of Agricultural Environmental Services. *Suggested pesticide recordkeeping form for organo-auxin herbicides.* Available: http://forms.freshfromflorida.com/13328.pdf.

Florida Department of Agriculture and Consumer Services and Florida Department of Environmental Protection. 1998. *Best management practices for agrichemical handling and farm equipment maintenance.* Available: http://www.dep.state.fl.us/water/nonpoint/docs/nonpoint/agbmp3p.pdf

Florida Department of Environmental Protection. 2008. *Florida stormwater, erosion, and sedimentation control inspector's manual.* Tallahassee, Florida: Nonpoint Source Management Section, MS 3570, 3900 Commonwealth Blvd.., Tallahassee, Florida 32399-3000. Available: http://www.dep.state.fl.us/water/nonpoint/docs/erosion/erosion-inspectors-manual.pdf.

———. December 27, 2002. *Environmental risks from use of organic arsenical herbicides at south Florida golf courses.* FDEP white paper. Available: http://fdep.ifas.ufl.edu/msma.htm.

———. April 2002. *Florida water conservation initiative.* Available: http://www.dep.state.fl.us/water/waterpolicy/docs/WCI_2002_Final_Report.pdf.

______. 2015. "Florida-friendly Best Management Practices for Protection of Water Resources by the Green Industries", Florida Department of Environmental Protection. Revised December 2008, 3rd printing 2015. https://fyn.ifas.ufl.edu/pdf/grn-ind-bmp-en-12-2008.pdf

———. 2012. Best Management Practices for The Enhancement of Environmental Quality on Florida Golf Courses. Florida Department of Environmental Protection. 3rd printing, September 2012. http://www.dep.state.fl.us/water/nonpoint/docs/nonpoint/glfbmp07.pdf

———. Revised August 2009. *A guide on hazardous waste management for Florida's auto repair shops.* Available: http://www.dep.state.fl.us/waste/quick_topics/publications/shw/hazardous/business/Paint_and_Body8_09.pdf.

———. October 2005. *Checklist guide for 100% closed loop recycle systems at vehicle and other equipment wash facilities.* Available: http://www.dep.state.fl.us/water/wastewater/docs/ChecklistGuideClosed-LoopRecycleSystems.pdf.

———. October 2005. *Guide to best management practices for 100% closed-loop recycle systems at vehicle and other equipment wash facilities.* Pollution Prevention Program and Industrial Wastewater Section. Available: http://www.dep.state.fl.us/water/wastewater/docs/GuideBMPClosed-LoopRecycleSystems.pdf.

———. 2006. *State of Florida erosion and sediment control designer and reviewer manual.* Nonpoint Source Management Section. Available: http://www.dep.state.fl.us/water/nonpoint/erosion.htm.

———. 2016. Operation Cleansweep for Pesticides Web site. Available: http://www.dep.state.fl.us/waste/categories/cleansweep-pesticides.

———. December 1, 2005. *Standards and specifications for turf and landscape irrigation systems,* 5th Ed. Available: http://ufdc.ufl.edu/UF00076845/00001.

———. December 2006. *Landscape Irrigation & Florida-Friendly Design Standards.* Florida Department of Environmental Protection, Office of Water Policy, 3900 Commonwealth Blvd., MS 46, Tallahassee, FL 32399-3000. Available: http://www.dep.state.fl.us/water/waterpolicy/docs/LandscapeIrrigationFloridaFriendlyDesign.pdf

Gilman, E. 2006. *Pruning shade trees in landscapes.* Available: http://hort.ufl.edu/woody/pruning/index.htm.

Golf Course Superintendents Association of America. 2012. Golf Course Environmental Profile; Volume IV; Energy Use and Energy Conservation Practices on U.S. Golf Courses. Available: https://www.gcsaa.org/Uploadedfiles/Environment/Environmental-Profile/Energy/Golf-Course-Environmental-Profile--Energy-Use-and-Conservation-Report.pdf

Golf Course Water Resources Handbook of Best Management Practices (Pennsylvania). 2009. Available: http://pecpa.org/wp-content/uploads/Golf-Course-Water-Resources-Handbook-of-Best-Management-Practices.pdf

Havlin, J.L., et al. 2004. *Soil fertility and fertilizers*, 7th Ed. Prentice Hall.

Haydu, J.J., and A.W. Hodges. 2002. *Economic impacts of the Florida golf course industry.* UF–IFAS Report EIR 02-4. Available: http://economicimpact.ifas.ufl.edu/publications/EIR02-4r.pdf.

Helfrich, L.A., et al. June 1996. *Pesticides and aquatic animals: A guide to reducing impacts on aquatic systems.* Virginia Cooperative Extension Service. Publication Number 420-013. Available: http://www.ext.vt.edu/pubs/waterquality/420-013/420-013.html.

Hornsby, A.G., T.M. Buttler, L.B. McCarty, D.E. Short, R.A. Dunn, G.W. Simone. Revised September 1995. *Managing pesticides for sod production and water quality protection.* Circular 1012. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/SS053.

Insecticide Resistance Action Committee Web site. Available: http://www.irac-online.org/.

King, K.W., and J.C. Balogh. 2001. Water quality impacts associated with converting farmland and forests to turfgrass. In: *Transactions if the ASAE, Vol. 44(3): 569-576.*

Lehtola, C.J., C.M. Brown, and W.J. Becker. November 2001. *Personal protective equipment. OSHA Standards 1910.132-137.* AE271. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/OA034.

McCarty, L.B., and D.L. Colvin. 1990. *Weeds of southern turfgrasses.* Gainesville, Florida: University of Florida.

Midwest Plan Service. Revised 1995. *Designing facilities for pesticide and fertilizer containment.* MWPS-37. Midwest Plan Service, 122 Davidson Hall, Iowa State University, Ames, IA 50011-3080. Tel.: (515) 294-4337. Available: http://infohouse.p2ric.org/ref/50/49471.pdf.

Mitra, S. 2006. *Effects of recycled water on turfgrass quality maintained under golf course fairway conditions.* WateReuse Foundation, 1199 North Fairfax Street, Suite 410, Alexandria, VA 22314. Available: http://www.watereuse.org/Foundation/documents/wrf-04-002.pdf.

National Pesticide Telecommunications Network. December 1999. *Signal words.* Fact Sheet. Available: http://npic.orst.edu/factsheets/signalwords.pdf.

Nesheim, O.N., and F.M. Fishel September 2007, reviewed August 2013.*Interpreting PPE statements on pesticide labels.* P116. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: https://edis.ifas.ufl.edu/pdffiles/CV/CV28500.pdf.

Nesheim, O.N., and F.M. Fishel. March 1989; revised November 2005. *Proper disposal of pesticide waste.* PI-18. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/PI010.

Nesheim, O.N., F.M. Fishel, and M. Mossler. July 1993. *Toxicity of pesticides.* PI-13. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/pdffiles/PI/PI00800.pdf..

O'Brien, P. July/August 1996. Optimizing the turfgrass canopy environment with fans. *USGA Green Section Record, Vol. 34(4), 9-12* Available: http://gsrpdf.lib.msu.edu/ticpdf.py?file=/1990s/1996/960709.pdf.

O'Brien, P., and C. Hartwiger. March/April 2003. Aerification and sand topdressing for the 21st century. *USGA Green Section Record, Vol. 41(2), 1-7.* Available: http://turf.lib.msu.edu/2000s/2003/030301.pdf.

Olexa, M.T., A. Leviten, and K. Samek. December 2008, revised December 2013. *Florida solid and hazardous waste regulation handbook: Table of contents.* FE758. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/fe758.

Otterbine Barebo, Inc. 2003. *Pond and lake management.* 3840 Main Road East, Emmaus, PA 18049. Available: http://www.otterbine.com/assets/base/resources/PondAndLakeManual.pdf.

Peterson, A. 2000. *Protocols for an IPM system on golf courses.* University of Massachusetts Extension Turf Program.

Pennsylvania Department of Environmental Protection, LandStudies, Inc., The Pennsylvania Environmental Council. Golf Course Water Resources Handbook of Best Management Practices. June 2009. http://pecpa.org/wp-content/uploads/Golf-Course-Water-Resources-Handbook-of-Best-Management-Practices.pdf

Pettinger, N.A. 1935. Useful chart for teaching the relation of soil reaction to availability of plant nutrients to crops. *Virginia Agri. Ext. Bul. 136, 1-19.*

Portness, R.E., J.A. Grant, B. Jordan, A.M. Petrovic, and F.S. Rossi. 2014. Best Management Practices for New York State Golf Courses. Cornell Univ. Available: http://nysgolfbmp.cals.cornell.edu/ny_bmp_feb2014.pdf

Rao, P.S.C., and A.G. Hornsby. May 1993; revised December 2001. *Behavior of pesticides in soils and water.* Fact Sheet SL40. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/SS111.

Rao, P.S.C., R.S. Mansell, L.B. Baldwin, and M.F. Laurent. n.d. *Pesticides and their behavior in soil and water.* Ithaca, New York: Cornell Cooperative Extension. Available: http://psep.cce.cornell.edu/facts-slides-self/facts/gen-pubre-soil-water.aspx.

Rodgers, J. n.d. *Plants for lakefront revegetation.* Invasive Plant Management, Florida Department of Environmental Protection, 3900 Commonwealth Blvd., MS 705, Tallahassee, FL 32399. Available: http://myfwc.com/media/2518526/LakefrontRevegetation.pdf .

Sartain, J.B. 2000. *General recommendations for fertilization of turfgrasses on Florida soils.* Fact Sheet SL-21. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/LH014.

———. 2001. *Soil testing and interpretation for Florida turfgrasses.* SL-181. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/SS317.

———. 2002. revised October 2006. *Recommendations for N, P, K, and Mg for golf course and athletic field fertilization based on Mehlich-I extractant.* SL-191. Available: http://edis.ifas.ufl.edu/SS404. Gainesville, Florida.

Sartain, J.B., and W.R. Cox. 1998. *The Florida fertilizer label.* SL-3. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/SS170.

Sartain, J.B., G.L. Miller, G.H. Snyder, and J.L. Cisar. 1999a. Plant nutrition and turf fertilizers. In: J.B. Unruh and M. Elliott (Eds.). *Best management practices for Florida golf courses.* SP-141 2nd ed. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida.

———. 1999b. Liquid fertilization and foliar feeding. In: J.B. Unruh and M. Elliott (Eds.), *Best management practices for Florida golf courses.* SP-141 2nd ed. Gainesville , Florida: Institute of Food and Agricultural Sciences, University of Florida.

Sartain, J.B., G.L. Miller, G.H. Snyder, J.L. Cisar, and J.B. Unruh. 1999. Fertilization programs. In: J.B. Unruh and M. Elliott (Eds.). *Best management practices for Florida golf courses.* SP-141 2nd ed. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida.

Schueler, T.R. 2000. Minimizing the impact of golf courses on streams. Article 134 in: *The practice of watershed protection.* T. R. Schueler and H. K. Holland (Eds.). Ellicott City, Maryland: Center for Watershed Protection. Available: http://www.stormwatercenter.net/.

Schumann, G.L., et al. January 1998. *IPM handbook for golf courses.* Indianapolis, Indiana: Wiley Publishing, Inc.

Seelig, B. July 1996. *Improved pesticide applicationBMP for groundwater protecton from pesticides.* AE-1113. Fargo, North Dakota: North Dakota State University Extension Service. Available: http://www.ext.nodak.edu/extpubs/h2oqual/watgrnd/ae1113w.htm.

Smajstrla, A.G., and B.J. Boman. April 2000. *Flushing procedures for microirrigation systems.* Bulletin 333. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/WI013.

Staples, A.J. 2. Golf Course Energy Use Part 2: Pump Stations. Golf Course Management, July 2009.

https://www.gcsaa.org/Uploadedfiles/Environment/Resources/Energy-Conservation/Golf-course-energy-use-Part-2-Pump-stations.pdf

Tennessee Department of Agriculture. Tennessee Handbook for Golf Course Environmental Management. Available: http://tennesseeturf.utk.edu/pdffiles/golfcourseenvironmgmt.pdf

Thostenson, A., C. Ogg, K. Schaefer, M. Wiesbrook, J. Stone, and D. Herzfeld. 2016. Laundering pesticide-contaminated work clothes. PS 1778. Fargo, ND. North Dakota State Univ. Cooperative Extension. https://www.ag.ndsu.edu/pubs/plantsci/pests/ps1778.pdf

Trautmann, N.M., K.S. Porter, and R.J. Wagenet. n.d. *Pesticides and groundwater: A guide for the pesticide user.* Fact Sheet. Ithaca, New York: Cornell Cooperative Extension. Available: http://psep.cce.cornell.edu/facts-slides-self/facts/pest-gr-gud-grw89.aspx

University of Florida—Institute of Food and Agricultural Sciences. Center for Aquatic and Invasive Plants Web site. Available: http://plants.ifas.ufl.edu/.

———. Insect Identification Service Web site. Available: http://edis.ifas.ufl.edu/SR010.

———. Nematode Assay Laboratory Web site. Available: http://edis.ifas.ufl.edu/SR011.

———. Pesticide Information Office Web site. Available: http://pested.ifas.ufl.edu/

———. Plant Disease Clinic Web site. Available: http://plantpath.ifas.ufl.edu/extension/plant-diagnostic-center/

———. Rapid Turfgrass Diagnostic Service Web site. Available: http://turfpath.ifas.ufl.edu/rapiddiag.shtml.

Unruh, J.B. November 1993. *Pesticide calibration formulas and information.* Fact Sheet ENH-90. Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://edis.ifas.ufl.edu/WG067.

Unruh, J.B. 2006. *2006 University of Florida's pest control guide for turfgrass managers.* Gainesville, Florida: Institute of Food and Agricultural Sciences, University of Florida. Available: http://turf.ufl.edu.

Unruh, J.B., and B.J. Brecke. Revised January 1998. *Response of turfgrass and turfgrass weeds to herbicides.* ENH-100. Gainesville, Florida: Department of Environmental Horticulture, University of Florida. Available: http://edis.ifas.ufl.edu/WG071.

Unruh, J.B., and M. Elliot. 1999. *Best management practices for Florida golf courses,* 2nd ed. UF–IFAS Publication SP-141. Gainesville, Florida.

Unruh, J.B., J.L. Cisar, and G.L. Miller. 1999. Mowing. In: J.B. Unruh and M.L. Elliot (Eds.). *Best management practices for Florida golf courses,* 2nd ed. Gainesville, Florida: University of Florida Institute of Food and Agricultural Sciences.

Unruh, J.B., A.E. Dudeck, J.L. Cisar, and G.L. Miller. 1999. Turfgrass cultivation practices. In: J.B. Unruh and M.L. Elliot (Eds.). *Best management practices for Florida golf courses,* 2nd ed. Gainesville, Florida: University of Florida Institute of Food and Agricultural Sciences.

U.S. Environmental Protection Agency. 2005. *GreenScapes: Environmentally beneficial landscaping*; Washington, D.C. Office of Solid Waste and Emergency Response. Available: https://archive.epa.gov/greenbuilding/web/pdf/brochure.pdf

United States Golf Association. 2004. *Recommendations for a method of putting green construction.* Available: http://www.usga.org/content/dam/usga/images/course-care/2004%20USGA%20Recommendations%20For%20a%20Method%20of%20Putting%20Green%20Cons.pdf.

van Es., H.M. October 1990. *Pesticide management for water quality: Principles and practices.* October 1990. Ithaca, New York: Cornell Cooperative Extension. Available: http://psep.cce.cornell.edu/facts-slides-self/facts/pestmgt-water-qual-90.aspx.

Virginia Golf Course Superintendents Association. 2012. Environmental Best Management Practices for Virginia's Golf Courses. https://pubs.ext.vt.edu/ANR/ANR-48/ANR-48_pdf.pdf

White, C.B. 2000. Turfgrass manager's handbook for golf course construction, renovation, and grow-in. Sleeping Bear Press. Chelsea, MI.

Witt, J.M. n.d. *Agricultural spray adjuvants.* Ithaca, New York: Cornell Cooperative Extension. Available: http://pmep.cce.cornell.edu/facts-slides-self/facts/gen-peapp-adjuvants.html.

Yergert, M.B. Austin, and R. Waskom. June 1993. *Best management practices for turfgrass production.* Turf BMP Fact Sheet. Colorado Department of Agriculture. Agricultural Chemicals and Groundwater Protection Program. Available: http://hermes.cde.state.co.us/drupal/islandora/object/co%3A3063/datastream/OBJ/download/Best_management_practices_for_turfgrass_production.pdf.