

BEST MANAGEMENT PRACTICES FOR THE SPORTS FIELD MANAGER: A PROFESSIONAL GUIDE FOR ENVIRONMENTAL SPORTS FIELD MANAGEMENT

SportsTurf
MANAGERS ASSOCIATION



BEST MANAGEMENT PRACTICES FOR THE SPORTS FIELD MANAGER: *A PROFESSIONAL GUIDE FOR ENVIRONMENTAL SPORTS FIELD MANAGEMENT*

April 2021



**STMA advances professionalism in sports field management and safety
through education, awareness programs, and industry development**

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Sports Turf Managers Association (STMA)

STMA is the non-profit, professional association for the men and women who manage outdoor sports fields worldwide. Since 1981, we have been providing education and practical knowledge in the art and science of sports field management. The single goal of our more than 2,700 members is to manage sports field playing surfaces to the safest level possible.



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ACRONYMS

ASBA	American Sports Builders Association	lbs	pounds
AST	aboveground storage tank	LDS	localized dry spot
ASTM	American Society for Testing and Materials	LEED	Leadership in Energy and Environmental Design
BMPs	best management practices	N	nitrogen
CaCO ₂	calcium carbonate	NTEP	National Turfgrass Evaluation Program
CFB	Certified Field Builder	OM	organic matter
CSFM	Certified Sports Field Manager	OMRI	Organic Materials Review Institute
DU	distribution uniformity	OSHA	Occupational Safety and Health Administration
EPA	United States Environmental Protection Agency	P	phosphorus
ET	evapotranspiration	PCI	playing conditions index
FIFRA	Federal Insecticide, Fungicide, and Rodenticide Act	PGR	plant growth regulator
ft ²	square feet	PPE	personal protective equipment
GDD	growing degree days	ppm	parts per million
GI	green infrastructure	QA/QC	quality assurance/quality control
HIC	head injury criterium	STC	Synthetic Turf Council
HOC	height of cut	STMA	Sports Turf Managers Association
IPM	integrated pest management	TMDL	Total Maximum Daily Load
		UST	underground storage tank

1 INTRODUCTION

Whether watching a children’s soccer game at a community park, a lacrosse match at the local high school, or a professional football game at a stadium, the quality of the playing surface is typically only noticed if it is not adequate or safe. Providing a safe, playable, and aesthetically pleasing natural grass field requires intensive effort on the part of a dedicated sports field manager. Turfgrass management is unique in that turfgrass plants routinely take a lot of abuse from the wear and tear that sports exact on a live playing surface. Athletes need a firm surface to run, turn, and stop quickly, but the surface also has to be soft enough to absorb impacts. Furthermore, sports field management must take into consideration a number of different sports played at all levels, from municipal recreational fields all the way to professional sports fields.

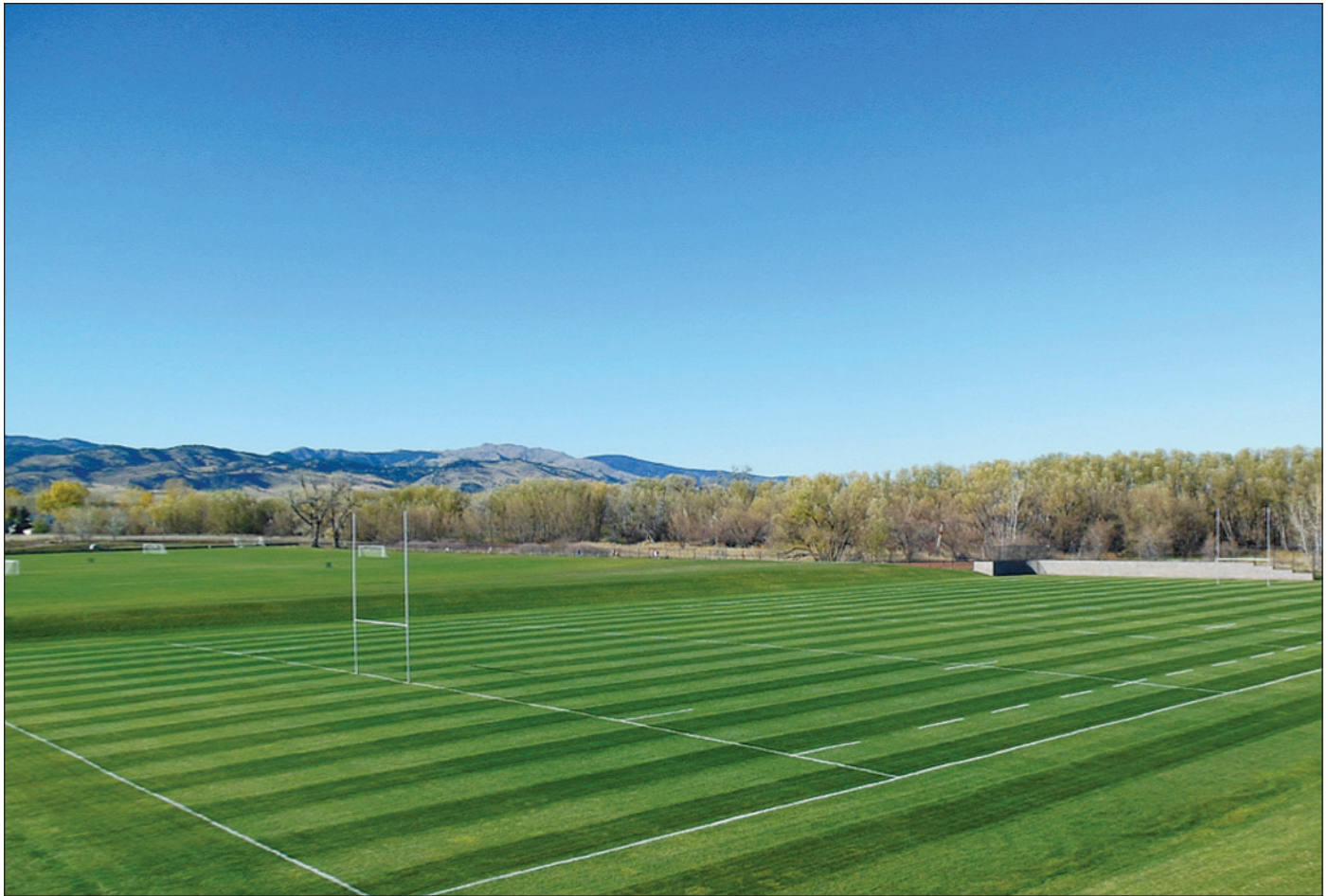
The Sports Turf Managers Association (STMA) has developed *Best Management Practices for the Sports Field Manager: A Professional Guide for Environmental Sports Field Management* with the help of subject matter experts

including sports field manager professionals, leading turfgrass faculty and research scientists, and industry representatives. The best management practices (BMPs) provide guidance to sports field managers with respect to the latest scientific information on environmental sustainability efforts. This guide was developed as a nationwide template that can be adapted to each region of the country to include specific agronomic BMPs and regulatory information.

This document also provides the justification for allocating resources to the professional management of sports fields. It is well established that managed turfgrass, particularly in urban settings, offers many socioeconomic and environmental benefits, well beyond recreation. For example, the World Health Organization suggests that the availability, accessibility, quality, and security of public green spaces in urban areas is an indicator of a healthy city. Turfgrass and associated greenspace also enhance the creative, intellectual, and cognitive skills of children (Brosnan et al., 2020).



Open Space Park, Credit: STMA



Pleasantview Championship Field, Credit: STMA

Sports Field Management

The art and science of sports field management and the long hours of work during playing seasons demonstrate the dedication that sports field managers must have to ensure that sports fields meet safety and playability demands. In addition, sports field managers must take into consideration the sustainability of natural resources. By implementing the BMPs described in this document, sports field managers are utilizing the most effective and practical methods and techniques of protecting the environment. Essentially, BMPs provide a sustainable approach to offering environmental, economic, and social benefits to athletes and the community.

To assist sports field managers, the non-profit organization STMA provides education, information and practical knowledge in the art and science of sports field management. The STMA is comprised of more than 2,700 members across 32 local chapters who oversee facilities at schools, colleges and universities, parks and recreational facilities, and professional sports stadiums. Playing surfaces/fields cared for by sports field professionals include football, baseball, softball, soccer,

lacrosse, rugby, field hockey, and tennis. Continuing education is available for sports field managers to stay abreast of these advancements by taking advantage of educational opportunities, such as STMA conferences and involvement in STMA chapter activities.

Certification for experienced sports field managers is available through STMA. The Certified Sports Field Manager (CSFM) professional designation is achieved through a thorough understanding of all aspects of managing sports fields and draws upon all aspects of a manager's education and experience in the field in order to pass the certification test. After certification, continuing education credits are necessary to retain certification. The CSFM designation recognizes the knowledge, skills, and abilities of sports field managers and identifies them as leaders in the industry.

Best Management Practices

Incorporating BMPs requires dedication, experience, and education of sports field managers. The varied areas that require the attention of a sports field manager include, but are not limited to, the following diverse responsibilities:

- Designing and constructing new and/or renovated sports fields.
- Creating a nutrient management plan to apply only the necessary nutrients where and when needed.
- Utilizing cultural practices including irrigation, mowing, cultivation, etc. to grow the healthiest turfgrass possible, even under the stress of athletic wear and tear and seasonal stress.
- Implementing an integrated pest management (IPM) approach to control diseases, insects, and weeds that would otherwise impair the sports field.

The emphasis in this guide to sports field management BMPs is on the protection and conservation of water resources. These BMPs form an integrated water quality protection system, based on a tiered concept: prevention (preventing problems from occurring), control (putting safeguards in place to control and mitigate potential problems), and detection (using a monitoring program to detect changes in environmental quality). These strategies for minimizing potential risk can be achieved through the successful implementation of these BMPs. Additional benefits of incorporating BMPs include:

- Recognition by regulators, athletes, parents, and the community at large of sports field managers as environmental stewards.
- Cost savings associated with more efficient irrigation and other water conservation efforts.
- Environmental and cost benefits associated with a reduction in product inputs such as fertilizer and pesticides.
- Care practices that support improved soil health.

Water Conservation

Water is a fundamental element for physiological processes in turfgrass such as photosynthesis, transpiration, and cooling, as well as for the diffusion and transport of nutrients. Turfgrass quality and performance depend on an adequate supply of water through either precipitation or supplemental irrigation. Too little water induces drought stress and weakens the plant, which decreases resilience to wear from athletes. Too much water causes saturated playing surfaces and compacted soils, often leading to anaerobic conditions that stunt plant growth and promote disease. Excessive water can also lead to runoff or leaching of nutrients and pesticides into groundwater and surface water.



Christopher Newport University, Credit: STMA

Many BMPs in this document focus on water conservation. Proper irrigation scheduling, careful selection of turfgrass species, and incorporation of cultural practices that increase the water holding capacity of soil are addressed through these BMPs. In addition, considerations in the design, construction, and maintenance of natural grass fields and synthetic turf fields are also discussed that help to conserve water resources.

Integrated Pest Management

Turfgrass used on sports fields is expected to provide dense, uniform, and safe playing surfaces all season long. However, when natural grass faces excessive stress from wear or environmental conditions such as heat or drought, pest pressures can become a serious problem. Sports field managers can implement comprehensive and effective approaches to pest management, termed IPM programs. An IPM approach considers all strategies to reduce pest damage to manageable and acceptable levels in the most economical means, while simultaneously considering potential impacts on humans, property, and the environment. In sports field management, these programs involve various agronomic practices, as well as the option to consider the use of chemical applications in situations when other means have been exhausted or deemed ineffective.

Where allowed, pesticide use can be incorporated into an overall IPM strategy that also includes non-chemical control methods such as biological controls, cultural methods, or pest monitoring. The judicious use of pesticides, when needed, helps to control diseases, insects, and weeds that can compromise the quality and safety of the playing surface. The safe and effective use, storage, and handling of pesticides is highly regulated, which helps to ensure that their relative risk is largely mitigated. Licensed professional applicators are subject to a certification process and must be regularly recertified, further ensuring the safety of pesticide applications.

Assessment Tools

Assessments in sport field management can help determine whether the goals of the management program are successfully being met, can affect decisions about turfgrass management that have budgetary implications, and can often answer important questions regarding the safety of playing surfaces. Examples of assessment tools that turfgrass professionals currently use are soil tests, STMA's Playing Conditions Index (PCI), and field assessments such as those from University of Connecticut, Cornell University, and The Ohio State University.

Field assessments are used to analyze and review all management practices that influence field condition and performance. Field assessments should be conducted before, during, and after each season. Writing detailed observations, keeping maintenance records, documenting use and taking photos help to inform the assessment. This data can be used to set priorities for management efforts and to communicate the needed resources to decision-makers.

In addition to field assessments, an [Environmental Facility Certification](#) provided through STMA confirms that environmental best practices are implemented throughout the facility in 10 areas of management.

The PCI is an in-depth assessment of the playability of sports fields. It addresses the complexities involved in conditioning sports fields for safety, playability, and fan enjoyment. Information from the PCI can be shared with administrators, coaches, and athletic directors and provides a basis for joint decision-making regarding play. More information and PCI worksheets for both natural grass and synthetic turf fields are available on the [STMA](#) website.

Landscaped Areas

While care of sports fields will always be the highest priority for sports field managers, native areas may also be an important component of sports field managers' responsibilities. Landscaped and natural areas, such as trails, may provide additional recreational opportunities, wildlife habitat, and natural buffers that help delineate field or property boundaries and moderate external noise. While these areas serve to enhance the quality of life for recreation enthusiasts and spectators, they can also provide habitat for pollinators—a recent focus of numerous conservation efforts. Developing or expanding naturalized areas may also reduce dependence on water, chemical, and fuel inputs, while allowing more intensive maintenance to be reserved for areas dedicated to sports.

Synthetic Turf Fields

Some facilities utilize synthetic turf fields to allow time for natural grass fields to rest and recuperate from constant, relentless activity. This can be especially helpful during times of the year when turfgrass is dormant or growth is slow or when weather and field conditions are not favorable. When synthetic turf fields are desired, they must be installed by experienced professionals specializing in synthetic turf field construction. It is highly



Signs in landscaped areas can communicate important information. *Credit: B. Polimer.*

recommended that the contractor be certified through the [American Sports Builders Association \(ASBA\)](#) as a Certified Field Builder (CFB). In addition, such fields must be maintained strictly in accordance with the product warranty to avoid invalidating it. While most of this document covers BMPs with respect to natural grass fields, the Synthetic Turf chapter discusses issues specifically related to synthetic turf fields.

Communication

As the point of contact for all communication and decision-making regarding turfgrass management, the sports field manager must consider communication an integral component of the job. Sports field managers must walk the fields regularly with coaches, administrators, or municipal officials to identify areas that need immediate attention for safety reasons and playability. In addition, communicating field assessment information is important to help explain the resources needed to maintain safe, playable fields.

Besides communicating with officials and decision-makers, communicating with various constituent groups—parents, coaches, and players—helps each to understand the balancing act required to grow natural grass that is both playable and safe. Developing a communication strategy about field use and playing conditions through

in-person, online and social media options can also help communication efforts.

Signs in landscaped or native areas can also communicate important information such as marked sections that should not be entered. Educational signs can be posted in environmental areas such as wetlands, rain gardens, and pollinator gardens to promote their importance to the public.

Education

Sports field managers are professionals in a field that continually evolves due to scientific research and technological advancements. Continuing education is available for sports field managers to stay abreast of these advancements by taking advantage of educational opportunities, such as chapter field days, STMA conferences, STMA outreach documents, and involvement in STMA chapters.

Region-specific support, information, and education are also available to sports field managers. University Extension specialists can provide a wealth of information and guidance on agronomic conditions, best-adapted turfgrass, pests, and other issues of regional importance. STMA chapters are another great source of region-specific information by offering field days and networking

opportunities. Sports field managers are encouraged to join their local chapter to access these resources.

How to Use This Document

This document offers a national template for state and regional STMA chapters to develop their own customized BMP documents to provide relevant regulatory and agronomic information. These state/regional documents can be used to provide information to a variety of stakeholders, including sports field managers, decision-makers such as athletic directors, facility managers, and municipal managers, regulatory agencies, municipal committees, parent organizations, and the interested public. Individual sports field managers can adapt state/regional BMPs to their facility.

The information presented here represents the latest science, current management techniques, and regulatory information related to BMPs. However, as with any

Each section of this document covers a sports field management topic related to natural grass management and a separate chapter on the management of synthetic turf. Within each section, the pertinent detailed information is discussed and BMPs provided at the end.

discipline, new information, scientific advancements, and technological innovations become available over time and continue to advance sports field management. Therefore, it is envisioned that these BMPs will be periodically reviewed and updated as needed. Sports field professionals are encouraged to remain current with the latest turfgrass research by communicating with Extension faculty in their area, interacting with the STMA and STMA chapters, and utilizing opportunities for education and certification.

2 PLANNING, DESIGN, AND CONSTRUCTION

Any new development requires careful consideration of the health of the ecosystem during planning, design, and construction. The thoughtful use of BMPs during planning, design, and construction results in an environmentally sustainable facility that operates efficiently. Additional BMPs that must be considered during this phase include many of the topics addressed in the rest of this document, such as turfgrass selection, nutrition, irrigation, and stormwater management.

Sports fields should be planned, designed, and constructed specifically for the sport to be played in order to meet the specifications for that sport. Each sports field has standard dimensions, contours, and drainage specifications that aid in the rapid shedding of stormwater.

If possible, orient fields to minimize the time that players must look directly into the sun during games. Generally, the long axis of the rectangular field should be in a north-south direction. This also minimizes the field area shaded during the winter months if there are trees along the south side of the field. Rule books for baseball and softball fields recommend orientating the field so that center field from home plate to the outfield fence is in an east-northeast direction. In addition to orientation, a good design provides an adequate irrigation and drainage system, as well as grade plan.

2.1 Planning and Design

While many issues must be addressed during the planning and design phases, a number of considerations have significant impacts on the overall sustainability and functionality of the final sports field performance.

2.1.1 Project Team Critical Roles

The planning and design phase of sports field construction involves numerous personnel and should include the sports field manager whenever possible. In order to ensure that new sports fields are planned and constructed properly, a sports field architect and a CFB are critical to avoid expensive failures. These critical roles should be filled as soon as possible, and these experts should be involved in all phases of planning, design, and construction.

2.1.2 Site Assessment

The team planning any new field installation must consider many factors, including how the proposed site and the project will be impacted by site characteristics, such as:

- Existing soil composition
- Existing drainage patterns
- Existing infrastructure and slope surveys
- Site surroundings/surveys
- Pre-mapped drainage systems, including any existing municipal sewer systems
- Proposed drainage system
- The type of stone used in the base system
- The planarity of subgrade soils
- The planarity of the stone base

As part of the site assessment, any review of natural or historical resources (e.g., wetlands surveys, listed species review, archaeological review) needs to be conducted, as required by state regulations or local ordinances.

2.1.3 Soil Profile Selection

One of the first decisions made during the planning process is the selection of the type of soil profile: native soil, modified native soil, or sand-based soil. Each has pros and cons, which must be evaluated before a final decision is made.

2.1.4 Maintenance Considerations

The maintenance of natural grass sports fields must be reviewed prior to construction as the resources needed to maintain a field are significant. All newly constructed fields must have a detailed maintenance plan that encompasses utilizing a sports field manager to ensure the investment is cared for properly. Care involves ensuring proper agronomic practices are followed and the field is protected from pest damage. Maintenance includes proper mowing, fertilization, irrigation, cultivation and topdressing, and mitigation of mechanical, environmental, and pest-related turfgrass stress. Field usage also influences turfgrass maintenance. For example, heavily used fields typically require more inputs to maintain turfgrass cover. Essential natural turfgrass maintenance practices are discussed in detail in the Cultural Practices chapter.

Once the planning and design phases are complete, construction must be carried out in a way that minimizes environmental impacts. Maintaining a construction progress report, as well as following regulations and coordinating with regulatory agencies as required, helps to ensure compliance.

2.2 Drainage

Within the field, efficiently ensuring that precipitation drains through the surface and subsurface is critical to maintaining playability. Water drains or exits a field through evaporation, surface runoff, internal root zone drainage, and eventually out of the root zone profile, preferably, through an underground drainage network.

2.2.1 Surface Drainage

Moving water the shortest distance possible over the playing surface is the best strategy for achieving adequate surface drainage. For rectangular fields constructed using fine textured, native soils, crowning is preferred over a simple slope from one side to another, with the crown constructed with a minimum 1.5% slope. Stakeholders involved in ball roll sports (e.g. soccer, field hockey) may be reluctant to accept aggressively pitched surfaces. Consultation with a certified builder, sports field manager, or university Extension agent can be used to determine the best design for the specific application. If native soil construction is employed and stakeholders are unable to accept crowned surfaces > 1.5% and/or inclusion of sand-slit drainage, expectations for field drainage should be lowered.

Generally, baseball and softball outfields are crowned toward the outfield fence or crowned through center field with runoff toward the sidelines. Infields only have 0.5% slope from the pitcher's plate to the bases. Skinned areas have variable slopes from 0.5% to 1.5%. The baseball pitcher's plate is 10" above home plate while the softball pitcher's plate is level with home plate.

2.2.2 Subsurface Drainage

Because native soil fields retain more water than other field systems, subsurface drain tiles within the playing may be installed. Properly installed tiles within the playing area maintain their function over time. Proper installation includes appropriate tile depths, spacing, and crowns, as well as the use of appropriate backfill materials. If not installed and maintained correctly, the system will not function properly. Proper function allows water to passively enter the tile and then move to its next collection point by gravity. Once installed, subsurface drainage systems require maintenance, such as cleaning of catch

basin structures. A university Extension agent should be consulted for assistance in subsurface drainage issues.

2.3 Stormwater Management

Stormwater management is the control and use of runoff and includes planning for runoff, maintaining stormwater systems, and regulating the collection, storage, and movement of stormwater. The sports field manager and administration must be aware of the principles of water management and integrate them into the design and construction that influence surface and subsurface drainage both on and off the field. Additional stormwater control measures can be incorporated throughout the facility to manage stormwater runoff.

By ensuring the involvement of the sports field manager in all efforts related to water management, time, effort, and often costs can be saved by incorporating the proper structures and landscape features that assist in drainage and stormwater management. In addition, these efforts increase the sustainability of the entire facility by effectively slowing down stormwater, allowing the opportunity for infiltration to effectively remove any contaminants, and conserving water through water reuse for irrigation or for greywater purposes.

Runoff, or the movement of water across the land surface from either precipitation or irrigation that does not infiltrate into the ground, is the conveying force behind nonpoint source pollution. Stormwater management refers to runoff from precipitation, but the principles can also apply to irrigation runoff as well. Off the field, stormwater should be managed to ensure that it does not contribute to nonpoint source pollution of water resources. BMPs should be used to reduce stormwater volume, peak flow, and nonpoint source pollution by promoting infiltration, retention, and filtering. BMPs help achieve such goals by:

- Keeping stormwater close to where it falls.
- Slowing down stormwater runoff.
- Allowing stormwater to infiltrate into the soil.

2.3.1 Source Controls

Source controls help prevent the generation of stormwater runoff or the introduction of pollutants into stormwater runoff. For example, during construction or redesign activities, strict adherence to erosion and sedimentation

controls helps to prevent, or at least minimize, the possibility for sediment, nutrients, and chemicals to impact water quality through runoff. After construction, implementation of BMPs can reduce the potential for off-site movement of nutrients and pesticides.

2.3.2 Structural Controls

Structural controls are design and engineering features used both in construction and as part of ongoing management practices that help to remove, filter, retain, or reroute potential contaminants (e.g., sediments, nutrients, and chemicals) carried in surface runoff. The controls may also be combined to increase the treatment of stormwater. For example, sediment forebays can be used to pretreat stormwater before it is discharged to a dry extended detention basin, wet basin, constructed stormwater wetland, or infiltration basin. Periodic inspection and maintenance of all structural controls are essential to ensure they function as designed. Maintenance includes periodic cleaning of small basins, ponds, and forebays to remove sediments.

Erosion and Sediment Controls: Through the process of erosion, particles of sand, silt, and clay, can be transported off-site by flowing water and blowing winds. Sedimentation occurs when eroded material settles out of the water column, degrading water quality by increasing turbidity, harming aquatic plants, and impairing habitat for aquatic organisms. In addition, soil contaminants may be transported with eroding soil. During construction, erosion and sediment control measures must be inspected regularly to ensure that they are functioning as designed.

Erosion and sediment control plans are a regulatory requirement at the state level. Additional regional or local regulations may also exist, such as mandated buffer distances.

2.3.3 Non-Structural Controls

Non-structural controls often mimic natural hydrology (e.g., constructed wetlands), hold stormwater, and filter stormwater via vegetative practices (e.g., filter strips and grassed swales). Turfgrass areas are extremely effective in reducing soil losses compared with other cropping systems, due to the architecture of the turfgrass canopy, the fibrous root system, and the development of a vast macropore soil structural system that encourages infiltration rather than runoff. Additionally, turfgrass density, leaf texture, rooting strength, and canopy height physically restrain soil erosion

and sediment loss by dissipating impact energy from rain and irrigation water droplets.

Buffers: Buffers around the shore of surface waters, wetlands, or other sensitive areas filter runoff as it passes across the ground. Buffers are the last line of defense to minimize sediment and solute (mostly fertilizer and pesticide) contamination of waterways. These are relatively more important in areas with high precipitation.

Depending upon site-specific conditions, including the amount of available space, a range of buffer widths can be considered. Buffer widths as narrow as 10 feet have been shown to be effective. In most cases, a wide buffer is needed to effectively protect aquatic resources. Smaller buffers still afford some level of protection to the surface waters and are preferable to no buffer at all. Protection of the biological components of wetlands and streams typically requires significantly greater buffer widths.

For vegetated buffer zones, ornamental grasses, wetland plants, or emergent vegetation around the perimeter and edges of surface waters serve as a buffer and wildlife habitat for many aquatic organisms and can be aesthetically pleasing. Use native plants for these plantings whenever possible. See the Sustainable Landscaping chapter for more guidance on plant selection and the benefits of utilizing native plants.

Riparian buffers along streams and rivers can be up to three different plant assemblages, progressing from sedges and rushes along the water's edge to upland species. Riparian buffers of sufficient width intercept sediment, nutrients, and chemicals in surface runoff and reduce nutrients and other contaminants in shallow sub-surface water flow. Woody vegetation in buffers provides food and cover for wildlife, stabilizes stream banks, and slows out-of-bank flood flows.

Wetlands and Floodplains: Wetlands are transitional areas between aquatic and dry upland habitats. They are flooded or saturated by surface or groundwater at a frequency and duration long enough during the growing season to support plants and other life adapted to saturated soils where oxygen is limited and unique chemical properties form. Riparian habitats include the dense and diverse vegetation growing along streams, rivers, springs, wetlands, ponds, and lakes. They often support plants adapted to highly fluctuating water availability (from spring flooding to summer drought). In addition, wetland and riparian habitats are essential for many fish, wildlife,

invertebrate, and plant species. Nearly half of bird species rely on wetland and riparian habitats, as well as numerous other game, fish, and other wildlife species.

Conserving any wetlands and riparian areas within the facility boundaries protects water quality and biodiversity, while reducing the potential for flooding and soil erosion. To protect these natural resources, wetlands should be identified in the field by qualified wetland specialists during the design phase and before the permitting process is initiated. Facility design should minimize any impact to wetlands and streams tied to activities such as filling, dredging, flooding, or converting areas from one habitat type to another. In addition, natural buffers should be retained around wetlands (as with other waterbodies) to protect water quality.

2.3.4 Green Infrastructure

In and around the buildings, parking areas, and other structures, opportunities should be identified to slow down the movement of water from impervious surfaces (i.e., paved areas) and allow for infiltration. Green Infrastructure (GI) features can be used as an effective and economical way to improve the safety and quality of life (EPA, 2017) through the intentional use of the ecosystem services provided by plants in the managed landscape. Green roofs, rain gardens, bioswales, cisterns, and permeable pavements are examples of GI landscaping. In using these kinds of stormwater control methods, the natural drainage patterns should be utilized and runoff should be channeled away from impervious surfaces.

Green Infrastructure conserves, restores, or replicates the natural water cycle by reducing and treating stormwater runoff, thus turning a potential pollutant into an environmental and economic benefit.

Green Roofs: A green roof is a building roof partially or completely covered with vegetation and a growing medium, planted over a waterproofing membrane. It may also include additional layers such as a root barrier or drainage and irrigation systems. Green roofs can reduce stormwater runoff, help regulate a building's internal temperature, and mitigate the urban heat island effect. Green roofs can catch 40-60% of stormwater, reducing flow into a city's sewers (EPA, 2008) and can reduce approximately 65% of peak flows and 55% of runoff volumes (Jaffe et al., 2010). Green roofs can also offer significant economic benefits, including a longer roof

life and heating and cooling energy savings. Green roofs require special engineering and should be designed and constructed by certified professionals.

Rain Gardens: A rain garden is a small, shallow area designed to temporarily capture rainwater that drains from a roof, parking lot, or other open area. A rain garden is not a pond, water garden, or wetland. It is dry most of the time and briefly holds water after a rain. Rain gardens typically are planted with a mixture of deep-rooted perennial flowers, ornamental grasses, and woody shrubs that are adapted to wet and dry conditions. There are a variety of specialists (such as Extension agents and horticultural professionals) who can provide guidance on plant selection appropriate for rain gardens. See the Sustainable Landscaping chapter for more information on plant selection.

Installing rain gardens in locations where they catch and temporarily hold water helps control stormwater runoff, remove contaminants before releasing water into the surrounding soil or aquifer, and conserve water by reducing supplemental irrigation needs. Water collected in the rain garden slowly infiltrates into the soil to support plant growth and to lessen runoff into storm drains and nearby streams or lakes. In a properly sited and constructed rain garden, standing water disappears within 24 to 48 hours.

Bioswales: Bioswales are stormwater conveyance systems that provide an alternative to storm sewers and can absorb low flows or carry runoff from heavy rains to storm sewer inlets. Bioswales concentrate and convey stormwater runoff while removing debris, sediments, nutrients, etc. They improve water quality by infiltrating the first flush of stormwater runoff and filtering the large storm flows they convey. They are typically vegetated, mulched, or xeriscaped.

Cisterns: Cisterns are receptacles for holding precipitation, such as runoff from rooftop downspouts and gutters. They can range in capacity from a few gallons to thousands of cubic yards in storage tanks placed either above or below ground. The stored water can then be used in non-potable manners such as landscape irrigation, rinsing gardening tools or washing equipment. By storing water, cisterns reduce the amount of stormwater runoff to streams and storm sewers, particularly for small storms. A filter is used to remove any debris from the runoff before entering the cistern. A gutter guard can also be used to reduce the leaves, dust and debris that may enter the cistern.

Permeable Pavements: Maximizing the use of pervious pavements, such as brick or concrete pavers separated by sand and planted with grass or porous asphalt, allows stormwater

to infiltrate into the soil as opposed to running off. Crushed stone and other permeable products are available for walking paths or parking lots. Mowable drives and walks can be used by adding a rigid lattice designed for distributing traffic yet allowing grass to grow through the lattice.

2.4 Field Design and Construction

The majority of sports fields constructed today in high schools, clubs, and smaller communities are native soil fields because they typically cost less to construct and are considered to be easier to maintain. The type of existing soil is an important consideration in the design of a new sports field. For example, soils high in clay and/or silt hold adequate nutrients (as compared to sandier soils) resulting in relatively simple fertilization programs. Soils high in clay and/or silt also have high water holding capacity compared with sandy soils. Soil testing should be conducted during the design phase to understand the soil structure of the native soil.

2.4.1 Native Soil Fields

Native soil fields use existing soils very often comprised of silt and clay and depend primarily on surface drainage to remove excess water. Native soil fields hold adequate nutrients, have a high water-holding capacity, are stable, have good shear strength, and provide good traction. However, most native soil fields provide inadequate internal drainage, compact easily, and are prone to surface rutting and puddling. In addition, native soil fields may become saturated during periods of heavy rain leading to

compaction and turfgrass damage. Properly crowned native soil fields are important to mitigate these conditions.

Sand slit drainage systems can also be used to improve the drainage capability of an existing natural turfgrass field. The sand slit drainage system is a means by which the drainage of a natural turfgrass field can be improved without requiring a major reconstruction.

2.4.2 Modified Native Soil Fields

Modified native soil fields have had a coarse physical amendment, such as sand, mixed uniformly with the existing soil to significantly improve drainage performance. The cost of modified native fields can be high, especially if the physical amendment must be custom screened. However, this increased cost is compensated, in part, by improved playing conditions. Modified native soil fields have better internal drainage and are less susceptible to compaction versus unmodified native soils. However, drainage may still be limited, irrigation is needed, and fertilization needs are greater than on native soil fields. Furthermore, proper construction with respect to achieving an appropriate ratio of native soil to sand is an important factor. Physical testing of native soil to sand ratios in the modified native soil should be performed by a reputable soils laboratory to avoid costly mistakes and a field that does not meet performance specifications. Hire a reputable soils laboratory to test soil mixtures for any type of soil modifications.



Sand-slit drainage system installation. Credit: B. Polimer.

The particle size range of the coarse physical amendment is important though it may be difficult to obtain the desired size range without paying a premium for specially screened material. Also, it is essential to obtain a uniform mixture of the soil and physical amendment, which can be very difficult to impossible to achieve if mixing on-site instead of off-site.

Like native soil fields, modified native soil fields require surface drainage. Surface drainage should be an even and consistent crown/grade. Modified native soil fields may benefit from subsurface drainage. When installed, subsurface drainage should be installed under the modified native soil using the same type of drainage as described for sand-based fields.

2.4.3 Sand-Capped Fields

The construction method used for sand-capped fields is the same as for modified native soil fields. Sand-capped fields include a “cap” of a 3” to 6” pure sand layer over the native soil that is added during the construction process and not mixed into the subgrade. The depth of the sand layer should be evaluated by a physical testing laboratory with regards to its particle size and the anticipated amounts of rainfall (with more precipitation requiring greater sand depths). If the subgrade is compacted during construction, drainage may still be inadequate, leading to saturated fields and thinned turfgrass. Deep tillage (4” to 8”) of the subgrade prior to adding the sand cap can help to avoid this potential problem. Subsurface drainage can help to remove excessive water on sand-capped fields.

2.4.4 Sand-Based Fields

Sand-based fields are generally used for, but not exclusive to, professional or high-profile college sports. These fields require intensive management. They contain a high percentage of sand (>90%) as well as a percentage of organic matter and/or soil, as recommended by a certified independent soil laboratory. All proposed materials should be tested by a reliable laboratory in developing final mixing percentages for a soil that meets performance expectations.

Construction of sand-based fields should follow ASTM F-2396 Standard Guide for Construction of High Performance Sand-Based Rootzones for Sports Fields.

Although quite expensive initially, sand-based fields offer several advantages over native or modified native soil fields. If the proper sand size is used, these fields will have

excellent internal drainage and a lower percent of crown can be used for surface runoff (0.5% to 0.75%). Also, soil compaction is lower. As with modified native soil fields, the sand particle size range is extremely important. It is difficult to obtain the desired size range without a custom blending of the sand and the organic matter.

Sand-based fields almost always contain internal drainage tiles within the playing area to direct and remove the water that rapidly percolates through the sand. Two types of drainage systems are in current use: the first, and more common, system is a root zone mix over a 4” layer of “pea” gravel (for a sand-based field, the size of “pea” gravel is typically between 1/8”-3/8” in diameter, depending on sand type), with 4” drain tiles embedded in the subsoil. The second drainage system deletes the 4” layer of “pea” gravel while retaining the root zone layer at the desired depth. The first system provides the best drainage, especially during heavy rains and allows for the flattest surface.

Establishing grass cover from seed in cool season areas is more difficult on sand than with a soil medium. However, seeding is recommended in preference to sodding when commercial turfgrass sod produced on sand is unavailable. The use of turfgrass sod grown on peat or native soil negates the infiltration advantage of the sand by creating a layer that impedes water infiltration and percolation.

Warm season turfgrasses, like bermudagrass, are commonly vegetatively established by sprigs (shredded stems) as many improved cultivars cannot be seeded. Like with seeding, sprigging requires very intensive irrigation scheduling and monitoring during establishment.

Sand-based fields have greater irrigation and fertility needs than native or modified native soil fields because the nutrient and water holding capacity of sand-based fields is minimal.

2.5 Baseball/Softball Field Planning, Design, and Construction

2.5.1 Infield Skinned Areas

The integrity and performance of infield skinned areas in baseball and softball competition is crucial to the quality of play in each of these sports. Sports field managers greatly influence the playability of skinned surfaces with game day grooming practices and the sufficient application of water to the infield soil surface as needed. To be in position to have a successful infield surface, some standard practices on material selection and installation need to be followed during construction or substantial renovations.



Red Bull Arena field construction. *Credit: Z. Holm.*

The percentage of sand, silt, and clay is a critical consideration during the planning phases. Mixes of all types should have a silt to clay ratio of 0.5 to 1. Fields with greater sand content are better suited for low maintenance situations. Higher silt and clay surfaces are more typical of professional or college fields with dedicated sports field managers providing daily grooming and watering. Choose an infield soil that can be managed according to the labor and budget of the facility. For example, a professional level infield mix is 60% sand, 18% silt, and 22% clay with a silt to clay ratio of 0.82. A lower maintenance level infield mix may have a blend of 72% sand, 12% silt, and 16% clay with a silt to clay ratio of 0.75. The professional mix holds up to heavy traffic better. Both mixes require use of a tarp in heavy rain on game days and consistent watering to keep surfaces from drying out and becoming too hard. Water should be consistently applied so that moisture infiltrates all the way through the soil profile to ensure that the ball rolls and reacts consistently.

When looking at material sizing tests for an infield mix, no particles should be greater than 3 millimeters. Five percent or fewer of particles must be retained in a sieve at 2 millimeters. Regarding sand size, the combined amount of sand retained on medium, coarse, and very coarse sieves should total a minimum of 65% of the total sand content. The delivered product should be free of rocks, stones, or

any particle greater than 3 millimeters. Weeds or weed seed contamination is unacceptable. Testing of the finished product for particle sizing is strongly recommended at least once during the installation process. A lab that conducts tests in accordance with ASTM F-1632 should be used.

Prior to installation of the new infield skin mix, the subgrade should be established and graded to match the slope of the finish grade. Flexibility with use of subgrade materials is possible, but at minimum it should be free of large rocks or excessive organic matter and should be clean enough to be laser graded to a tolerance of $\pm 0.25''$ in any direction.

It is critical that the slope of the subgrade match the slope of the finished grade. Drainage lines under the infield skin are not necessary. Proper surface drainage is all that is needed to remove water from



Application of infield mix. *Credit: Z. Holm.*

the skinned area. Irrigation lines should be avoided under infield skin areas.

A minimum of 4” of the imported infield mix must be installed consistently over the entire skin and baseline areas. As much as 6” of material is acceptable, as long as the depth of the product is consistent throughout the infield. Sufficient moisture should be present in the material to ensure proper compaction.

The new infield material should be installed in lifts, no more than 2” at a time. Each lift should be rough graded, rolled, and compacted. Then it should be scarified prior to the next layer being installed, to ensure bonding of the product. Sufficient moisture should be present in the material to ensure proper compaction. The range for the finish grade slope of skin areas is between 0.5% and 1.5%. A skinned area with a lower percentage of slope results in better playability. Flatter fields require a full-sized infield tarp. Laser grading of the finish grade must be a requirement of any construction specification. Finished infield skinned areas should be laser graded to a tolerance of + or — 0.25” in any direction.

The use of conditioners is strongly encouraged to aid in moisture retention and to improve playability of infields. Conditioners, applied at 0.25” in depth, should be the choice of the sports field manager. Three widely used and proven conditioners are calcined clay, vitrified clay, and expanded shale. Once an infield skinned area material is properly installed, moisture management of the product becomes the most vital aspect of day-to-day maintenance.

2.5.2 Pitcher’s Mound and Batter’s/ Catcher’s Box Areas

The construction of the pitcher’s mound, as well as of the batter’s and catcher’s box areas of home plate, requires a firmer material than the infield skinned area. These areas should consist of 6” in depth of the specified mound clay product (Table 1). Higher quantities of clay are recommended for collegiate or professional applications. The pitcher’s mound dimensions should be designed in accordance with the appropriate league’s specifications.

During installation of the clay product in these areas, the clay should be compacted in lifts of no more than 2” depth, then scarified to assure bonding prior to adding



Watering the infield pre-game. Credit: Z. Holm

Table 1. Mound clay (by volume)

Sand	30% or less
Clay	30% or more
Silt/Clay	0.75-1.25%

more material. Slightly more moisture in the base than the added material should be present so that the product bonds more consistently. These areas should be compacted using a manually operated small plate compactor. Detail finishing of areas around the pitching rubber can be done with an 8" square hand tamper. A minimum of 1.5 tons of material per cubic yard of installation is typically used during construction. For game conditions, topdressing materials should be applied at no more than 0.25" depth. Products for topdressing can be calcined clay, vitrified clay, or expanded shale. It is critical to always tarp these spots when not in use, always retain moisture, and prevent rain from saturating or eroding the areas.

2.5.3 Baseball Infield Stormwater Management

Infield soil should have been graded during construction so that stormwater runs off instead of forming puddles. Raking and dragging after every use assists in keeping the field safe for play and helps to maintain the proper grade. A rake should be used along the grass edges, to avoid dragging too closely, risking the infield mix forming a lip along the transition areas. The home plate and pitcher's area should also be repaired and compacted with fresh material free of conditioners or topdressings. Low spots should be filled with loose material and tamped into place to help maintain the grade and stop unsafe low spots and puddle potential. Always drag slowly to avoid unnecessary movement of infield material, and never drag with a truck, SUV, or automobile.

2.6 Water Quality Monitoring

While water quality monitoring is typically voluntary, monitoring results demonstrate a commitment to water quality and can serve as a source of litigation/penalty protection. In some locales, monitoring is required. Furthermore, providing monitoring information to local, regional, and state regulatory authorities and to watershed groups can help foster positive relationships with these stakeholders.

For new sports fields or renovation projects in the planning stage, baseline water quality levels should be measured prior to construction at points of entry and exit of flowing water sources on or surrounding the facility and on any

surface water. This information can be used to form a baseline of flow and nutrient/chemical levels. Ongoing, routine water sampling provides meaningful trends over time. Post-construction surface-water quality sampling should begin with the installation and maintenance of turfgrass and landscaping and should continue through the first three years of operation and then during the wet and dry seasons every third year thereafter, provided that all required water quality monitoring has been completed and all management plans continue to be implemented. A single sample is rarely meaningful in isolation. It may also be wise to sample if significant turfgrass management changes have been made, construction or renovation activities have taken place, or new landscape or green design features have been installed that capture stormwater.

2.6.1 Water Quality Sampling

The number of monitoring samples is highly variable and depends on the size, location, and number of water sources on or near the facility. The entry and exit points of water sources are logical sampling points. However, sampling and analysis of standing water sources (i.e., ponds), springs, and any other irrigation sources should also be included. Consult a water or soil scientist that specializes in water quality for assistance.

2.6.2 Water Quality Analysis

Testing protocols can be simplified to sample only those parameters that are directly influenced by the actual management of the sports field or recreational area, such as sampling of organic and inorganic levels of nitrogen and phosphorus or a screen for selected chemicals used as part of the management program. The fertilization recommendations in the Cultural Practices chapter should be followed. Additional analytes can include watershed basin-specific parameters of concern, such as sediments, suspended solids, and heavy metals. Dissolved oxygen, pH and alkalinity can be sampled in situ.

Samples should be analyzed by a qualified laboratory (in some locales certification of the laboratory is required), and all quality assurance/quality control procedures (QA/QC) must be followed. The purpose of QA/QC is to ensure that chemical, physical, biological, microbiological, and toxicological data are appropriate and reliable. If a sports field should ever need to produce data for an agency or for litigation to defend the facility and management practices of the sports field manager, the data must meet QA/QC standards to be defensible. For example, laboratory participation for soil and water analysis with the North

American Proficiency Testing program, administered by the Soil Science Society of America, is a means of assessing QA/QC. These reports can be requested from the laboratory to assure that they are capable of high quality soils analysis. Similar programs are available for drinking water analysis.

2.6.3 Interpreting Water Quality Results

Water quality can be analyzed by independent or university laboratories. Interpretation and use of water quality monitoring data depends to a large extent on the goal of the monitoring program. For example, the results may be analyzed to compare:

- Values over time.
- Values following implementation of BMPs, such as IPM measures.
- Monitoring points entering the site and leaving the site.

Results should also be interpreted and compared with the state's water quality standards, if standards have been established for the parameter being evaluated. Data analysis can also be used to identify issues that may require corrective action, such as an observable spike in nutrient levels. For example, an extreme weather event, an operator misapplication or some combination of factors may be responsible for a detectable change during the monitoring process. Water quality problems can sometimes be addressed by simple changes to a sports field's existing nutrient management program.

2.7 Planning, Design, and Construction Best Management Practices

Planning Best Management Practices

- Include a sports field manager during the planning phases of sports field construction projects.
- Consider the future maintenance budget as part of the planning process.
- Have a qualified wetland specialist identify wetlands during the design phase and before the permitting process is initiated.
- Minimize impacts to wetlands and streams associated with construction activities such as filling, dredging, flooding, or converting adjacent areas from one habitat type to another.
- Retain natural buffers around wetlands (as with other waterbodies) to protect water quality.

Drainage Best Management Practices

- Plan the crown of the field as appropriate for the sport.
- Surface drainage should be an even and consistent slope with a final surface grade tolerance of +/- 0.25" in 50 feet.
- If adding subsurface drainage, ensure that it is properly designed and installed.

Stormwater Management Best Management Practices

- Design stormwater control structures to hold stormwater for appropriate times to help remove total suspended solids.
- Use bioswales to slow and infiltrate water and trap pollutants in the soil, where they can be naturally broken down by soil organisms.
- Maintain healthy turfgrass or other vegetated cover adjacent to surface waters to slow sediment accretion and reduce runoff flow rates.
- Vary the width, height, and type of vegetation to meet the specific functions of the buffer and growing conditions at the specific location.
- Encourage clumps of native emergent vegetation at shorelines.
- Plant shrubs and trees away from edges of waterbodies so that leaves stay out of the water.
- When mowing near buffer areas, return clippings away from the water or collect them (such as for composting in a designated area) so that runoff does not carry turfgrass clippings or remnants of vegetation into water.
- Keep all chemical applications away from the water's edge when using rotary spreaders and/or boom sprayers, following label directions and applicable state or local requirements regarding distance or other requirements.
- When fertilizers or pesticides are needed in the buffer area, spot treat weeds or use drop spreaders or shielded rotary spreaders and boom sprayers to minimize the potential for direct deposit of chemicals into the water.
- Develop, enhance, restore, and protect wetland buffers. Manmade buffers should be designed to improve habitat diversity and include a mixture of fast and slow-growing native trees, shrubs, or grasses to provide a diverse habitat for wildlife.
- Encourage robust coastal and riparian vegetated buffers along the banks of wetlands, perimeters of ponds and other waterbodies, and undeveloped uplands.
- Do not fertilize riparian buffer areas below the high-water mark. Leave them in a natural state.

- Reduce the frequency of mowing at a waterbody edge. Take clippings to upland areas.
- Maximize the use of pervious pavements, such as brick or concrete pavers separated by sand and planted with turfgrass. (Special high-permeability concrete and asphalt products are available for walking paths or parking lots.)
- Minimize the direct connection of impervious area drainage to storm sewers to the extent practical.
- 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. In landscaped areas, use natural drainage patterns and directional site grading to channel runoff away from impervious surfaces onto planted areas such as grass swales, filter strips, or rain gardens.
- Install rain gardens in locations where they can catch and temporarily hold runoff.
- Incorporate other GI structures (e.g., cisterns, green roofs) when feasible.

Construction Best Management Practices

- Use a CFB to construct sports fields.
- Hire a reputable soil testing lab to test soil mixtures for any type of soil modifications.
- Achieve an appropriate ratio of native soil to sand for modified native soil field construction.
- Use a reputable soils laboratory to perform a particle soil analysis of native soil to sand ratios for modified native soil fields.
- Obtain the appropriate particle size range of the coarse physical amendment during construction of modified native soil fields and sand-based fields.
- Obtain a uniform mixture of the soil and physical amendment for modified native soil fields.
- For sand-capped fields, the depth of the sand layer should be evaluated with respect to anticipated amounts of rainfall, with more precipitation requiring greater sand depths.
- If the subgrade is compacted during construction of sand-capped fields, deep till (4" to 8") the subgrade prior to adding the sand cap.

- Ensure soil used for sod best matches the existing soil of the field.

Infield Skin Construction Best Management Practices

- Select an infield mix material suited to the level of play and maintenance evaluated by a physical testing laboratory with regards to particle size and anticipated amounts.
- Choose clean infield mix material from a reputable source and have it tested.
- Install a minimum of 4" depth of infield mixes over a clean, compacted subgrade. Import material no more than 2" at a time and compact with a roller. Finish infield with laser grading equipment.
- Ensure that moisture is consistent all the way through the soil profile and that the finish surface has appropriate firmness and moisture for playing conditions.

Mound and Batter's/Catcher's Boxes Best Management Practices

- Install mound and plate clay to a depth of 6", utilizing product with at least 30% clay content. Import in 2" lifts with manual plate compactor.
- Always ensure adequate moisture through the entire depth of mound and batter's/catcher's boxes.
- Repair to finish grade prior to competition.
- Use tarps as needed to prevent erosion.

Water Monitoring Best Management Practices

- Review existing sources of groundwater and surface water quality information.
- Develop a water quality monitoring program.
- Establish baseline quality levels for the different water sources used at the sports facility.
- Identify appropriate sampling locations and consistently sample appropriate amounts at the same locations pre-season, in-season and post-season.
- Visually monitor/assess any specific changes of surface waterbodies.
- Follow recommended sample collection and analytical procedures.
- Conduct seasonal water quality sampling. The recommendation is four times per year.

- Partner with other groups or volunteer water quality monitoring programs if possible, to share data and monitoring costs.
- Compare water quality monitoring results to benchmark quality standards.
- Use corrective measures when necessary.

3 TURFGRASS ESTABLISHMENT

3.1 Turfgrass Selection

Selection of turfgrass species and improved cultivars is one of the most important decisions a sports field manager can make to ensure a healthy turfgrass stand. Selecting the wrong species can contribute to poor density, poor playability, and alterations in nutrient and water inputs. Sports field managers should select turfgrass species and cultivars based on the existing site conditions, the intended maintenance, expected wear and the intended use of the turfgrass. Criteria include the selection of:

- Drought-tolerant species and cultivars where water is limited or not available.
- Wear- and compaction-tolerant species and cultivars for heavy play, high traffic areas, and recovery rate.
- Disease-tolerant and endophytic cultivars to reduce pest damage and pesticide use.
- Shade-tolerant species and cultivars for areas with limited or restricted light.

Turfgrass breeding programs have made tremendous advances in the development of improved turfgrass species

and cultivars. Within each turfgrass species, cultivars can now be selected for improved characteristics such as increased lateral growth and tillering that help provide denser playing surfaces, tolerance of a lower height of cut (HOC), increased stress tolerance to drought and wear, speed of recovery, and improved pest resistance, shade tolerance, and salinity tolerance. As a result, managers can select species or cultivars requiring less water and fertilizer inputs.

When considering natural grass options, managers can consult with Extension specialists who can provide guidance on turfgrass selection for sports fields (e.g., wear tolerance and recuperative potential). In addition, the [National Turfgrass Evaluation Program \(NTEP\)](#), the [Alliance for Low-Input Sustainable Turf](#), and the [Turfgrass Water Conservation Alliance](#) provide information on high performance cultivars for different regions of the country. The NTEP website provides searchable data from NTEP testing locations in different states. Sports field managers can also learn about new and improved cultivars by attending educational conferences, workshops, and university turfgrass field days.



NTEP field trial at the University of Delaware. Credit: E. Ervin.

3.1.1 Warm Season Turfgrasses

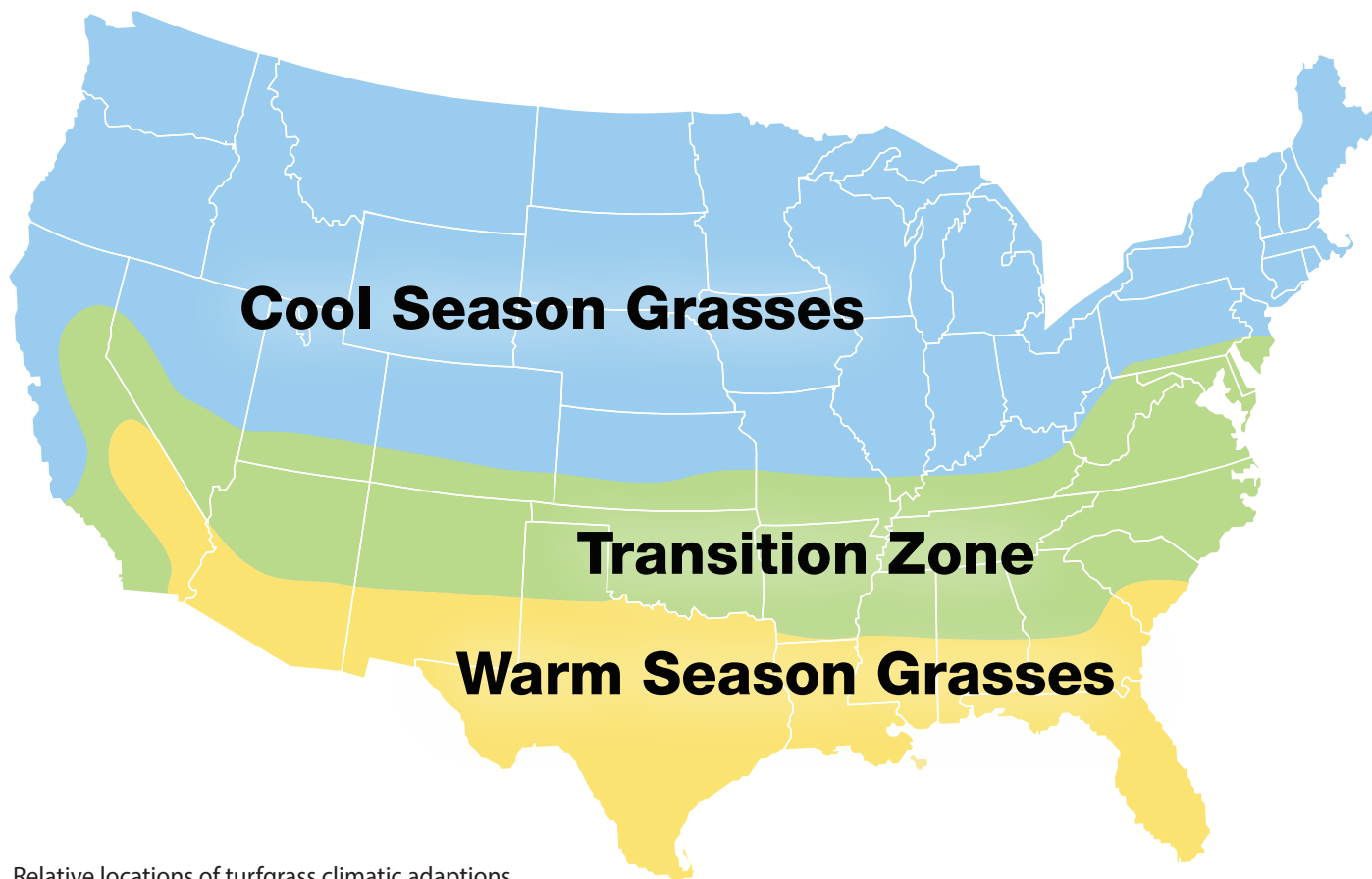
Common bermudagrass (*Cynodon dactylon*) and hybrid bermudagrass (*C. dactylon* x *C. transcaalensis*) are typically the preferred warm season grasses for sports field surfaces. Breeding efforts, particularly for hybrid bermudagrass, have yielded improved varieties that are more wear tolerant and have improved cold tolerance. Hybrid bermudagrasses are established by sod or sprigs, whereas common bermudagrass can also be established by seed. While the choices in cultivars of bermudagrasses are limited compared with those available for cool season grasses, there are important differences in establishment method (seed or vegetative), stand density, cold tolerance, growth rate, and pest tolerance that should be considered in the selection of a bermudagrass cultivar best suited for a sports field.

Zoysiagrasses (*Zoia matrella* and *Z. japonica*) and seashore pasplum (*Paspalum vaginatum*) are warm season grasses that are also used for sports fields. Zoysiagrasses exhibit greater shade tolerance and seashore paspalum has excellent salt tolerance.

3.1.2 Cool Season Turfgrasses

Cool season turfgrasses used in sports fields include Kentucky bluegrass (*Poa pratensis*), perennial ryegrass

(*Lolium perenne*), and turf-type tall fescue (*Schedonorus arundinaceus*, formerly *Festuca arundinacea*). Based on its recuperative potential from rhizome regrowth, Kentucky bluegrass has long been a popular sports turfgrass species. Perennial ryegrass blends well with Kentucky bluegrass in both appearance and management requirements, but its rapid germination and establishment rate makes it an important turfgrass of heavily trafficked cool season fields. New improved turf-type tall fescue cultivars have better tolerance to lower mowing heights and improved tolerance to cold, drought, wear, and disease. Breeding improvements have expanded the acceptability of turf-type tall fescue further north beyond the transition zone. Therefore, once turf-type tall fescue is established, these improvements have expanded the use of turf-type tall fescues on sports fields, and especially lower input, non-irrigated sports fields. While Kentucky bluegrass and perennial ryegrass are cool season grasses best suited for fields that require a lower mowing height, turf-type tall fescue may offer an option for multi-use fields. For sports fields requiring a lower height of cut specific for a desired ball roll or bounce characteristic (e.g., baseball or field hockey), turf-type tall fescue might not be suitable as more frequent inputs and increased maintenance would be required.



Relative locations of turfgrass climatic adaptations.

3.1.3 Transition Zone

Growing acceptable turfgrass on sports fields in the transition zone can be challenging. Cool season turfgrasses are stressed during prolonged hot and humid summers, while bermudagrass has a 4-5 month dormancy period (loss of green color and no active growth) and annual concerns with winterkill potential. More information about turfgrass selection is published in [*Grass Options for Athletic Fields in the Transition Zone*](#), University of Kentucky. More information on managing bermudagrass in the transition zone can be found in the Virginia Cooperative Extension publication [*Optimizing Bermudagrass Athletic Field Winter Survival in the Transition Zone*](#).

Another grassing option in the transition zone that has attracted a great deal of interest is a perennial two-grass system of bermudagrass and Kentucky bluegrass (often referred to as “bluemuda”). The goal is to provide an actively growing playing surface (and green color) regardless of the season. Practitioners and researchers alike continue to refine the management protocol and expectations of the end product, but the strategy has been implemented on sports fields all across the transition zone to varying degrees of success.

3.2 Turfgrass Establishment

The turfgrass establishment phase requires greater quantities of water and nutrients compared with routine maintenance of established turfgrasses. To this end, establishment requirements should be considered carefully to minimize environmental risk during construction, as discussed in the Planning, Design, and Construction chapter.

3.2.1 Site Preparation

Whether seeding, sodding, or sprigging, proper site preparation aids establishment and can help avoid long-term problems, such as drainage issues and surface smoothness. No amount of water, fertilizers, and pesticides can overcome an unsuitable soil resulting from poor field construction. Trying to overcome soil limitations with excessive water and chemical inputs increases the level of effort and management expense needed to manage the sports field. Additionally, an increased chance of runoff exists that can potentially impact water quality.

Prior to turfgrass establishment, any drainage issues should be corrected through grading and installation of drainage technologies. Site preparation includes removing any debris

that could hinder root growth and limit access to water and nutrients. Soil tests should be conducted to address any limitations (e.g., insufficient nutrient levels or pH). Prior to planting, soil pH adjusters and fertilizer materials should be incorporated into the top 4” to 6” of soil, as needed based on soil test results, especially for immobile nutrients. This is also the time to incorporate any organic or inorganic amendments recommended to improve the physical or biological properties of soil.

Little (or no) soil preparation of thinning or degraded natural grass areas often leads to failed turfgrass establishment. Sowing seed or installing sod into/on a sparse turfgrass canopy will ultimately not be successful if the underlying issues have not been corrected. In compacted soils, the newly emerged seedlings may root but may not adequately penetrate the soil such that the new plants persist. For spot seed renovations, it is recommended to core cultivate the soil in multiple directions, seed, and then drag the cores back into the area after seeding to ensure soil to-seed contact.

3.2.2 Seeding Cool Season Turfgrasses

Turf-type tall fescue, Kentucky bluegrass, and perennial ryegrass sports fields take several months to become fully established. Even 100% coverage does not automatically mean that the playing surface is ready for use. New advancements in turfgrass management may alter the timetable for grow-in in some situations. Fields should not be used until they are able to tolerate and recover from consistent wear. Frequent mowing during establishment encourages tillering in turf-type tall fescue and perennial ryegrass and encourages rhizomatous growth in Kentucky bluegrass. The degree of success and the time required for establishment totally depends on environmental conditions, available nutrients, irrigation and rest during the establishment period. A spring renovated field stressed by summer heat or drought may take longer to fully establish than a field seeded in late summer/fall.

In the transition zone, cool season species should be seeded in the late summer and should not be utilized for play until the spring. If summer conditions are moderate, sports fields renovated and seeded in the early spring can be used in the fall. However, a hot and dry summer will stress the young turfgrass seedlings and may damage the turfgrass stand. Therefore, delaying play until the following spring rather than subjecting the field to play while conditions are stressful, might warrant consideration.

3.2.3 Seeding Warm Season Turfgrasses

Warm season fields can be seeded, with the exception of hybrid bermudagrass, though sprigging is more common. Warm season fields can often begin to tolerate traffic within eight to 12 weeks of establishment, if weather conditions are favorable and adequate nutrition and irrigation are available. However, a longer establishment period is recommended to allow a field to mature and better tolerate traffic occurring from play.

If not yet mature, 100% turfgrass coverage does not equate to a playing surface ready for use.

3.2.4 Sodding

The optimal time to install turfgrass sod is during the growing season, which encourages rooting. However, late-season turfgrass sodding can be an option if the preferred timing is not possible. Turfgrass sod that is laid late in the season can require less water to root and establish as temperatures are more favorable for shoot and root growth. Irrigation requirements are lower when sodding late in the season rather than in the height of summer. In the northern regions of the U.S., sod can be installed until the ground freezes as roots will “knit in” as temperatures begin to warm in the spring.

For a sand-based field, sod should be selected that has been grown on a soil with a similar physical structure as the field. Sod that is grown on clay or organic soils and then installed on a sand-based field will often fail because it will not root properly due to the layering effect of the dissimilar soils. An aggressive cultivation program reduces the layering effect, but it is a long-term process and ideally avoided by matching soil types of sod and field. Layering of fine soil over coarse soil reduces water infiltration and percolation rates, leading to a saturated playing surface.

Turfgrass sod, whether on a native soil field or a sand-based field, can be topdressed to fill in the gaps between the sod pieces to aid in establishment and create a smooth uniform playing surface. The sod should be inspected, regularly after installation to reduce evidence of gaps that might appear and should be topdressed with matching soil.

3.2.5 Establishing Sprigs

Bermudagrass sprigs (shredded stems) are generally planted from mid-spring through mid-summer. Southern areas may benefit from early to late spring plantings while areas further to the north in the transition zone may need to

wait until between late spring and early summer. It is preferable to sprig as early in the bermudagrass season as possible so the stand can be well established to withstand cooler temperatures and traffic in the fall and winter. While it is certainly not the norm, dormant sprigging has been employed successfully in some locations, but there is obvious potential that a late spring freeze can injure poorly rooted, actively growing plants.

Sprigs can be planted in rows or furrows or by broadcasting them uniformly over the entire field surface; typical planting rates range from 400 to 800 bushels (1,000-1,200 bushels for zoysiagrass) of sprigs per acre. Higher rates are planted if it is a late planting date, better coverage is desired, or sprigging into existing turfgrass. Planting early in the season (early to late spring for warm climates and late spring to early summer for the transition zone) may require fewer bushels because the bermudagrass has more time to establish and provide optimum coverage.

Cultural management during the first growing season is crucial for survival and success of bermudagrass sprigs. Depending on soil temperature, moisture, and management, sprigged fields can be 100% covered in turfgrass within eight weeks after sprigging. However, what might be a great looking playing surface actually has very poor traffic tolerance at this time; sprigged fields that are only eight weeks old are not mature.

3.3 Overseeding Bermudagrass

Bermudagrass enters some degree of winter dormancy in many areas of the United States with persistent air temperatures less than 50°F and shorter days in the winter. To provide color and an actively growing playing surface as bermudagrass growth slows, many bermudagrass sports fields are overseeded with a cool season grass, typically perennial ryegrass, in early to mid-fall. Potential issues can arise in the spring when the overseeded cool season grass competes with the dormant bermudagrass when it begins to actively grow. A general overview of overseeding in the transition zone is published in [The Need to Overseed](#), Texas A&M Agrilife Extension.

Though winter overseeding is a common practice for warm season sports fields, careful attention is required to encourage growth of cool season grasses without negatively affecting the underlying bermudagrass.

3.3.1 Timing of Overseeding Bermudagrass

The timing of the seeding event, and the selection of the appropriate turfgrass species, are important considerations in the overseeding process. If seeded too early in the fall, the bermudagrass can still outcompete the overseeded cool season species. If seeded too late, the cool season grass might not establish adequately before the cooler temperatures predominate. To increase overseeding success, the overseeding event should be timed with night temperatures that are consistently around 50°F, two to three weeks prior to the first killing frost.

3.3.2 Spring Management of Overseeded Bermudagrass Fields

In the spring, additional early spring fertilizer applications may be necessary to ensure proper growth and development of the overseeded cool season grass. As the temperatures warm and daylight hours increase, cool season turfgrass competes very aggressively with the transitioning and green-up of bermudagrass. This competition can be an issue until air temperatures consistently reach a high of 80°F. Such competition delays total bermudagrass fill-in and, if a heat wave causes the overseeding to quickly die, results in a thin, soil-exposed stand of bermudagrass. Therefore, gradual transitions from bermudagrass to cool season grass in the fall and back to bermudagrass in late spring are necessary to maintain consistent playability.

To transition from cool season grass to bermudagrass in the spring, a number of methods can be used to manipulate populations of the overseeded cool season turfgrass. Applications of plant growth regulators (PGRs) may be beneficial but must be timed appropriately and prior to bermudagrass green up. Transition-assisting herbicides, such as those in the sulfonylurea chemical class, may be needed to adequately eliminate the cool season turfgrass. These herbicides require warm soil temperatures (> 60°F) for best activity and remove ryegrass from a bermudagrass stand in 2-4 weeks.

3.4 Overseeding Cool Season Turfgrass Fields

In cool season grass regions and some areas of the transition zone, overseeding consists of adding new seed of cool season turfgrasses to an existing field of cool season turfgrasses. Generally, that means seeding more Kentucky bluegrass or perennial ryegrass, or a mix of the two, into a Kentucky bluegrass field or a field with a mix of cool

season grasses. This type of overseeding provides a better playing surface for current season play and increases turfgrass density for future seasons.

The selection of improved cultivars of Kentucky bluegrass, perennial ryegrass, and turf-type tall fescues for overseeding should take into consideration the differences in germination rate. This helps maximize seed germination and complete establishment of all species in the seed mix. A strategy can be to use a mixture of species with the percentage of each changing from early to late fall overseeding. University Extension specialists can assist in devising a regionally appropriate overseeding strategy.

3.5 Erosion and Sediment Control

Exposed, bare or thin fields can be prone to the loss of topsoil. Soil carried by wind and water transports contaminants, which may impair water quality of nearby surface waters. For example, erosion can enrich surface waters, where phosphorus and, to a lesser extent, nitrogen can cause eutrophication. When sediments and soils enter water, they can also increase turbidity, blocking sunlight and impacting aquatic plants and animals. Therefore, prior to any field construction or renovation, erosion and sediment control measures should be documented in an erosion and sediment control plan. Erosion and sediment control measures should be installed prior to any soil disturbance. Once established, turfgrass provides excellent erosion and sediment control.



Sediment and erosion control measures. Credit: B. Polimer.

3.6 Cultural Practices

Cultural practices for newly established turfgrass fields include mowing, nutrient management, and irrigation. These practices are described below with respect to establishment and are covered in detail in the Cultural Practices chapters of this document.

3.6.1 Mowing

Regular mowing promotes new tiller formation and stimulates turfgrass growth and density. The turfgrass should be allowed to initially grow one-third to one-half higher than the desired HOC before mowing. As an important cultural practice, mowing newly established sports fields should follow the one-third rule. Maintaining cutting units (i.e. providing the sharpest and properly balanced mowing blades or consistent reel to bedknife contact) is critical because it supports a healthier turfgrass plant. The soil should be dry and stable enough to support the weight of mowing equipment without rutting.

One-Third Rule

Remove no more than one-third of the leaf tissue with the first and each subsequent mowing event.

3.6.2 Nutrient Management

Soil tests should be conducted prior to seeding or sodding. Unless soil tests report deficiencies, supplemental micro- and macronutrient, besides nitrogen may not be needed during establishment. In phosphorus-deficient soils, phosphorous (P) should be applied to the soil before seeding or sodding based on soil test recommendations. For example, a rate ranging from 0.5 to 1.5 pounds (lbs) P_2O_5 per 1,000 square feet (ft^2) (22 to 65 lbs P_2O_5 per acre) may be recommended. A follow-up application of phosphorus fertilizer may be required four to eight weeks after seedling germination or sodding. If a soil test indicates a deficiency in phosphorus or if symptoms of phosphorus appear (such as purple-blue color, thin canopy, poor nitrogen response) a second application may be justified. Soils with a pH greater than 7.5 are at greater risk of phosphorus deficiency during establishment. Therefore, higher rates and a second application of phosphorus fertilizer are recommended for high pH soils, unless otherwise not allowed by state or local nutrient management regulations.

Nitrogen (N) management is also essential during establishment for native and sand-based fields. For turfgrass establishing on native or sand-based soils, soluble sources of N fertilizer should be applied with a goal of delivering approximately 0.25 lb N per 1,000 ft^2 per week. To reduce the frequency of applications of soluble fertilizers on sand-based soils and to reduce the loss of soluble N from leaching through the sand profile, the grow-in fertility program is commonly supplemented with

nitrogen. These nitrogen sources are typically 50% or greater slow-release N in order to provide uniform nitrogen release for a period of six to 10 weeks. This usage maintains consistent N feeding to the developing turfgrass. The concept also applies to native soils in terms of optimizing N use efficiency, but it is not as critical given the limited N leaching potential of the native soil.

Micronutrients may be beneficial during establishment, especially on sandy or high pH soils with low nutrient holding capacity, based on soil tests. Grow-in fertility programs under these conditions often include a micronutrient package. Periodic tissue testing is the most effective way to determine deficiencies on established turfgrass.

3.6.3 Irrigation

Light and frequent irrigation is required throughout the turfgrass establishment phase. Seeded fields should be moist on the surface and down to 0.25" in depth until germination. If seed mixtures are used, germination of all the species needs to be considered as well as field conditions and weather. Once all species have germinated, irrigation frequency should be reduced while the duration of the irrigation event is increased. Sodded fields should be irrigated as the sod takes root. Rooting should be checked by lightly pulling a sod corner. Irrigation frequency can be reduced when the sod cannot be pulled back from the soil surface.

3.7 Covers

Turfgrass covers are an excellent tool to extend color at least four to six weeks in the fall and encourage spring greening by one to two months (Goatley et al. 2005). On newly planted or renovated fields, turfgrass covers can also enhance seedling development and sod rooting in winter in some regions of the country. Covers may also help protect turfgrasses from frost or freeze damage. Covers should also be considered to encourage and accelerate as much off-season recuperation as possible for high wear areas on both warm season and cool season fields. Covered sports fields protect crowns/stolons/rhizomes from freezing temperatures, reducing the potential for winter damage from cold, desiccating winter winds.

The stimulation of turfgrass growth by the use of covers also requires special attention by the sports field manager, as pests also respond to the enhanced temperatures and moisture. Depending on environmental conditions and the blanket's characteristics, a fungicide treatment might be necessary on cool season or ryegrass-overseeded bermudagrass fields that remain covered for several weeks. More information on using covers on bermudagrass

fields is published in the Virginia Cooperative Extension publication [*Optimizing Bermudagrass Athletic Field Winter Survival in the Transition Zone*](#).

3.8 Turfgrass Establishment Best Management Practices

Turfgrass Selection

Best Management Practices

- Work with university Extension specialists as needed to evaluate selection recommendations.
- Select cultivars that are adapted to the sport, field characteristics, maintenance regimes, pest resistance, and spring or fall transition needs. Also consider other desired characteristics such as vigor, tolerance to environmental extremes, wear tolerance, speed of recovery, and shade tolerance (where applicable).
- Develop and implement strategies, such as overseeding, hydro-seeding, or sodding to effectively control sediment, minimize the loss of topsoil, and protect water quality.

Turfgrass Establishment

Best Management Practices

- Prepare seed/sod beds to maximize success during establishment.
- Ensure erosion and sediment control devices are in place and properly maintained.
- Seed cool season grasses in the timeframe that allows for optimal seed germination (typically early August to late September) and for development well before cold temperatures significantly slow growth prior to winter.
- Anticipate the wear on known heavy traffic areas by reseeding heavily and often for uniform playing surfaces.
- Establish turfgrass sod when plants are actively growing so the sod will root or “knit” down into the soil as quickly as possible.
- Fill gaps in sod seams with soil or sand to provide a uniform surface.

Overseeding

Best Management Practices

- Where allowed by regulations and ordinances, use seedling compatible, selective pre-emergence herbicides at the appropriate time to reduce weed competition and improve the chance of success with seeding establishment during the spring.

- Balance fertility programs between the needs of both the cool season and warm season grasses and apply fertilizers only during periods of active turfgrass growth.
- Consider the germination rate of the turfgrass species and cultivar in the timing of the overseeding event.

Warm Season Fields

- Time overseeding events on warm season bermudagrass when night temperatures are consistently around 50°F, two to three weeks prior to the first killing frost.
- Chemically or mechanically transition from ryegrass to bermudagrass as soon as possible upon the completion of spring sports to avoid weakening the bermudagrass from competition.

Cool Season Fields

- Overseed cool season fields to provide a better playing surface for current season play and increase turfgrass density for future seasons.
- Utilize improved varieties of cool season species to maximize turfgrass performance while limiting the need for inputs (e.g., fertilizer, water, pesticides).
- Utilize university Extension specialists to make recommendations for cool season seed mixtures.

Cultural Practices Best Management Practices

- Conduct soil tests to determine nutritional needs.
- If necessary and allowed by regulations and ordinances, apply a fertilizer containing phosphorus at the time of seeding. An additional application should be applied if soil or tissue tests demonstrate the need.
- Nitrogen and sufficient water are essential during establishment. Light and frequent applications of nutrients and water are most desirable. A slow-release nitrogen source will provide a consistent release of nutrients.
- Allow the turfgrass to initially grow one-third to one-half higher than the desired HOC before beginning to mow and never remove more than one-third of the turfgrass leaf at mowing.
- Keep mower blades sharp. Dull mower blades may dislodge or damage young grass.
- Consider mowing with a walk-behind mower rather than a heavier riding mower to avoid making wheel track depressions in the soil.
- Delay watering prior to mowing to help the soil dry and to better tolerate the weight of the mower.

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4 CULTURAL PRACTICES: MOWING

Mowing is the most basic and perhaps the most important cultural practice of managed natural grass systems that affects turfgrass quality and playability. Mowing practices impact turfgrass density, texture, root development, and wear tolerance. Failure to mow properly results in weakened plants with poor density and quality resulting in fields that offer poor play and can be unsafe.

Proper mowing height is a function of the quality of the cut, mowing frequency, the cultivar being managed, maintenance program, the sport and the intended use of the site. Other factors influencing HOC include frequency, equipment, time of year, root growth, and abiotic and biotic stress. For example, mowing frequency affects turfgrass growth as it increases shoot density, tillering, lateral growth of rhizomes and stolons, and also influences root growth. Frequent mowing increases tillering and shoot density, but if done improperly can decrease lateral stem and root growth. Therefore, mowing practices should balance these two physiological responses to enable quick turfgrass recovery through decisions related to HOC, frequency, and mowing patterns. Mowing too infrequently results in alternating cycles of vegetative growth followed by scalping, which further depletes food reserves of the plants. Proper equipment maintenance is also key to maintaining healthy turfgrass, as cutting units need to be properly maintained and provide sharp blades or consistent reel to bedknife (light) contact to reduce the risk of creating wounds that can favor microbial infection and, in some cases, dissemination of pathogens.

Mowing heights vary on the basis of a number of factors:

- Turfgrass species and cultivar
- Grass growth rate at a particular time of year
- Sport being played

- Mowing equipment
- Available labor/budget

The sports field manager must design a mowing program to produce a playing surface that is neither too short or too tall and adjust to meet changing environments, seasons, and sports.

The one-third rule (never remove more than one-third of the leaf blade at one mowing event) applies to most situations to minimize imbalances between root and shoot system development. This still allows for variation in HOCs depending upon the species and season and provides the sports field manager opportunities to optimize turfgrass health and playing quality.

Frequent mowing at the lower range of acceptable HOCs (Table 2) for species during periods of optimal turfgrass growth increases the rates of lateral growth from rhizomes and stolons and encourages tillering of bunch type grasses without being a drain on nutrient storage and root production. Frequent mowing at the lowest HOC ranges for a species during environmental stress periods gradually weakens plant health as shoot development is favored, compromising root growth and nutrient storage. Mowing too infrequently may result in a playing surface deemed unfit for use and is typically followed by a scalping mowing event that leaves excess clippings on the surface (creating shade, disease, and playability problems) and further depletes nutrient reserves of the plants as its recovery efforts are focused on regenerating shoots.

4.1 Height of Cut (HOC)

Determining the best HOC requires balancing the stress response of mowing the turfgrass species with the sport being played, playability requirements, mowing frequency,

Table 2. Recommended seasonal HOCs

Turfgrass	Range	Spring	Summer	Fall	Winter Overseeded Bermudagrass
Bermudagrass	0.5 — 2"	0.75 — 1"	0.5 — 1"	1 - 2 in"	0.5 — 2"
Turf-type tall fescue	1.5 — 3"	1.5 — 2"	3"	1.5 — 3"	n/a
Kentucky bluegrass	1 — 3"	1 — 2"	1 - 3"	1 — 2"	n/a
Perennial ryegrass	1.5 — 3"	1.5 — 2"	3"	1.5 — 2"	n/a

Source: Modified from *Sports Fields: Design, Construction and Maintenance, 2nd edition*.

weather conditions, and budget considerations. In general, turfgrass mown at a higher HOC offers a better defense to pests and other stressors. Ideal tolerance ranges for mowing height vary by species and within species (Table 2) and provides adequate density assuming water, nutrients, etc., are provided optimally.

Mowing height can also be varied seasonally to improve turfgrass responses to changes in weather and available sunlight, such as during spring greenup, the heat of the summer, and late fall as temperatures cool. Adjusting mowing HOCs incrementally a few weeks in advance of anticipated seasonal growth assists in maintaining a balance in root and shoot development.

During the growing season, the HOC is based on a number of factors, including the grass species/cultivar, nutrient management program, irrigation requirements, the type of mowing equipment, and field use. After selecting the most appropriate turfgrass mixture or blend, field use must be considered. Heavily used fields (e.g., practice fields), often are maintained at a higher HOC to help reduce wear and tear of the turfgrass. For high visibility/priority fields (e.g., game fields), HOCs can be set to meet the needs of the sport.

As day-length decreases and cooler temperatures become more frequent in early fall, turfgrass growth can be affected. In warm season climates, HOCs should be raised slightly on bermudagrass to increase the amount of green leaf tissue available for photosynthesis. This strategy can be applied to cool season fields in mid-late spring in anticipation of heat and moisture stress during the summer. Higher mowing HOC provides the following benefits: a slight benefit in terms of increased carbohydrate production and storage; insulation for crowns/stolons/rhizomes; and a dense, healthy canopy that can resist wear and in turn provides longer seasonal durability (Munshaw, et al., 2017).

4.2 Mowing Frequency

Maintaining an optimal root-to-shoot ratio is critical. Following the traditional one-third rule, mowing should be frequent enough so that no more than one-third of the top growth is removed at any one time. Removing more than one-third of the leaf surface inhibits root growth because the grass will use more energy to regenerate new shoots than for sustaining roots.

In addition to maintaining an optimal root-to-shoot ratio, mowing events should only be performed when both field and growing conditions are satisfactory to prevent

compaction and/or excessive stress. Extreme damage can occur from the use of equipment or even routine play when the field is saturated. Cool season grass under extreme drought/heat stress should not be trafficked as this can also severely damage or kill turfgrass. Under any of these conditions, stay off the field until favorable conditions for return. When mowing resumes, scalping should be avoided by lowering HOC in small increments so as not to remove more than one-third of the leaf blade per mowing event.

4.3 Mowing Patterns

Mowing patterns (especially with cool season grasses) provide the opportunity to turn a sports field into a living piece of art. At the same time, the goal of a sports field manager is to provide a playing surface where mowing pattern does not significantly alter ball roll or footing, which can sometimes be the case particularly on bermudagrass fields where the field managers repeat mowing patterns to “burn in” a striping pattern. Due to the combination of a repeated mowing and the exceptional density of the grass, the field develops grain (a particular direction of growth), impacting the speed and uniformity of ball roll with, against, or across the grain. To minimize the development of grain, periodically alter the direction of cut with mowing equipment, balancing both visual and playability goals of the field.

4.4 Mowing Equipment

Several types of mowers are available. Reel mowers are preferred for turfgrass maintained at a low HOC (<1.5”) because they produce the best quality cut compared with other types of mowers. The combination of the number of blades on the reel, the reel speed (rotational velocity), and the forward speed of the mower make up the clipping rate. It is critical that the clipping rate matches the HOC to provide the most uniform playing surface. Rotary mowers, when the blades are sharp and properly adjusted, deliver acceptable cutting quality for turfgrass maintained at a taller HOC (>2”), but note that technological advances in floating deck rotary mowers can provide quality cuts as low as 1”.

Mowing equipment should be examined before each use to ensure the best quality of cut. Mower blades should be sharpened or adjusted as often as necessary to achieve the desired quality of cut. Dull mower blades can shred leaf tissue, which increases water loss and opportunity for disease. Therefore, maintaining sharpened, properly balanced mowing blades is critical because it supports a healthier turfgrass plant.

4.5 Clipping Management

Whenever possible, clippings should be returned to the turfgrass canopy. Clipping return provides multiple benefits, such as:

- Nutrient recycling of N, P, and potassium (K), at rates up to 1 lb N per 1,000 ft² per year, as well as other essential nutrients.
- Reduced need for supplemental nutrients.
- No need to manage the disposal of clippings.

During a mowing event, if clippings clump on the playing surface, they should be evenly distributed to avoid injuring the turfgrass canopy. If clippings cannot be returned, they can be blown, dragged, or collected and composted. Composted clippings can be used as a soil amendment or as a component of topdressing during establishment of new fields or in landscaped areas (unless clippings have herbicide residues). Clippings should never be allowed to collect in or near stormwater drains or natural wetlands due to their nutrient content.

4.6 Mowing Best Management Practices

- Mow natural turfgrass fields frequently to ensure a dense uniform playing surface. If a sports field requires a change in HOC, the height should be gradually adjusted until desired HOC is achieved by following the one-third rule of leaf removal.

- Consider using a plant growth regulator (PGR) as a regular management tool to reduce mowing frequency, clipping volume, and to improve mowing quality, turfgrass density, and overall plant health.
- Increase HOC prior to times of stress (such as drought or anticipated temperature extremes) staying within the tolerance range to increase photosynthetic capacity and rooting depth of plants.
- Increase mowing frequency during periods of rapid turfgrass growth and decrease during periods of slow growth.
- Vary mowing patterns.
- Properly maintain mowing equipment to maximize quality of cut.
- Use reel mowers whenever possible for maintaining turfgrass that requires HOC below 2”.
- Keep blades of reel and rotary mowers sharp and properly adjusted.
- Return clippings to canopy whenever possible to recycle nutrients and reduce the need for fertilizer inputs.
- Remove or disperse clippings when the clipping amount is excessive and could smother the underlying turfgrasses.
- Dispose of collected clippings properly. Options include composting or dispersing clippings evenly in natural areas.

4 CULTURAL PRACTICES: NUTRIENT MANAGEMENT

Proper nutrient management in sports field management plays a key role in plant health and stress resistance, as well as overall aesthetics and playability (plant density, recovery, and wear tolerance). However, improperly applied nutrients can result in wasteful use of natural resources and nutrients. Thus, nutrient use should be undertaken with care and consider the impact of nutrient applications with respect to the environment, economy, and society.

Therefore, the goal of the nutrient program should be to achieve an acceptable, safe playing surface that maximizes plant nutrient uptake while applying a minimum of nutrients to achieve these results.

4.7 Essential Mineral Nutrients

Essential mineral elements are required for turfgrass growth. Phosphorus, potassium, sulfur, and, especially, nitrogen are most commonly deficient (Table 3).

Table 3. Essential plant nutrients with visual deficiency symptoms and plant tissue and soil test values.

Nutrient	Visual Deficiency Symptoms (all of these can result in poor shoot growth)	Typical Shoot Tissue Concentration ¹	Critical Soil Test Level ²
<i>Non Mineral Nutrients (obtained from air and/or water)</i>			
carbon (C)	never deficient	43-48%	n/a
hydrogen (H)	never deficient	2-4%	n/a
oxygen (O)	shoots never deficient, but roots can be deficient in saturated (especially compacted) soils	43-48%	avoid soil moisture saturation for extended periods
<i>Primary Macronutrients</i>			
nitrogen (N)	chlorosis, significantly poor growth/recovery (excessive nitrogen results in dark green color with excessive shoot growth/poor root growth)	3-4%	n/a (typical values are 5-10 parts per million [ppm] unless higher due to recent fertilization)
phosphorus (P)	poor root growth, in rare circumstances shoots will be red/purple	0.25-0.45%	18-30 ppm
potassium (K)	chlorosis, lack of turgidity (shoots lay over)	2-3%	150-200 ppm
<i>Secondary Macronutrients</i>			
sulfur (S)	chlorosis	0.23-0.30%	n/a (less likely to respond to sulfur fertilizer as organic matter levels increase above 3%)
calcium (Ca)	lack of turgidity (shoots lay over)	0.5-1.0	400-500 ppm
magnesium (Mg)	chlorosis	0.25-0.50	80-100 ppm

Nutrient	Visual Deficiency Symptoms (all of these can result in poor shoot growth)	Typical Shoot Tissue Concentration ¹	Critical Soil Test Level ²
<i>Micronutrients</i>			
iron (Fe)	general chlorosis, although interveinal chlorosis is common in most species, this type of chlorosis is difficult to see or not present in shortly mowed turfgrass; it is rare to see deficiencies in newer varieties	65-500	n/a (very poor correlation to plant response)
zinc (Zn)	chlorosis	22-50 ppm	>1-2 ppm
manganese (Mn)	chlorosis	35-60 ppm	6-10 ppm
copper (Cu)	chlorosis	5-8 ppm	0.4-0.6 ppm
boron (B)	chlorosis	8-15 ppm	>1-2 ppm
chloride (Cl)	chlorosis	unknown	>20-25 ppm
nickel (Ni)	not observed	unknown	unknown

¹Values shown are not intended to represent optimal ranges, but rather are what is commonly measured. Optimal levels vary by species, variety, use, and environment.

²The soil test values shown for the primary macronutrients have good confidence due to significant research, but the other nutrients have relatively less scientific backing and, instead, are based largely on observations and extrapolations with other species. The excessive soil test level shown is not meant to be a "sufficiency level", but rather the point at which there is virtually no chance that a fertilizer response would be likely.

By law in most countries, anything sold as fertilizer must list the percentage in the following order: N, P, K. The phosphorus is expressed as P₂O₅ and potassium as K₂O. For example, a 20-2-5 fertilizer has 20% N, 2% P₂O₅, and 5% K₂O¹. The fertilizer label often also includes the percentages of other nutrients and/or the materials from which the nutrients are derived.

4.8 Primary Macronutrients

4.8.1 Nitrogen

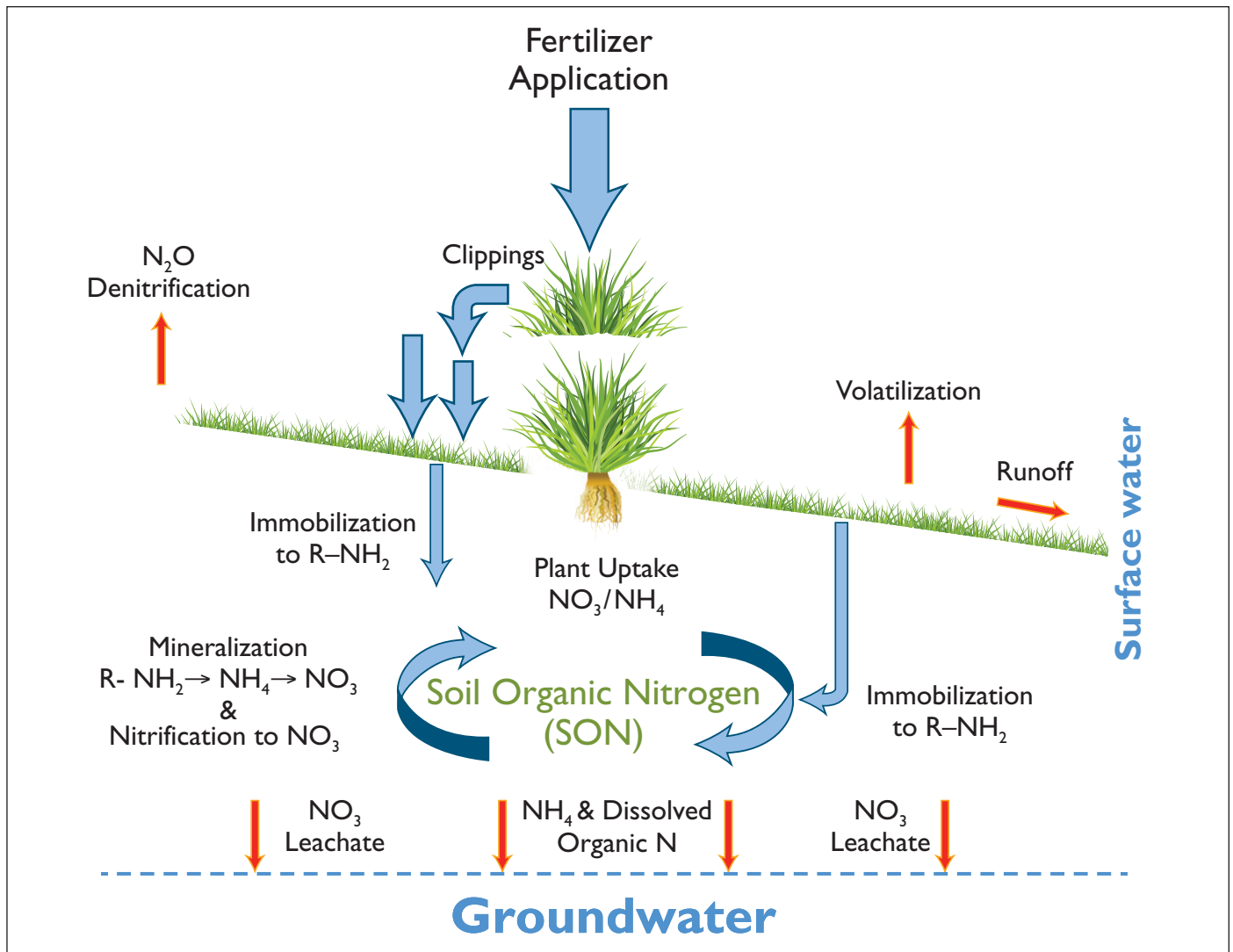
Nitrogen is the nutrient that has the greatest impact on plants. Turfgrass has variable nitrogen requirements based on the species and usage, fertilizer source and timing, seasonal evapotranspiration rates, precipitation, and soil properties. Turfgrass requires nitrogen in greater quantities than all but the non-mineral nutrients that come from air and water (carbon, hydrogen, and oxygen). Nitrogen plays a role in nearly all plant functions and is an essential component of amino acids, proteins, nucleic acids, etc. It is vital to understand the nitrogen cycle in order to maximize uptake by plants and minimize losses to the environment.

Understanding which nitrogen sources should be used is an essential component in an efficient nutrient

management program. In many cases, nitrogen sources are applied without regard to their release characteristics. This increases the risk of negative environmental impacts as well as management costs. Each nitrogen source is unique and therefore should be managed accordingly.

The first selection criterion in choosing a nitrogen fertilizer source is the rate at which it becomes plant available. Some sources are immediately plant available (quick release/water soluble nitrogen) and others become so over time (slow or controlled release/water insoluble nitrogen). The most common dry fertilizer sources that are readily plant available and dissolve into the soil solution are urea (46-0-0) and ammonium sulfate (21-0-0). The most common liquids that are readily plant available are urea (various concentrations) and urea ammonium nitrate (28-0-0; 32-0-0). These readily available sources provide quick uptake and rapid greening, which can be especially important during cool times of the growing season and just before/after sporting events. However, high rates applied at any one time result in excessive shoot growth and increased mowing requirements at the expense of decreased root growth and increased probability of infection of some pathogens. The risk from fertilizer burn is relatively high

¹ At times it is helpful to convert back and forth between these using the relationships that there is 44% P in P₂O₅ and 83% K in K₂O.



The nitrogen cycle. Credit: New York Golf Course Foundation.

with these quick release sources, especially when applied at high rates and/or when weather is hot and/or dry. Additionally, these rapid release sources are more likely to be lost to the environment. Within this group of “quick release” fertilizers, urea molecules rapidly convert to ammonia gas and then ammonium. Left on the surface, the ammonia can be volatilized—potentially losing much of the applied nitrogen. Additionally, the ammonium converted from urea or applied as a fertilizer can revert back to ammonia and be volatilized, especially in alkaline soils common in arid regions. Volatilization potential can be reduced by avoiding urea application under hot, humid, and/or windy conditions. After application, watering with 0.25” irrigation water reduces volatilization potential.

Ammonium converted from urea or applied as a fertilizer converts to nitrate within a few hours/days. The nitrate is prone to leaching below the root zone with high precipitation and irrigation rates, particularly in sand-based soils. Nitrate

is further lost to the environment due to emissions of nitrification/denitrification gases (e.g., nitrous oxide), especially with prolonged soil saturation. Thus, proper irrigation and drainage can help minimize losses of nitrate.

Use of fertilizers that are not “quick release” and become available over time can result in increasing nitrogen uptake and reducing losses. These fertilizers can effectively “spoon-feed” plants by releasing or converting nitrogen in a steady manner rather than a flood of it entering the soil solution. These nitrogen sources can reduce losses to the environment, decrease foliar burn potential, and reduce labor with fewer required applications. Although complex, understanding these sources of nitrogen fertilizers can be simplified by separating into two types:

- **Slow/Control Release**—Nitrogen is released slowly or, in some cases, engineered to release in a controlled rate. For example, long-chain molecules containing nitrogen (e.g., methylene urea and urea formaldehyde) are broken down

through microbial degradation—eventually resulting in ammonium and nitrate as breakdown products. Another example are the coated fertilizers, such as polymer coated urea. Composted animal and plant biosolids and similar sources are included in this category as well.

- **Stabilized**—Inhibitors are added to water soluble nitrogen products and slow down the nitrogen cycle to decrease the chance of loss and increase the window of when the plant available forms of nitrogen (ammonium and nitrate) are available for uptake. Inhibitors include:
 - **Urease Inhibitors**—The conversion of urea to ammonium is slowed as the enzyme that catalyzes this reaction is temporarily inhibited.
 - **Nitrification Inhibitors**—The conversion of ammonium to nitrate is slowed as microbes responsible for this conversion are temporarily inhibited in their activity.

While these enhanced efficiency fertilizers are generally more expensive on a cost per pound of nitrogen basis as compared with quick release materials, their benefits include increased efficiency (lower rates can be applied), reduced costs (fewer applications; reduced mowing needs; reduced clippings), reduced risk for nitrogen-related diseases, and reduced environmental impacts. Often, a blend including 30-50% of these sources along with quick release nitrogen is affordable and effective.

Proper nutrition is imperative as plants are preparing for dormancy late in the season. Therefore, nitrogen fertilization is often necessary. As always, any local regulations should be followed when applying fertilizers late in the year. It is also noteworthy that some irrigation waters, especially waste waters, can be high in nitrogen and should be tested and accounted for to avoid excessive nitrogen applications.

4.8.2 Phosphorus

As with nitrogen, phosphorus deficiencies or excesses are detrimental to plants and excesses are harmful to the environment. Phosphorus plays important roles in cell structures and in energy transformations. It is especially important for root development with newly established sod and seedlings. However, excessively high phosphorus can result in poor plant health and encourage weed infestation, particularly annual bluegrass.

However, in contrast to nitrogen, phosphorus is rarely deficient in well-maintained and established turfgrass and is readily managed through soil testing. Plant response is

well correlated to the proven soil tests, with no benefit to applying phosphorus when soil test values are sufficient. It is noteworthy that sports turfgrass tends to need relatively higher concentrations of phosphorus due to frequent overseeding and clipping removal. Despite this, there is no proven benefit, even in sports turfgrass, to continue to add phosphorus fertilizer when the soil test levels are very high. Doing so is a concern for water quality as it contributes to eutrophication. For this reason, fertilizer applications are regulated by some states/counties. In cases where phosphorus is not needed due to high soil test values and/or when prohibited, “phosphorus-free” fertilizer sources should be used. In most cases, uncoated/coated ureas, ammonium sulfate, and potassium chloride/sulfate suffice to provide the needed nutrients for turfgrass without application of any phosphorus.

More so than nitrogen, phosphorus fertilizer accumulates in the soil. Phosphorus is poorly soluble, especially at extreme alkaline and acid soil pH levels. Shortly after fertilizer is applied, the majority of the phosphorus precipitates into a solid form. Nutrients need to be dissolved into the soil solution for plant uptake and this solid phase phosphorus is temporarily not available for plants until it slowly solubilizes over time. This is not a concern if enough of these precipitates exist in the soil in proximity to the roots of each plant.

The forming of these solid phosphorus precipitates greatly minimizes phosphorus leaching, especially as compared with nitrate. However, phosphorus can be leached when soil test concentrations are high. Of greater concern is phosphorus loss due to surface water runoff when soil test values are excessive, especially in close proximity to surface water bodies. Fertilizer that lands on impervious surfaces (e.g., sidewalks) that lead to stormwater drains should be minimized and removed.

The most common forms of phosphorus fertilizer are the ammonium phosphates. However, there are a wide variety of phosphorus fertilizers that can generally be categorized as follows:

- **Traditional inorganic phosphates**—These are in granular (such as monoammonium or diammonium phosphate) or liquid (ammonium polyphosphate) form that quickly react in the soil to form precipitates.
- **Coated phosphates**—These are similar to the coatings for nitrogen that are released slowly over time.
- **Organic complexed phosphates**—These products have been reacted with organic acids or are bound in various

plant and animal biosolids (e.g., animal or plant manures or treated sewage sludge). These release nutrients into the soil as they are decomposed by microbes or chemicals. (Note: The phosphorus described here is potentially different than the phosphorus found in “organically certified” fertilizers, which can include these materials or most other sources listed here.)

- **Specialty products**—These include a wide range of products, which are primarily used for pathogen control and improvement of stress tolerance.

Recommended rates of phosphorus, when needed, are 1-4 lbs/1,000 ft², with the rate proportional to soil test values. Timing of phosphorus applications is not as critical as nitrogen. Typically, a single annual application is adequate, although more may be needed if the soil test is very low and/or with new sod/seed. It is recommended to apply phosphorus and incorporate into the soil ahead of establishing turfgrass if soil test values warrant its use.

4.8.3 Potassium

Potassium is essential for proper water relations in plants, as well as other functions as it supports stress resistance. The overapplication of potassium is wasteful of maintenance costs and natural resources. As with phosphorus, there are good correlations with plant response and soil test values. Potassium is intermediary compared with nitrogen and phosphorus with regard to soil holding capacity. It is held loosely in the soil by clay and organic matter, which means that it is not easily leached in soils with higher levels of these soil components, but is readily leached in sandy, low organic matter soils. In these, it tends to need careful management similar to nitrogen to provide for season-long availability. Otherwise, a single annual application is generally adequate.

Rates of potassium, when needed, should be based on soil test results. The most common forms of potassium fertilizer sources are potassium chloride and potassium sulfate, although other sources are available and potentially useful (e.g., potassium nitrate, potassium thiosulfate, etc.). Coated sources are available and can be helpful, especially in sandy, low organic matter soils.

4.9 Secondary Macronutrients

As with primary macronutrients, secondary macronutrients are found in plants at percent levels (>0.1%). However, they were classified as “secondary” because they are historically less commonly deficient in crop plants.

4.9.1 Sulfur

Sulfur deficiencies have become relatively more common, especially in turfgrasses, due to reductions in acid rain pollutants and increasingly pure fertilizer materials. Predicting sulfur deficiencies is difficult as the soil test is not well correlated to plant response. Rather, organic matter is a somewhat better predictor, with the likelihood of response diminishing as organic matter levels increase above ~2%. As with nitrogen, sulfur is prone to leaching losses. As such, sulfur is more likely to be needed on high sand, low organic matter soils, especially on those that receive high precipitation/irrigation rates. Irrigation water should be tested because many sources, especially greywater, can be high in sulfur.

When sulfur is likely to result in improved plant health, it is commonly added in conjunction with nitrogen as ammonium sulfate and/or with potassium as potassium sulfate. Micronutrients (zinc, iron, manganese, and copper) are also often applied as sulfate salts, although the rates may not supply enough sulfur to meet all needs. Gypsum (calcium sulfate) and Epsom salt (magnesium sulfate) also contain sulfur, although these are usually applied for reasons other than sulfur nutrition. Sulfur coated urea or elemental sulfur are good sources for steady release of sulfur over the growing season, which is especially helpful to soils prone to leaching. Excesses are not typically environmental or plant health concerns, although these are wasteful of resources and, as with all soluble fertilizers, can be a contributor to excessive salts/fertilizer burn.

4.9.2 Calcium and Magnesium

Although calcium and magnesium are essential to plant function, they are ubiquitous in the environment and, thus, rarely have documented deficiencies. Soil and irrigation water tends to be very high in these nutrients. Although much of the calcium and magnesium is found in solid form in soils, equilibrium chemistry assures that there is ample found dissolved in soil solution. When deficiencies do occur, they are typically on acidic sandy soils with no or minimal irrigation or with very pure irrigation water. Testing for and maintaining an appropriate pH with dolomitic limestone, which contains both of these nutrients, is generally enough to provide for healthy plant growth as both pH and nutrition is managed. Excess amounts of these nutrients are common and not typically concerning, although unwarranted applications are wasteful and potentially detrimental due to excessive salts.

4.10 Micronutrients

Micronutrients are typically found in relatively low concentrations in plant tissues, although they are just as essential for proper turfgrass health as macronutrients. They play a variety of roles in turfgrass biology, including photosynthesis, enzyme catalysis, protein synthesis, and a wide variety of other physiological activities and structural components. However, they are often found in ample concentrations in soils and turfgrass rarely shows response to their application. For example, nickel and molybdenum are needed in extremely minute quantities and there are no documented deficiencies in field grown turfgrass. Although rare, deficiencies of the other micronutrients have been documented. These are far more likely to occur in sand-based fields with low organic matter.

Generally, there is ample chloride in irrigation water and soils. It is also included with the most common source of potassium fertilizer which is “potash” (potassium chloride). Chloride deficiencies are more likely to occur in non-irrigated, high rainfall areas when potassium chloride fertilizer is not utilized.

Boron, zinc, manganese, copper, and iron are more likely to be deficient in alkaline soils due to poor solubility. In the past, iron chlorosis (yellowing) was somewhat common. However, modern varieties have been bred to mostly avoid chlorosis, especially with Kentucky bluegrass. Regardless, it is common to do a foliar iron spray a few days before high visibility sporting events. This doesn't necessarily improve plant health, but the practice typically results in visual response of greening.

Rates of micronutrient fertilizers are relatively low and should follow label recommendations. It is relatively easy to cross over from deficient to toxic given the fact that these are needed in such low quantities. This is especially true for copper and boron. In most cases when one or more micronutrients are needed, a single application annually will suffice. However, in severely deficient situations more frequent, generally foliar, applications are warranted. This is especially true for newly established sand-based fields.



Greenup on the right side of field 24 hours after a micronutrient spray on a low organic matter, sandy soil field. *Credit: B. Hopkins.*

4.11 “Natural” and “Organically Certified” Fertilizers

In some cases, communities or organizations require/prefer to use “natural” and/or “organically certified” fertilizers. However, these terms are often the subject of misinformation. It is important to realize that, despite popular opinion, these are not necessarily healthier with respect to human health. For example, arsenic is a natural compound, yet is highly toxic to humans.

In terms of plant nutrition, an atom of a nutrient is chemically identical regardless of source. For example, the fertilizer with greatest volume of use is urea. It is manufactured using nitrogen gas from the atmosphere that is converted to ammonia using natural gas in the Haber-Bosch process, which is then combined with carbon dioxide. The nitrogen in this and the urea molecule itself are identical in every way to the urea that is naturally produced in animal livers. Either source is beneficial to plants and pose no risk to plants or animals (including humans) when used properly. However, manufactured urea requires the use of non-renewable resources. Conversely, low nitrogen analysis fertilizers require more fossil fuel use for transportation in order to supply the same amount of nitrogen (e.g., urea is 46% nitrogen, whereas most of these alternative fertilizers are less than 10% nitrogen). Regardless, demand for these products exists and it is important to understand their properties and the management practices needed for their proper use.

The nutrients in any fertilizer, including natural and organically certified fertilizers, must be factored into the overall nutrient management planning. In addition, some regulatory requirements (e.g., phosphorus prohibitions) must be adhered to regardless of fertilizer source.

Labeling of fertilizers as “natural” is not subject to regulatory oversight. The definition is “existing in or caused by nature.” In reasonable consideration, so-called natural fertilizers tend to include protein-rich plant or animal wastes. These tend to have the benefit of including a broad spectrum of nutrients that are generally released slowly, mostly during the summer when temperatures drive high decomposition rates. These materials tend to have high carbon content, which can be beneficial if organic matter building of the soil is desired. This is typically helpful, although not in sand-based fields where excessive organic matter can result in reductions in drainage and increased compaction potential. Some of these materials, especially those with high fiber content, can be a source

of pathogen stimulation. Typically, the main disadvantage is that the low concentration of mineral nutrients in these sources correlates to higher costs of the fertilizer, as well as transportation, storage, and application.

Many sources of these materials exist, such as:

- Animal manures (uncomposted and composted wastes).
- Animal industry by-products (bone, blood, feather, fish, etc. meals).
- Green manures (plant-based composts).
- Liquid cocktails (manure extracts, seaweed extracts, compost teas, etc.).

By contrast, “organically certified” fertilizers are any materials approved by the [Organic Materials Review Institute \(OMRI\)](#). These can include any of the products listed previously, including those that are derived from carbon-based materials, typically animal and plant waste materials, but also can include inorganic salts (e.g., calcium carbonate, calcium sulfate, potassium sulfate) and many other materials. OMRI certifies products rather than providing generic certifications for chemicals. For example, one potash source may be certified for organic use after the review and labeling process while another, despite being chemically identical, will not be certified for organic use if it has not gone through the certification process.

Sports field managers should carefully review and evaluate each commercial product before use. Because considerable variation exists in the physical and chemical properties of the various fertilizers, they should be carefully evaluated when used as part of a nutrient management program. The evaluation criteria should include nutrient content and quality, release rates, cost, ease of handling and distribution, offensive smell or odor, infiltration rate, and any tendency to stain shoes and clothing.

4.12 Predicting/Identifying Nutrient Deficiencies

Predicting or identifying nutrient deficiencies can be done using the following tools:

- Visual assessment
- Soil analysis
- Plant tissue analysis
- Fertilizer response evaluation

4.12.1 Visual Assessment

Visual assessment is a valuable first step for identifying nutrient deficiencies in plants. However, these symptoms

are less specific in turfgrass compared with most other types of plants. It is also noteworthy that when avoiding urea application under hot, humid, and/or windy conditions there is often “hidden hunger” with no visible symptoms.

In general, nutrient deficiencies cause a reduction in chlorophyll, which results in chlorosis (yellowing) that can progress to necrosis (dead tissue). In many plants, the various nutrients show distinct patterns in terms of age of tissue and type of chlorosis that help in deficiency identification. However, in turfgrass, mowing and relatively thin shoots can make it difficult to see these patterns.

In most instances, when chlorosis occurs, it is usually a result of nitrogen deficiency, although sulfur, iron, and potassium deficiencies are also relatively common causes. Deficiencies in most of the other nutrients can also cause chlorosis, although these instances are rare. It is somewhat common for soils that are excessively wet for prolonged periods to exhibit chlorosis due to problems in soil chemistry. Phosphorus deficiencies are an exception. If severe, these deficiencies result in plant tissues turning dark green or even red/purple. Visual assessment needs to be coupled with the other assessment tools to effectively diagnose deficiencies.

4.12.2 Soil Analysis

Soil analysis is a tool that can help customize fertilizer needs in turfgrass with estimates of nutrient availability predicting plant response to an applied nutrient. Although a reliable tool, soil testing is not a perfect science. Some nutrients have been more thoroughly researched than others and some tests are more highly correlated to plant response than others (Table 3). The most reliable tests indicate native soils high in silt and clay are somewhat resistant to change in nutrient and pH levels, and therefore soil testing may only need to be conducted every one to two years (and no less than every five years), unless monitoring corrective action (such as liming an acid soil). Sand-based soils are less resistant to change in nutrient status or pH, and thus may require relatively more frequent sampling such as once per year.

For soil analysis to be effective, accurate and representative samples are needed. Each field should be sampled separately, with about 12-15 cores per sample (typically about a pint in total volume). Within a field, if there are areas that are behaving differently, these samples should be segregated. Laboratories and other organizations/businesses

dealing with soils can provide sampling instructions. Sampling depth for turfgrass is generally recommended at 3” to 4”. It is imperative to take separate samples from areas with varying soils and/or management. In addition, soil samples should not be collected following fertilization.

A laboratory with a record of sound QA/QC should be selected to conduct soil testing. Laboratories can provide documentation of their data quality, such as participation in proficiency testing. (See the [North American Testing Proficiency Program](#) for more details.) It is a good management practice to track data trends over time, which is difficult to do if switching soil test methods or laboratories because they often use different methods thus make comparisons difficult. In addition, it is important that the same phosphorus extraction method—the most common are the Sodium Bicarbonate, Bray P1, and Mehlich 3—is used for consistency in soil test interpretations relative to nutrient concentrations.

In general, soil testing is not extremely helpful for nitrogen and sulfur because the inorganic forms tested for (nitrate and, in some cases, ammonium for nitrogen and sulfate for sulfur) are very transient in their soil concentrations as they are regularly changing between plant available and unavailable forms due to rapid plant/microbial chemical transformations. Additionally, the amount of these nutrients released from soil organic matter is very difficult to predict. As such, it is generally best to develop a nitrogen and sulfur management plan based on reliable research studies and previous results and then use soil and plant tissue analysis to fine-tune the recommendations. For example, adjustments to the fertilization plans can be made if unusually high concentrations exist in the soil, plant tissue, and/or irrigation water.

The remaining nutrients are managed mostly by soil test values as the starting point. For most of these, a correlation exists between the soil test and probability of a positive plant response—with high likelihood of response at low soil test values with decreasing likelihood of response as soil test values increase. These correlations are relatively good and significant research exists for phosphorus and potassium. However, minimal data is available in turfgrass for the other nutrients, though there are reasonable correlations for calcium, magnesium, zinc, manganese, copper, boron, and chloride for other plants (mostly crops). These give us some basis for judgment, although the confidence in interpreting results is not as high as with phosphorus and potassium. Nevertheless, there is a slim

chance of a positive response to these nutrients if the soil test values are high.

Plant tissue analysis, as discussed below, is an additional tool that can be used to make decisions on these nutrients but it is rare to see responses in sandy soils with low organic matter. Iron is unique, as the correlations for soil testing are very poor. It can also be difficult to obtain clean tissue samples, as dust is very high in iron concentration. Rather, soil pH and plant species/variety selection are used to help manage for iron.

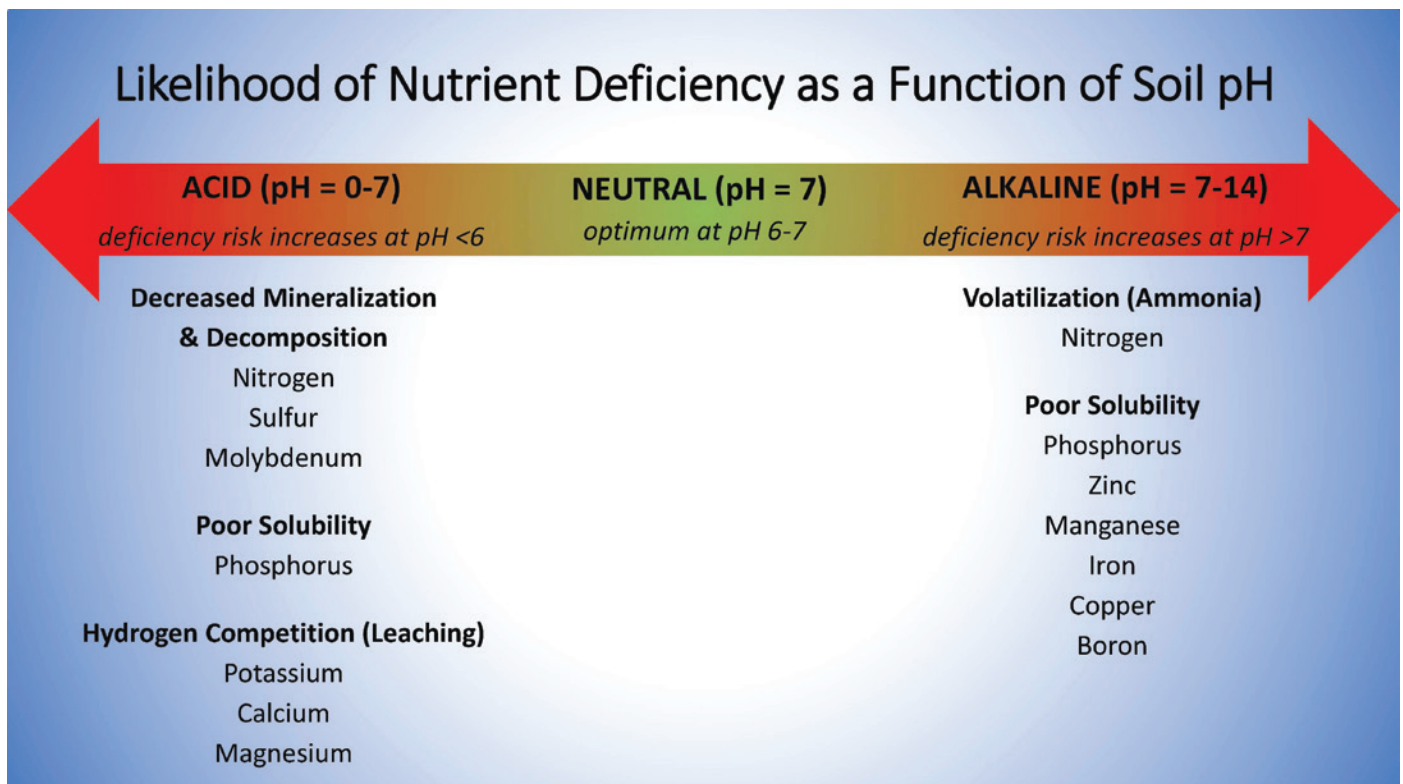
Soil pH is a measure of hydrogen ion (H⁺) activity (“active acidity”). The pH scale is 0 to 14 with 7 being neutral. Values below 7 are acidic, and values above 7 are alkaline. Soils tend to range from pH 4 to 8. The optimal soil pH for nutrient solubility is approximately 6 to 7. However, turfgrass is commonly grown successfully from pH 5.5 to 8.4.

Alkaline soil can result in poor solubility of plant nutrients. It is generally not practical or affordable to lower the pH as these systems are highly resistant to change due to carbonates in irrigation water (hard water) and in soil (limestone). Rather, the nutrient requirement is slightly higher and managers need to be aware to watch closely for deficiencies of these other nutrients.

Acidic soil also has nutrient solubility issues, as well as toxicities of aluminum and/or manganese (see Table 3).

These results are variable by soil, with some worse than others. Acidic soils can be neutralized with limestone (calcium and/or magnesium carbonate), burnt lime (calcium oxide), hydrated lime (calcium hydroxide), or similar, based on a Buffer pH soil test. The quality of the liming materials (calcium carbonate equivalent and fineness of grind) also needs to be factored in, as well as ease of handling and cost. Whenever possible, soil pH should be adjusted prior to establishment, as preplant incorporation greatly accelerates the neutralization of the acidity throughout the root zone. Once turfgrass is established, the ideal time to apply lime is in conjunction with core cultivation, which helps to move the liming material into the soil. Cooler temperatures help to minimize risk of foliar burn. Standard lime applications are usually suitable just about any time of year as long as they do not exceed 50 lbs/1,000 ft². Extremely acidic soils may require multiple applications over multiple seasons to sufficiently raise the pH. It is best to have a liming program with smaller annual applications to maintain pH at a reasonable level rather than waiting until it drops to a toxic level and then attempting a rescue.

Soil tests may include the following: organic matter, salinity, sodicity, texture, cation exchange capacity, and sand size distribution. A soil textural analysis (percentages of sand, silt, and clay) is important as soil texture can



Source: Hopkins et al. 2020.

impact water and nutrient holding capacity, as well as irrigation, drainage, and cultivation. Both texture and sand size distribution are vital for proper construction and maintenance to meet ASTM F-2396 specifications of sand-based root zones.

Organic matter (OM) is not only a source of nitrogen and sulfur, but also all other nutrients. In addition, organic matter increases nutrient and water holding capacity. Organic matter is often one of the main measures of soil health. Turfgrass is relatively efficient at creating organic matter over time, which is beneficial for the reasons above and as it stores carbon away from the atmosphere. Despite these benefits, organic matter can be detrimental to compaction potential and infiltration rate in sand-based fields.

Salinity and sodicity are important considerations where greywater is used for irrigation, as well as in certain arid zones where irrigation waters/soils can be natively high in salts. It is important to understand that there can be an overall salt problem (salinity) and/or specific ion toxicities (sodium, chloride, and boron are the most common) when irrigating with greywater.

When a soil test shows that the electrical conductivity used to measure salts is above 4.0 dS/m, the soil is considered “saline” although plants can experience stress before the salt concentration in soil gets this high. In this case, it does not matter which salts are present—as all contribute to the overall salt effect. Plants need salts for their metabolic processes and while all fertilizers are salts, excessive salts in direct contact with plant tissues will burn the foliage. In the soil, salts bind to water so strongly that plants can desiccate even when there is ample soil moisture. Saline soils are corrected by ensuring adequate drainage followed by irrigating to excess with reasonable quality water to move the salts below the root zone.

Specific ion toxicities occur when nutrients and other chemical elements are excessively high. Chloride and boron are both essential plant nutrients, but they are sometimes present in excessive amounts, usually in the irrigation water, which can kill plants. Again, soil testing can identify these toxicities. These are potentially corrected through leaching below the root zone.

Similarly, sodium is a beneficial nutrient (not essential) found in all soils and most irrigation waters. It can become a problem when its ratio relative to calcium and magnesium is high, creating a “sodic” soil. This is relatively more

common in arid regions, but also with some reclaimed irrigation waters. Sodic soils have an Exchangeable Sodium Percentage $\geq 15\%$ and/or a Sodium Adsorption Ratio ≥ 13 , but preventative action should be taken before reaching these levels. Sodicty results in the soil structure being destroyed as clay-based aggregates disintegrate, which is not a problem in sand-based fields. Sodic soils are remediated similar to saline soils except that a soluble calcium source (most commonly gypsum; limestone should not be used in alkaline soils) needs to be applied prior to leaching.

4.12.3 Plant Tissue Analysis

Visible plant symptoms and soil testing can offer helpful clues in diagnosing nutrient deficiencies but can also be confusing and misinterpreted. Tissue testing is an effective way to determine precisely what nutrients are in plant tissue at a particular point in time. While that data is beneficial, it does not necessarily reflect why the nutrient is at a deficient or excessive level. It is important to pair tissue testing with soil testing data to best determine nutrient management strategies and closely follow the lab’s guidelines for how to sample and prepare the tissue samples to get meaningful results.

Tissue testing can help to adjust nutrient management programs in these ways:

- Confirm a suspected nutrient deficiency or toxicity.
- Monitor plant nutrient concentrations for sufficiency.
- Pair tissue tests with soil tests for troubleshooting.

Plant tissue samples can be easily taken in turfgrass from fresh mowed clippings—taking them from multiple locations throughout the field. However, careful cutting with clippers may be needed when sampling small areas with visual symptoms for comparison to areas that appear to be healthy. (Soil samples should be taken from the same areas for comparison.) Samples should not be taken within a few days of a fertilizer or amendment application. For micronutrient analysis, plant samples should be rinsed lightly and quickly to remove any dust or soil particles and then air dried or oven dried at temperatures below 150°F) before being placed in clean paper bags and sent to the laboratory.

For diagnostic samples, plant tissue samples should be collected as soon as symptoms appear. Plants showing symptoms of severe deficiency are often the most difficult to interpret correctly, since a deficiency of one element may result in deficiencies or excess accumulation of other elements if uncorrected. Plants under prolonged stress

of any kind (temperature or moisture extremes, pests, flooding, mechanical damage, etc.) can have unexpectedly high or low nutrient levels due to the stress. As with soil testing, plant tissue analysis is a useful tool but is not always certain in its findings.

4.12.4 Fertilizer Response Evaluation

Another tool for managing nutrients, especially for correcting suspected, but unconfirmed deficiencies is the application of fertilizers to small test areas to observe whether greenup occurs. Application of a complete fertilizer containing all of the nutrients can help determine whether the problem is nutritional or related to some other stress. Application of individual or paired nutrients can help isolate which nutrient is deficient.

4.13 Fertilizer Types

4.13.1 Liquid vs. Dry

Turfgrass is unique among most fertilized plants. Each individual plant has a very narrow cylinder root contact with soil. As such, uniformity of fertilizer application is very important.

Dry fertilizers are relatively inexpensive, especially when purchasing common forms in bulk from agricultural suppliers. However, these can result in poor nutrient uniformity. Fertilizers with a high size guide number (SGN) (i.e., larger particle size) result in some plants getting excess fertilizer and others getting none. Conversely, fertilizers with a smaller SGN more uniformly deliver nutrients to all plants.

Liquid fertilizers, when properly applied using an accurately calibrated sprayer, can provide improved nutrient distribution—with every plant receiving nearly identical rates. However, liquid fertilizers do have some disadvantages. The liquid has direct and immediate contact with the shoots, which can have a high burn potential if the rate is high and/or the environmental conditions are hot, dry, and/or windy. Liquids can also have chemical reactions in spray tanks, hoses, nozzles, and other equipment. This can result in plugging that can be very costly to clean. This is particularly a problem with phosphorus due to its low solubility and highly reactive nature with calcium, magnesium, and other cations in the water and/or fertilizer blend. If the liquid is being injected into the irrigation system, distribution uniformity problems related to irrigation water distribution may arise. Finally, liquid fertilizers tend to be more costly if they are shipped already mixed, although some products, such as

urea, ammonium sulfate, potassium chloride, etc. can be purchased inexpensively in dry form and then dissolved.

4.14 Nutrient Application Programs and Strategies

Stewardship that considers the impact of nutrient applications with respect to the environment, economy, and society, includes the following “4R’s”:

- Right fertilizer sources
- Right rate
- Right timing
- Right placement

Applying a quick-release fertilizer at high rates on a hot, windy day near impervious surfaces is a good example of ignoring the 4R’s rule. This example represents a waste of natural and facility resources, results in contamination to the environment, and may result in poor plant health as well. Poorly managed fertilizer usage has resulted in some instances of serious environmental contaminations and adoption of regulatory requirements by many state or local agencies. Sports field managers need to be good environmental stewards to avoid further problems and additional regulation. A one-size-fits-all approach to nutrient application is not possible, given all the variables of turfgrass species, sports, traffic intensity, soil, climate, budget and equipment available. Some strategies, such as [Minimal Level of Sustainable Nutrition](#) strategy, can be used. Using the information presented in this chapter and consultation with Extension specialists can help managers develop an appropriate site-specific nutrient management plan.

4.15 Fertilizer Application Equipment and Calibration

Dry fertilizers are typically spread with a broadcast spreader (or a drop spreader in rare situations). Liquid fertilizers are applied with a sprayer or injected into the irrigation system.

The selection and calibration of application equipment is an important aspect of nutrient management, as not all fertilizers can be applied with every spreader. For example, coated fertilizers can crack, and their control release properties can be destroyed when handled roughly, such as with certain drop spreaders equipped with an agitator.

Accurately calibrated sprayers and spreaders are essential for proper fertilizer applications. Incorrectly calibrated equipment can result in an application of too little or



Incorrectly calibrated equipment can cause fertilizer burn. *Credit: B. Hopkins.*

too much fertilizer, resulting in deficiencies or toxicities, excess costs, and greater potential for nutrient pollution. In keeping with the BMPs for equipment washing, spreaders should always be thoroughly cleaned after each use to remove salt residue that corrodes metal parts of the spreader. Many universities have publications on proper calibration methods.

4.16 Nutrient Management Best Management Practices

- Soil test every one to two years (and no less than every five years).
- Collect representative soil and plant tissue samples, and separate samples with varying soils and/or management. Send to a reliable laboratory for analysis. Track soil test results over time and identify any trends.
- Fertilizers should be spread evenly using a turf-grade blend of uniform particle size with a low SGN number or with liquid applications with good uniformity.
- Calibrate fertilizer application equipment regularly.
- Apply nitrogen according to the sources, rate, and timings found as needed and following regulatory requirements.
- Any late season applications should be made at an appropriate time such that the fertilizer can be taken up before the end of the growing season and in keeping with any state or local regulations.
- Account for nutrients in some irrigation waters, especially greywater.
- Use a fertilizer containing phosphorus only when indicated by a soil test or during turfgrass establishment, following any applicable phosphorus fertilizer regulations.
- Phosphorus and potassium should be applied based on soil test recommendations.
- Apply sulfur at 10-30% of the nitrogen rate unless it is natively high in the soil and/or irrigation water.
- If using organically certified fertilizers, ensure that the nutrients are factored into the overall nutrient management planning, in addition to adhering to any nutrient regulations.

- Use plant tissue testing to confirm a suspected nutrient deficiency or toxicity and to monitor plant nutrient concentrations.
- Pair tissue tests with soil tests for troubleshooting.
- Conduct fertilizer response evaluations if needed to help determine if turfgrass issues are nutritional or related to some other stress.
- Keep accurate nutrient application records and conform to any local or state record-keeping regulations.
- Prevent fertilizers from being deposited onto impervious surfaces.
- Do not apply fertilizer when heavy rains are likely.
- Do not apply fertilizer on established turfgrass stands until greenup and active growth begins.
- Do not apply fertilizer to severely stressed turfgrass.
- Do not apply fertilizer to frozen ground.
- Follow label guidelines for the need and amount of irrigation following fertilization.

4 CULTURAL PRACTICES: IRRIGATION

Annual precipitation amounts vary greatly. The timing and amount of precipitation will change year to year and deviations from the average cannot be reliably predicted. Turfgrass transpirational water demands can exceed rainfall on a seasonal basis, which can lead to water stress, poor plant growth, dormancy, and, in extreme situations, death of established turfgrass. Water stress is amplified in very sandy native soils and sand-based sports fields with inherently low water holding capacities. Therefore, rainfall is typically supplemented with irrigation during the summer and early fall months to maintain adequate soil moisture, particularly during periods of drought.

Although irrigation may be needed, water conservation is also vital for socioeconomic and environmental reasons. As committed environmental stewards, sports field managers regularly conserve water while maintaining healthy, dense turfgrass necessary for the safe uniform surfaces on which athletes play. Balancing these demands with natural

resource conservation goals takes experience, training, and a comprehensive understanding of turfgrass management in relation to practical water management, including sound irrigation practices.

Irrigation is used to supplement seasonal water deficiencies to meet plant needs. Ideally, irrigation systems should be designed and managed to accurately and evenly apply just enough water to meet the needs of plants in order to maximize water conservation. Poorly designed and/or managed irrigation systems can lead to under- and over-watering, which can affect plant health, increase pest and disease pressure, waste water, and ultimately lead to unnecessary surface runoff or leaching.

Irrigation may have other uses in addition to meeting the turfgrass system's physiological needs, such as reducing surface hardness to lower the potential of athlete injury; infield management on baseball/softball fields; watering in fertilizer and pesticides.



Zoned irrigation. Credit: Z. Holm.

4.17 Irrigation Water Sources

Irrigation water must be dependable, reliable, and of sufficient quantity and quality to accommodate turfgrass grow-in needs and ongoing maintenance. It must also pose no threat to public health. Irrigation water can come from several sources:

- Ponds, lakes, or stormwater detention ponds
- Groundwater from wells
- Greywater sources
- Municipal sources
- Any combined supplemental sources from rainwater and stormwater collection

Whenever possible, alternative water sources should be used to conserve freshwater drinking supplies as the routine use of potable water is not a preferred practice. Municipal drinking water should be considered only when no acceptable alternatives exist. Greywater is defined as any water that has been treated after human use and is suitable for limited reuse, including irrigation. Such water is also referred to as reclaimed, waste, and effluent water. Using greywater may also be part of nutrient reduction strategies to meet total maximum daily load (TMDL) goals in impaired watersheds.

4.18 Irrigation Water Quality

Irrigation water should be evaluated to determine its suitability for irrigation and plant growth. Some water sources (especially greywater or water from storage and retention ponds) should be tested regularly to ensure that quality stays within acceptable limits to protect soil quality and turfgrass performance. Water suppliers, especially those providing greywater and municipal water, are often required to do testing to show that water is safe for human contact. These tests often contain information on nutrients, toxins, and salinity. Test results are generally available upon request. For other sources, water samples can be taken by the manager and submitted to a credible laboratory for analysis.

4.18.1 Nutrients and Toxicities

Nutrients and other elements dissolved in irrigation water should be accounted for in nutrient management programs to avoid toxicities and over-fertilization, resulting in plant health problems and/or environmental contamination. Most irrigation sources are derived from water that has passed through or over soil and, thus, has picked up various minerals. Calcium and magnesium

carbonates (hard water) are extremely common and found at relatively high concentrations in most irrigation sources. Sulfur, chloride, boron, and, less commonly, nitrogen and potassium can also be high enough to significantly supply plants with these nutrients. Phosphorus is dissolved in some waters to the point of being an environmental concern, but it is very rare for it to be found at levels sufficient to provide for plant needs.

Specific ion toxicities occur when nutrients and other chemical elements are excessively high. For example, chloride and boron are both essential plant nutrients, but they can harm plants if they are present in excessive amounts in irrigation water. When these nutrients are present in significant quantities in irrigation water, the fertilizer rates for each nutrient can be reduced partially or completely. If such nutrients are present in the soil in excess amounts, leaching by irrigating to excess with reasonable quality water may be needed to move these nutrients below the root zone. Careful monitoring and managing these issues may be necessary depending on the timing and amount of local rainfall. Irrigation water quality and soil testing are essential BMPs to help identify these issues.

4.18.2 Salinity and Sodicity

All nutrients and many other chemical elements are “salts.” In addition to needing individual nutrients, plants need salt for proper water regulation. However, salt has a high affinity for water and excess in the soil desiccates plants—even when the soil is saturated with water. This requires salinity management.

Sodium is not an essential nutrient but is considered to be part of the salt complex in soil that can be beneficial to plants. However, soil aggregates containing clays can be destroyed when the salt concentration is high relative to calcium and magnesium. This requires sodicity management.

Some irrigation waters, particularly greywaters, can be saline and/or sodic (Harivandi, 2007). This is relatively more common in arid regions, but groundwater sources in shoreline areas might also be affected due to saltwater intrusion.

Irrigation water quality analyses (as well as routine soil testing) can be used to help identify plant health problems related to salinity and sodicity. Salt tolerant species and/or varieties may need to be used, along with soil remediation management, if irrigation water is saline.

Recommendations for correcting salt-affected soils include the following:

- Alternative irrigation water sources and/or blending sources to improve quality.
- For saline soils, maintain soil moisture at relatively high levels, especially during hot periods.
- Provide for drainage. (Salts must have somewhere to go.)
- For sodic soils, add a soluble calcium source (e.g., gypsum) before leaching.
- Leach the salts below the root zone using reasonable quality water.
- Retest the soil and water frequently.

4.19 Irrigation Systems

Sports field irrigation systems are designed to be either in-ground or portable systems. In-ground irrigation systems are the most efficient and convenient method and allows for good uniformity when properly designed, installed, and maintained. While the initial expense is typically greater than for portable systems, the increase in efficiency conserves water and reduces labor costs. Portable systems (typically a large water cannon) can be used for rescue during drought or when the main system is off-line during construction/repair. Portable irrigation systems typically require massive flow rates and manual operation and tend to have poor uniformity.

Design and Installation: A properly designed irrigation system requires a professional to design and maximize the distribution uniformity (DU). Architects should require a minimum DU of >75-80%. An irrigation system must have:

- Adequate and consistent water pressure.
- Properly sized pipes and irrigation zones to provide adequate flow rate.
- Efficient sprinkler heads and correct nozzles.
- Head-to-head placement of sprinkler heads for 100% overlap.

Incorporating the use of “smart” computerized irrigation controllers can significantly improve water conservation and system performance. The cost and availability of these controllers has become very reasonable. Water savings should more than cover the cost of purchase and installation. These controllers provide many advantages, including remote adjustments of irrigation as needed. The controller should account for:

- Weather conditions (evapotranspiration as impacted by temperature, solar intensity, wind speed, precipitation, and humidity).
- Soil characteristics (water content and/or potential, water holding capacity).
- Irrigation system parameters (application rate unique to each zone).

The controllers should be frequently monitored and adjusted for seasonal changes in turfgrass growth, rooting depth, and variable environmental conditions. Smart controllers typically access evapotranspiration (ET) data as part of their computerized decision making. Weather stations close to the field better inform smart controllers with more accurate information on evapotranspiration. Soil moisture sensors placed in multiple locations also aid in informing smart controllers.

Irrigation Audits and Maintenance: Properly working systems are necessary for efficient irrigation. Irrigation efficiency degrades with time as sprinkler head positions are altered, nozzles wear, and leaks develop. Irrigation audits should be conducted regularly by field staff or outside contractors to assess the system function, ensuring that the irrigation system works reliably and



Master valve and flow sensor installation. Credit: B. Polimer.

cost effectively. Some regions have water organizations, university Extension, or other groups that often sponsor programs to help with these assessments. The [Irrigation Association](#) has published irrigation audit guidelines. Irrigation audits measure DU and Scheduling Coefficient, which is the measurement of the average water applied to the driest, most critical parts of an area under test and compares that with the average.

Routine checks of the irrigation system should be conducted to ensure that the system is working as it should be, especially if the DU drops below the optimum. These inspections include looking for broken sprinkler heads, misaligned heads, sunken heads, water pressure irregularities, leaks in the lines or heads, and improper/incomplete rotation. In properly designed, installed, and maintained systems, sprinkler heads specifically designed for use on sports fields are not a hazard to players.

4.20 Irrigation Decision-Making

Irrigation decision making starts with a rudimentary understanding of soil-plant-water relations and then determines how often (frequency) and how much (rate) to apply. An irrigation system should be operated based on the water needs of the turfgrass and not on a calendar-only approach. Water requirements of established turfgrass stands depends on the species, soil type, soil moisture, weather conditions, and time of year.

4.20.1 Understanding Soil-Plant-Water Relations

Water Infiltration: Irrigation systems should not apply water faster than the soil can take it in (infiltration rate). Soil texture impacts water infiltration (estimates

shown in Table 4). However, compaction greatly hinders infiltration rates and lowers these values. Cultivation and, when possible, topdressing are critical to enable adequate infiltration rates (and to provide for air exchange). Most soils are subject to compaction, although some have higher potential than others. Sand-based fields that are precisely built and maintained to meet ASTM specifications are resistant to compaction, but even slight increases in clay and silt above these specifications results in a field that is highly prone to compaction. For example, sandy loams are among the soil textures with the highest compaction potential with reduced infiltration rates.

In addition to soil texture, soil organic matter impacts infiltration, improving water and nutrient holding capacity. However, if soil organic matter is elevated in sandy fields, it can greatly decrease water infiltration rates. Proper cultivation and topdressing can help moderate soil organic matter.

Furthermore, soils, especially sands, are prone to developing localized dry spot (LDS) due to hydrophobicity when the soil repels water after extreme drying. In these cases, water infiltration rates are zero, with water running off high spots and accumulating in low areas and/or running off-site. LDS is corrected with treatment with a high-quality wetting agent labeled for turfgrass use.

Water Holding Capacity: Once water infiltrates the soil, it is either held in storage or leaches below the root zone. Water holding capacity is a function of soil texture and organic matter. Clays have a high affinity for water, with silt and sand significantly less. As such, textures with high clay percentages tend to have high water

Table 4. Available soil moisture and infiltration rates for common soil textures when the soil is not compacted.

Soil Texture	Soil Type	Typical plant-available moisture per foot of soil depth (inches)	Infiltration rate (inches h ⁻¹)
Light, sandy	Coarse sand	0.25 – 0.75	Fast (0.5 – 6+)
	Fine sand	0.75 – 1.00	
Medium, loamy	Loamy sand	1.10 – 1.20	Moderate (0.25 – 0.5)
	Sandy loam	1.25 – 1.40	
	Fine sandy loam	1.50 – 2.00	
	Silt loam	2.00 – 2.50	
Heavy, clay	Silty clay loam	1.80 – 2.00	Slow (0.1 – 0.25)
	Silty clay	1.50 – 1.70	
	Clay	1.20 – 1.50	

holding capacity. Soil organic matter is also an important component of water holding capacity.

In order to understand irrigation needs, it is important to understand the rule of halves, which is:

- About half of an “ideal” soil is comprised of soil pores that hold some combination of water and air.
- About half of this water, the gravitational water, is drained after the soil pores are saturated within ~24 hours (less time for sandy soils with little water holding capacity and more time for compacted soils).
- About half of this water is plant available, with the other half is held so tightly in the soil that plants are not able to utilize it.
- About half of the plant available water can be used (the depletable water) before plants start encountering moisture stress.

Ideally, the soil moisture is replenished with irrigation after the depletable water is utilized. Also, it is important to realize that the ideal soil isn't common in the urban landscape, especially with compacted soils, but this rule of halves enables a close approximation of irrigation needs.

Evapotranspiration: Stored water is lost through ET, which is the combined transpirational loss of water from plant shoots and evaporative water loss from the soil. The ET increases as solar intensity, temperature, and wind speed increase and relative humidity decreases. In general, water lost to ET should be replaced through precipitation and/or irrigation, although plants are able to survive to varying levels if water deficits exist temporarily.

In general, it is common to have maximum ET rates of about 0.25” to 0.33” of water loss per day. ET losses during

cool times of the year can approach zero. Thus, it is vital to understand these losses in order to efficiently irrigate. ET rates can be gathered from various government, university, and private websites or with onsite weather stations.

Water Needs Vary by Species/Variety: There are differences between turfgrass species, and varieties within species, with regard to the amount of water needed to achieve optimal health and function. In general, the largest difference exists between cool and warm season species, with the latter tending to require relatively less total water.

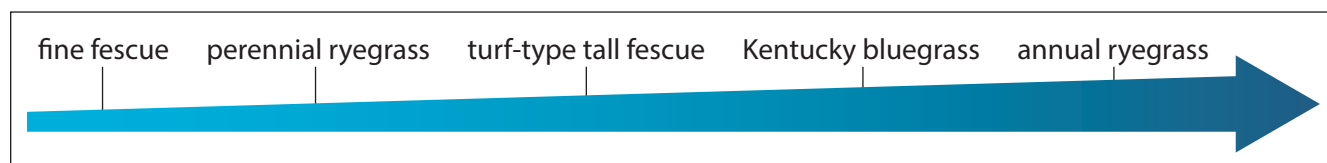
Cultural management practices or environmental factors that result in a significant change in leaf area or shoot density of a given species may have a significant impact on the relative rankings compared to other species.

For more information on selecting the best turfgrass species/variety for site specific conditions, including irrigation needs, see the Turfgrass Establishment chapter. Selection should be based on water efficient/drought resistant evaluations provided by the National Turfgrass Evaluation Program, Turfgrass Conservation Alliance, and the Alliance for Low-Input Sustainable Turf.

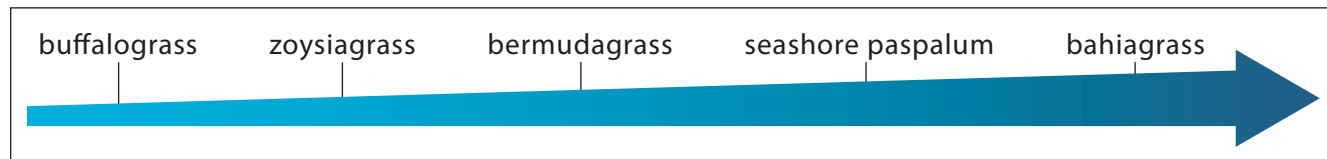
Root Depth: The effective root zone is defined as the depth to which a large majority of the root system exists. This changes throughout the season and with maturity. Plant health status also impacts root depth, with poor health potentially resulting in a poor root system. For example, root-attacking insects and nematodes and deficiencies/excesses in nutrients (especially N and P) affect root depth.

Kentucky bluegrass is a common species in cool season and transition zone areas. Much like other cool season grasses, it is relatively shallow rooted and water inefficient.

Although there is variability due to a host of situations and circumstances, within cool season species, the general order of water requirements, from least to greatest is as follows for cool season grasses:



Within warm season species, the general order of water requirements from least to greatest is as follows:



In contrast, hybrid bermudagrass is the most common sports turfgrass species used in warm season areas. It is relatively water efficient as it has deep and prolific rooting and relatively low water use rates. Its effective root zone is approximately double that of Kentucky bluegrass, which allows for more efficient water use.

A soil's water holding capacity within the effective root zone is used to estimate the soil water holding reservoir available to the plant. Irrigation water should be applied to the depth of the root zone or slightly below. Water that passes below can wick back upward, but water is wasted if leaching is excessive.

4.20.2 Irrigation Frequency

In general, turfgrass should be irrigated as infrequently as possible without causing drought stress injury. This produces higher quality turfgrass while saving water and money.

Approximately half of the total water holding capacity of the soil is "plant available." Approximately half of the plant available water can be utilized before plants begin experiencing moisture stress. For example, a silty clay loam soil with 2% organic matter is determined to have 4" of total water holding capacity in one foot of soil. According to the rule of halves, about half of this is plant available. Of this 2" of plant available water, about half (1") of this is the depletable water that can be utilized before irrigation is needed. However, short-mowed turfgrass roots in sports field root zones rarely exist down to one foot. In this case if, for example, the effective root zone is 6" then only 0.5" can be lost to ET before irrigation is needed in order to avoid stress. In contrast, a loamy sandy soil with very little organic matter could easily have half of this amount.

Some older systems utilize an irrigation clock that runs daily or multiple times a day. This calendar-based approach is not good for grass health, surface playability, or environmental stewardship. Rather, soil type, root depth, and weather should determine irrigation frequency. Depending on weather, sports field managers may irrigate every 10 to 20 days in the spring and every two to five days in the summer without any negative impacts.

Three basic approaches are used to determining irrigation frequency. The first is visual, with daily or multiple times daily in-person evaluations. This is done by watching the grass and irrigating once the grass appears to be stressed (dull greyish-bluish color and doesn't bounce back when stepped upon). This approach can be a problem if the grass slides into stress immediately prior to an event. This

visual approach is relatively more common in areas where irrigation is not as commonly needed and/or for venues with relatively low profile. Collegiate and professional venues and areas where irrigation is routinely needed generally require a more sophisticated approach.

The second approach is commonly referred to as the "checkbook" or ET method. This refers to the water holding capacity of the effective root zone, which shifts as a function of many variables that change over the course of a growing season. A smart irrigation controller greatly assists in using this method. An automated system can account for soil properties and weather, but typically do not account for rooting depth changes during the season. Therefore, monthly assessments should be used to adjust the system. Smart controllers' accuracy is improved with data from onsite weather stations.

The third approach is a more sophisticated and potentially more accurate method that involves measuring moisture in the root zone with sensors. This is critical to understanding turfgrass water needs. Sensor technology is changing rapidly with newer models providing greater accuracy and more options. There are two approaches to measuring soil moisture:

- Water content sensors indicate the total volumetric water content in the soil including plant available water or, in other words, the moisture content at the point the plant wilts. The percent moisture at which irrigation is triggered is variable with soil properties.
- Soil water potential (or tension) sensors are a recent development to measure the energy of water. These are an improvement over water content sensors used alone in that their output and interpretation is not dependent upon soil properties and, thus, is more accurate and easier to use to trigger irrigation events.

4.20.3 Irrigation Amount and Rate

The amount of irrigation water to be applied needs to bring the bottom of the root zone to field capacity. If the root zone becomes saturated, water will continue to move downward as gravitational water and will potentially be lost for plant use. Generally, the amount that is needed is the depletable water. Using the previous examples, the silty clay loam would need 0.5" and the sandy loam would need 0.25" to be applied as irrigation to replace the depletable water in the effective root zone.

In addition to consideration of the total amount of water to apply, water should not be applied faster than the soil can take it in (infiltration rate). Infiltration rate tables are



Morning irrigation. *Credit: Z. Holm.*

available, although the rate is so variable that it is a good practice to observe when water ceases to infiltrate and begin to run off. If this occurs before the total amount of water needed is applied, then adjustments need to be made. Cultivation will improve infiltration rate. In severe cases, low flow heads/nozzles should be used. Alternatively, irrigation can be cycled intermittently by shutting it off temporarily to allow for some infiltration and drainage before applying the remainder of the total amount needed to move water to the bottom of the root zone. This cycling can be repeated as many times as necessary in order to apply the desired total rate. Multiple cycle irrigation controllers can be programmed to do this automatically in installed systems.

4.20.4 Irrigation Timing

Early morning is typically considered the best time to irrigate, when wind speed and evaporation rates are low. Watering late in the evening or at night extends the time that leaves remain wet, significantly increasing the chance for disease. Mid-afternoon watering can lead to nonuniform distribution and evaporative losses if wind speeds and/or

temperatures are high. In addition to these considerations, the sports field manager must also contend with the usage schedule to determine the best time to irrigate. Fields should not be too wet during play to minimize slippage and compaction.

4.21 Irrigation Best Management Practices

Irrigation Water Supply Best Management Practices

- When possible, use alternative water supplies/sources that are appropriate and sufficiently available to supplement water needs.
- Water mains must have a thorough cross-connection and backflow prevention device in place that operates correctly.

Irrigation Water Quality Best Management Practices

- Assess the irrigation water quality (salinity, sodicity, toxicities, and nutrient content) by obtaining lab data

from the water supplier or taking and submitting samples to a reliable laboratory.

- Account for the nutrients in irrigation water when making fertilizer calculations.
- If the water source is saline, use salt-tolerant turfgrass varieties to mitigate saline conditions and/or leach salts from the soil.
- If water is sodic, add a soluble calcium source and leach.

Irrigation Systems Best Management Practices

- Maximize the DU in the design and maintenance of the irrigation system. Architects should require a minimum DU (>75-80%).
- Incorporate the use of “smart” computerized irrigation controllers to significantly improve water conservation and system performance.
- Frequently monitor controllers and adjust for seasonal changes in turfgrass growth, rooting depth, and variable environmental conditions.
- Routinely check irrigation system (broken sprinkler heads, misaligned heads, sunken heads, water pressure irregularities, leaks in the lines or heads, and improper/incomplete rotation) to ensure that the system is working as designed, especially if the DU drops below the optimum.
- Regularly conduct pre-season audits to assess the system function, ensuring that the irrigation system works reliably and cost effectively.

Irrigation Decision Making Best Management Practices

- Intentionally allow grass to be mildly moisture stressed twice during spring to promote deeper rooting.
- Consider water use and drought resistance when selecting turfgrass species and varieties.
- Avoid keeping the soil saturated to promote deeper rooting.
- Evaluate ET losses daily and irrigate if needed.
- In conjunction with ET, evaluate soil moisture using soil moisture sensors, preferably with water potential sensors used alone or in combination with water content sensors.
- Check rooting depth throughout the season and irrigate to the depth of rooting (i.e., water deeply and infrequently).
- If events allow, do not irrigate until the depletable water is utilized—allowing soil to dry to minimize disease and root oxygen deficiency.
- Apply enough water so that the bottom of the root zone reaches field capacity without reaching saturation in order to minimize leaching losses.
- Do not apply water faster than soil infiltration. Use cultivation, low flow nozzles, and/or intermittent cycling to minimize water runoff.
- Water during morning hours when feasible and when the field schedule allows.

4 CULTURAL PRACTICES: CULTIVATION AND SURFACE MANAGEMENT

Cultivation practices disturb the soil or thatch through the use of implements to relieve soil compaction, support thatch/organic matter reduction, and improve the opportunity for a healthy water and air exchange. However, cultivation should be used judiciously as it can disrupt field use and require significant time for recovery. Table 5 shows the relative agronomic benefits of cultivation practices.

Cultivation frequency should be determined by the amount and timing of field use, degree of soil compaction, soil type, and the amount of accumulation of excessive thatch and organic matter. Excessive organic matter

reduces root growth, encourages disease, and creates undesirable playing conditions. Cultivation events can be stressful to turfgrass, so they should occur when turfgrass recovery potential is optimized, aiding in the quick recovery of surface density. If done improperly, cultivation can decrease lateral stem and root growth.

4.22 Cultivation Methods

Cultivation events vary in the degree of injury or stress to the turfgrass plant (Table 5). Some cultivation tactics can be used during the playing season with minimal disruption to the playing surface. Some cultivation methods are more aggressive, increasing the time required for turfgrass recovery. If shallow irrigation pipes are present, they should be taken into consideration in terms of cultivation method and depth.

4.22.1 Hollow Tining

Hollow tining is the most effective practice for relieving soil compaction, increasing oxygen levels in the root zone, and aiding in improvement of soil drainage by physically removing small cores from the soil profile. Cores are usually 0.25” to 0.75” in diameter, with depths ranging from 3” to 10”. Working depths depend on equipment and soil conditions. Surface disruption potential is high with hollow tining, often requiring several days to a few weeks before the effects are no longer visible. While the cores can be harvested, they are frequently allowed to dry and then dragged back over the surface to serve as topdressing.



Core aeration. Credit: B. Polimer

Table 5. Turfgrass cultivation methods and rankings of agronomic benefits.

Method	Compaction Relief	Thatch control	Water/air movement
Hollow tining	High	Medium	High
Solid tining	Low	None	High
Spiking/slicing	None	Low	Low
Deep drilling	Medium	Low	High
Water and Air Injection	Medium	Low	High
Vertical mowing	Low	Medium – High	Medium
Fraise mowing	Low	Very High	Medium



Deep tine aeration. *Credit: B. Polimer.*

4.22.2 Solid Tining

Solid tining causes less disturbance to the field surface than hollow tining and can be used to immediately create channels for water infiltration, temporarily reduce compaction, and soften surface hardness. However, the benefits of solid-tine cultivation are temporary because no soil is removed from the profile, except when using a deep tine aerator with a “kicking action” that results in some soil fracturing. “Venting” or “needle-tining” is often used to describe the practice of solid tine cultivation using small-diameter tines (0.25” to 0.375” in diameter). This is an effective tool that can increase gas exchange to root systems. It is primarily employed during times when the turfgrass is under stress and/or use of the field does not permit more aggressive cultivation.

4.22.3 Spiking/Slicing

Spiking/slicing reduces surface compaction and promotes water infiltration with minimal surface damage. Slicing is a faster cultivation process than core cultivation but is less effective in reducing compaction. Spiking can break up crusts on the soil surface and enhances lateral spread of creeping grasses since it severs rhizomes and stolons. The effects on surface compaction and water infiltration are short lived as the slits rapidly close from traffic (play or maintenance equipment) on the surface. Recent equipment advancements have led to the use of deep slicer units (up to 15” depths possible) that provide a response called “linear

decompaction.” The benefits of the machine are essentially immediate improvements in water infiltration and percolation through the profile with very limited surface disruption. The vibration of the machine during operation also has been shown to fracture sub-surface soil layers.

4.22.4 Deep Drilling

Deep-drill cultivation creates deep holes in the soil profile through use of drill bits. As the name implies, the hole depths are typically 9” to 12”. 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 clay/silt soils with sand or other soil amendments in an effort to improve water infiltration into the soil profile.

4.22.5 Water and Air Injection

Water injection machines use a blast of water to create a hole and a vacuum to pull soil material into the hole. While this is disruptive to play on the field surface, the disruption is not long lasting. Air injection machines utilize tines that penetrate the soil and inject a burst of air near the maximum depth of penetration. For specific high traffic areas, air injection machines are now regularly used and have slight surface disruption.

4.22.6 Vertical Mowing

Vertical mowing (verticutting) can be incorporated into a cultural management program to achieve several goals.

The grain of the sports field can be reduced by setting a verticutter to a depth that just nicks the surface of the turfgrass. Deeper penetration of knives stimulates new growth by cutting through stolons and rhizomes while removing accumulated thatch. Deep vertical mowing (0.5” to 1” depth) removes a greater amount of thatch than core cultivation and can be considered for aggressive thatch removal as it can remove up to 15% of the thatch at one time. However, it is aggressive and should only be done during less stressful times (e.g., cooler temperatures) and on well-rooted turfgrass. Unlike deep vertical mowing, shallow vertical mowing (0.5” or less) does not remove thatch. Instead, it severs rhizomes or stolons promoting new growth and standing up blades to allow removal of old growth and minor canopy thinning. Shallow vertical mowing can be practiced regularly during the growing season except in times of drought or excessive heat.

4.22.7 Fraise Mowing

Fraise mowing is a cultural practice that was devised in the Netherlands during the mid-1990s and is similar to vertical

mowing. While vertical mowing partially impacts the surface, fraise mowing’s impact is absolute, encompassing 100% of the surface and potentially reaching up to 2” depths in a single pass. This makes fraise mowing an appealing thatch management tool. Other demonstrated benefits of fraise mowing include *Poa annua* control and overseeding removal (McCauley et al., 2019; Brosnan et al., 2020). While fraise mowing was originally developed to mechanically harvest annual bluegrass plants from cool season sports fields, its use has expanded from cool season sports fields to warm season bermudagrass sports fields.

This very important field rejuvenation tool removes sports fields from play for at least eight to 10 weeks under ideal growing conditions and restores “new field” conditions, vigor, and growth rates. With renovation of cool season fields, often aggressive overseeding immediately follows a fraise mowing event. Fraise mowing can also help smooth uneven fields, removing high spots. Fraise mowing should only be undertaken under optimal turfgrass growing conditions.



Fraise mowing. Credit: B. Polimer.

4.23 Topdressing

Topdressing is often combined with core cultivation practices. Topdressing is the application of a uniform thin layer of soil, sand, or compost over the turfgrass surface. Frequent topdressing can level the playing field when minor variations or depressions are apparent, amend physical soil properties, create a better growing environment for the turfgrass, reduce thatch, and dilute organic matter.

Selecting an appropriate topdressing material is a critical aspect of a topdressing program. The topdressing material must be consistent in type and particle size to the existing root zone, as well as be available for future topdressing. Variations in particle size can lead to layering, which impedes drainage and rooting.



Sand topdressing. Credit: B. Polimer.

4.24 Rolling

Rolling is often performed on sports fields to help smooth surfaces and produce a firm surface to increase ball roll speed (e.g., soccer) or improve ball bounce (e.g., baseball, tennis). Freeze/thaw cycles often lead to frost heave of soils, causing uneven playing surfaces. In these cases, lightweight rolling is often the quickest way to smooth these soils. If done in conjunction with a standard cultivation program to mitigate surface compaction, rolling is a very valuable tool to enhance playability.

Some research has shown that rolling can reduce disease incidence on low cut sports fields. This reduction in disease incidence is directly related to the use of lightweight rollers used first thing in the morning, whereby the roller is helping to remove dew/guttation water from the leaf tissue.

As with all cultural practices, rolling should be done under the appropriate field conditions in order to reduce stress. Adequate soil moisture (but not saturation) reduces the potential for compaction. For more information, see [Rolling Athletic Fields](#) on The Ohio State University's Sports Turf Management website.

4.25 Plant Growth Regulators (PGRs)

Plant growth regulators are frequently used to reduce clipping yield, improve stress tolerance, and improve turfgrass quality and performance, including lateral shear strength of the turfgrass canopy, a factor in footing and traction by the athlete. PGRs can also be added to paint mixtures to extend the life of field markings on practice or low-input fields. An additional benefit of using PGRs can be the possible reduction in the use of other inputs, such as irrigation and decreased mowing.

PGRs require frequent reapplication during the growing season to maintain consistent growth suppression, but excessive PGR use in either rate or frequency can result in undesirable side effects. These side effects might include mild discoloration, stressed turfgrass, and segregation of grasses. These effects can be confused with disease and can intensify damage from pests and traffic. Some turfgrasses may also experience a rebound effect when the growth regulation wears off resulting in a temporary flush of top growth.

Warm and cool season grasses (and even some cultivars within species) often vary in response to PGRs. Label recommendations should be very carefully followed, in conjunction with site-specific experimentation to evaluate the levels and frequency that best meet site-specific needs.

The best approach to planning PGR applications is to use growing degree day (GDD) thresholds instead of a calendar-based schedule. Free tools are available online for assistance in using GDD information to schedule PGR applications.

4.26 Wetting Agents

Wetting agents can be used for a number of reasons, such as:

- Preventing dry spot development.
- Treating dry spots.
- Moving water into and through the soil.
- Improving irrigation efficiency.
- Serving as a spray adjuvant when applying pesticides or PGRs.

Wetting agents are especially helpful when applied to sandy soils that can become hydrophobic (water repellent). Turfgrass grown on sand-based root zones can develop severe localized dry spots (LDS) especially when the turfgrass is irrigated deep and infrequently. Surfactants help promote water infiltration into these hydrophobic areas which prevents and alleviates LDS.

Research shows preventative applications of wetting agents can increase soil water uniformity and sustain high visual turfgrass quality at very low levels of irrigation (30% potential ET). Preventive applications of wetting agents can also increase irrigation precision, potentially reducing water usage.

4.27 Cultivation and Surface Management Best Management Practices

Cultivation Best Management Practices

- Cultivation should be conducted only when turfgrass is actively growing and not under stress in order to aid in quick recovery. Areas with the highest traffic and wear should be prioritized.
- When cores are not collected, they should be air dried and then dragged back over the turfgrass surface to serve as topdressing.
- When cores are collected, backfill holes with new root zone material that matches the existing root zone or improves the root zone.
- Vary cultivation depths when possible to prevent development of compacted layers in the soil profile.
- Avoid cultivation events on ground that are either too wet or too dry to avoid compacting the soil.
- Cultivation should be periodically performed to relieve surface compaction and help provide oxygen to root zones, particularly prior to the onset of summer stress for cool season grasses and winter stress for bermudagrass. It can also help dry out excessively wet soils.

- Regularly slice and/or spike sports fields to provide the temporary benefits of relieving surface compaction, increasing water infiltration and percolation, and to sever stolons and rhizomes.
- Use vertical mowers to physically manage thatch on sports fields, particularly when thatch layers start to exceed 0.5” in depth. Conduct vertical mowing during periods of optimal turfgrass growth and then fertilize and irrigate afterward to promote turfgrass recovery.
- Fraise mowing should only be attempted when turfgrass is actively growing. Periodic fraise mowing is an excellent renovation strategy. Fields should be removed from play to allow for adequate recovery.

Topdressing Best Management Practices

- Topdress when the turfgrass is actively growing.
- Select an appropriate topdressing material, which must be consistent in type and particle size to the existing root zone, as well as available for future topdressing.
- Do not apply excessive amounts of topdressing in one application.

Rolling Best Management Practices

- Avoid rolling on saturated soils to prevent compaction.
- Use lightweight rollers to minimize potential compaction.

Plant Growth Regulators Best Management Practices

- Use GDD to plan PGR use.
- Consider the selection and timing of PGR applications, which is critical to achieve desired turfgrass responses.

Wetting Agent Best Management Practices

- Preventive applications of wetting agents should be made to high risk (sandy) soils.
- Frequent preventative applications prevent development of LDS and increases soil water uniformity.
- Water-in wetting agents sufficiently.
- Apply wetting agents to reduce water repellency in soils and reduce the potential for LDS.

4 CULTURAL PRACTICES: INTEGRATED PEST MANAGEMENT (IPM)

Turfgrasses used on sports fields are expected to provide dense, uniform, and safe playing surfaces all season long. However, when turfgrasses face excessive stress from wear or environmental conditions such as heat or drought, pest pressures can become a serious problem. Sports field managers should implement a comprehensive and effective approach to pest management, termed IPM. The Environmental Protection Agency (EPA) defines IPM as an “effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices.”

An IPM approach considers all strategies to reduce pest damage to manageable and acceptable levels in the most economical way, while simultaneously considering potential impacts on humans, property, and the environment. On sports fields, these programs involve a variety of agronomic practices as well as chemical applications in situations where other means have been exhausted or deemed ineffective.

4.28 IPM Overview

IPM is comprised of a range of pest control methods or tactics designed to prevent pests (insects, pathogens, nematodes, weeds, etc.) from reaching unacceptable levels of damage while creating the least risk to the environment. IPM programs have basic components that provide the opportunity to make informed decisions on the control of pests on sports fields. Five basic steps for an effective IPM program for sports fields are as follows:

Step 1: Monitor for pest damage and record the extent and severity of the damage.

Step 2: Identify pests causing damage and understand their biology.

Step 3: Determine acceptable threshold levels and continue monitoring.

Step 4: Consider a variety of control methods and select the most appropriate.

Step 5: Evaluate the IPM program.

IPM is a flexible approach to pest management. Sports field managers balance sports field quality and environmental goals through IPM implementation. Growing and managing healthy turfgrass is the best and first line of defense against pests. For example, cultural conditions that predispose turfgrass to weeds include heavy

traffic, inadequate or excessive nitrogen fertility, frequent or excessive irrigation, inadequate thatch management, and poor drainage. Following cultural, nutrient, and irrigation BMPs can often help alleviate these conditions. However, even under optimal conditions, pests can still sometimes cause excessive damage to sports fields and must be controlled to ensure safety to athletes.

The sports field manager should consider an IPM approach to managing pests as one that provides multiple “tools in the toolbox.” A number of non-chemical and chemical control options are available for use on sports fields. When non-chemical options cannot effectively mitigate a pest problem, selection of an appropriate pesticide should follow an evaluation process that considers potential impacts on beneficial organisms and the environment, as well as the potential for development of pesticide resistance, as discussed in the Pesticide Management chapter.

4.29 Identifying and Understanding Pests

Pests must be properly identified in order to be optimally managed. Understanding the biology of pest species and their vulnerable life stages assists with management. Sports field managers and staff should continually hone their diagnostic skills by attending training seminars and field days, obtaining reference materials, and providing peer-to-peer training. Communicate with university Extension specialists to confirm the identification of a pest and seek advice on appropriate control methods.

4.29.1 Weeds

Because of the mechanical stresses associated with normal play on sports fields, bare spots provide an advantageous environment for encroachment by weeds. Over time, weeds can become a persistent presence on the playing surface, comprising player safety, disrupting playability, harboring other pests, and competitively displacing desirable turfgrass, in addition to being unsightly. For example, University of Tennessee research found that natural grass sports fields dominated by weeds, such as large crabgrass (*Digitaria sanguinalis* L.) and white clover (*Trifolium repens* L.), significantly compromise both player safety and field aesthetics (Brosnan et al., 2014).

Minimizing weed pressure can be accomplished with the following cultural practices:

- Addressing compaction
- Mowing practices
- Turfgrass selection
- Nutrient management programs
- Irrigation
- Overseeding

Two major weed types impact field quality and function: annual weeds, such as crabgrass, annual bluegrass (*Poa annua*), and knotweed (*Polygonum arenastrum*), and perennial weeds, such as plantain (*Plantago* spp.), clover, dandelion (*Taraxacum officinale*), and ground ivy (*Glechoma hederacea*). While some weeds are easily identified, others may be more difficult. The [Weed Science Society of America](#) maintains links to university Extension specialists and other industry experts across the country that can provide more information and weed identification assistance.

Because of the importance of soil quality in growing healthy turfgrass, emphasis should be placed on relieving soil compaction, replacing sod, and testing soil to maintain

turfgrass that can withstand pressure from weeds. In addition, cleat seeding/overseeding to fill in voids can help prevent weed germination.

Irrigation plays an important role not only in influencing weed populations, but also with efficacy of control products. Pre-emergent products form a “barrier” on the soil surface preventing germination of grassy and broadleaf weeds. Products applied to natural grass fields without a natural rainfall event or supplemental irrigation may limit efficacy of the product. Conversely, sites that are over-irrigated may have higher densities of weeds.

4.29.2 Insects/Arthropods

Many arthropods (especially insects and mites) live in turfgrass and ornamental plant beds. Some are beneficial (e.g., pollinators, decomposers, and natural enemies) or are aesthetically attractive (e.g., butterflies), while others may be nuisance pests or may negatively affect plant health, particularly those that feed on turfgrass roots. Arthropods can cause various types of damage to grass plants, depending on where they attack the plant. Annually recurring insect pests that can negatively affect turfgrass include species such as armyworms (*Spodoptera* spp.), chinch bugs (*Blissus* spp.) nuisance ants, and annual white grubs.



Slime mold. Credit: Z. Holm.



Grey leaf spot. Credit: Z. Holm.

White grubs can destroy significant areas of turfgrass, with damage appearing when plants undergo stress. Turfgrass is damaged when grubs feed on roots just below the soil surface, reducing the ability of the plants to access water and nutrients required to withstand the stress of hot, dry weather conditions. Drought stress and/or insufficient irrigation may compound this damage. Scouting for these pests is critical as management of white grubs is most efficient when the specific population causing damage is identified, particularly in the first or second instar, early in the life cycle of the insect. Additionally, species identification is also an important component to effectively managing white grub infestations on sports fields.

4.29.3 Diseases

In general, healthy, well-managed turfgrass better withstands disease outbreaks and recovers more rapidly than stressed or unhealthy turfgrass. Even under favorable environmental conditions when turfgrass is healthy, diseases can develop. The first line of defense to mitigate the severity of disease includes incorporating biological or cultural practices that enhance turfgrass growth, such as the use of improved turfgrass species developed to resist disease.

The second line of defense is effectively incorporating disease diagnosis and treatment into an IPM program. An understanding of the diseases that a given species or cultivar is susceptible to, as well as the environmental conditions associated with the disease pathogens, is essential. Turfgrass diseases most commonly occur in the summer for cool season grasses and the spring or fall for warm season grasses. Scouting for anticipated disease outbreaks as weather-induced stress increases is important. Historical knowledge of past disease outbreaks, in addition to scouting for anticipated symptoms of disease as weather-induced stress increases, can assist in correctly diagnosing the causal agent. Proper diagnosis helps to develop the appropriate IPM protocol to prevent damage to natural grass fields. Diagnostic services, which are often available from a university or from private laboratories, can confirm a diagnosis as well as provide a recommendation for an appropriate management strategy to alleviate damage.

4.30 Monitoring Pests and Recording Information

In an IPM plan, pest monitoring or “scouting” efforts should be described for all areas of the playing fields as well as adjacent turfgrass and landscaped areas. Scouting methods include visual inspection, soil sampling, soap flushes, and trapping for insects. Additional monitoring

efforts can include use of GDD, which can be helpful for predicting potential weed, insect, and disease development. For example, warmer temperatures combined with high humidity often favor the development of turfgrass diseases such as dollar spot (*Clarireedia homeocarpa*) and brown patch (*Rhizoctonia solani*). Additional information can refine predictive models, such as the Smith-Kerns dollar spot model. This model is a logistic-based model that uses a five-day moving average of daily relative humidity and daily average air temperature to create a probability that dollar spot will occur on a given day (Smith et al., 2018). Using this information, managers can accurately time fungicide applications to control dollar spot.

4.30.1 Recording Monitoring Information

When pests are discovered during monitoring, the pest pressure should be quantified with measurements such as:

- Number of pests (weeds, insects, disease symptoms) per unit area.
- Percent of area affected.

Documentation should include useful information such as photographs, delineation of pest boundaries on an area map, outbreak date, description of the prevailing weather conditions, and recent management practices. This information can be used to build a database for reference in future seasons and for updating the IPM plan.

4.30.2 Growing Degree Days (GDD)

In certain situations, pest management decisions based on GDD accumulation can be more effective than those made using a calendar or schedule-based approach. Growing degree days can be particularly useful for controlling pests preventatively (i.e., before they are visibly noticeable via scouting).

Growing degree days represents the accumulation of “heat units” based on air temperature and can be summarized daily over the growing season. One method of calculating

Growing degree day accumulation can be found in places such as:

- Websites such as [Online Phenology and Degree-day Models](#)
- Mobile applications
- University Extension websites
- Manufacturers’ websites

GDD is to compare the average air temperature for a given day to a pre-determined base temperature as follows: $(\text{high} + \text{low})/2$. This difference is summarized over a period of time to represent GDDs accumulated. This information can help predict disease development, insect emergence or development, weed germination, and seedhead emergence of broadleaf and grassy weeds.

If GDD accumulation totals cannot be accessed directly, sports field managers are encouraged to make site-specific calculations using basic weather data from sources such as the [National Oceanic and Atmospheric Association](#). University Extension specialists can provide assistance with making these calculations as well as incorporating use of GDDs into IPM programs targeting weeds, insects, and diseases.

Certain phenological indicators can also be used to optimally time certain pest management applications. For example, crabgrass (*Digitaria* spp.) germination occurs when soil temperatures exceed 55°F in spring for a continued period. Border forsythia (*Forsythia x intermedia*) bloom occurs at similar soil temperatures and offers field managers a visual indicator of when to apply preemergence herbicides for crabgrass control. University Extension specialists are a source of information on appropriate phenological indicators.

4.31 Determining Threshold Levels

IPM is commonly used in agricultural crop production where economic thresholds for key pests have been established. Using IPM is more challenging on sports fields than in an agricultural setting, as agricultural thresholds are based on crop yield whereas sports field thresholds are qualitative, involving turfgrass density, playability, and safety. These thresholds can be determined scientifically or based on site-specific experience. For example, pest infestations leading to meaningful changes in an assessment score (e.g., PCI score) typically warrant treatment. Ongoing education of athletes, the public, and maintenance personnel often allows for minor aesthetic damage to remain non-treated if it does not hamper sports field safety or quality.

4.32 Control Methods

Once a pest problem reaches the established treatment threshold, different methods can be used to control the problem, including cultural, mechanical, biological, and chemical. Selecting the most appropriate approach depends on a number of factors, including the site-specific location on a field, efficacy of control options for the particular situation, economics, and pest populations.

When pesticides are used, whether synthetic, organic, or biological, they must be applied by a state licensed and certified applicator. The use of all pesticides must follow the label and adhere to state and federal regulations, as described in the Pesticide Management chapter.

4.32.1 Role of Cultural Practices in IPM

Cultural practices, especially irrigation, mowing, topdressing, overseeding, and core cultivation, greatly affect both short- and long-term turfgrass health. Especially in times of stress, using and/or altering appropriate cultural practices can be an alternate or supplemental approach to help natural grass better withstand weed, insect, and disease pressure. See Appendix E for more information on the influence of various cultural practices on weeds, insects, and diseases. It is important to recognize that turfgrass management practices such as core cultivation and sand topdressing should occur when plants are actively growing to facilitate recovery. If these practices are implemented when growing conditions are not optimal, they can stress sports fields and make them more susceptible to pest invasion. Cultural practices are not curative. However, when optimized, they render a field less susceptible to pest infestation.

4.32.2 Mechanical or Physical Controls

Mechanical or physical control methods can be used to control specific pests, particularly weeds, when overall populations are low. Some methods, such as hand pulling weeds, may be time consuming and labor intensive. Fraise mowing, as discussed in the Cultural Practices chapter, is a tool that has been used to mechanically suppress annual bluegrass (Brosnan et al., 2020).

In situations where the pest pressure exceeds acceptable threshold levels, a partial or full field renovation may be a more effective and economically advantageous alternative to controlling pests. For more information on renovation, see the Planning, Design, and Construction chapter.

4.32.3 Biological Pest Control

Biological pest control (BPC) is gaining increased interest as an option to control insects, diseases, and weeds. Biological pest control utilizes living organisms, such as bacteria, fungi, or predatory/parasitic agents that introduce natural substances to reduce pest populations. Examples of BPC agents used to manage turfgrass pests are *Bacillus thuringiensis* var. *galleriae*, a bacterium that controls white grub species; turfgrass cultivars containing endophytic fungi that deter leaf- and stem-feeding insects; and

beneficial parasitic nematodes for chinch bug (*Blissus* sp.) control. BPCs are applied by licensed pesticide applicators.

Some BPC products can be used as an alternative to synthetic pesticides or in locations where EPA-registered pesticides are not preferred or permitted. However, the efficacy of many BPC products currently available for managing turfgrass pests is inconsistent at best. Research is ongoing to optimize application strategies of these products to achieve better and more consistent control.

Biopesticides

Biopesticides are derived from such natural materials as animals, plants, bacteria, and certain minerals. Biopesticides are classified separately from other pesticides by the EPA and are usually more target/host-specific than conventional pesticides. Biopesticides are divided into three types:

- Microbial pesticides include microbes (e.g., bacteria, fungi).
- Biochemical pesticides include natural substances (e.g., insect hormones) that repel insects or cause mating disruption.
- Pesticidal substances produced by plants containing added genetic material, called plant-incorporated protectants.

For more information on biopesticides, see the EPA's [Biopesticide Registration](#) page. For a database of registered biopesticides, see the searchable [IR-4 database](#).

Beneficial Nematodes

Some nematodes, such as *Heterorhabditis bacteriophora* and *Steinernema scarabaei*, may naturally suppress insect pests such as white grubs. Nematodes sold for pest management are in the infective juvenile stage, which is the only stage that survives outside the insect host.

To use beneficial nematodes, the following general guidelines should be followed:

- Keep nematodes viable until application.
- Avoid application during daylight with high UV intensity.
- Ensure nematodes can safely penetrate the soil during the application process. Use proper pressure to move the nematodes through the thatch layer and into the soil profile. Maintain agitation of the spray tank so that nematodes are dispersed and do not settle to the bottom of the tank. Irrigate turfgrass areas before, during, and after nematode application to maintain enough soil moisture to allow nematodes mobility as they travel to grub hosts.

More information on nematodes as a control method for turfgrass pests can be found in the University of Connecticut's [Using Beneficial Nematodes for Turfgrass Insect Pest Management](#).

4.32.4 Chemical Controls

Chemical control is an acceptable IPM practice when other methods cannot alleviate a pest problem. Licensed pesticide applicators are certified by state agencies. The certification process ensures that applicators understand how to use products according to label directions and why it is important to do so. Additionally, these individuals are required to regularly recertify with state agencies every 12 to 24 months to stay current in the discipline of pesticide use. This process ensures minimal risks to applicators, athletes, and the environment.

The selection and use of any chemical control measure should follow these criteria:

- Correctly identify a pest to select an appropriate pesticide.
- The pesticide selected should be effective in treating the pest problem.
- The timing of the pesticide application should be based on the appropriate stage of the pest life cycle to ensure maximum effectiveness.
- Any restrictions on the pesticide label must be reviewed prior to application and rigorously followed.
- Pesticides should be rotated based on resistance classification specified by the following committees: [Fungicide Resistance Action Committee](#), [Herbicide Resistance Action Committee](#), and [Insecticide Resistance Action Committee](#).
- Costs and re-entry period should be considered.
- Applications should be made to optimize environmental quality. Consider spot treatments instead of blanket treatments.

Site-specific field characteristics and prevailing conditions should be considered when implementing a chemical control treatment. Factors such as soil pH, soil texture, and organic matter content can affect pesticide effectiveness. Moreover, environmental conditions at application (e.g., soil moisture content, air temperature, humidity, and wind speed) should also be accounted to ensure a treatment performs optimally.

4.33 Evaluation and Record Keeping

It is essential to capture and record the results of IPM-related efforts to develop historical information, document patterns of pest activity, and evaluate overall turfgrass health. Records of turfgrass management practices and pesticide use are highly recommended and may be required by state regulatory agencies. State regulatory agencies and university Extension programs may be able to provide sample record keeping forms that meet state regulatory requirements.

For IPM purposes, records should be kept for all pesticide applications and should include additional information, such as monitoring records, weather records, cultural management logs, and pest response.

4.34 IPM Best Management Practices

Basic IPM Best Management Practices

- Develop a written IPM plan that supports turfgrass health and playing surface safety.
- Train personnel to monitor and scout for pests.
- Select recommended turfgrass species and cultivars best suited for the intended use and environmental conditions of a specific site.
- Correct soil physical and chemical properties that may impact turfgrass ability to resist pests.
- Evaluate the potential impact of cultural practices and fertilizer applications on the incidence of pest problems.
- Divert traffic away from areas that are stressed by insects, nematodes, diseases, or weeds.
- Document all IPM-related activities, including pesticide usage.

Pest Identification Best Management Practices

- Identify key pests of turfgrass prevalent to your area.
- Determine the pest life cycle and know which stage to target (e.g., for insect pests, whether it is an egg, larva/nymph, pupa, or adult).
- For diseases, correctly identify the disease pathogen. This often involves sending samples to diagnostic clinics.
- Identify weeds accurately, which can often involve sending samples to a diagnostic clinic.
- Where applicable, consider targeted pest control measures rather than blanket applications of pesticides.

Monitoring Best Management Practices

- Monitor prevailing environmental conditions for their potential impact on pest problems.
- Train personnel how to regularly monitor pests by scouting or trapping.
- Identify alternative hosts and overwintering sites for key pests.
- When possible, use GDD information to predict pest incidence before it is visible via scouting.
- Correctly identify the specific disease, weed, and/or insect problem to ensure appropriate control measures.
- Assess pest damage when it occurs, noting particular problem areas, such as the edges of sports fields, shady areas, or poorly drained areas.
- Document when the symptoms of pest damage occur, noting the time of day, date, and flowering stages of nearby plants.
- Map pest outbreak locations to identify patterns and susceptible areas for future target applications.

Pest Threshold Best Management Practices

- Use assessment tools (e.g., PCI score) to evaluate field condition.
- Establish acceptable threshold levels for injury caused by key pests and document appropriate treatment options for these pests when these thresholds are exceeded in the written IPM plan.

Weed Control Best Management Practices

- To prevent weed encroachment, maintain cultural practices that enhance turfgrass growth and minimize stress from wear, drought, or extreme temperatures.
- Repair thin, worn areas or reduce open spaces to minimize exploitation of openings in the turfgrass canopy for weed germination.
- To reduce weed infestation, address improper turfgrass management practices, such as mowing height or frequency, irrigation, or fertilization. Additionally, address the negative effects of foot traffic such as soil compaction and mechanical damage to turfgrass.
- Fertilize to encourage optimal turfgrass density and vigor to better resist diseases, weeds, and insects.
- Materials such as sand, soil, compost, and plant material (i.e., sod, sprigs, seed) from outside sources should be devoid of weeds.

- If allowed and necessary, apply a preventative herbicide application to turfgrass to maintain a uniform and safe playing surface. When weeds escape a preventative application, spot-treatments of post-emergence products can be used to control rogue plants when pressure is warranted. Consider both environmental conditions and availability of supplemental irrigation when selecting the appropriate formulation of the control product.

Disease Control Best Management Practices

- Encourage proper cultural practices that reduce turfgrass stress and enhance growth.
- Select and incorporate turfgrass cultivars or species that are best suited to resist disease.
- Review all cultural practices (e.g., mowing, irrigation, and nutrient program) to reduce turfgrass stress.
- If necessary, based on weather conditions and historical assessments, apply a preventative fungicide to susceptible turfgrass if unacceptable levels of disease are likely to occur.
- Confirm diagnosis of disease pathogen to help select management strategy or to confirm curative treatment to stop disease activity.

Insects/Arthropods Control Best Management Practices

- Identify key regional insect pests.
- Select and incorporate endophytic turfgrass cultivars into seed mixtures that deter surface-feeding insects.
- Review all cultural practices (including mowing, irrigation and fertility program) to reduce turfgrass stress.
- For preventive insecticide applications, especially those that contain a neonicotinoid product, mow turfgrasses that contain populations of clover or any flowering weed, to reduce foraging traffic of bees.
- For insecticide application aimed at targeting root-feeding insects, irrigate turfgrass before and/or after an application, in accordance with the label.

Biological Pest Controls Best Management Practices

- To support efficacy and application of BPC products aimed to control surface or thatch dwelling insects, as well as root-feeding insects such as white grubs, irrigate turfgrass before and/or after an application, in accordance with label instructions.
- Consider timing applications to coincide with appropriate soil temperatures, active soil microflora, and the life cycle of a targeted insect pest.
- Follow guidelines for utilizing beneficial nematodes in order to increase efficacy.

Chemical Pesticides Best Management Practices

- Train employees in proper pest identification and pesticide selection options.
- Select the best pest-specific product to optimize environmental quality and safety.
- Ensure that any chemical applications are made by licensed applicators or supervised by licensed applicators, following state pesticide regulations. Follow all BMPs related to chemical handling and application.
- Time pesticide applications for the appropriate stage of the pest life cycle to be controlled to maximize effectiveness.
- Review and follow all restrictions on pesticide label prior to application.
- Rotate pesticides based on resistance classification.
- Consider costs and re-entry periods in product selection.

Record Keeping and Evaluation Best Management Practices

- Observe and document natural grass conditions regularly using approved assessment forms (daily, weekly, or monthly, depending on the pest). Note which pests are present so that informed decisions can be made regarding the damage they are causing and what control strategies are necessary.
- Determine whether the corrective actions effectively reduced or prevented pest populations. Record and use this information to assist in making similar decisions in the future.

5 PESTICIDE MANAGEMENT

Pesticide use can be part of an overall IPM strategy that includes biological controls, cultural methods, pest monitoring, and other applicable practices, as discussed in the Integrated Pest Management chapter. The judicious use of pesticides, applied by or supervised by certified and professionally licensed pesticide applicators, can be an effective tool used as part of an IPM program. Minimizing damage to turfgrass surfaces caused by pests contributes to a dense, uniform playing surface, which is also a safer playing surface.

Concern over the use of pesticides typically focuses on the potential risk to human and environmental health. However, the relative risk of pesticides is largely mitigated through governmental regulation. The products are certified and continually recertified using state-of-the-art technology to ensure safety. Storage and handling of pesticides are also subject to federal, state, and some local laws that pertain to the site selection, design, construction, and operation of facilities, and areas used for storing and handling pesticides. In addition, pesticides must be applied by certified and professionally licensed applicators (or the applications supervised by the licensed applicator) who are subject to a certification process and must be regularly recertified, further ensuring safety.

5.1 Federal Regulatory Considerations

The EPA regulates pesticides under broad authority granted by the Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA). The process of registering a pesticide includes scientific, legal, and administrative procedures to ensure the product meets all scientific and regulatory requirements, as described below. Pesticides are approved for distribution, sale, and use only after all scientific and regulatory requirements are fulfilled.

5.1.1 Pesticide Registration and Re-Registration Process

In evaluating a pesticide registration application, the EPA assesses a wide variety of potential human health and environmental effects associated with use of the product. Scientific data must be generated to address concerns pertaining to the identity, composition, and environmental fate of each pesticide, as well as the fate of that pesticide in the environment. Tests conducted address the following:

- Product chemistry
- Product performance
- Hazards to humans and domestic animals
- Hazards to non-target organisms
- Post-application exposure studies
- Applicator/user exposure studies
- Pesticide spray drift evaluations
- Environmental fate
- Residue chemistry

The types of tests are summarized on the [Data Requirements for Pesticide Registration](#) page on the EPA website. Once testing data is received, EPA scientists perform risk assessments that evaluate the potential for:

- Harm to humans, wildlife, fish, and plants, including endangered species and non-target organisms.
- Contamination of surface water or groundwater from leaching, runoff, and spray drift.
- Human risks ranging from short-term toxicity to long-term effects.

These health and environmental risk assessments undergo a process of peer review by scientific experts. Details on these risk assessments and evaluation processes are described on the [Understanding the Science behind EPA's Pesticide Decisions](#) page on the EPA website.

The EPA utilizes the same process to re-register pesticides. All pesticides are reviewed and re-registered at least every 15 years to ensure that they continue to meet current FIFRA standards for registration.

5.1.2 Pesticide Labeling

FIFRA and its implementing regulations govern what must be included on pesticide labels. Pesticide product labels provide critical information about how to safely and legally handle and apply pesticides. Unlike other types of product labels, pesticide labels are enforceable and must include the statement: "It is a violation of Federal law to use this product in a manner inconsistent with its labeling." In other words, the pesticide label is the law.

A critical function of the label is to translate the results of the scientific evaluations into a set of conditions, directions, precautions, and restrictions that ensure pesticides are used safely and effectively.

5.1.3 Pesticide Storage

All pesticide storage areas must meet state (and local, if applicable) regulatory requirements.

5.2 Pesticide Classification

Both organic and synthetic pesticides are classified based on toxicity. The toxicity of any substance (pesticide or otherwise) refers to its capacity or ability to cause injury or illness through one of four routes of exposure: dermal (skin), inhalation (lungs), oral (mouth), and eyes. Acute toxicity refers to injury from a single exposure, generally of short duration. Chronic toxicity refers to injurious effects accrued over an extended period, usually after repeated or continuous exposure.

5.2.1 Signal Words

Pesticide labels may contain a “Signal Word” that is indicative of acute toxicity. These signal words are CAUTION, WARNING, and DANGER. Certain pesticides offer such a low toxicological risk that the EPA determined that no signal word is required on the label. Examples include chlorantraniliprole (Acelepryn, Syngenta Professional Products) and indaziflam (Specticle Flo, Bayer Environmental Sciences).

Many herbicides are less toxic than common chemicals such as caffeine (found in coffee, tea and many soft drinks) and nicotine (found in tobacco products). To better understand the relative risk of pesticides, the University of Tennessee published [*Safety of Herbicides Compared to Other Commonly Used Chemicals*](#). This publication provides information on the acute toxicity of herbicides used in turfgrass management to control weeds and commonly used household chemicals.

5.3 Limiting Pesticide Exposure

5.3.1 Personal Protective Equipment

Exposure to pesticides can largely be mitigated by practicing good work habits and using application equipment correctly. Personal protective equipment (PPE) is used to reduce applicators’ risk of pesticide exposure. Product labels provide information on PPE required to minimize exposure and first-aid information specific to the product. Examples of commonly used PPE when making a pesticide application include gloves, long sleeve shirt and pants (or similar coverall), socks, and shoes. Applicators should always read and follow the label before using a pesticide in addition to following standard safe practices. Safety Data Sheets (SDS) also provide information on appropriate PPE to wear while handling the product as formulated.

To avoid contamination, PPE should not be stored in a pesticide storage area. For more information, see the [Personal Protective Equipment](#) information on the [Pesticide Environmental Stewardship](#) website.

5.3.2 Re-entry Intervals (REI)

Re-entry intervals are periods of time in which entry into a pesticide-treated area is restricted. When required, these periods are listed on the pesticide label. Re-entry signs may be required by state or local laws, or facility rules. For example, public properties require posting of intended applications and signs must remain posted for at least 24 hours after the application. It is the applicator’s responsibility to keep the public off treated areas. Municipalities/schools also may post notice of intended applications on their respective websites, have a list of constituents to notify prior to treatment, and signs placed at points of entry. University Extension agents can also be consulted to determine whether state or regional REI requirements exist.

Even when not required, re-entry should not be allowed in public areas until spray treatments have dried or dust has settled. A one-hour re-entry period following pesticide applications has been shown to reduce worker and player pesticide exposure (Putnam et al., 2008; Doherty, 2017). Note, applying pesticides at night to provide a re-entry period before the following day does not effectively reduce pesticide transfer and can actually increase pesticide exposure compared with daylight applications (Putnam et al., 2008). Therefore, play should be delayed on fields in early mornings for three to four days following pesticide application, with the delay of sufficient duration to allow the leaf canopy to re-dry in the morning (Jeffries et. al., 2016).

Post-application Irrigation: Post-application irrigation is often indicated on the pesticide label. Irrigating pesticide-treated turfgrass immediately following application can move some pesticide residues from the foliage into the lower canopy, or to the thatch and soil. This practice can reduce dislodgeable foliar pesticide residues 9-fold to 30-fold compared with turfgrass that is not irrigated after pesticide application (Doherty, 2017; Jeffries et al., 2016). Post-application irrigation may be an effective way to reduce pesticide exposure and may help target some turfgrass pests (e.g., grubs, root pathogens, pre-emergent weeds). It can also delay volatilization of chemicals. However, irrigating treated turfgrass can reduce efficacy of some pesticides, particularly contact materials absorbed via foliage.

5.4 Application Equipment and Calibration

Application equipment must ensure that the pesticide reaches the intended target at the proper rate. Labels specify legal application rates and sometimes suggest the appropriate equipment for use with the product. While different kinds of application equipment are available, nearly 90% of all pesticides are formulated for spraying. The size of the equipment (tank size, boom width, etc.) should be matched to the scale of the facility, the maintenance budget, and areas of application.

5.4.1 Sprayer Calibration

To apply pesticides at the proper rate, properly calibrated application equipment is essential. These practices help mitigate environmental and human health concerns, reduce the chances of over- or under-applying pesticides, and optimize pesticide efficacy. More information and a calibration worksheet are available online in [*Calibration & Safety of Pesticide Application Equipment*](#) (Nedin, 2012).

Sprayer output is dependent on several variables (e.g., speed, nozzle size, pressure). Spray coverage is often reduced at greater application speeds, regardless of nozzle size. To maximize efficacy of pesticide applications, applicators should consider optimizing spray coverage with respect to spray speeds. Equipment should also be checked frequently for leaks and malfunctions and should be repaired promptly.

5.4.2 Sprayers

Various types and sizes of application equipment are readily available. The size of the application equipment (tank size, boom width, etc.) should match the scale of the target area. Larger ride-on sprayers are more efficient for large areas, while small walk-behind boom sprayers are well suited for smaller areas. Smaller boom lengths may increase the accuracy of applications, minimizing overspray on non-target areas. Newer technologies incorporating GPS allow for precision application, which can reduce pesticide usage.

5.4.3 Nozzles

Nozzle selection may be dictated by the pesticide label. As always, the label is the law and must be followed. Spray nozzle size and design affect the spray drop size, which can be an important factor influencing the potential for drift and off-target movement of pesticides. Smaller droplet sizes can improve the efficacy of some pesticides, although they are more susceptible to drift. Larger droplets are more resistant to drift, although may reduce the efficacy

of some pesticides due to reduced coverage. Nozzles designed to encapsulate an air bubble within the droplet (e.g., air induction nozzles) provide a good compromise between drift reduction (larger droplet size) and coverage and efficacy (drops burst into small drops on impact). Additionally, nozzles designed with a wider spray angle (i.e., 110° versus 80°) enable booms to be set lower to the ground where they are less susceptible to drift.

5.5 Pesticide Storage

Storage and handling of pesticides in their concentrated form can pose a potential risk to surface or groundwater. For this reason, facilities that store and handle these products must be properly sited, designed, constructed, and operated. These sites should facilitate the secure, dry storage of pesticides; provide safe working conditions for personnel with easy access to PPE; and provide containment of incidental spills due to normal mixing/loading practices and secondary containment of large accidental spills.

General guidelines for pesticide storage include the following:

- The storage area must be secured or locked to prevent unauthorized access.
- Pesticides must be stored in a separate building or, at a minimum, must be separated by a physical barrier from work areas and from food, feed, fertilizer, seed, and safety equipment.
- A warning sign must be placed on the exterior of the storage area.
- Pesticides must be stored in a dry, ventilated, climate-controlled area.
- The pesticide storage area must be kept clean.
- A supply of absorbent material sufficient enough to absorb a spill equivalent to the capacity of the largest container in storage must be kept in the storage area.
- The storage area must contain only properly labeled pesticide containers that are free of leaks.
- Pesticides should be stored in their original containers.
- The storage area must have an appropriate fire extinguisher available.
- Pesticides must be stored in an area located at least 50 feet from any water well or stored in secondary containment, or distance specified by regulation or local ordinance.

5.5.1 Storage Locations

Storage areas should be located where risk to human health and the environment associated with potential spills, contaminated runoff, or fire is minimized, such as a minimum of 50 feet downhill from drinking water supplies. The location should be easily accessible to service vehicles in case of an emergency.

5.5.2 Engineering Controls

Walls and doors: Storage buildings should be built to contain and resist potential fire. Interior walls should be impervious to pesticides (e.g., painted steel, aluminum, fiberglass). Doors should be lockable, steel (solid core), and set in a steel frame that opens to the outside.

Floors and concrete specifications: Concrete floors with impervious sealant or comparable surface should be used for pesticide storage facilities. Type I or Type II cement is suggested. Epoxy, urethane, polyester, vinyl, chlorosulfonated polyethylene, and polyurea coatings prevent corrosion of floors due to fertilizers and pesticides. Coating efficacy varies and should be selected based on types of products stored in the facility. A continuous sill should surround the floor to contain 125% of the volume of the largest container in storage.

Lights and ventilation: Storage facilities should include enough light to clearly read pesticide labels. A ventilation system should be installed to dissipate potential chemical vapor and ensure a safe workspace. Fans should be wired to turn on with lights and displace six air changes per hour.

5.5.3 Storage Conditions

Pesticides should be stored in their original container with the label clearly visible. Pesticides within the storage facility should not be exposed to direct sunlight, freezing temperatures, or extreme heat. Flammable materials should be stored in fireproof containment. Separate the fungicides, insecticides, and herbicides within the storage area to prevent unintended usage. Dry pesticides should be stored separately from liquid formulations to prevent contamination in case of leakage. Place pesticide containers within chemical-resistant bins or on shelves with a raised lip to contain leaks. Food, feed, potable water, seed, and personal protective equipment should not be stored within pesticide storage areas.

5.6 Pesticide Inventories

Pesticides degrade over time and therefore large quantities of pesticides should not be stored for long periods. The “first in–first out” principle should be adopted, with the



Pesticide storage. Credit: J. Brosnan.

oldest products used first to ensure that product shelf lives are not exceeded. Computer software systems should be used to record inventory and use. Safety Data Sheets for all pesticides on hand should be kept in an easily identifiable location, outside the pesticide storage facility.

5.7 Pesticide Mixing/Washing

Proper cleaning of equipment helps prevent residues from reaching surface waters, groundwater, drainage pipes, or storm sewers. The residues from washing equipment include grass clippings, soil, soaps, oil, fertilizers, and pesticides. Therefore, equipment washing should be conducted under controlled conditions in an appropriate contained area with minimal risk to the environment and to prevent adverse washwater and stormwater runoff impacts. Equipment washing guidelines and restrictions should be established that reduce the potential for pollutants to reach stormwater runoff, surface water, or groundwater.

For equipment with pesticide residues, BMPs should be followed to ensure that washwater does not become a pollution source. Captured washwater can be used as a dilute pesticide per label, or it may be pumped into a rinsate storage tank for use in the next application and used as a dilute pesticide per the label.

5.8 Pesticide Container Management

Handling of empty pesticide containers must be done in accordance with label directions as well as with all federal, state, and local laws and regulations. Under the federal Resource Conservation and Recovery Act, a pesticide container is not empty until it has been properly rinsed. However, pesticide containers that have been properly rinsed can be handled and disposed of as non-hazardous solid waste. Federal law (FIFRA) and state laws require pesticide applicators to rinse all empty pesticide containers before taking other container disposal steps.

After following proper procedures (such as pressure rinsing, triple rinsing, puncturing, etc.), pesticide containers must be either recycled through an approved program or disposed of by depositing them in a licensed sanitary landfill. The [Ag Container Recycling Council](#) website lists empty pesticide container recycling programs.

5.9 Pesticide Spill Response and Containment

Accidents can happen. Advance preparation on what to do when an accident occurs is essential to mitigate potential

negative impacts on human health or the environment.

A spill containment kit containing absorbent materials (e.g., reusable gelling agents, cat litter, clay, soil, or sand), a garbage can, and a shovel should be available for small spills. Hydrated lime or bleach can be used to neutralize and clean surfaces where spills occur. Spill containment kits should be easily accessible within the pesticide storage area. Ensure that PPE, a first-aid kit, and eye-wash stations or eye-wash bottles are accessible outside the pesticide storage and mixing area.

A Pesticide Spill Response Plan containing actions to take and personnel to contact in the event of a spill or accident should be in place. The plan should include the following information:

- Names and quantities of pesticides in inventory.
- Location of property, including a map and directions (to relay over phone in emergency).
- Names, addresses, and phone numbers of the designated spokesperson, sports field manager, and key employees.
- Plan of facility showing pesticide storage locations, flammable materials, electrical service, water supply, fuel storage tanks, fire hydrants, storm drains, and nearby wetlands, ponds, or streams.



Eye wash station. Credit: J. Brosnan.

- Location of emergency equipment supplies.
- Contact information for fire, police, hospital, pesticide regulatory agency, and facility owner, and any other contact information deemed important.

Ensure that copies of the plan are located near the pesticide storage facility and the office and distributed to local police and fire departments. Maintain copies in English and any other language commonly used by employees. Be sure to update the information regularly for local police and fire departments.

5.10 Pesticide Record Keeping

Maintaining accurate records of pesticide-related activities (e.g., purchasing, storage, inventory, and applications) is essential. Applicators must maintain records of pesticide applications as required by law. These records must be kept for the regulated amount of time (at least two years).

Pesticide record keeping should include the following information at a minimum:

- Date and time of application.
- Address.
- Product name and active ingredient.
- EPA registration number.
- Mode of action group.
- Classification of pesticide used.
- Rate of product per unit.
- Application rate and total product used.
- Pest treated.
- Site treated.
- Total acres or volume of area treated.
- Wind direction, estimated velocity, and weather conditions.
- Type of application equipment used.
- Applicator name and license number and/or person making the application.

5.11 Pesticide Management Best Management Practices Risk Reduction Best Management Practices

- Read and follow all label directions before making a pesticide application.
- Follow all requirements for posting notice of pesticide applications when and where required.

- Restrict staff and player entry to pesticide treated areas for at least one hour or until leaf surface has dried following application. In the three to four days after an application, restrict early morning activity until leaf surfaces are dry.

Limiting Pesticide Exposure Best Management Practices

- In accordance with label directions, 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.
- 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.
- The federal Occupational Safety and Health Administration (OSHA) requires employers to fit-test workers annually who are required to wear respirators for pesticide application.
- Meet requirements for [OSHA 1910.134 Respiratory Protection Program](#).
- Water-in pesticides after application, unless otherwise indicated by the pesticide label or if product efficacy will be decreased.

Application Equipment and Calibration Best Management Practices

- Ensure that the spray technician is properly trained properly licensed and certified, or supervised by a licensed and certified pesticide applicator.
- Minimize off-target movement of pesticides by using properly configured application equipment.
- Properly calibrate all application equipment at the beginning of each season (at a minimum) and 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 and other variables.
- Use wide-angle, air-induction, flat-fan nozzles to minimize spray drift to non-target areas.

Pesticide Storage Best Management Practices

- Store, mix, and load pesticides away from sites that directly link to surface water or groundwater.
- Whenever possible, store pesticides in a lockable concrete or metal building that is separate from other buildings.
- Locate pesticide storage facilities away from other types of structures 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.
- Light and fan switches should be located outside the building, so that both can be turned on before employees enter the building and can be turned off after they leave the building.
- Avoid temperatures less than 40°F or greater than 100°F inside the pesticide storage facility.
- Personal protective equipment 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 equipment.

Pesticide Inventories Best Management Practices

- Avoid purchasing large quantities of pesticides that require storage for greater than six months.
- Adopt the “first in–first out” principle, using the oldest products first to ensure that the product shelf life does not expire.
- Ensure labels are on every package and container.
- Consult inventory when planning and before making purchases.
- Control temperature to avoid extreme hot or cold.

Pesticide Mixing/Washing Best Management Practices

- Load and mix pesticides over an impermeable surface so that spills can be collected and managed.
- Mix pesticides for spray applications according to pesticide labels.
- The mixing station surface should offer easy cleaning and the recovery of spilled materials.
- Pump the sump dry and then clean it at the end of each day.
- Liquids and sediments should be removed from the sump and the pad whenever pesticide materials are changed to an incompatible product (i.e., one that cannot be legally applied to the same site).
- Apply liquids and sediments from the sump 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 hazardous waste.
- Sweep up solid materials and use as intended.
- Collect washwater (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 Container Management 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, rinsed pesticide containers and dispose of them according to the label.

Best Management Practices for Spill Response and Containment

- Develop a pesticide spill response plan that includes procedures to control, contain, collect, and store spilled materials.
- An inventory of the pesticides kept in the storage building and the SDS for the chemicals used in the

operation should be accessible on the premises, but not kept in the pesticide storage room itself.

- 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 can speak on behalf of the facility should an emergency occur.
- Host a tour for local emergency response teams (e.g., firefighters) to show them the facilities and to discuss the emergency response plan. Seek advice on ways to improve the plan.

Pesticide Record Keeping Best Management Practices

- Keep and maintain records of all pesticides used to meet legal (federal, state, and local) reporting requirements.
- Use electronic or hard-copy forms and software tools to properly track pesticide inventory and use.
- Keep a backup set of records in a safe but separate storage area.
- Develop an IPM plan and update the document annually or as needed during the season. Assign location of the IPM plan for public record-keeping purposes and keep document up-to-date and available for public record.
- Use records/assessment forms to monitor pest control efforts and to plan future management actions.

6 SUSTAINABLE LANDSCAPING

While care of sports fields is the highest priority for sports field managers, native areas may also be an important component of sports field managers' responsibilities. Landscaped and natural areas provide additional recreational opportunities, such as areas and paths for walking, wildlife habitat, and natural buffers that help delineate field or property boundaries, while also moderating external noise. Maintaining these aesthetically pleasing areas for the safety of recreational users and as sustainably as possible is economically advantageous and supports biodiversity. Developing or expanding naturalized areas may also reduce dependence on water, chemical, and fuel inputs, while allowing more intensive maintenance to be reserved for areas dedicated to sports (Lyman et al., 2007; Gross and Eckenrode, 2012).

Facilities with additional acreage can provide an ideal opportunity for environmental stewardship and conservation. Vegetated areas with a greater diversity of plant species support wildlife by providing forage and habitat (Tallamy, 2009). Less intensively managed vegetation (e.g., tall grass and naturalized areas) directly correlates with a higher biodiversity for plants, animals, and insects (Colding and Folke, 2009; Dobbs and Potter, 2013). Properties can contribute to plant and pollinator diversity by expanding natural habitat throughout the property, both in the native areas and in high-visibility areas, such as the property surrounding outbuildings and parking lots.

6.1 Benefits of Sustainable Areas

An ecosystem with a healthy variety of plants fosters a robust biodiversity of animal and insect species. Plants provide a primary food source and habitat, yield nutrients, improve soil health, and produce oxygen. Properties can provide a critical link that connects wildlife corridors by increasing naturally vegetated habitat, including unmown grass and native wildflower meadow areas. Benefits of increasing the sustainability of native areas include:

- Attracting beneficial wildlife, supporting pollinator habitat, enhancing biodiversity, and creating aesthetic interest that provides year-round visual pleasure for sports enthusiasts using sports fields and users of recreational fields or trails.
- Providing an option for native areas that requires fewer non-renewable inputs (fertilizer, water, and gasoline) to maintain.

- Protecting soils, natural vegetative cover, water resources, and water quality.
- Increasing plant biomass production than what is found in high maintenance areas (Wissman, 2016).

6.2 Sustainable Landscaping Concepts

According to the American Society of Landscape Architects, “sustainable landscapes sequester carbon, clean the air and water, increase energy efficiency, restore habitats, and create value through significant economic, social, and environmental benefits.” As land becomes developed, the importance of sustainable landscapes providing these ecosystem services in open, managed tracts of land cannot be overstated. In addition, naturalized areas can offset the higher carbon demands for maintenance activities (such as mowing) as compared with more intensively managed sports fields.

When designing a sustainable landscape, plants should be selected for much more than simple aesthetic value. Native plants should be selected whenever possible as they are already adapted to the existing soil conditions, available water, and the microclimate, reducing or eliminating additional inputs of irrigation, fertilizer, and soil amendments. Native plants have also evolved in concert with native wildlife and pollinators, providing the foundation of local food webs that enable butterflies, birds, and other wildlife to survive. Furthermore, most native herbivorous insects and pollinators are specialists that cannot survive on introduced or exotic plant species.

6.3 Sustainable Landscape Design Approaches

Two distinct approaches to sustainable landscape design are as follows:

Traditional Design: Uses native plants as an alternative for introduced or exotic ornamental species in a formal garden, often including mulched landscape beds and lawn areas. Required maintenance is the same as any typical garden area, with possibly reduced irrigation if drought tolerant plants are used. This type of design is best suited for high visibility areas, such as around buildings and other areas that provide aesthetic focal points.

Naturalized Design: Uses maturing and evolving native plant communities, such as tall grass, meadow, and forested areas. This style is a more viable and cost-effective option in the long term for large tracts of land. Required maintenance is consistent with meadows and periphery areas.

Facility managers seeking to conserve water and protect ecosystems on their properties can incorporate sustainable landscaping GI systems. Green infrastructure is effective, economical, and improves the safety and quality of life through the intentional use of the ecosystem services provided by plants in the managed landscape (EPA, 2017). Green infrastructure conserves, restores, or replicates the natural water cycle by reducing and treating stormwater runoff, thus turning a potential pollutant into an environmental and economic benefit. Green roofs, rain gardens, bioswales, cisterns, and permeable pavements are examples of GI landscaping. See the Planning, Design, and Construction chapter for more on these types of stormwater treatment features.

Sustainable landscaping is part of the required protocol when seeking Leadership in Energy and Environmental Design (LEED) certification. LEED is an internationally recognized green building certification system. Developed by the U.S. Green Building Council, LEED provides facility owners and operators a concise framework for identifying and implementing practical and measurable green building design, construction, operations, and maintenance solutions.

LEED buildings are designed, built, and operated with techniques and strategies that improve performance with respect to energy savings, water efficiency, carbon dioxide emissions reduction, improved indoor environmental quality, and stewardship of resources and sensitivity to their impacts.

6.3.1. Sustainable High Visibility Areas

Landscaping in high visibility areas around buildings makes a lasting impression on players, sporting event attendees, and the community at large. Sustainable landscaping concepts can be incorporated into these landscaped areas to fulfill both the facility's environmental commitment and its aesthetic goals in focal areas. Sound design includes the selection of site-appropriate plant cultivars that permit reduced maintenance to remain healthy and attractive. For turfgrass areas, the [National](#)

[Turfgrass Evaluation Program](#), [Alliance for Low Input Sustainable Turf](#) and [Turfgrass Water Conservation Alliance](#) can provide information on improved cultivars of turfgrasses that perform well with fewer inputs.

Whenever new construction or renovation occurs, landscaped areas should be amended to include more native plant material. Incorporating native plants supports a reduced maintenance program that requires less time and expense to maintain. Keys to establishing strong, healthy landscaping plantings are as follows:

- Soil testing and modification (if needed).
- Weed management during the establishment phase.
- Supplemental irrigation to encourage plant establishment (if possible).

In landscaped areas, low quality, highly disturbed soils promote the growth of weeds, including invasive weeds, that outcompete desired plants. Therefore, soil tests that provide data on nutrient levels and soil structure can provide the information needed to modify soils if warranted, prior to planting, greatly improving the success of these efforts. Weed management during the establishment phase is critical to allow the native plants the chance to establish themselves before competition from weeds decreases the quality and density of the native plantings. Lastly, during establishment, especially during drought, supplemental irrigation helps to promote plant growth. Once established, native plants are acclimated to local climate and conditions.

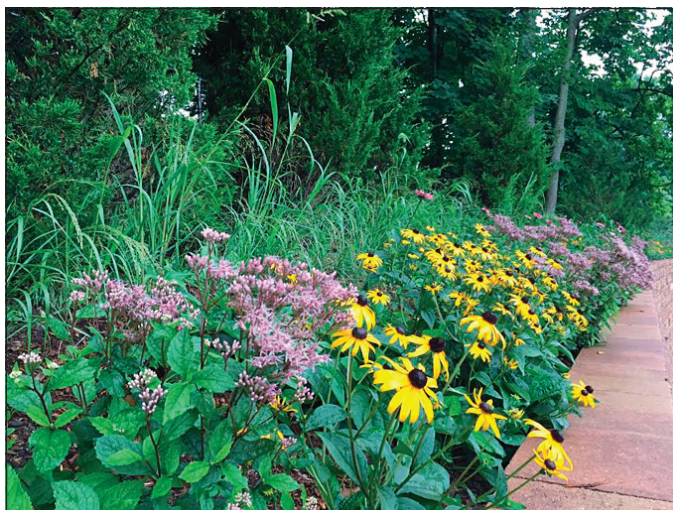
6.3.2 Sustainable Naturalized Areas

Sustainable naturalized areas can help managers meet their goals to improve both environmental protection and economic sustainability. While sports fields normally require sufficient irrigation for overall plant health and recovery from wear, other areas of the facility will not need to be as intensely maintained. In particular, facilities that experience increased seasonal water limitations may consider design alterations of non-turfgrass areas to increase or reduce the amount of natural grass areas that require irrigation.

These non-turfgrass areas can also help to restore habitat and increase biodiversity. Conventional landscapes use less than 15 species in an average landscaped lot, while the average undisturbed forest or meadow can support 100 species in the same area. In addition, diverse, multi-storied plantings store more carbon than mown turfgrass areas (Selhort, 2012). Plantings can also be made specifically to

support pollinator habitats, discussed in the next section.

While developing a plan to improve and expand wildlife habitat, existing native habitats should be protected and existing natural amenities expanded or enhanced. Retain or restore existing native vegetation, where possible. Where appropriate, existing vegetation should be enhanced through the supplemental planting of native species around native areas and water sources. Wet areas and waterways (streams and ponds) should be planted with native wetland vegetation utilized by many wildlife species. Nuisance, invasive, and exotic plants should be removed and replaced with native species adapted to the site.



Native landscaping. Credit: A. Siegel-Miles.

6.3.3 Pollinator Habitat

Habitat for pollinators includes foraging habitat, nesting sites, and available water sources. Pollinator-friendly habitat contains a diversity of blooming plants of different colors and heights, with blossoms throughout the entire growing season. Native plants provide the most nutritious food source for native pollinators.

Increasing habitat to meet pollinator needs can be accomplished simply by adding to existing plantings or through more intensive efforts to establish a larger native area. Pollinator habitat includes grassy areas and landscaped areas. Areas renovated specifically with pollinator habitat as a priority includes native plants, wildflowers, and flowering trees and shrubs. To convert existing areas to a new native area, site preparation is key and may require more than one season of effort to reduce competition from invasive or other undesirable plants prior to planting. For more information on establishing a native area, university Extension specialists and published information, such as [Making Room For Native Pollinators](#), can be consulted.

In addition to foraging habitat, pollinators require nesting sites. Providing nesting sites for native species can be accomplished by making simple alterations in landscaped or natural areas, such as:

- Leaving exposed patches of bare soil in natural areas.
- Leaving dead trees, stumps, and posts.
- Planting hollow stem grass species.
- Providing stem bundles of hollow plant stems like bamboo.
- Creating bee blocks for solitary nesters such as mason and leafcutter bees.
- Creating artificial boxes for bumble bees.

A clean, reliable source of water is another essential habitat consideration for pollinators. Pollinators can use natural and human-made water features such as running water, pools, ponds, and small containers of water. Water sources should have a shallow or sloping side, so the pollinators can easily approach the water without drowning. In addition, irrigation management practices that preserve ground-nesting pollinators include irrigating at early morning before pollinators leave their nests to forage and avoiding flooding any areas.

6.3.4 Habitat Corridors

Sports field facilities can make a positive and significant impact on wildlife diversity by creating new habitat corridors or expanding existing corridors. Corridors are areas of habitat physically connecting plant and animal populations that cannot maintain healthy, genetically diverse populations when highly fragmented due to human activities or structures (UC-Davis, 2008). To achieve the goal of creating or expanding corridors, habitat patches can be linked with continuous strips of natural vegetation both within the facility and linking to patches outside the facility boundaries. This increases the area available to native wildlife species.

6.3.5 Invasive Species

Invasive species are non-native plants and animals that may negatively affect the environment, human health, and the economy. These species include noxious weeds, non-native insects (such as earthworms and other soil-dwelling pests that may be found in soils and potting media) and some non-native animals. University Extension specialists and publications can provide information on the species that may be found in the region and management steps that may be taken to control their spread.

Unwanted invasive species should be promptly managed to prevent their spread or, where practical, eradicated. Areas of large populations of any unwanted species that is invasive should be delineated and monitored to contain further expansion of these areas, including at new construction sites. Whenever possible, native plants should be used to revegetate disturbed areas. Intentionally planting or propagating certain invasive plants may be in violation of state, regional or local regulations or ordinances.

6.4 Meadows/Tall Grass Areas

A meadow is an area of natural grasses and/or native wildflowers that, over time, becomes self-sustaining. Native meadow plants are resilient, are accustomed to the regional climate, and can survive adverse conditions. Meadow plants have adapted to the existing soil conditions, water availability, and microclimate challenges. For example, these plants have a deep-penetrating fibrous root system making them highly drought resistant. Meadows that are successfully incorporated into landscape management programs can reduce some facility maintenance expenses, such as labor for mowing and equipment wear and tear.

In an increasingly developed world, meadows provide valuable habitats for a variety of birds, pollinators, and other wildlife. In addition, community groups are often interested in partnering with facilities in different ways, such as to install, maintain, and monitor nesting and roosting sites. For example, meadows provide appropriate

habitat for many bird species, such as bluebirds and purple martins. Other ideas that have been implemented at some facilities with community support include the installation of beehives, bat boxes, etc.

6.4.1 Establishment

Proper site selection, plant selection, site preparation, and maintenance are critical to designing, establishing, and sustaining a flourishing, beautiful meadow. Lists of recommended meadow plants for your region can be obtained from university Extension programs.

Most meadow plants prefer full sun. A substantial portion (about 40%) of a meadow should be comprised of grasses (Zimmerman, 2010), in order to reduce weed seed germination and establishment surrounding the desired perennial forbs. Time spent on site preparation that eliminates competing vegetation leads to fewer weeds in subsequent years. Soil surface disturbance during site preparation should be minimized whenever possible, to prevent unnecessary weed germination at the soil surface. Less disturbance to the site also maintains soil structure and integrity.

As part of the overall meadow establishment protocol, an effective maintenance plan should be developed before planting and should be implemented for the successful longevity of the meadow. The initial three years of meadow establishment require both patience and focused effort. During establishment, a nurse crop such as a quick-



A meadow is an area of natural grasses and/or native wildflowers. *Credit: A. Siegel-Miles.*

Table 6. Species that provide the greatest support to native butterfly and moth caterpillars.

Trees		Perennials	
Common Name (Botanical Name)	Butterfly/Moth Species Supported	Common Name (Botanical Name)	Butterfly/Moth Species Supported
Oak (<i>Quercus</i>)	534	Goldenrod (<i>Solidago</i>)	115
Black Cherry (<i>Prunus</i>)	456	Aster (<i>Symphyotrichum</i>)	112
Willow (<i>Salix</i>)	455	Sunflower (<i>Helianthus</i>)	73
Birch (<i>Betula</i>)	413	Joe Pye Weed (<i>Eutrochium</i>)	42
Poplar (<i>Populus</i>)	368	Blue Grass (<i>Poa</i>)	42
Crabapple (<i>Malus</i>)	311	Sedge (<i>Carex</i>)	36
Blueberry (<i>Vaccinium</i>)	288	Lupine (<i>Lupinus</i>)	33
Maple (<i>Acer</i>)	285	Rye, Blue Wild (<i>Elymus</i>)	31
Elm (<i>Ulmus</i>)	213	Violet (<i>Viola</i>)	30
Pine (<i>Pinus</i>)	203	Wild geranium (<i>Geranium</i>)	24

Credit: D. Tallamy.

establishing, clump-forming grass can be used to reduce weed invasion, hold the seed or young plants in place, and protect the soil from erosion.

In the first growing season, perennial meadow plants grow slowly, with an average overall height of 2” to 6”, depending on the species. Annual weeds proliferate and grow quickly if given the opportunity. Therefore, regular mowing and spot treating can prevent weeds from growing too tall and outcompeting the desired perennials.

6.4.2 Maintenance

After the first year, maintenance of native areas typically requires annual mowing in late winter or early spring. Annual mowing encourages seed/soil contact of desired wildflowers and grasses, reduces growth of unwanted woody species, and helps to manage weed populations. This maintenance should be timed before the growing season begins.

6.5 Plant Selection

The fundamental principle for the environmentally sound management of landscapes is “right plant, right place”. Proper plant selection is the most important step in designing a sustainable landscape planting. Use a detailed, completed site analysis to select appropriate plants for the site and ensure successful establishment based on sunlight requirements, soil conditions, and water availability.

Native plants should be an integral component of the landscape design at key focal points and around the property periphery. The goal of species selection in a sustainable landscape is to maintain as close to a natural ecosystem as practical. The majority of the non-sports field areas should be maintained with reduced inputs or left unmown during the growing season, where possible. Retaining as much natural vegetation as possible and supplemental planting of native trees, shrubs, and herbaceous vegetation provides the highest quality wildlife habitat. For example, native species such as oak and aster best sustain species of native butterfly and moth caterpillars in a Mid-Atlantic location (Table 6), while non-native species such as Ginkgo or Zelkova support none. Planting species that attract native insects is the most effective means to maintain and improve biological diversity, as it increases the complexity of the biota the native area can support. The [native plant finder website](#) can provide the same kind of species information and rankings by ZIP code.

6.6 Irrigation

Regardless of their ability to tolerate drought, all plants typically require supplemental irrigation during establishment. If supplemental irrigation is not available for larger expanses of native areas, the plants should be established at the most ideal time of year to take advantage of natural occurring rainfall. To increase water-use

efficiency and improve plant establishment in landscaped areas, consider hand-watering individual plants for the first several months of the growing season. When irrigation is needed, plants should be watered in the early morning to conserve water and to avoid water loss due to evaporation. Water new trees and shrubs at least once a week to a depth of one foot and more frequently during dry weather. When using a hose, allow the water to trickle out for at least an hour, and move the hose several times around the base of the tree. Keep trees well-watered throughout the entire establishment period (one year or more depending on the caliper) with deep, slow watering. Apply at least five gallons when watering from a container, pouring it slowly over the back of a shovel to spread the water. Watering bags are effective tools for applying water slowly.

If trees and shrubs are planted in an area with an existing irrigation system, assess the coverage to determine whether changes should be made to identify areas where efficiency can be improved. Carefully assess landscape watering patterns to minimize spray on impervious surfaces, blockage of spray by plants or other obstructions, and runoff on slopes, clay soils, or compacted sites. Focus on the irrigation of woody plants at or beyond the dripline to promote extensive rooting. Periodically throughout the growing season, check the performance of the landscape irrigation system.

6.7 Use of Mulch

Mulch conserves soil moisture, mitigates temperature extremes, and reduces weed competition. During the growing season, mulch also serves as a visual reminder to keep mowers and string trimmers away from shrub stems and tree trunks. In winter, mulch helps prevent soil cracks from forming and exposing roots to cold temperatures and winter desiccation. Organic mulches include herbicide-free grass clippings (though avoid applying too deeply to avoid matting and heating the soil), shredded bark, bark chunks, composted sewage sludge, one-year-old wood chips, pine needles, and composted, shredded leaves. Organic mulches are preferred, as non-organic mulches such as stone may add heat stress around annuals and perennials.

Annuals and perennials grow best with no more than 2” of mulch. Around trees and shrubs, mulch should be no more than 3” deep. With any planting, place mulch between the plants and not on top of the crown or against tree trunks or shrub canes. In the winter after the ground freezes, a deeper layer of coarse mulch (evergreen branches) over bulbs and other perennials can delay or prevent early growth and can be used to protect tender plants. Do not

place a new layer of mulch over the old layer each year. Each spring, rake the old mulch to break up any hard crust and add only enough new mulch to maintain a 2” to 3” layer.

6.8 Pest Management

The same principles and methods identified in the IPM chapter can be applied to landscaped areas. University Extension publications can provide information on the pests of regional concern and provide guidance on pest management techniques to manage them. In addition, many Extension programs have diagnostic laboratories that can be utilized when needed.

6.8.1 Pollinators

Most flowering plants need pollination to reproduce and grow fruit. While some plants are pollinated by wind, many require assistance from insects such as solitary bees, bumble bees, flower flies, and butterflies, as well as other animals (e.g., birds and bats). In the absence of these pollinators, many of the fruits of wild plants, would fail to survive.

Pollinators are facing a number of threats that can alter their health and abundance, such as loss of genetic diversity of the plants required for survival, loss of habitat, and exposure to pesticides. Because of the potential for non-target effects of pesticide products sometimes used in landscape and sports field management, licensed pesticide applicators are trained on the impact that they may have on pollinator species and their habitat.

Incorporating IPM best management practices can reduce the need for pesticide applications often used to maintain healthy dense turfgrass playing surfaces, though pesticides may need to be applied when necessary and allowed. Sports field managers can utilize IPM best management practices that protect pollinators by following these simple steps:

- Maintain landscape, right of way areas, woodland or natural areas that border sports fields and other grass areas to reduce pest damage to natural grass playing surfaces.
- Scout for both pests and beneficial insects. Identify and confirm true pests as well as understand the threshold number when unacceptable pest damage will occur.
- Determine if higher pest thresholds are acceptable in non-play areas.
- Monitor bee/pollinator activity to avoid applying pesticides during peak foraging times.

- Mow to remove flowers that attract pollinators before applying a pesticide.

When pesticides are necessary to provide uniform and safe playing surfaces, being mindful of pollinators, includes selecting products with the following types of characteristics:

- Lowest toxicity to all bees/pollinators.
- Short residual toxicity.
- Properties repellent to bees.

Pesticide labels include pollinator protection language that licensed pesticide applicators must follow. In addition, applicators should be aware of the behavior of honey bees, wild bees, and other pollinators, to avoid applying pesticides when and where these insects are present. Numerous documents that provide the basics of pollinator biology useful for pesticide applicators are available, including ones from the [Xerces Society](#) and university Extension offices.

In addition, the Pollinator Partnership has published visual depictions of [honey bee](#), [solitary bee](#), [colony](#), and [general pollinator life cycles](#) that are useful as well.

Due to the potential for drift, caution should be exercised when applying any products near flowering plants, including flowering weeds, that might attract foraging pollinators into the nearby area. Where possible, applications should be delayed until after nearby plants have completed flowering. Applicators are also encouraged to utilize [FieldWatch](#), or similar regional databases, that provide information on any nearby apiaries or specialty crops before applying pesticides on ground properties.

6.9 Communication

Addressing any safety-related issues is the highest communication priority for the sports field manager. In addition, communicating the benefits of native areas, pollinator gardens, etc. that add to the landscape provides opportunities for education along with recreation.

THE NEW EPA BEE ADVISORY BOX

On EPA's new and strengthened pesticide label to protect pollinators

- Alerts users to separate restrictions on the label. These prohibit certain pesticide use when bees are present.**
- The new bee icon helps signal the pesticide's potential hazard to bees.**
- Makes clear that pesticide products can kill bees and pollinators.**
- Bees are often present and foraging when plants and trees flower. EPA's new label makes it clear that pesticides cannot be applied until all petals have fallen.**
- Warns users that direct contact and ingestion could harm pollinators. EPA is working with beekeepers, growers, pesticide companies, and others to advance pesticide management practices.**
- Highlights the importance of avoiding drift. Sometimes, wind can cause pesticides to drift to new areas and can cause bee kills.**

The science says that there are many causes for a decline in pollinator health, including pesticide exposure. EPA's new label will help protect pollinators.

Read EPA's new and strengthened label requirements: <http://go.usa.gov/jHH4>

Credit: EPA.



Communicating benefits of native areas to the public.
Credit: B. Polimer.

Finding opportunities to add signs increase the visibility of your efforts in the non-play areas and the benefits to the community. Articles in community newsletters and on community websites are additional efforts that may be undertaken. Lastly, partnering with birding, apiary, and gardening groups can provide another layer of communication with the interested public.

6.10 Sustainable Landscape Best Management Practices

Landscaping High-Visibility Areas Best Management Practices

- Integrate low-maintenance turfgrasses and native plant species into landscape areas around the buildings and other focal areas.
- Perform a soil test and analysis when analyzing problems or when renovating landscapes.

- Use organic amendments (e.g., compost, compost tea, or leaf mulch) as part of the overall nutrient management plan, to build healthy soils, establish beneficial soil organisms, and release nutrients over the long term.
- Utilize native plants wherever possible, integrating them into the landscape along with annuals to maintain season-long color and aesthetic interest.
- Group plants with similar watering, pH, and fertilizer requirements together to allow for the most efficient use of resources.
- Where irrigation is necessary, utilize high-efficiency irrigation systems (e.g., drip irrigation) in all landscaped areas for maximum efficiency. If possible, design recycling water features, such as collecting rainwater for greywater use.
- Where necessary, maintain 2” to 4” of organic mulch over the surface of soil, applied a few inches from the base of trees and plants, to keep soil moist and minimize weeds.

Sustainable Naturalized Areas Best Management Practices

- Actively manage open-space areas to support native habitats and avoid introduction and establishment of invasive species.
- Incorporate well-adapted, drought-resistant plants, including low-growing ground covers, shrubs, and trees that require little, if any, supplemental irrigation once established.
- Allow beneficial “weeds” (e.g., milkweed, which supports the survival of monarch butterflies) to grow and mature in out of the way areas where they will not interfere with integral in-play areas.

Pollinator Habitat Best Management Practices

- Follow site preparation guidelines when renovating areas to ensure success.
- Choose south-facing sites whenever possible for establishing native areas.
- Place plants in masses (three or more) to attract pollinators.
- Select plants that feature different shapes, sizes, and colors and that bloom at different times of the year.
- Select native grasses that provide foraging and nesting habitat.
- Use both perennials and annuals.
- Leave stems and coarse, woody debris in native areas for pollinator nesting.

- Leave exposed patches of well-drained soil in native areas for pollinator nesting.
- Provide water sources with shallow sides for pollinators.

Habitat Corridors Best Management Practices

- Manage natural areas to encourage wildlife diversity and to provide habitat connectivity by linking habitat patches using habitat corridors.

Invasive Species Best Management Practices

- Consult with university Extension specialists and other sources of information, such as the [Center for Invasive Species and Ecosystem Health](#), to identify regional invasive species and appropriate control methods for these species.
- Remove invasive and exotic plants and replace them with native species adapted to the ecological conditions prevalent at the site.
- Do not introduce invasive or potentially invasive plants.

Meadows/Tall Grass Areas Best Management Practices

- Select an area for a meadow that receives no less than half a day of direct sunlight to ensure success with sun-loving plants.
- For multi-year health of the meadow, include both short-term species (nurse grasses, annuals, and biennials) and long-term perennial species that take multiple years to establish.
- Include turfgrass species as part of the plant population of a new meadow.
- Prepare the site by removing competing vegetation, while avoiding unnecessary disturbance to the soil to maintain soil structure and integrity.
- Where meadows are begun by seed in bare soil areas, utilize an annual “nurse” crop in the first year to aid in establishment.
- Mow every four to six weeks to a height of 4” to 6” during the first growing season to control weeds, along with spot treating weeds as needed.
- Mow established meadows annually either in late winter or early spring before the next year’s growth begins.

Plant Selection Best Management Practices for Meadows/Tall Grass Areas

- Consider the soil characteristics, climate, sun exposure, water conditions, and pest possibilities when selecting plants. Select plant material not regularly browsed by deer or other wildlife.

- Utilize university Extension publications for lists of native plants in your area and their requirements.
- Utilize a diverse range of species (preferably native species) in plant selection.
- Incorporate well-adapted, drought-resistant plants, including low-growing ground covers, shrubs, and trees that require little, if any, supplemental irrigation once established.

Landscape Irrigation Best Management Practices

- Establish during times when natural rainfall is most prevalent.
- Irrigate frequently during establishment.
- Water established plants based on their needs and, when needed, deeply and infrequently.
- Irrigate in the early morning to conserve water.
- Avoid water runoff onto impervious surfaces or slopes.
- Evaluate landscape irrigation performance periodically.

Mulching Best Management Practices

- Use mulch in landscaped beds.
- If using grass clippings as mulch, use only herbicide-free grass clippings.
- Protect bulbs and other perennials in winter with a layer of evergreen branches to protect plants during the winter months.

Pest Management Best Management Practices

- Utilize IPM methods to reduce reliance on chemical applications to control pests, to set pest damage thresholds, and to determine appropriate control methods.
- When pesticides are required to manage pest populations, select products that have a less damaging impact on pollinators. See Cornell’s [A Pesticide Decision-Making Guide to Protect Pollinators in Landscape, Ornamental and Turf Management](#) for more information.
- If practical, consider the use of a granular formulation to control a pest, instead of a liquid formulation to reduce drift and pollinator exposure, if native areas or landscape beds are near sports fields. Granular formulations of pesticides are generally less hazardous to most bees, although honey bees may gather the granular version and pack it into cells in hives. (Gels, J.A. et al., 2002; Larson et al., 2014; Larson et al., 2017.)

- Restrict pesticide applications to early morning or evening when foraging pollinators are not as active.
- Whenever possible, avoid applying chemicals when flowering plants, including weeds, are in bloom, and always mow turfgrass areas intended for a pesticide application prior to the treatment, to remove blossoms of flowering weeds (such as white clover) and reduce the potential for pollinator foraging.
- Follow irrigation recommendations on the pesticide label to ensure the effectiveness of the pesticide and to reduce the risk of direct exposure to pollinators.

7 SYNTHETIC TURF

Synthetic turf fields can be played on essentially 24 hours a day, seven days a week, in conjunction with an appropriate field maintenance plan. Synthetic turf fields are beneficial when natural grass fields need time to recuperate after heavy use or are saturated from heavy precipitation events.

Synthetic turf fields require maintenance practices that differ from natural grass management. If a facility has both natural grass and synthetic turf fields, proper maintenance equipment will be needed to meet the needs of each type of field. Sports field managers should be well acquainted with the specifications of the synthetic turf to ensure it performs and is maintained appropriately.

Maintenance should always be performed in accordance with the warranty to avoid invalidation.

7.1 Regulatory Issues

Stormwater management requirements and drainage issues require consultation with local regulatory authorities. Drainage regulatory requirements for a synthetic turf field vary from one jurisdiction to another and will depend in part on whether the synthetic turf field is considered a pervious or impervious surface. The ASBA publication [*Sports Fields: A Construction and Maintenance Manual*](#) (2014) includes the following information on different regulatory scenarios:

- In some parts of the country, permitting authorities consider synthetic turf fields to be impervious, like asphalt. Therefore, perimeter drainage must be designed to collect and handle all water, including anything falling on the field itself.
- In some jurisdictions, synthetic turf will be considered porous and the base and compacted subgrade will be required to handle a specific amount of precipitation.
- Some jurisdictions require the drainage plan handle a specific amount of stormwater, i.e., the 10-year average precipitation, two years total precipitation or even the precipitation caused by a 100-year storm.

Other issues that may arise during the permitting process include concerns related to the following: exposure to infill materials (e.g., crumb rubber); potential leaching of chemicals to the environment; and disposal of synthetic turf components at the end of their life cycle. Crumb rubber is recycled rubber produced from scrap tires. The

rubber contains a range of organic contaminants and heavy metals that can volatilize into the air and/or leach into the ground, posing a potential risk to the environment and human health. A limited number of studies have shown that the concentrations of volatile and semivolatile organic compounds in the air above synthetic turf fields are typically not higher than ambient concentrations, while the concentrations of heavy metals and organic contaminants in the field drainage is generally below regulatory limits (Cheng et al, 2014). Human health risk assessments indicate that athletes playing on synthetic turf fields with crumb rubber infill do not face any health risks (Pronk et al., 2020) and that exposure to the components of crumb rubber do not exceed EPA guidelines (Perkins et al., 2019). With respect to any disposal limitations, the sports field manager should review any local ordinances and monitor any state-wide restrictions.

7.2 Planning and Design

A number of people are involved in the selection process for determining the best installer and manufacturer for a new synthetic turf field. The sports field manager should be part of the team and should be aware of all the data needed to understand the synthetic materials, the warranty, etc. The use of design professionals and certified builders with demonstrated expertise and success in the development of synthetic turf systems is highly recommended and will increase the likelihood of a successful project.

Many of the same planning and design principles for natural grass fields (as discussed in the Planning, Design and Construction chapter) are relevant for the planning and design of a synthetic turf field. In addition, when considering installing a synthetic turf system, several selection criteria should be discussed by the project team, such as:

- Who is the end user of the field (professional, college, high school, parks and recreation) and what are the needs?
- What is the climate where the field will be located (tropical, arid, temperate, etc.)?
- Is the proposed site appropriate for a synthetic turf field (i.e. not a floodplain)?
- Is the installation of a synthetic turf field financially feasible?

- Is the selection of a synthetic field cost effective for the intended use with respect to installation, maintenance, and eventual disposal?
- Are the maintenance requirements described in the warranty understood and can they be followed?
- Is there a program/budget for replacing the synthetic field at the end of its life?
- Is there an understanding of the life cycle of different components (e.g., pads, drainage, infill) and options for recycling, reusing, or repurposing these components?

7.3 Base System

The stone base of a synthetic turf system is critical to the overall performance, drainage capabilities, long term surface stability, and planarity of a synthetic turf field. The components of a standard base system include the following:

- Native sub-grade soil
- Proper soil stabilization
- Base stone and finish stone
- Stone/soil interface
- Drainage pipes
- Peripheral drainage elements
- Drainage and shock attenuation pads

Designing and building a stone base must balance the maintenance of the base’s stability at an optimal level while preserving the whole system’s percolation and water transmission properties.

7.4 Drainage

A synthetic turf drainage system encompasses the synthetic turf fibers and infill, base, drainage water evacuation



Installing curb drainage. Credit: B. Polimer.

system and, ultimately, the municipality's stormwater/runoff collection points. The ASBA publication *Sports Fields: A Construction and Maintenance Manual* (2014) includes the following considerations for evaluating drainage system design:

- Specific use or uses of the field
- Local climate
- Availability and cost of materials
- Quality and characteristics of local stone
- Financial resources and commitment of the owner
- Time constraints for field construction
- Annual amount and intensity of rainfall
- Local codes and regulations regarding stormwater management.

The drainage design specifies pipe diameters or the sizes of flat drains, locations and distances of laterals, collection systems, and storm sewer tie-ins for the drainage system.

Once constructed, an infiltration test should be conducted to verify that the entire system meets STC minimum infiltration rate standards of 14" per hour.

An estimate of the amount of water the field needs to handle can be made using the following formula:

Length of the field (in feet) x width of the field (in feet) x 0.623 gallons = gallons of water produced by 1 inch of rainfall

(Source: *Sports Fields: A Construction and Maintenance Manual*).

7.4.1 Surface Drainage

Surface grading is critical in the design of a synthetic turf surface. Typically, crowns can be kept at a minimum (not exceeding 1% slope, depending upon site conditions and needs), as drainage relies more on percolation than it does on surface runoff. A crown of 0.5% is found on many, if not most, professional synthetic turf sports fields (Goatley, 2008). It is also preferable to maintain relatively mild crowns



Synthetic turf installation. Credit: B. Polimer.

so that there is as little lateral displacement as possible of the synthetic turf infill during intense rain events.

7.5 Synthetic Turf Field Installation

When a synthetic turf field is selected, it must be installed by experienced professionals specializing in synthetic turf field construction. It is highly recommended that the contractor be certified through the [American Sports Builders Association](#) as a CFB and that they reference the STC technical guidelines for installation and maintenance of synthetic turf athletic fields.

7.6 Synthetic Turf Maintenance

The maintenance program for synthetic turf depends on the climate, amount of use, the level and kind of sports played, the type of synthetic turf, and the quality of construction. The Synthetic Turf Council (STC) publishes [Guidelines for Maintenance of Infilled Synthetic Turf Sports Fields](#) (2013), which augment, but do not replace, the maintenance requirements and procedures provided in the warranty for the field and installation. Manufacturers' specific recommendations for maintenance should always be followed to avoid invalidating the warranty. However, typical maintenance activities could include:

- Checking and replenishing the infill level, especially in high use areas.
- Sweeping and dragging to keep the carpet fibers in an upright position.
- Troubleshooting for common problems and minor repairs, such as seam repair.
- Grooming to loosen and redistribute infill as needed.
- Walking the field and noting any loose fibers, seam issues, divots, and uniformity in the carpet.
- Removing debris.
- Cleaning with solvents and cleansers for difficult to remove items.

7.6.1 Weed Control

Weeds can occur on synthetic turf, as windblown dust can foster their growth. Organic infills have more issues with weed control than does rubber. When weeds occur on synthetic turf, sports field managers should refer to the manufacturer of the synthetic turf system for appropriate methods of weed control.

7.6.2 Winter Maintenance

Like natural grass fields, synthetic turf systems can freeze during the winter. When the surface is frozen, play should be delayed until it thaws. For synthetic turf fields, snow can be removed in accordance with the manufacturer's warranty. STMA publishes recommendations in [Snow Removal on Natural and Synthetic Athletic Surfaces](#).

7.7 Field Safety

7.7.1 Field Surface Temperatures

High field-surface temperatures may be experienced by athletes using synthetic turf fields on clear, sunny, and hot days. One study published by Penn State has shown maximum surface temperatures during hot, sunny conditions averaging from 140°F to 170°F (Serensits et al., 2011). In comparison, natural grass fields rarely exhibit surface temperatures above 85°F, regardless of air temperature.

Dangerous temperatures occur at the surface, which can increase the chances for heat related stress in athletes. Synthetic turf fibers radiate heat, which can be transferred through an athlete's foot and must be dissipated by the body. While watering the field cools the synthetic turf surface, temperatures rebound often as quickly as 20 minutes after water is applied. Therefore, application of water is deemed an ineffective method of cooling. Various alterations in the synthetic system, such as organic infills, have been tried to ameliorate surface temperatures. Most only lower surface temperatures by approximately 10°F to 20°F, and surface temperatures will remain significantly higher than natural grass fields when exposed to direct sunlight. Though synthetic turf fields heat up quickly under clear, hot, sunny conditions, the fields do not act as a heat sink. While the surface can have very high temperatures, the air temperatures measured two and five feet above the surface are typically only 5°F to 10°F higher than ambient air temperatures. Heat is not stored because synthetic turf fibers reflect solar radiation and the infill acts as insulation limiting transfer of heat into the system. Therefore, at night or under cloud cover, surface temperatures quickly approach the ambient temperature.

During clear, sunny conditions, it is suggested that sports field managers, coaches, and trainers monitor heat index and surface temperatures and make appropriate adjustments to practice and game schedules. It is strongly recommended to use an infrared thermometer to easily monitor surface temperatures.

7.7.2 Field Hardness

The hardness of a surface has been identified by numerous entities as an important parameter of athletic surfaces. Gmax testing, also known as impact testing, measures the shock attenuation of both synthetic turf and natural turfgrass athletic fields. Surface hardness is measured by dropping a weight (referred to as a missile) from a fixed height onto the playing surface. The missile contains an accelerometer that measures how fast the missile stops once it hits the surface. A numerical value, referred to as Gmax, is then generated. A high Gmax value indicates the missile stopped quickly and the surface is harder than a surface with a lower Gmax. Harder surfaces may influence athlete injury. Gmax should be tested at numerous locations across the field, with special attention being paid to high-use locations, such as mid-field areas and goalmouths. At a minimum, testing should occur yearly, but more frequent testing is desirable as field conditions may vary throughout a season.

Various measuring techniques have been developed to evaluate playing surface hardness. ASTM International has designated the ASTM F355 Missile A device in ASTM F1936-19, Standard Specification for Impact Attenuation of Turf Playing Systems as Measured in the Field. ASTM F1936 states that the maximum limit for a playing surface is 200 Gmax using Missile A. According to ASTM, values of 200 Gmax and above are values at which life-threatening head injuries may be expected to occur. STC recommends Gmax not exceed 165 Gmax for the life of the field when using the F355 Missile A device.

The National Football League uses the F355 Missile D device, typically referred to as the Clegg Impact Tester (ASTM F1702). If any location on the field measures above 100 Gmax using the Clegg, steps must be taken to reduce surface hardness and the field must be re-tested prior to use.

World Rugby uses the F355 Missile E device to measure head injury criterium (HIC) on synthetic turf. To meet World Rugby standards, a synthetic turf field must measure below 1,000 HIC from a 1.3 m drop height.

Typically, the most effective way to mitigate surface hardness issues is the application of additional infill (i.e., crumb rubber) via topdressing and grooming. Infill depth should be regularly monitored to maintain the manufactures' suggested minimal depth.

7.8 Synthetic Turf Best Management Practices

- Include the sports field manager as part of the team from the planning stages for a synthetic turf field project.
- Include regulatory issues in the decision-making process.
- Include life cycle considerations (such as expected lifespan of the components, ability to recycle components, etc.) as part of the evaluation process when selecting a synthetic turf field manufacturer.
- The contractor installing the synthetic turf field should be certified through the American Sports Builders Association as a CFB and reference STC's *Guidelines for Maintenance of Infilled Synthetic Turf Sports Fields*.
- All field maintenance should be carried out in accordance with the warranty.
- Develop a maintenance schedule that specifies maintenance routines, such as annual, monthly/weekly, and pre- and post-game maintenance activities.
- Use only methods indicated by the warranty for weed control, if necessary.
- Monitor the field temperature, preferably with an infrared thermometer, on hot, sunny days.
- Postpone or reschedule practice sessions or games to protect human health when the surface temperature is too high or cannot be maintained adequately.
- Measure field hardness annually (at a minimum) to ensure the level of hardness is lower than the level specified by ASTM standards.
- Use an independent or third-party tester to measure field hardness at least annually.

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8 MAINTENANCE OPERATIONS

The proper storage, handling, and disposal of chemicals, washwater, and greywater is an important part of turfgrass management. The Pesticide Management chapter discusses maintenance operations-related BMPs specifically related to the use of pesticides.

8.1 Storage Facilities

Well designed, maintained, and ventilated storage facilities protect human health and environmental quality. Storage areas should be secure and provide containment features. Such facilities protect personnel from exposure to chemicals, protect chemicals from extreme temperatures and excess moisture, and, in general, reduce liability concerns and potential environmental risk. In addition, having a climate-controlled storage facility can prevent some storage issues. For example, some dry fertilizers can be prone to caking in non-climate-controlled storage.

Any leaks and spills of chemicals in the storage area must be responded to promptly and adequately to prevent a release that extends beyond the storage area, using the same methods and equipment as described in the Emergency Preparedness chapter. Local Extension offices can be consulted for detailed information on regulatory requirements and guidance on storage facilities.

Safety Data Sheets for all chemicals stored in a storage facility should be readily available at all times to employees, employers, and any emergency personnel. Safety Data Sheets provide important information on hazardous chemicals, including PPE requirements.

8.2 Equipment Storage and Maintenance

Equipment storage and maintenance facilities should be designed to prevent the accidental discharge of chemicals, fuels, or contaminated washwater from reaching water sources. Properly storing and maintaining equipment also extends the useful life of machines and reduces repairs.

8.3 Equipment Cleaning

Equipment cleaning guidelines and restrictions should be established that reduce the potential for pollutants to reach surface water or groundwater. Proper cleaning of equipment helps prevent residues (grass clippings, soil, soap, oil, fertilizer, and pesticide) from reaching surface waters, groundwater, drainage pipes, or storm sewers.

If possible, equipment cleaning should be conducted under controlled conditions in an appropriate contained area.

The nitrogen and phosphorus nutrients in grass clippings can increase the nutrient loading to surface waters through washwater drainage. Using compressed air or a leaf blower to blow clippings off mowers before washing can help reduce the amount of nutrients that enters drains via washwater. The use of high powered air is also recommend for those areas of the machine that water should not be used.

Always follow the manufacturers recommended cleaning processes.

The best practice is to have a dedicated cleaning area with a catch basin to collect remaining grass clippings. Clippings can be collected, then composted or removed to a designated debris area. When formal cleaning areas are not available, using a short, portable hose to wash off the grass at random locations, away from surface waters, wells, or storm drains, is an option.

For equipment with possible pesticide residue, BMPs should be followed to ensure that washwater does not become a pollution source. Captured washwater can be used as a dilute pesticide per label, or it may be pumped into a rinsate storage tank for use in the next application and used as a dilute pesticide per the label.

8.4 Paints

Best management practices related to the handling and storage of paint used on sports fields with respect to protecting environmental quality prevent paint and paint residue from becoming a water quality contaminant and reduce the amount of paint wasted.

8.4.1 Paint Selection

Water-based paints adhere to turfgrass without impeding photosynthesis and therefore are the preferred choice for natural grass fields. Chalk, typically limestone or marble, builds up over time and slows down water movement into the soil. Chalk should only be used on the skinned infield surfaces of baseball or softball diamonds, applied lightly and dragged into the base infield material after games or removed with a shovel. Chalk can be avoided altogether by spray-painting baselines and batter's boxes. For paint



Paint application to sports field. *Credit: Z. Holm.*

to adhere cleanly to soil or clay, the ground must first be wetted down.

When using turfgrass paints, two ingredients in the paint are of importance: titanium oxide (pigment) and calcium carbonate (filler). Paints containing low amounts of titanium oxide typically contain higher concentrations of calcium carbonate (CaCO_2); colored paints typically have the highest concentrations of CaCO_2 . If applied frequently enough in the same area, CaCO_2 can harden the soil and weaken the turfgrass.

8.4.2 Paint Mixing and Cleaning

To prevent any paint or paint residue from reaching surface waters, paint should be prevented from reaching a storm drain or any other kind of drain that does not go to a water treatment facility. Try to always mix and clean paint machines over a water recycling station or a sanitary

sewer inlet. Any time paint is handled or stored, or paint equipment cleaned, the paint should be prevented from getting into a storm drain or any other kind of drain that does not go to water treatment facility.

8.4.3 Paint Management and Storage

The paint inventory should be managed to avoid having paint stored for an extended period of time. This will help lessen the potential for waste; fresh paint also performs better for field marking. When stored, paint should not be exposed to extreme heat or freezing cold. If possible, paint should be stored inside. If stored outside, it should be covered with a tarp.

8.5 Fueling Facilities

Designated fueling areas should be sited on impervious surfaces and located away from surface waters and water wells. Catch basins in fueling areas should be directed

toward an oil/water separator or sump to prevent petroleum from moving outside any containment structure. Floor drains in fueling areas should be eliminated unless they drain to containment pits or storage tanks.

Various fuel storage methods may be employed by different sized facilities. Newer facilities may utilize aboveground storage tanks (AST) to store fuel. ASTs are easy to monitor for leaks and are a preferred storage method. Older facilities may utilize underground storage tanks (UST). Because of the potential for groundwater contamination from leaking USTs, leak detection monitoring is a critical

aspect of UST compliance. Finally, smaller facilities often use gas cans to store fuel. These fuel cans must be properly labeled. The containment methods must be adequate in case of any spill or leak. A spill kit or a bucket of “oil dry” should be in the immediate vicinity. Any leaks or spills must be contained and cleaned immediately.

8.6 Waste Handling

Facilities need to regularly review how they handle the disposal of unwanted, expired, or accumulated items, including chemicals, paints, pesticides, tires, batteries, used oils, solvents, paper products, plastic or glass containers,



Fueling area. Credit: S. Kingsbury.

and aluminum cans. Developing recycling programs reduces waste and minimizes the quantity of waste reaching landfills. In some cases, recycling of some wastes may be required locally, and sports field managers should be aware of these requirements.

All packaging from chemicals, their containers, and other wastes should be properly disposed of. Pesticide-specific waste handling requirements are identified on the pesticide label and are discussed in more detail in the Pesticide Management chapter.

8.7 Maintenance Operations

Best Management Practices

Storage Facilities Best Management Practices

- Storage facilities should not be located in areas with high probability of flooding.
- Unless stored in a totally enclosed building, all nonliquid fertilizer materials should be covered and stored within an appropriate secondary containment storage structure.
- Construct liquid fertilizer secondary containment capable of holding 125% of the volume of the largest container, plus the volume all other containers inside the liquid containment area.
- Construct dry storage for secondary containment that is of sufficient thickness and strength to withstand loading conditions.
- Design loading areas to prevent spills onto unprotected areas and create a proper cleanup area by installing curbed containment.
- Post warning signs on chemical storage buildings, especially near entry or exit areas.
- Storage facilities should be secured and allow access only to authorized staff.
- Install backflow prevention devices or use air gap separation on water supply lines used for fertilizer mixing or equipment rinsing.
- Lock valves and shutoff devices while storage containers and facilities are not in use.
- Follow hazard safety rules, worker protection laws, and fire prevention rules while handling and storing fertilizer.
- Apply appropriate sealant to seams and cracks in all storage facilities and load/wash/rinse pad areas.
- Use approved containers designed for and compatible with the fertilizer being stored.
- Shelves should be made of plastic or reinforced metal.

Metal shelving should be coated with paint to avoid corrosion. Wood shelving should not be used due to its ability to absorb spilled chemicals.

- Exhaust fans and an emergency wash station should be provided.
- Light and fan switches should be located on the exterior of the storage facility.
- Store liquid materials below dry materials to prevent contamination from a leak.
- Train staff and other management on how to access and use SDS information.
- Complete a chemical inventory annually and keep SDS of each chemical on site. A duplicate set of SDS should be kept in a location away from the chemicals but easily reached in an emergency.

Equipment Cleaning

Best Management Practices

- Brush or blow off accumulated grass clippings from equipment using compressed air before washing.
- Clean equipment on a concrete pad or asphalt pad that collects the water, if possible. After the collected material dries, collect and dispose of it properly.
- Cleaning areas for equipment not contaminated with pesticide residues should drain into oil/water separators before draining into sanitary sewers or holding tanks.
- Do not wash pesticide-application equipment on pads with oil/water separators. Do not wash near wells, surface water, or storm drains.
- Minimize the use of detergents. Use only biodegradable, non-phosphate detergents.
- Use non-containment washwater for irrigation.
- Do not discharge non-contaminated greywater during or immediately after a rainstorm, since the added flow may exceed the permitted storage volume of the stormwater system.
- Do not discharge washwater to surface water, groundwater, or susceptible/leachable soils either directly or indirectly through ditches, storm drains, or canals.
- Never discharge to a sanitary sewer system without written approval from the appropriate entity.
- Never discharge to a septic tank.
- Do not wash equipment on a pesticide mixing and loading pad. This keeps grass clippings and other debris from becoming contaminated with pesticides.

- Solvents and degreasers should be used over a collection basin or pad that collects all used material.

Equipment Storage and Maintenance Best Management Practices

- Store equipment in areas protected from rainfall. Rain can wash residues from equipment and potentially contaminate the surrounding soil or water.
- Perform equipment maintenance activities in a completely covered area with sealed impervious surfaces.
- Follow the manufacturer's recommended maintenance intervals for equipment.
- Drains should either be sealed or connected to sanitary sewer systems with the approval of local greywater treatment plants.
- Solvents and degreasers should be stored in locked metal cabinets away from any sources of open flame.
- Complete a chemical inventory and keep SDS of each on site. A duplicate set of SDS should be kept in locations away from the chemicals, but easily reached in an emergency.
- Use PPE when working with solvents.
- Use containers with dates and contents clearly marked when collecting used solvents and degreasers.

Paint Best Management Practices

- Avoid using a product that has a large amount of calcium carbonate or chalk to avoid buildup.
- Manage inventory to avoid storing paint for extended periods of time.
- Store paint properly so as not to be exposed to extreme heat or freezing temperatures.

Fueling Facilities Best Management Practices

- Aboveground fuel tanks are preferred as they are more easily monitored for leaks as compared with underground tanks.
- Fueling stations should be located under roofed areas with concrete pavement whenever possible.
- Develop a record-keeping process to monitor and detect leakage in USTs and ASTs.
- Visually inspect any AST for leaks and structural integrity.
- Secure fuel storage facilities and allow access only to authorized and properly trained staff.
- Fuel stored in gas canisters should be properly labeled and have adequate containment in case of leak or spill.
- Spill kits should be located near any stored fuel.

Waste Handling Best Management Practices

- Label containers for collecting used solvents, lubricants, and degreasers.
- Recycle lead-acid batteries. If not recycled, batteries are classified as hazardous waste.
- Store old batteries on impervious surfaces in areas protected from rainfall.
- Recycle used tires, paper products, plastic or glass containers, aluminum cans, and used solvents, lubricants, and degreasers.
- Provide a secure and specifically designated storage for the collection of recyclable waste products.
- Recycle or properly dispose of light bulbs and fluorescent tubes.

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9 EMERGENCY PREPAREDNESS

Facilities related to the storage and handling of fertilizers, pesticides, and other chemicals, especially in their concentrated form, pose the highest potential risk to water sources if accidentally released in quantity. Learning proper procedures for dealing with pesticide spills is part of being a licensed applicator. Anyone storing, mixing, or loading potentially hazardous chemicals should treat all leaks, spills, and fires as emergencies and be prepared to respond to these emergencies promptly and correctly. For unintended releases of any chemicals, an emergency plan, spill kit, and first-aid kit should be readily available.

9.1 Planning

Planning and preparations should be made for potential emergencies related to unintended releases of any chemicals. Local emergency personnel such as fire departments should be consulted, be notified about the locations of pesticide and fertilizer storage and be given regularly updated lists of chemicals stored. Storage areas should have proper signs. Training and orientation should also be conducted annually with employees to review plans and preparations.

9.1.1 Pesticide Spill Response Plan

For facilities that store pesticides, a Pesticide Spill Response Plan with actions to take and personnel to contact in the event of a spill or accident should be in place. The plan should include the following:

- Names and quantities of pesticides in inventory.
- Location of property, including a map and directions (to relay over the phone in an emergency).
- Names, addresses, and phone numbers of the designated spokesperson, sports field manager, and key employees.
- Plan of facility showing pesticide storage locations, flammable materials, electrical service, water supply, fuel storage tanks, fire hydrants, storm drains, and nearby wetlands, ponds, or streams.
- Location of emergency equipment supplies.
- Contact information for fire, police, hospital, pesticide regulatory agency, and facility owner, as well as any other contact information deemed necessary.

Ensure that copies of the plan are located near the pesticide storage facility and the office and are distributed to local police and fire departments. Maintain copies in English

and any other language commonly used by employees. Be sure to update the information regularly for local police and fire departments.

9.2 Safety Data Sheets (SDS)

OSHA's Hazard Communication Standard – 29 CFR 1910.1200(g), revised in 2012 – requires that the chemical manufacturer, distributor, or importer provide SDS for each hazardous chemical to users to communicate information on these hazards. More information on SDS can be found on the [Hazard Communication Standard: Safety Data Sheets](#) page of the OSHA website.

An up-to-date file should be maintained with copies of all the SDS for all chemicals used. The file should be stored on the property and made available to employees. Copies of these files can be provided to local fire departments and hospitals in case of any emergency.

9.3 Spill Containment

Spill kits should be used for incidental releases. The following procedures should be followed to safely contain the release:

- Consult the appropriate SDS and label (for pesticides).
- Wear the appropriate PPE.
- Contain the spill. Prevent spread or escape from the area by using sorbents.
- Clean up the spill. Never hose down an area until the cleanup is completed.

To clean up pesticides:

- Recover as much product as possible in a reusable form. Store and use as intended.
- Recover the rest of the product as a waste product by using an absorbent or sweeping compound.
- When all recoverable material is secured, clean contaminated surface residues using triple-rinse technique. For instance, a spill of liquid on the floor requires that the area be damp-mopped three times.

To clean up all other chemicals:

- Small liquid spills can be cleaned up with a commercially available absorbent. Avoid using paper towels; they increase the surface area and the rate of evaporation, increasing the fire hazard.

- For acid or base spills, use a sorbent that will neutralize the liquids (trisodium phosphate, sodium bicarbonate, or other commercially available products).
- Use a dustpan and brush to sweep up the absorbed spill. Wash the contaminated area with soap and water.
- Dispose of absorbents used to clean spilled materials properly.

9.4 First Aid

Adequate provisions should be provided to immediately treat any person exposed to chemicals. These include eye wash stations and showers. First-aid kits should be available to treat skin contact, ingestion, or inhalation.

9.5 Natural Events

Natural events and disasters (e.g., lightning, flooding, hurricanes, etc.) can and do occur. An emergency response plan for any facility should contain information to be followed to protect human health and the environment. The sports field manager should have a copy of the plan and understand decision-making responsibilities, lines of communication, and roles in implementing the plan in case of a natural event or disaster. The plan should include how to protect players, staff, and members of the community from adverse impact from any such events, how to prevent any exposure to chemicals, and how to secure stored chemicals and equipment.

9.6 Emergency Preparedness Best Management Practices Spill Response and Containment Best Management Practices

- Develop a pesticide spill response plan that includes procedures to control, contain, collect, and store spilled materials.
- An inventory of the pesticides kept in the storage building and the SDS for the chemicals used in the operation should be accessible on the premises but not kept in the pesticide storage room itself.
- 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 can speak on behalf of the facility should an emergency occur.
- Host a tour for local emergency response teams (e.g., firefighters) to show them the facilities and to discuss the emergency response plan. Seek advice on ways to improve the plan.

Emergency Preparedness Best Management Practices

- Personnel should be familiar with an emergency preparedness plan for the facility.
- All chemicals and equipment should be secured in a location where human health and the environment are protected in case of a natural disaster.

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APPENDICES

Appendix A: Glossary

Acidic Soil: Acidic soil is soil that has a pH below 7.

Alkaline: Having a pH greater than 7.

Best Management Practices: Methods or techniques found to be the most effective and practical means of achieving an objective, such as preventing water quality impacts or reducing pesticide usage.

Chlorosis: Yellowing of leaf tissue due to a lack of chlorophyll.

Cleat seeding: Seeds applied prior to athletic play, with the expectation that the athlete's cleats will press the seed into the soil surface.

Cultivar: A plant variety that has been produced in cultivation by selective breeding.

Drift: The physical movement of pesticide droplets or particles through the air at the time of pesticide application or soon thereafter from the target site to any non- or off-target site. (EPA definition)

Erosion: The loss of soil along the slope or unsheltered distance caused by the processes of water and wind.

Eutrophication: The increase in the concentration of phosphorus, nitrogen, and other plant nutrients in an aquatic ecosystem, which fuels the excessive growth of algae and aquatic plants. This excessive growth decreases the dissolved oxygen levels, impairing the habitat for aquatic organisms.

Evapotranspiration (ET): Loss of water from the soil both by evaporation from the soil surface and by transpiration from the leaves of the plants growing on it.

Field capacity: The amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased.

Fungicide: Fungicides are biocidal chemical compounds or biological organisms used to control parasitic fungi or their spores.

Herbicide: An agent, usually chemical, for controlling or inhibiting the growth of unwanted plants, such as residential or agricultural weeds and invasive species.

Insecticide: Any toxic substance used to control insects. Such substances are used primarily to control pests that infest cultivated plants or to eliminate disease-carrying insects in specific areas.

Integrated Pest Management: IPM is a balanced, tactical approach to pest control. It involves taking action to anticipate pest outbreaks and to prevent potential damage. IPM is a pest management strategy that utilizes a wide range of pest control methods or tactics. The goal of this strategy is to prevent pests from reaching economically or aesthetically damaging levels with the least risk to the environment.

Leaching: Transport of water-soluble plant nutrients or chemicals from the soil as water moves through the soil profile and into the saturated zone.

Necrosis: Death of cells or tissues.

Nonpoint Source: Pollution not originating from a discrete location; comes from many different sources including land runoff, precipitation, atmospheric deposition, drainage, seepage, or modifications to natural waterways.

Overseeding: The periodic application of seed to an existing turfgrass stand to improve turfgrass density.

Plant available water (PAW): The store of soil water readily available to a plant for purposes of transpiration and consequently growth.

Pesticide: Any substance or mixture of substances intended for preventing, destroying, repelling, or mitigating any pest. Categories of pesticides include insecticides, herbicides, and fungicides.

Plant Growth Regulator (PGR): A natural or synthetic chemical that is sprayed or otherwise applied to a seed or plant in order to alter its growth characteristics.

Potential ET: The combined loss of water through the plant's process of transpiration via its vascular system, and evaporation of water from the earth's surface.

Runoff: Water flow along the ground's surface that can pick up contaminants, such as fertilizers and pesticides. Runoff occurs when the soil is saturated, compacted, high in clay particles, or has lost soil structure (large pores).

Sediment Forebay: A sediment forebay is a settling basin constructed at the incoming discharge points of a stormwater BMP. The purpose of a sediment forebay is to allow sediment to settle from the incoming stormwater runoff before it is delivered to the balance of the BMP.

Sedimentation: The transport of soil particles (sediment) in runoff that are deposited into surface waters.

Sodic: Containing a higher proportion of sodium than usual, such as sodic soil.

Soil pH: A measure of the acidity or basicity (alkalinity) of a soil. pH is defined as the negative logarithm (base 10) of the activity of hydronium ions (H or, more precisely, H₃O⁺ aq) in a solution.

Sprigging: The planting of sprigs, plant sections cut from rhizomes or stolons that includes crowns and roots, at spaced intervals in furrows or holes.

Stormwater: Water that originates as some form of precipitation, either rainfall or snowmelt.

Total Maximum Daily Load: the calculation of the maximum amount of a pollutant allowed to enter a waterbody so that the waterbody will meet and continue to meet water quality standards for that particular pollutant.

Volatization: The conversion of a chemical substance from a solid or liquid to a gas or vapor.

Appendix B: ASTM Standards References

ASTM C-136. Standard Test Method for Sieve Analysis of Fine and Coarse Aggregates

ASTM F-355. Standard Test Method for Impact Attenuation of Playing Surface Systems, Other Protective Sport Systems, and Materials Used for Athletics, Recreation and Play.

ASTM F-1632. Standard Test Method for Particle Size Analysis and Sand Shape Grading of Golf Course Putting Green and Sports Field Rootzone Mixes.

ASTM F-1702. Standard Test Method for Measuring Impact-Attenuation Characteristics of Natural Playing Surface Systems Using a Lightweight Portable Apparatus.

ASTM F-1936. Standard Specification for Impact Attenuation of Turf Playing Systems as Measured in the Field

ASTM F-2060. Standard Guide for Maintaining Cool Season Turfgrasses on Athletic Fields

ASTM F-2269. Standard Guide for Maintaining Warm Season Turfgrasses on Athletic Fields.

ASTM F-2396. Standard Guide for Construction of High Performance Sand-Based Rootzones for Athletic Fields.

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Appendix C: Website Addresses

(As of April 2021)

Chapter 1:

- STMA: <https://www.stma.org/>
- Environmental Facility Certification: <https://www.stma.org/environmental-facility-certification-program/>
- American Sports Builders Association: <https://sportsbuilders.org/>

Chapter 3:

- National Turfgrass Evaluation: www.ntep.org.
- Alliance for Low-Input Sustainable Turf, <http://a-listturf.org/>
- Turfgrass Water Conservation Alliance: <https://www.tgwca.org/>
- *Grass Options for Athletic Fields in the Transition Zone*: <http://www2.ca.uky.edu/agcomm/pubs/AGR/AGR237/AGR237.pdf>
- *Optimizing Bermudagrass Athletic Field Winter Survival in the Transition Zone*: https://www.pubs.ext.vt.edu/content/dam/pubs_ext_vt_edu/CSES/CSES-200p/CSES-200P.pdf.
- *The Need to Overseed*: https://aggieturf.tamu.edu/wp-content/uploads/Overseed_proof12.pdf

Chapter 4:

- Organic Materials Review Institute (OMRI): www.omri.org.
- North American Testing Proficiency Program. <https://www.naptprogram.org/>
- Minimal Level of Sustainable Nutrition: https://www.paceturf.org/journal/minimum_level_for_sustainable_nutrition
- *Rolling Athletic Fields*: <https://u.osu.edu/athleticfieldmanagement/2016/04/05/rolling-athletic-fields/>
- Weed Science Society of America, <https://wssa.net/>
- National Oceanic and Atmospheric Association: https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/cdus/degree_days/
- Online Phenology and Degree-day Models: <http://uspest.org/cgi-bin/ddmodel.us>
- Biopesticide Registration: <https://www.epa.gov/pesticide-registration/biopesticide-registration>
- IR-4 database: <http://ir4app.rutgers.edu/biopestPub/labelDb.aspx>
- *Using Beneficial Nematodes for Turfgrass Insect Pest Management*: <http://ipm.uconn.edu/documents/raw2/html/977.php?aid=977>
- Fungicide Resistance Action Committee: <http://www.frac.info/>.
- Herbicide Resistance Action Committee, <http://www.hracglobal.com/>
- Insecticide Resistance Action Committee, <http://www.iraconline.org/>.

Chapter 5:

- Data Requirements for Pesticide Registration: <https://www.epa.gov/pesticide-registration/data-requirements-pesticide-registration>
- Understanding the Science behind EPA's Pesticide Decisions: <https://www.epa.gov/pesticide-registration/understanding-science-behind-epas-pesticide-decisions>
- *Safety of Herbicides Compared to Other Commonly Used Chemicals*: [http://www.tennesseeturfgrassweeds.org/Lists/Fact%20Sheets/Attachments/29/W270updated2015%20\(with%20table\).pdf](http://www.tennesseeturfgrassweeds.org/Lists/Fact%20Sheets/Attachments/29/W270updated2015%20(with%20table).pdf)
- Personal Protective Equipment: <https://pesticidestewardship.org/personal-protective-equipment/>
- Pesticide Environmental Stewardship: <https://pesticidestewardship.org/>

- *Calibration & Safety of Pesticide Application Equipment*: <https://sturf.lib.msu.edu/article/2012sep20.pdf>
- Ag Container Recycling Council: <https://acrecycle.org/>

Chapter 6:

- National Turfgrass Evaluation: www.ntep.org.
- Alliance for Low-Input Sustainable Turf: <http://a-listturf.org>.
- Turfgrass Water Conservation Alliance: <https://www.tgwca.org/> native plant finder website: <https://www.nwf.org/NativePlantFinder/Plants>
- Center for Invasive Species and Ecosystem Health: <https://www.invasive.org/species.cfm>
- *A Pesticide Decision-Making Guide to Protect Pollinators in Landscape, Ornamental and Turf Management*: https://pollinator.cals.cornell.edu/sites/pollinator.cals.cornell.edu/files/shared/documents/Pesticide%20Decision%20Making%20Guide%20for%20Landscape%2C%20Ornamental%20and%20Turf%20Management_022619.pdf

Chapter 7:

- *Sports Fields: A Construction and Maintenance Manual*: <https://sportsbuilders.org/page/OnlineStore>
- *Guidelines for Maintenance of Infilled Synthetic Turf Sports Fields*: <https://www.syntheticurfCouncil.org/store/viewproduct.aspx?id=17587530>
- *Snow Removal on Natural and Synthetic Athletic Surfaces*: <https://11luuvtufne6f2y33i1nvedi-wpengine.netdna-ssl.com/wp-content/uploads/2017/11/c6faf2aa-c0d6-4fc9-8aca-c365a85c0dc7.pdf>

Chapter 9:

- Hazard Communication Standard: Safety Data Sheets: https://www.osha.gov/Publications/HazComm_QuickCard_SafetyData.html

Appendix D: Photo Credits

Chapter 1

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Chapter 2

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Jim Brosnan, Ph.D., University of Tennessee

Chapter 6

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Chapter 8

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Appendix E: Tables

Table 1. Insect/Invertebrate Responses to Cultural Practices.

Cultural Practice	Insect/ Invertebrate	Response	References
Fertilization	White grubs	Fall N fertilization promotes root development and recovery; spring/summer fertilization may exacerbate grub damage.	Crutchfield et al., 1995
	Fall armyworm	Development rate faster on tall fescue receiving medium and high rate urea applications than on unfertilized turfgrass.	Davidson and Potter, 1995
	Earthworms	Abundance and biomass of invasive European earthworms was greater in fertilized than unfertilized turfgrass.	Davidson and Potter, 1995
	Aphids	<i>Schizaphis graminum</i> , <i>Rhopalosiphum padi</i> preferred and developed faster on fertilized vs unfertilized turfgrass.	Davidson and Potter, 1995
Mowing	White grubs	Increased mowing height reduced white grubs.	Potter et al., 1996
	Ants	Decreasing mowing height increases surface mounding.	Maier and Potter, 2005
Irrigation	White grubs	Irrigation during adult flight increases attractiveness and lead to higher grub density. However, irrigation during damage period may enhance turfgrass tolerance recovery.	Potter et al. 1996; Crutchfield et al. 1995
	European crane fly	Reducing irrigation during egg laying may decrease habitat suitability for future larvae.	Peck et al., 2006
Other	White grubs	Amendments with composted manure or milorganite increased green june beetle grub densities.	Potter et al., 1996
	White grubs	Aerification prior to adult flight had no impact on grubs in summer/fall; aerification reduced grub density.	Potter et al., 1996
	White grubs	Replacing damaged turfgrass with or integrating tall fescue increases tolerance of grub damage; however adult scarabs showed preference for laying eggs in tall fescue over other turfgrass types.	Wood et al, 2009.
	Hairy chinch bug	Positive correlation between thatch thickness and chinch bug density; thatch management reduces suitability of turfgrass for chinch bug.	Davis and Smitley, 1990
	Hairy chinch bug	Higher chinch bug mortality in endophyte infected perennial ryegrass versus PR with low infection, however; turfgrass stands with mixed endophyte infection levels are still susceptible to chinch bug damage due to high mobility of pest.	Carreire et al., 1998

Cultural Practice	Insect/ Invertebrate	Response	References
Other	Hairy chinch bug	suggested that top dressing improves turfgrass tolerance of chinch bug damage.	Maxwell and MacLeod, 1936
	European crane fly	Slower development of larvae on endophytic versus non-endophytic tall fescue; effect limited to young turfgrass.	Petersen and Peck, 2013
	Bluegrass and hunting billbug	Overseeding with endophyte-infected perennial ryegrass reduced billbug damage.	Richmond et al., 2000 Huang and Buss, 2013
	Exotic earthworms	Soil amendment had mixed effects on earthworm casting activity.	Boyle et al., 2019

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Table 2. Effect of Various Cultural Practices on Turfgrass Diseases.

Cultural Practice	Disease	Response	References
Fertilization	Brown patch	Brown patch was more severe in plots treated with nitrogen, but nitrogen did not affect fungicide performance.	Fidanza and Dernoeden, 1996
	Dollar spot	Dollar spot was less severe in plots treated with nitrogen.	Williams et al., 1996
	<i>Pythium</i> blight	<i>Pythium</i> blight severity increased with nitrogen application.	Moore et al., 1963
	Red thread	Disease was more severe in nitrogen-deficient turfgrass.	Cahill et al., 1983
	Summer patch	Patch severity was reduced with application of ammonium sulfate compared with calcium nitrate.	Thompson et al., 1995
	Take-all patch	Acceptable levels of control were achieved in plots treated with ammonium chloride.	Dernoeden, 1987
	Anthraco nose	Anthraco nose severity was reduced with increased mowing height.	Inguagiato et al., 2009
	Brown patch	Clipping removal had no effect on disease.	Settle et al., 2001
Mowing	Dollar spot	Morning mowing reduced disease.	Ellram et al., 2007, Williams et al., 1996
	Brown patch	Clipping removal had no effect on disease.	Williams et al., 1996
	<i>Pythium</i> blight Anthraco nose	Clipping removal had no effect on disease.	Settle et al., 2001
		Minimizing drought stress, while avoiding continuous high soil water content reduced disease severity.	Roberts et al., 2011
	Brown patch	Daily irrigation did not affect brown patch.	Settle et al., 2001
Irrigation	Anthraco nose	Irrigation reduced brown patch severity.	Rowell, 1951
	Brown patch <i>Pythium</i> blight Anthraco nose	Daily irrigation reduced brown patch severity on perennial ryegrass.	Jiang et al., 1998
		Daily irrigation aggravated <i>Pythium</i> blight in some cases.	Settle et al., 2001
		Light-frequent or heavy-infrequent sand topdressing resulted in lower anthracnose severity.	Inguagiato et al., 2012
	<i>Pythium</i> blight	Lightweight rolling every other day reduced anthracnose.	Roberts et al., 2012

Cultural Practice	Disease	Response	References
Other	Anthracnose Dollar spot	Shallow verticutting did not affect anthracnose severity.	Inguagiato et al., 2008
		Rolling to remove dew reduced disease.	Williams et al., 1996
		Dew displacement reduced disease.	Ellram et al., 2007
	Dollar spot	Dew displacement improved efficacy of chlorothalonil.	McDonald et al., 2006
		Lightweight rolling daily reduced dollar spot.	Giordano et al., 2012

Table adapted from Koppenhoffer, A.J., R.M. Latin, B. McGraw, J.T. Brosnan, and W. Crow. 2013. Integrated Pest Management Chapter. Pp: 933-1006. In. Turfgrass Monograph. 2nd edition. ASA-CSSA-SSSA International. Madison, WI. Editors: J.C. Stier, S.A. Bonos, and B.M. Horgan.

Table 3. Effect of Various Cultural Practices on Turfgrass Weeds

Cultural Practice	Weed	Response	References
Fertilization	Crabgrass	Increased N rate reducing populations.	Murray et al., 1983; Voigt et al., 2001; Jagschitz and Ebdon, 1985)
	Kyllinga	Increased N encouraging lateral spread.	Lowe et al., 2000
	Annual Bluegrass	Increased phosphorus encouraging encroachment.	Raley et al., 2013; Lawson ,1999; Lodge et al., 1990; Dest and Allison, 1981; Waddington et al. ,1978; Goss et al., 1975
	Dandelion	Increased K leading to increased abundance.	Tillman et al.,1999
Mowing	Crabgrass	Increased mowing height reducing infestation.	Jagschitz and Ebdon ,1985; Dernoden et al., 1993; Voigt et al. , 1991; Hoyle et al. 2013
	Bermudagrass	Increased mowing height reducing infestation.	Brede ,1992; Cutulle et al., 2014
	Goosegrass	Increased mowing height reducing infestation.	Arrieta et al., 2009
	Kyllinga	Reducing mowing height increasing populations.	Lowe et al. , 2000
Irrigation	Crabgrass	Reduced moisture at surface lowering infestations.	Gibeault et al., 1985; Dernoeden et al., 1994
	Dallisgrass	Increased soil moisture reduced competitiveness.	Henry et al., 2009.

Table adapted from Koppenhoffer, A.J., R.M. Latin, B. McGraw, J.T. Brosnan, and W. Crow. 2013. Integrated Pest Management Chapter. Pp: 933-1006. In. Turfgrass Monograph. 2nd edition. ASA-CSSA-SSSA International. Madison, WI. Editors: J.C. Stier, S.A. Bonos, and B.M. Horgan.

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