Priority Turf Research Needs

Introduction

More than 90 percent of all Americans come into contact with turfgrass on a daily basis. Millions of acres are on home lawns, commercial landscapes, roadsides, parks, athletic fields, and golf courses. Turfgrass adds to our quality of life with its use in open spaces. It creates recreational and business opportunities, enhances property values, and helps conserve our important natural resources. With its above-ground network of leaves, shoots, and stems and an extensive fibrous root system, turfgrass reduces soil erosion, removes dust and dirt from the air, releases oxygen that provides a cooling effect, filters water by trapping potential groundwater pollutants, and produces a safe playing surface for children and adults.

Urbanization has contributed to the rapid growth of the U.S. turfgrass industry, which today is estimated to be a $40 billion annual business. Rapidly expanding uses of turf has also affected natural resource conservation and environmental quality. However, turf must compete with other urban activities for land and finite water resources. In addition, turfgrasses have been under increased scrutiny for its use of water, fertilizer, pesticides, and machinery for turf establishment and maintenance because of growing concern about the environment. In some locations, the use of fertilizer, water, and pesticides for turf maintenance could be severely restricted, if not eliminated. For instance, severe drought conditions in many regions have prompted government-imposed water restrictions or the required use of lower-quality effluent water sources. Also, in some communities where concern about exposure to chemicals has reached heightened proportions, pesticide use on turf is now banned. At the same time, a growing, more prosperous population is increasingly demanding more from current recreational facilities, such as parks, athletic fields, and golf courses. New facilities will have to be constructed on abandoned sites such as landfills, industrial wastelands, gravel pits, or mine spoils. Turf will play an important role in both reclamation and recreation in these areas.

Society's growing expectations for turfgrass will require new management strategies to meet multiple economic and environmental goals. The research needed to provide and integrate the knowledge, plant varieties, and technologies to develop these new strategies will require sustained and cooperative effort among federal, state, and private sectors. The Agricultural Research Service (ARS) can make unique contributions to turf research through its national network of multidisciplinary laboratories and its commitment to long-term research. To identify how best to contribute to the economic and environmental sustainability of the turfgrass industry, ARS scientists met with turf providers, managers, and users at a workshop in Dallas, Texas, January 22-25, 2002.

Six research priority areas were identified based on input received at the workshop. These areas include: (1) Improvement of Water Management Strategies and Practices; (2) Collection, Enhancement and Preservation of Turfgrass Germplasm; (3) Improvement of Pest Management Practices; (4) Understanding and Improvement of Turfgrass' Role in the Environment; (5) Enhancement of Soil and Soil Management Practices; and (6) Development of Integrated Turf

Management Systems. Each of these six research priority areas is described in the sections that follow.

Component I. Improvement of Water Management Strategies and Practices

A. Basic Biology for Turf Water Management

Problem Statement

Rationale. Water management is a key component of healthy turfgrass and directly affects nutrient-use efficiency and turf growth, as well as potential nutrient and pesticide losses into the environment. The need for water varies greatly among soils and environments and among turfgrass species and varieties. New and improved technologies need to be developed to better understand turfgrass-soil-water-atmosphere relationships and to achieve a turf quality consistent with its intended use.

What is known. Basic plant-water relationships are known for selected turfgrass species and varieties, but these parameters are known to differ and interact with soil hydraulic properties, soil salinity, water chemistry, irrigation method, and atmospheric evaporative demand. Considerable research has been done on turfgrass water use as a reference crop in irrigation scheduling models, but the basic aerodynamic and crop canopy resistances are known to differ by species, variety, grass height, and grass management, especially if irrigated with saline or waste waters.

Gaps. The physical expression of water stress in many agricultural crops has been well characterized using various hand-held instruments and remote devices, such as infrared thermometers and photosynthesis meters, but such data are limited for turfgrass. Basic plant-water relationships for turfgrass species and varieties need to be identified for various soil physical and chemical properties, water salinity and qualities, and atmospheric evaporative demand.

Goals

- Develop basic turfgrass leaf plant-water characteristics in relation to a wide range of stress vectors such as soils, salinity, atmospheric evaporative demand, and environmental temperatures to characterize turfgrass drought and temperature hardiness;
- Measure water use by turf species and varieties under a range of environmental and management conditions;
- Develop improved water stress measurement tools for turfgrass biochemical and biophysical responses; and
- Modify and develop improved water stress and plant growth models for turfgrass to quantify growth and development.

B. Management of Available Water

Problem Statement

Rationale. Increasing demands and competition for potable water require that turfgrass be irrigated more efficiently. Better technologies are needed for applying irrigation water more efficiently to meet crop needs based on site-specific factors such as soil type, topography, and sun exposure so as to achieve the desired turfgrass quality. Best Management Practices (BMPs) are needed for efficient use of water and nutrients to achieve desired turfgrass quality.

What is known. The water requirements for turfgrass, as with other crops, change throughout the year. Water needs of turfgrass depend on management practices such as cultivar selection, foot or vehicle traffic, nutrient management, salinity management, and mowing height and frequency. Water availability depends on the rooting depth of the plants, water holding capacity of the soil, and physical or man-made impediments to rooting, water storage, and water movement in soil. Much is known about the simple considerations for turfgrass management, but little is known about the compound interactions existing in nature. Clearly, uniform application of water is not efficient for every circumstance. Further, inefficient use of water caused by over application or poor uniformity can cause a leaching of nutrients and other chemicals, compaction, and disease.

Gaps. Water management in turfgrass could take a major step forward if irrigation systems and management practices were designed to integrate spatial aspects of topography, landscape features, and soil properties (infiltration rate, water holding capacity, and subsoil features) with temporal aspects of plant water needs. More site-specific monitoring and management techniques could increase turf water-use efficiency.

Goals

- Develop and evaluate water conservation measures with respect to water consumption and turf quality;
- Develop improved irrigation technologies for a wide range of geographic environments and soils for use in BMPs that utilize water and nutrients efficiently, minimize on- and off-site water quality concerns, and achieve turf quality appropriate for intended use; and
- Develop improved BMPs to meet site-specific turf requirements for quality, mowing height, mowing frequency, cultivar selection, nutrient management, fertigation, composting residues, and plant growth regulators.

C. On-Site Water Quality Impacts and Opportunities

Problem Statement

Rationale. Greater competition for potable water has increased cost and decreased availability of high-quality, potable water for irrigating turfgrass. To increase water availability for turfgrass irrigation, we must utilize treated and untreated waste water from both animal and municipal sources, as well as from food processing plants. Some of these waste waters contain contaminants – pathogens, heavy metals, and organic compounds – which may threaten human health and soil resources. Consequently, movement and accumulation of these contaminants in the atmosphere, plant tissues, soil profile, and ground water must be determined.

What is known. Potable water surely will become a more valuable commodity as the world's population increases. Some civilizations, locations, and industries have learned to reuse surface water effectively and others are considering this approach. Contamination of water by pathogens, nutrients, and other chemical compounds is a major concern when considering reuse of water. Numerous examples of illnesses and even death have been documented in which humans and animals have ingested or come in contact with contaminants. Irrigation of crops with saline water is fraught with difficulties. Plant tolerance to salinity is known to be species- and cultivar-specific. Therefore, opportunities exist to select turfgrass plants that might thrive, or at least survive, under elevated levels of soil and water salinity, especially sodium. Saline growing conditions in soil can be induced by inherent soil properties or irrigation water, but drainage must be established and maintained to sustain growth of terrestrial plants, especially healthy turfgrass.

Gaps. In the past, entities usually sought new water sources when a need for potable water arose. Intuition suggests that many problems could develop if nonpotable water were used to irrigate turf. Opportunities are abundant to integrate management practices across business and social interests that are concerned with water conservation. However, much more information is needed about possible interactions with vegetation, humans, animals, and wildlife exposed to turfgrass irrigated with nonpotable water. Technologies are needed for easy identification of topographic features in landscapes and other situations in which salinity is likely to inhibit terrestrial plant growth. The interactions between irrigation practices that involve saline water and temporal aspects of plant growth need studying before irrigation with saline water can be advanced.

Goals

- Develop technologies to utilize waste waters (both treated and untreated effluents) from concentrated animal feeding operations, agricultural and municipal waste treatment plants, and urban and rural storm runoff to meet local, state, and federal regulations across a wide range of geographic environments and soils;
- Determine the on-site impacts and the transformation and movement in the air, soil, plant, and ground water of biological and chemical substances contained in treated and untreated waste water used for irrigation of turfgrass;
- Develop and evaluate technologies for blending water sources to meet turfgrass water needs while providing required potable water for domestic needs;
- Determine turfgrass response to irrigation waters specific to the areas affected;
- Develop models that will predict areas of salt stress; and
- Identify herbicide/plant growth regulator and salinity interactions in turfgrass and weed growth

Component II. Collection, Enhancement and Preservation of Turfgrass Germplasm

A. Available and Properly Evaluated Plant Materials (Germplasm)

Problem Statement

Rationale. Genetic resources are essential for the continued development of improved turfgrass cultivars. Genetic material is needed to solve new and existing problems associated with turf production, quality, and longevity. Introduced grass species have been the foundation of the turf industry, but highly adapted naturalized (species that have been grown in the U.S. for several generations) and native grasses or nontraditional species also may be utilized. Lack of new germplasm and insufficient evaluation and characterization of existing collections are serious constraints to solving problems associated with pests, extreme temperatures, water, and other plant stresses that limit turf performance and persistence. Germplasm collections not only provide turf breeders a source of new plant material for developing improved cultivars, but also provide diverse genetic material for other scientists to study turf biology and genetic mechanisms to establish new turf breeding criteria and techniques. Turfgrasses and their successive variations that lack sufficient representation and diversity in present collections need to be collected and made accessible for research. Collections must be maintained and preserved to limit the loss of genetic integrity and characterized to quantify diversity and enhance utilization.

What is known. The turf industry depends largely on a supply of new, diverse, plant genetic resources to meet current and future needs. Breeders have acquired plant material independently and through the ARS National Plant Germplasm System (NPGS) for their plant improvement programs. Most major turf species have been introduced into the United States, and access to their germplasm collections has been a key factor in the development of improved cultivars. Although not as well-collected and conserved, naturalized turf species also have been utilized in turf improvement programs. Meanwhile, interest is growing in the use of native and nontraditional species for turf purposes. Collections of turfgrasses made through the NPGS are maintained and distributed to scientists upon request. They are used to develop cultivars for diverse environmental conditions and applications and in biologic and genetic studies to improve future turf breeding criteria and techniques. Sound regeneration programs that preserved the genetic integrity of collections have improved the quality of germplasm available for research. Although comprehensive data often are lacking, information about the growth and genetic characteristics of turfgrass collections has enhanced their utilization.

Gaps. The genetic diversity critical to the development of turfgrass cultivars should be collected and conserved. For most turfgrass species, publicly available germplasm collections are very limited or contain accessions with limited potential. Therefore, potentially important germplasm resources are not available because they have not been identified, collected, and regenerated. Research is needed to improve regeneration and preservation techniques so that high quality genetic resources can be provided to users as rapidly and efficiently as possible. Naturalized populations, when collected, have not been consistently conserved and evaluated. Also, utilization of germplasm collected is limited by the lack of comprehensive evaluation and characterization information, especially for key pest and environmental stress problems. The extent of diversity and duplication in existing collections needs to be clarified to enhance the efficiency of future collections and to improve collection management. Resources – including both funding and facilities – for proper regeneration and maintenance of many collections are limited, which reduces the capacity for conservation, distribution, and utilization of germplasm by plant breeders and other scientists.

Goals

- Collect and maintain germplasm of native and introduced turfgrasses and nontraditional species;
- Evaluate and characterize germplasm by agronomic and molecular methods and document data in the Germplasm Resources Information Network (GRIN);
- Develop a nationally coordinated competitive funding source for evaluation of new germplasm sources in diverse locations and for diverse uses;
- Distribute collected germplasm to customers for research purposes; and
- Preserve genetic resources of turf species, by seed or vegetative, to ensure genetic integrity, viability, and accessibility.

B. **Fundamental Understanding of Turfgrass Biology and Genetic Mechanisms for Stress Tolerance**

Problem Statement

Rationale. Turf plants contribute to soil stabilization, conservation, water quality, recreation, and general environmental quality. The utility and efficiency of turf plants, however, are much greater than currently realized. In many cases, the growth and development of plant organs or the organism as a whole, and the physiological and biochemical processes that lead to this growth and development, are governed by many different genes. This means that the molecular mechanisms cannot easily be analyzed. This research focuses on the cellular physiological and biochemical processes and genetic regulation of those processes that control plant growth and development, efficiency, and stress tolerances. The responses of these processes to environmental influences – particularly stressful conditions – are especially important because of current environmental limitations of using turf plants.

What is known. Genetic research in other crops has identified and solved numerous problems that inhibit plant improvement. Consequently, it is important that this type of research in the more genetically complex grasses continue so it can complement conventional breeding programs. The basic biology, chromosome number, and reproductive behavior of some turf species are well understood; and this knowledge already has contributed to turf plant improvement. Novel breeding methods have been developed to improve grasses that do not reproduce by typical sexual reproduction. Research in molecular biology is progressing rapidly in some crops and generating large amounts of data, technology, and genetic materials. These advances include: development of methods to identify molecular markers associated with improved plant performance; use of these markers to select desirable plants; discovery, isolation, and characterization of new genes and their use in plant improvement; and development of datahandling techniques to utilize the large data sets being developed as part of this discovery process. We are beginning to develop genetic linkage maps for several turf species, as well as genetic transformation and regeneration systems for several turf species.

Gaps. Environmental stresses limit turf establishment, persistence, and growth efficiency. Little is known about the genetic basis of turf-plant adaptation to plant stresses or about genes from related or unrelated species that might condition or control enhanced stress tolerance. Our knowledge in this area is limited because we know so little about the biochemical and physiological processes regulating these plant characteristics. Controlling these processes – which affect specific stages of plant growth and development, including seed germination, vegetative growth, and seed production – would provide a means to improve the utility of many turf species. Genomic information developed from model plants might be useful for identifying genes that control similar biochemical and physiological processes in turf plants. However, we need to develop methods to screen large databases specific to the model organisms and adapt that information for turf research. In addition, a coordinated effort is needed to identify, characterize, and map genes that control the physiological processes for agronomically important quantitative traits (i.e., control "how much" rather than "either/or") in turf plants. Protocols for introducing foreign genes into turf species are lacking or inefficient and there is a need for basic genetic information. We need to identify tissue- and stage-specific gene promoters to regulate the expression of new genes in transformed plants or genes already present in non-transformed plants. An understanding of cellular and physiological processes and reproductive behavior of novel germplasm is required for introduction into breeding programs.

Goals

- Identify physiological and biochemical functions or genetic mechanisms that control resistance or tolerance of turf plants to stresses caused by disease, drought, flooding, salt, insects, temperature (hot and cold), shade, traffic, management, and soil conditions;
- Characterize and map genes controlling stress reduction and provide genetic screening techniques to improve plants used for turf and seed production;
- Develop strategies to regulate expressions of functional genes in turf plants; and
- Identify morphological and physiological characteristics that improve turf plant performance and incorporate them into germplasm.

C. Genetic Improvement of Turf Plants

Problem Statement

Rationale. Little is known about the biology and genetics of most species used for turf, many of which are genetically complex. Additionally, turf is grown on a variety of environmentally variable sites and under widely differing use and management conditions. Many turf systems are labor- and resource-intensive to meet the desired level of growth and appearance. However, that intervention may override the plants' full expression of genetic tolerance to stresses. Even when grown under favorable conditions turf plants still can be affected by pests and diseases to which some genotypes are otherwise resistant. New turf plant materials are needed that can withstand abiotic and biotic stresses, require reduced inputs of fertilizers, pesticides and labor, while providing the aesthetically pleasing turf desired by users. Genetic improvement of both native and introduced turf plant germplasm is needed to meet the broad requirements and uses of turf in multiple landscape settings.

What is known. Many new or improved turf cultivars are available. However, they are often similar to each other and most are from elite (already highly developed or improved) genetic sources. New germplasm resources of both native and introduced turf plants lacking elite genetic backgrounds will require enhancement techniques that recognize genetic potential**.** Based on information from other crops, turf cultivars can be developed with improved resistance to insects, diseases, and environmental stresses and that require less reliance on agrochemicals. Genetic enhancement of plants for increased resistance to environmental stresses, however, has been limited for turf plants. Variable soils, turf use requirements, and diverse environmental conditions prevent maximum utilization of most plants for turf. Abiotic stresses, including temperature extremes, drought, excess soil salinity, flooding, soil acidity, and nutrient excesses and deficiencies, adversely affect turf. Imposition of abiotic stresses often increases susceptibility to biotic stresses (pests and diseases). Understanding the genetic basis of plant adaptation and resistance to adverse growing conditions is essential to improving turf plants and promoting an economic and environmentally sound turf culture.

Gaps. Research into genetic enhancement of turf plants to improve environmental stress tolerance might be perceived as less of a priority that research of major food crops and plants used for forage and conservation. However, demand is increasing for turf that can be grown on poor soils with less water and maintained with low-quality or recycled water. Most of these management practices cannot be used on food crops. New plant materials that have predictable performance under a wide range of environmental conditions are needed for turf applications. An understanding of the interactions between plant genetic mechanisms and environmental variables that limit adaptation and productivity is woefully lacking in turf plants. Plant breeding and selection for genes that can regulate important turf traits, including reproductive processes and resistance to pests and environmental stresses, are needed to improve sustainability of the turf industry. This includes turf used for landscaping and for seed production systems that provide genetic resources for turf. As is the case with plants used for forage and conservation, development of technologies for turf plant improvement will require close cooperation between traditional plant breeding and biotechnology. Understanding the interaction and coordinated expression of multiple genes controlling many turf plant traits is required. The genetic, physiological, and hormonal mechanisms that control these interactions are poorly understood, particularly for high-utilization turf areas.

Goals

- Identify genes or gene markers with close genetic linkage to turf characteristics that can be used for efficient genetic enhancement of turf plants;
- Enhance turf plants to improve resistance to, or tolerance of, stresses caused by disease, drought, flooding, salt, insects, temperature, shade, traffic, management, and soil conditions;

- Improve adaptation of plants used for turf in specific environments, including those in poor and variable soils, those using recycled effluent water or in micro-infiltration/treatment water basins, those in riparian and flood zones, and those with low-input management, such as reduced irrigation and chemical inputs;
- Provide new genetic sources from alternative or native species or through genetic transformation that can enhance turf plant performance under low maintenance and reduced inputs;
- Quantify gene flow and genetic contamination among and between cultivated turfgrasses and/or native plants and prevent gene flow if a substantial risk is identified; and
- Assess risks associated with incorporating new genes in turf plant improvement through genetic transformation or from wide crossing with wild relatives and provide protocols for controlling contaminants if a substantial risk is identified.

Component III. Improvement of Pest Management Practices

A. Diagnosis and Treatment of Pathogens

Problem Statement
Rationale. Most of the leading problems associated with the production or use of turf plants are caused by fungi. However, viruses, bacteria, or other infective agents, as well as new and emerging diseases, also are of concern. These diseases reduce revenue from seed and sod sales, decrease property values and aesthetic appeal, and increase costs for treatment and renovation. Reduced pesticide use and economical and efficient disease management practices, including revegetation, could save millions of dollars annually. These measures also would reduce potential hazards to humans, wildlife, and the environment from chemical runoff, leaching, and volatilization. Reliable diagnostic techniques, disease-resistant cultivars, and economic and environmentally sound management practices are needed to address these problems.

What is known. We have established basic information on life cycles and disease development of common fungal and nematode turf pathogens and on macro environmental requirements for disease development. Diagnosis of turf diseases currently relies on time-consuming and costly conventional diagnostic techniques based on isolation and identification of fungal or nematode pathogens. Diagnoses based on symptom expression are less accurate with greater potential of misidentification. Pesticide trials have identified chemical products with efficacy against specific pathogens and rates of application have been established. Adverse environmental impacts of some products, such as methyl bromide, have been identified and their use will soon be restricted. Disease control based on management practices and biological approaches are of limited effectiveness.

Gaps. Molecular technologies to identify pathogens on turf are generally not available. Determining the presence of a microorganism, the causal agent of disease, or a component of a disease can be subjective. Population genetics and variability within turf pathogen populations are not well characterized, and the genetics and biochemical interactions between the pathogen and corresponding host populations are even less understood. Factual data are lacking to support nematode thresholds for pesticide applications and fungicide resistance management strategies. Little information is available concerning genetics and physiology of host resistance to turf pathogens. Nor is there much information on the biochemical and physiological processes in the host and pathogen during infection and disease progression. A better understanding is needed of the complex interactions among the host, pathogen, and environment. Impacts of new turfgrasses and their management requirements on disease development have not been assessed. Conditions predisposing hosts to infection cannot be reproduced reliably for many diseases, hindering resistance assessments. Limited information is available to integrate monitoring of micro-environmental conditions with accurate and user-friendly disease forecasting systems.

Goals

- Develop or apply molecular biological tools for efficient and reliable identification and characterization (race, biotype, and virulence) of fungal, bacterial, viral, and nematode pathogens of turf;
- Develop turf germplasm with resistance to fungal, viral, bacterial, and nematode pathogens using conventional and molecular genetics approaches;
- Develop basic knowledge of biochemical and physiological processes in the host and pathogen during infection and the disease process; and
- Develop environmentally friendly approaches to disease management using knowledge of pathogen-host-environment interactions and pathogen population biology and dynamics.

B. Control of Weed Invasion and Infestation

Problem Statement
Rationale. Weeds in turf can decrease revenue, property value, and functional and aesthetic quality, and contribute to soil erosion. Competitive stands of turfgrass are the first line of defense against weeds by limiting the establishment of seedling broadleaves and grasses. Established broadleaf turf weeds are currently controlled almost exclusively with herbicides. Weedy perennial grasses often cannot be controlled except by turf replacement. Weedy annual grasses are frequently targets of herbicide applications, but control is often poor. Misuse of chemical herbicides potentially can contaminate the environment by runoff, leaching, and volatilization, possibly injuring plants, animals, and humans. Losing registration of older products means the number of herbicides available for weed control is declining. New methods of weed control and management are needed that will reduce costs and the use of synthetic herbicides.

What is known. Many pest problems are limited to specific ecoregions and can be exacerbated by inappropriate use of turf cultivars outside their range of adaptation. These uses include suboptimal quality or quantity of water, nutrients, and soil structure, and by poor establishment practices. Managing turf to favor the competitive ability of desired plants is a common practice and should be improved upon. Some turf plants may be able to biochemically inhibit the germination or development of weeds, while some plant pathogens have been formulated as biological herbicides. Collecting clippings during mowing to remove weed seed has sometimes been used. Weeds often become established in turfgrass through their presence in seed used to initially establish or subsequently overseed the turf. As a consequence, a desire to minimize the presence of weedy species in turf seed dominates many aspects of seed production and marketing. Unintended consequences of this focus on "weed-free" grass seed include increased selection pressure for herbicide resistance in seed production fields and the "dumping" of low-priced and low-quality (i.e., weed infested) seed in certain sectors of the retail trade. Improved seed conditioning methods, seed testing techniques, and seed labeling practices could reduce the introduction of weed seeds into turf.

Gaps. We need to understand why certain plant species are successful weeds to be able to develop innovative management practices. Competitive ability of turfgrass germplasm could be improved through breeding or genetic modification. There is a shortage of known microorganisms and insects that can be used as biological control agents of weeds. Plant pathogens can be used as biological herbicides, but better formulations are needed. Further, the turfgrass industry is missing critical knowledge on the relative importance of weeds naturalized at any site versus those introduced through the seed. Efforts to procure seed that is free of annual bluegrass seed may be extremely worthwhile in some situations and a total waste of resources in others. The ongoing proliferation of herbicide-resistant weeds in seed production fields further complicates management decisions in such areas as renovation techniques, choices of seed, herbicide treatments, and cultural practices. Use of genetic engineering to develop herbicide-resistant turfgrass cultivars potentially solves many current weed control problems, but also creates risks of future problems.

Goals

- Characterize weed species and their population dynamics to understand why they are successful weeds (know your enemy);
- Develop more competitive turfgrass varieties;
- Discover microorganisms and insects that destroy weed seeds or prevent seedling establishment;
- Develop plants or chemical formulations that inhibit germination of weed seeds;
- Develop turf plants or select varieties that can biochemically inhibit weeds;
- Discover and formulate plant pathogens to use as biological herbicides;
- Discover and demonstrate safety of insect biological control agents to control alien weeds; and
- Identify turf management and ecological implications of introducing herbicide-resistant turfgrass cultivars (e.g., Roundup-Ready creeping bentgrass).

C. Control of Damage by Vertebrate Animals

Problem Statement

Rationale. Various types of vertebrate animals can cause considerable damage to turfgrasses in parks, playgrounds, athletic fields, lawns, cemeteries, and turf farms. Although the severity of specific animals as turf pests varies regionally, significant vertebrate pests may include moles, rodents (particularly gophers and voles), grub-feeding mammals (e.g., armadillos, skunks, raccoons), and geese. Because turfgrasses tend to be managed intensively on a sustained basis, more resources may be available for control of such pests in turf systems than in natural areas or agroecosystems. Some possible avenues of control have not been attempted, while others have been attempted on such a limited basis or for such a short duration that questions remain regarding their efficacy. There is a need for developing alternatives to chemical pesticides and lethal agents because these traditional pest control measures foster negative public opinion and pose inherent dangers to humans and pets in the urban and suburban settings typical of managed turf. In addition to direct or indirect techniques aimed at controlling vertebrate pests, plant breeding offers the potential to develop new turfgrass varieties with improved resistance to damage by vertebrates.

What is known. Certain vertebrates that damage turfgrass are increasing in cities and/or suburban areas. Canada geese, for example, now often forgo migration and remain at more northern latitudes during winter because cities and suburbs offer ample open water (e.g., ponds in parks and golf courses) and nearby grazing resources in the form of turfgrass. Their foraging causes significant direct damage as well as an accumulation of droppings. Use of feeding repellants has resulted only in limited, short-term success. Tunneling and creation of runways through turf by small mammals such as gophers, voles, and moles not only damages turf, but may also expose humans to risk of injury.

Gaps. Potential control techniques for vertebrate pests have not been widely tested. For example, use of natural enemies may be effective against some vertebrate pests, as it is in the biocontrol of invertebrates (e.g., insects), but test results are not generally available. Other control techniques that have been tested – such as feeding repellants to discourage geese – have generally not been highly successful. Further testing of some vertebrate pest control practices may be warranted.

Goals

- Increase basic knowledge of habitat requirements of vertebrate pests of turfgrass for use in developing new control technologies;
- Develop new techniques to reduce damage to turfgrass by vertebrates using natural enemies, ultrasonic repellants, diversionary food resources, and/or habitat modification;
- Improve success of current nonchemical techniques for controlling vertebrate pests of turfgrass such as feeding repellants, behavior modification through aversive stimuli, mechanical trapping, hunting, and/or relocation; and
- Develop new turfgrass varieties with improved resistance to damage by vertebrates.

D. Control of Damage by Insects

Problem Statement

Rationale. Damage from turf insect pests costs homeowners, farmers, seed producers, and turf managers throughout the United States millions of dollars each year. The costs include chemical insecticides, turf replacement, reduced seed yields, environmental contamination, soil erosion and loss of aesthetics. Pest species and damages vary with regional climate and turf use- patterns. Because of this variability, knowledge of the pest within the context of its regional and local habitat will facilitate development of improved methods of environmentally compatible control practices. We need to combine the use of new chemical insecticides, insect parasites and pathogens, and insect-resistant grass cultivars – including transgenics – in integrated plant health management programs fitted to climate, region, and turf use.

What is known. Most turf insects have been controlled in recent times by organo-phosphate and carbamate insecticides. These popular materials are under extensive review by the Environmental Protection Agency (EPA) as required by the congressionally mandated Food Quality Protection Act of 1996. Most have been, or most likely will be, withdrawn from the market. Over the past several years, "new chemistry" insecticides have been developed. These materials generally are effective in controlling target pests and cause fewer harmful side effects on non-target invertebrates and the environment. However, these new chemicals do not fit well into integrated pest management (IPM) programs since many must be used as a prophylactic treatment. There is renewed interest in using insect pathogens – such as bacteria, nematodes, fungi, and protozoans – against turf pests. In addition, parasitoids (insect parasites of insects) also have been identified for use against white grubs, fire ants, aphids, and other turf pests.

Gaps. Improved understanding of pest biology and behavior will directly facilitate development of pest management practices that can be integrated into site-specific turf management programs. Although some basic knowledge about many of the pest species is available, their role in the turf ecosystem and the effective short- or long-term methods of removing them from pest status are often not known. Because of the obscure or subterranean nature of many turf insects, efficient detection and monitoring techniques are needed to implement IPM. The use of genetically modified grasses is being proposed, but there is insufficient data to convince the public about the efficacy and safety of such an approach. We do not have integrated programs to study insect resistance in new cultivars using either genetically modified organisms (GMOs) or standard breeding techniques. Parasitoids and pathogens for turf insects exist, but to date they have not been used by turf managers as effective replacements for conventional insecticides.

Goals

- Develop a better understanding of the population biology of insect pests in various turfgrass ecosystems;
- Improve the insect detection and monitoring techniques available to scientists and turfgrass managers;

- Develop new turfgrass cultivars, by GMO or conventional methods, that are more resistant to damage from insects that feed both above and below ground;
- Integrate more fully the use of parasitoids and insect pathogens into suppression programs against insect pests; and
- Develop fully integrated plant health management techniques in IPM systems that will include new and emerging chemicals and demonstrate their use in solving insect pest problems.

Component IV. Understanding and Improvement of Turfgrass' Role in the Environment

A. Assessment and Characterization of Environmental Impacts of Turf

Problem Statement

Rationale. Turf systems, including golf courses, turf farms, city parks, residential lawns, roadsides, and cemeteries, are integral components of the landscape. The establishment and maintenance of some turf systems often require substantial inputs of water, nutrients, pesticides and energy to enhance their aesthetic and functional values. However, nutrients, pesticides, heavy metals, and other constituents may accumulate on-site or move off-site with potential consequences for human health and environmental safety. An assessment of turfgrasses' function as a source or sink for pollutants is of vital importance in addressing the role of turf in the landscape.

What is known. Previous studies of turf nutrient and pesticide movement from surface and subsurface pathways generally have focused on small areas, from plots up to individual components (e.g., a green or fairway in a golf course setting or a single lawn from a residential site). In addition, some limited hydrologic and nutrient loss data from watershed-scale turf systems do exist. While studies on small scales are valuable, they may not represent the diversity and connectivity associated with a watershed-scale turf system. Many turf studies suggest that properly managed turf systems may not cause substantial contamination of surface and subsurface water.

Gaps. We have identified research needs in water quality, resource allocation, and environmental issues specifically related to turf on existing and proposed sites. In addition, we need to determine the environmental, cultural, and economic benefits of turf. Some of the potential benefits could include erosion control, adsorption of atmospheric pollutants, carbon sequestration, mitigation of water pollution problems, dust control, cooling effects, noise abatement, and provision of wildlife habitat. The potential for off-site movement of nutrients, pesticides, pathogens, sediment, and heavy metals into surface water and ground water needs to be quantified. The exposure levels of beneficial soil organisms, wildlife, and aquatic systems to pesticides and/or fertilizers also need quantifying. We need to assess the sediment and nutrient loss from renovation and construction sites, poorly drained areas, shaded spots, and high-traffic areas. During development or renovation, the impacts of converting vegetation, changing topography, and increasing the use of water and nutrients to establish water and nutrient balance at the watershed-level need evaluation. There is also a need to evaluate the potential impact of turf systems on wetland disturbance and loss and on use of turf as vegetative buffers for protection of sensitive bodies of water.

Goals

- Collect data sets at a range of temporal and spatial scales that capture and quantify both positive and negative potential contributions of turf systems to environmental concerns related to soil, water, and air because of nutrients, pesticides, sediment, pathogens, and heavy metals;
- Assess the impact of exposure to applied chemicals on beneficial and nontarget soil organisms and mammals; and
- Determine the mechanisms controlling transformation and movement of nutrients, pesticides, sediment, pathogens, and heavy metals in turf systems.

B. Management and Technology to Enhance Environmental Quality of Turf Systems

Problem Statement
Rationale. The approximately 50 million acres of turf in the United States is managed to varying degrees. In some instances, demand for high-quality turf systems has led to intensive management strategies that include cultural, physical, and chemical approaches. Management of turf in both rural and urban areas can have major implications for natural resource conservation. The development, improvement, and implementation of integrated turfgrass management practices and technologies will improve our ability to take advantage of the environmental, cultural, and economic benefits that turf systems provide and eliminate or mitigate detrimental impacts.

What is known. Most intensive turf management utilizes site-specific Turfgrass Management System (TMS) plans to maintain high-quality turf while protecting and preserving natural resources. TMS plans include integrated BMPs involving irrigation, fertilization, pest and disease control, soil and water conservation practices, and simulation technology. Of existing documented research concerning the development or implementation of TMS plans, most have been completed at plot scales without taking into consideration how the surrounding landscape or entire watershed would be affected. A few attempts have been made to use existing water quality computer models to assess and address environmental concerns about watershed-scale turf management. The findings of these studies suggest that computer simulation technology offers an adequate means of evaluating turf management. Specific turf improvements could further advance this technology.

Gaps. Research is needed to develop, improve, and test the efficacy of management practices and technologies designed to reduce movement of nutrients and pesticides and to promote and enhance the environmental benefits of turf. Additional information is needed to better determine and promote the environmental, cultural, and economic benefits of turf. We need to develop region- and species-specific integrated TMS approaches based on physical, cultural, mechanical, and chemical strategies to minimize input requirements and the potential for off-site contamination. Also needed is a natural resource simulation tool that accurately represents the role of turf systems in the total landscape. The ability to test new options in functioning whole systems is an essential component of developing strategies to exploit beneficial functions and mitigate undesirable impacts of turfgrass production. This would allow a real-world assessment of suggested conservation practices, as well as reveal interactions with other turf management operations that might limit the adoption of a practice.

Goals

- Develop new and modified physical, biological, and chemical conservation practices that further exploit the environmental benefits of turf systems and mitigate undesirable impacts;
- Develop methods to reduce inputs and increase input use-efficiency including rate, time, and methodology while maintaining turf quality;
- Develop region- and species-specific guidelines to design, construct, and use turf production systems that maximize environmental benefits and mitigate or eliminate negative impacts; and
- Synthesize findings and developments into a useful computer model that permits a realistic evaluation of the effects of land-use management from turf systems on soil and water resources.

Component V. Enhancement of Soil and Soil Management Practices

A. Overcoming Soil Limitations to Turf Production, Establishment, and Use

Problem Statement

Rationale. Soils degraded by natural processes or human activities can possess physical, chemical, and biological limitations that make it difficult to establish and maintain turf. Problems such as soil erosion; loss of organic matter; poor soil structure; soil compaction; soil acidification; buildup of salts, trace elements, and organic chemicals; and limited or nonexistent populations of beneficial soil microorganisms can create unfavorable conditions for root proliferation, water storage and use, aeration, and nutrient supply and cycling. Correcting these soil limitations will improve turf production, growth, and use.

What is known. Soil degradation, which has reduced the productivity of our soils and damaged adjacent ecosystems, can be caused by accelerated soil erosion, loss of vegetative cover, oxidation of soil organic matter, or impairment of other soil physical, chemical, and biological properties and processes. All of these processes can be accelerated by construction and other land preparation activities. Worldwide, erosion by water, wind, and land management practices is a major cause of soil degradation and a primary environmental concern. Soil erosion reduces plant productivity through loss of nutrients, organic matter, and the ability of the soil to absorb and retain water for subsequent plant use. A considerable amount of information is available about changes in soil properties and processes as a result of erosion and the effect these changes have on plant productivity. Soil organic matter increases water infiltration into soil and soil-water holding capacity; improves soil structure; contributes to nutrient supply and recycling;

increases soil microbial populations and activities; and increases the population of beneficial organisms such as earthworms. Soil biota may be beneficial, neutral, or detrimental to plant growth. From a beneficial standpoint, soil biota can stabilize soil aggregates; enhance nutrient cycling; control crop diseases and pest infestations; and detoxify natural and man-made contaminants. Soil compaction reduces soil pore volume and results in changes in soil properties and processes. Soil compaction can reduce the movement of water, air, and agricultural chemicals into and through the soil and can prevent root growth into the subsoil. Natural processes and improper land and water management practices have resulted in soils that are acidic and/or contaminated by high concentrations of salts and toxic trace elements. These conditions can limit turf establishment and production.

Gaps. Buildup of soil organic matter is an important part of the remediation process in soils degraded by erosion or human activities. Information is needed to determine the most effective way to encourage carbon sequestration over a range of turf applications. This outcome would improve soil properties and reduce losses of greenhouse gases, such as carbon dioxide, to the atmosphere. A better understanding of the ecology of beneficial and harmful soil organisms and their interaction with one another and with their environment is needed to utilize and control their expression in turf management systems to improve turf production and overall sustainability. While the causes of compaction are understood, sufficient information is lacking to be able to develop effective preventive and remediation strategies. The length of time required to produce a serious compacted condition within a management system is unknown, both for the direct and indirect effects related to biological and chemical processes. We also lack knowledge of how soil degradation due to contamination affects specific soil chemical, physical, and biological processes. We do not fully understand how these processes may be used to rehabilitate impaired soil. Research is needed to characterize soil limitations to turf growth and development, to develop cost-effective management practices to overcome these limitations, and to develop decision tools to allow site-specific correction of these problems.

Goals

- Identify desirable soil characteristics for a specified turf use;
- Develop management practices and decision tools to overcome soil limitations to turf production in existing turf; and
- Develop management practices and decision tools to overcome soil limitations prior to turf establishment.

B. Using Agricultural, Municipal, and Industrial Byproducts for Turf Production, Establishment, and Use

Problem Statement

Rationale. Many byproducts of our farms, cities, and industries could have considerable value as low-cost soil amendments in the turf industry. They can be used to improve soil properties in existing turf, to create favorable soil conditions where new turf is to be established, and to create artificial soils for a variety of turf applications.

What is known. Animal wastes and crop residues from farms, biosolids and selected solid wastes from cities, and appropriate byproducts from industry can improve conditions for turf production and sustainability by supplying nutrients, increasing soil organic matter, improving soil physical properties, and creating a more favorable environment for beneficial soil organisms. Poultry litter has been processed with added nutrients to produce granular fertilizer for use on golf greens and fairways. A landscape mulch prepared by blending wastepaper with animal manure has been used as a fertilizer source by homeowners and for erosion control and grass establishment on embankments and golf course fairways. Many byproducts have characteristics that would be useful in creating artificial soil. Mixing, blending, and co-composting various byproducts can be used to create artificial soil for specific turf applications to include golf courses, sports turf, roadsides, and home lawns. Manufactured topsoil for lawns has been produced from blends of organic (municipal biosolids, animal manure) and inorganic (foundry sand, fly ash) byproducts.

Gaps. Research is needed to assess the benefits and risks of these low-cost inputs and to develop management practices for effective use of these materials in turf production and sustainability. Risks to the environment and human health from trace elements, synthetic organic compounds, and pathogens in byproducts used in turf systems need to be assessed. The capability of selected byproducts to supply nutrients needed for turf growth over time needs to be determined. Use-specific characteristics of artificial soils need to be determined, as well as the development of predictive tools to allow duplication or these characteristics by mixing, blending, and co-composting appropriate byproducts.

Goals

- Determine benefits and risks of using byproducts for turf applications;
- Develop guidelines for the use of byproducts in turf applications; and
- Develop use-specific guidelines for construction of artificial soil using byproduct materials.

Component VI. Development of Integrated Turf Management Systems

A. Decision Tools for Economic Management Systems to Enhance Environmental Quality

Problem Statement

Rationale. Turf managers need information tools to be able to identify the best economic combinations of management practices for their enterprises. They must be able to address local natural resource concerns and integrate them into management plans for other enterprises within their communities. When problems exist, managers need to know how to rectify those problems to enhance beneficial effects. Because managed turf has a range of uses and is found at different landscape scales, solutions would be needed for the home lawn, golf course, and watershed levels.

What is known. Many activities benefit and detrimentally affect community environmental quality. Managed turf can have different degrees of impact depending upon its use (e.g., golf courses, municipal parks, and home lawns) and management sophistication. Often there is contention regarding the relative impacts among different turf uses, as well as with other business and recreational enterprises. Technology is available to assess the economic, physical, and biological impacts of agricultural management practices. Integration tools also are available to interpret the relative impacts of different enterprises within a landscape.

Gaps. Little is known about the actual relative impacts of different turf uses on natural resource quality and how these compare to other business and recreational activities within communities. Integrated community-wide management plans need to be established to determine the best options to address identified natural resource quality issues. The relative impacts of managed turf within a landscape can be interpreted and utilized as an integrated component for overall management of natural resource quality within a community.

Goals

- Collect management practice and operation cost information from a broad range of turf enterprises and use results to adapt and validate economic and environmental quality assessment tools for turf management applications;
- Develop optimization models for greatest economic return that comply with local and regional environmental regulations and standards;
- Build and test a user-friendly interface for use on the World Wide Web that is accepted by a panel of turf managers and deliver to the industry; and
- Produce management plans that economically address natural resource concerns at the landscape level.

B. Decision Tools for Integrated Management Practices

Problem Statement

Rationale. Research results generally are available to help managers choose the single best practice for managing fertilizer applications, insect and weed pests, mowing, and irrigation for specific locations where the research was conducted. However, what are often lacking are ways to consider the interrelated effects of different practices and ways to recommend the optimal management configurations at the least cost with the greatest environmental benefits. The industry needs management decision aids that utilize expert knowledge to illustrate the best options for turf management.

What is known. Because of the high costs of maintaining turf, managers are looking for ways to reduce costs and maintain high aesthetic and utility quality, while minimizing negative effects on natural resources. Turf managers have acquired a wealth of personal knowledge about how to manage their local enterprise. Extensive research has been done in different turf settings to identify generally the best approaches to manage irrigation, mowing, and pest control. Computer decision aids have been developed to assess the economic and environmental impacts of traditional agricultural practices, but these have not been adapted for turf applications. Simple decision tools also have been developed to contrast different management and conservation approaches in production agriculture settings.

Gaps. Easy-to-use decision tools are not available to help turf managers choose the best combinations of production practices. They need production practices that optimize economic return and minimize negative impacts to customers and to natural resources that come in contact with turf landscapes. Management information must be synthesized for widely diverse turf uses and users. One-size-fits-all decision solutions will not work. Therefore, tools should utilize features that fit different user needs, ranging from simple printed guides for the homeowner to computer-based systems that provide solutions for large-scale golf and park operations. Component technology software used in business can be configured to link expert knowledge with computer-based finance and conservation predictions. These predictions, based on research that assesses the economic and environmental impacts, will enable managers to choose among the best options that suit their local conditions and needs.

Goals

- Assess the research to date regarding optimal management practice effects nationally and by region;
- Determine the kinds of research and regions where data gaps occur and conduct additional research to fill these gaps;
- Create management and economic optimization analyses;
- Produce an analysis tool that allows managers to use their expert knowledge to choose the best combinations of practices suited for their local conditions; and
- Create a user-friendly decision aid interface for the World Wide Web that is tested and accepted by a turf manager panel.