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BENEFICIAL CONTRIBUTIONS OF TURFGRASSES TO OUR ENVIRONMENT AND QUALITY-OF-LIFE

by

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Final Report

The value of most industries is measured by income derived from products or services. However, this is not entirely germane to a major portion of the diverse turfgrass industry. Rather the value encompasses a range of beneficial contributions to our environment and quality-of-life that are not easily quantified in monetary terms. Thus, the objective of this study was to conduct a detailed assessment of the research literature to obtain a valid scientific base source of information documenting the benefits of turfgrasses. Over 400 scientific references were identified, obtained, and assessed. Some were difficult to obtain as they were in obscure reports. Much time was spent in conducting over 170 personal phone calls with individuals involved in the actual research. In addition, much time was devoted to assessments of the scientific soundness of the research, including the experimental methodology, actual conduct of the experiments, and valid interpretation of the results. An extremely diverse range of technical subjects were addressed. Scientists knowledgeable in these individual specialties were contacted to confirm the validity of the research papers being considered for citation. A total of 116 scientific papers were identified as most germane to the objectives of this project.

The principle charge from the USGA Green Section Research Committee was to develop a scientifically based paper on the benefits of turfgrasses targeted for publication in Science or Scientific American. The paper has been completed and reviewed by fourteen key world respected scientists representing the broad range of technical subjects addressed. It has also been reviewed by the Texas Agricultural Experiment Station personnel and approved for publication. The topic areas include: (a) turfgrass evolution; (b) history of turf use; (c) turfgrass functional benefits including soil erosion control and dust stabilization, ground water recharge and surface water quality, organic chemical decomposition, carbon sink, heat dissipation - temperature moderation, noise abatement - glare reduction - visual pollution control, decreased noxious pests - allergy related problems - human disease exposure, safety in vehicle operation - equipment longevity, security for vital installations - lower fire hazard, and wildlife habitat; (d) turfgrass recreational benefits; (e) turfgrass aesthetic benefits including improved mental health via a positive therapeutic impact and contributions to social harmony and improved occupational productivity; (f) contemporary issues such as water conservation and ground surface water quality preservation as related to pesticide and fertilizer use.

To have the best potential for acceptance in a nationally recognized scientific publication, that extends well beyond agronomic and turfgrass scientists, the paper is generic in nature across the broad array of turfgrass applications. More recently, the USGA Green Section Research Committee has indicated a desire for an additional publication addressing specifically the golf course dimensions. This type of paper has a better chance of being accepted for a scientific agronomic publication such as the Journal of Environmental Quality. This publication will focus on golf course turfgrass benefits, plus increased emphasis on the pesticide and fertilizer dimensions in comparison to utilization levels in other areas of applied plant management. Appropriate mathematical computations have been made to provide utilization comparisons. The second paper is targeted for completion by late 1992.

THE EVOLUTION OF TURFGRASSES FOR ENVIRONMENTAL PROTECTION AND THEIR BENEFITS TO HUMANS

by

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To the botanist grass is a member of the family *Poaceae*. To humans, grasses are the most important of all plants. The cereal grains and corn, all members of the grass family, serve as food for humans and animals. A host of grazing ruminant animals utilize grasses as their major food source as forage, pasture, and prepared feeds. Bamboo, a grass, is a major building material. Also, grasses of all types represent a large source of biomass for production of methanol, an alternative energy source. Perennial grasses protect the environment against soil erosion, serve as a filter for improving ground water quality, and absorb atmospheric pollutants. Finally, perennial grasses provide a relatively safe playing surface for the myriad of human's active recreational pursuits that contribute to human health and are a major factor contributing to the aesthetic appeal and human mental health benefits of ornamental landscapes. Often overlooked are these functional contributions of grasses that enhance the quality-of-life for humans. The purpose of this paper is to document these beneficial contributions of grasses (Figure 1).

The *Poaceae* is the most ubiquitous of the higher plant groups found on this earth (Gould, 1968). With an estimated 600 genera and 7,500 species, the *Poaceae* ranks third in number of genera among families of flowering plants. In respect to completeness of representation in all regions of the world and to percentage of the total world's vegetation, it far surpasses all others. Grasses are one of the first permanent vegetations to reappear after disasters, such as volcanic activity, extended droughts, floods, fires, explosions, abandoned urban ghettos, and battlefields. Without the forgiveness of the *Poaceae*, many ill-advised construction excavations and certain agricultural activities would have had far more disastrous effects on one of our most vital natural resources, the earth's surface soil mantle on which terrestrial plants and animals live. Fortunately, the turfgrass species now in use evolved starting approximately 50 million years ago and they have been cultured by humans to provide an enhanced environment and quality-of-life for over 1,000 years.

TURFGRASS EVOLUTION

Based on the limited fossil records available, the *Poaceae* probably began to emerge as a distinct family of angiosperms approximately 70 million years ago during the late Cretaceous period of the Mesozoic era to the Paleocene epoch of the Tertiary period and Cenozoic era (Clayton, 1981; Gould, 1968). The herbivorous grazing mammals evolved later during the Eocene and Oligocene Epochs (Clayton, 1981; Stebbins, 1981). There were significant concurrent evolutionary developments of grass species and grazing animals beginning during the Eocene epoch, 45 to 55 million years ago and continuing to the present (Hartley and Williams, 1956; Stebbins, 1981). The grazing mammals exploited the grasslands by evolving to a different type of feeding via mouth parts that allowed closer grazing. This resulted in natural selection towards those *Poaceae* that were morphologically adapted to survive close, continuous defoliation. A key feature of the *Poaceae* is that the leaves grow from basal meristems rather than from the plant apex.

Those species of *Poaceae* best adapted to close, frequent mowing typical of higher quality turfs evolved in regions where the close-grazing *Bovidae*, the cattle, sheep, and goats, evolved. Morphological adaptations that are particularly significant for turfgrass use include the ability (a) to form short basal internodes and even stacked nodes in the form of basal crowns, (b) to branch via multiple basal tillers, stolons, and rhizomes, and (c) to initiate lateral shoots from basal buds when the primary shoot is removed by defoliation (Figure 2). The result is a relatively high shoot density, a prostrate growth habit, and a good recuperative potential: all important morphological components of quality functional turfgrasses (Beard, 1973). Humans aided in the distribution of the turf-type *Poaceae* throughout the world through transport in the form of bedding materials and hay for animal feed.

HISTORY OF TURF USE

Turfgrasses or their forerunner have been cultured for over 1,000 years (Table 1). The forerunner of turfed lawns, the lawn garden, was developed by advanced civilizations, such as the "Persian pleasure garden carpets" and later the "Arabian gardens" (Loudon, 1878). The plants utilized in these lawn gardens are unknown, but are thought to have consisted of low-growing, flowering species. Subsequently, the Greeks and then the Romans adopted lawn gardens as an integral part of to their cultures. Perennial grasses were used in open woodlands within animal parks on estates of noblemen in China, Japan, and Europe.

The culture of turfed lawns, similar to that practiced today, had its beginnings in the 12th century, according to the available literature (Beard, 1973). These lawns were composed of low-growing grasses interplanted with flowers similar to the vegetation of a natural meadow (Rohde, 1928). Sodding was described by the Japanese, in 1156 in the Satu-tei-kai, the oldest Japanese book on gardening. It probably involved unmowed, low-growing ornamental *Zoysia* spp. (Maki, 1976).

The use of turfs composed solely of grasses evolved in the 13th century (Albertus, 1867). The first references to the sport of bowls being played on turfs appeared in the late 1200's (Linney, 1933; Monro, 1951). The game of bowls is much older, but there is no documentation that it was played on turfgrasses prior to this time. Turfed bowling greens were the forerunner of our modern fine turfs used on many types of sports surfaces, such as golf putting greens. Thus, the use of grass as a surface for outside sports played a vital evolutionary role in the development of turfs.

The 14th century was a period of toilsome times in Europe. Lawn gardens were limited to royalty, monasteries, and church land. In contrast, writings in Japan suggest that turfed lawns were being mowed manually in 1320 (Maki, 1976).

During the Renaissance of the 15th century, with emergence of commerce, travel, cities, and industry, the use of turfgrasses for ornamental lawns and recreational areas expanded greatly, including records concerning the game of golf being played on turfs in Scotland (Beard, 1982). Elaborate formal gardens were created at the height of the Renaissance during the 16th century (Hill, 1568; Gothein, 1979). Turfed lawns were common on estates in European countries which are now known as Great Britain, Germany, France, Italy, the Netherlands, and Austria. Turfed areas for games were popular in the mid-1500's (Gothein, 1979). Most towns and villages developed a turfed central park area called a green or common. The team sport of soccer was played on these turfed public greens during the 16th century.

In the 17th century, country houses flourished in England. The first significant gardening books appeared during the latter half of this century. John Rea's extensive writings are of particular note (Rea, 1665).

The first Japanese book that addressed solely the establishment and culture of turf was published in the early 18th century. The commercial production of sod (*Zoysia* spp.) was recorded in 1701 in Japan (Maki, 1976). In England, turfs were cultured for use in lawn gardens, flower gardens, and pleasure gardens and for both bowling and putting greens.

The Great Houses built during this period in Europe were designed with large lawns. The first records of tennis being played on turf appeared in the late 1700's (Godfree and Wakelam, 1937).

A hallmark of the 19th century was the invention of the first lawn mower, a reel, by Edwin Beard Budding in 1830 (Hall, 1984). This introduced an era of trial-and-error attempts to develop specific turf cultural practices that would improve the density and functional performance of turfgrasses for sport, recreational, and ornamental uses. The first turfgrass research findings were published by the noted botanist Dr. W. Beal of the Michigan Agricultural Experiment Station in the 1890's (Beal, 1892; 1893). Subsequently, during the early part of the 20th century, numerous turfgrass research projects were developed at major universities in the United States and at a few research institutes in other countries around the world (Beard, 1973).

The extensive use of turfs for lawns and for recreational purposes evolved concurrently with the development of industrial civilizations. The resultant major concentrations of people in urban centers emphasized great value of plants in enhancing the quality-of-life of urban residents. The more technologically advanced the civilization, the more widely turfs have been utilized. Quality turfed landscapes increased property values and commercial appeal. A major expansion in turfgrass use and allied turfgrass research occurred from 1945 to date (Table 2), which has resulted in great improvements in the functional, recreational, and aesthetic benefits of turfgrasses. Now the research emphasis is to sustain these benefits at a lower cost while continuing to protect the associated ecosystem.

The modern turfgrass industry has grown rapidly in the past three decades. It contributes substantially to the national economy, with numerous employment opportunities. The annual expenditure for maintaining turfgrass in the United States, including labor but excluding capital expenses was estimated to be a conservative $25 billion (Cockerham and Gibeault, 1985). These figures have increased substantially during the past 10 yr to $45 billion. Note that the fixed assets of turf installations are many times that of the annual maintenance expenditures.

TURFGRASS FUNCTIONAL BENEFITS

Soil Erosion Control and Dust Stabilization. Turfgrasses are inexpensive, durable ground covers that protect our valuable, non-renewable soil resources. Agricultural operations and similar activities such as construction involve extensive land disruption, in contrast to turfed land areas, which are maintained in a long-term stable state. Runoff water from agriculture and urban areas currently account for 64 and 5%, respectively, of the nonpoint surface-water pollution affecting the 265,485 km of rivers in the United States and 57 and 12%, respectively, of the nonpoint surface-water pollution affecting the 3.3 million hectares of lakes in the United States (Carey, 1991). Sediment and nutrients account for 47 and 13%, respectively, of the nonpoint surface-water pollution in rivers and 22 and 59%, respectively, of the nonpoint surface-water pollution in lakes. In the 1987 USDA National Resources Inventory it was estimated that the annual sheet and rill erosion on the 153 million hectares of cultivated cropland in the United States was 9,184 kg ha^{-1} (USDA, 1989).

Gross *et al.* (1991) reported sediment losses of approximately 10 to 60 kg ha^{-1} from turfgrass plots during a 30 min. storm that produced 76 mm h^{-1} of rainfall; soil loss for bare soil plots averaged 223 kg ha^{-1}. They concluded that well-maintained residential turfgrass stands should not be a significant source of sediment entering bodies of water. It is generally recognized that a few large storms each year are responsible for most soil erosion losses (Menzel, 1991). Other studies and reviews (Gross *et al.*, 1990; Morton *et al.*, 1988; Petrovic, 1990; Watschke and Mumma, 1989; Watson, 1985) have demonstrated or concluded that quality turfgrass stands modify the overland flow process so that runoff is insignificant in all but the most intense rainfall events. The ability of turfgrass sites to greatly reduce the quantity of sediment transported into surface streams and rivers is supported by the well-documented ability of vegetative filter strips that are situated downslope of cropland, mines, and animal production facilities (Barfield and Albrecht, 1982; Dillaha *et al.*, 1988; USEPA, 1976; Young, 1980). A key characteristic of mowed turfgrasses that contributes to this very effective erosion control is a dense ground cover with a high shoot density ranging from 75 million to > 20 billion shoots ha^{-1}; putting and bowling greens mowed at a 4-mm height possess in the order of 66 billion shoots ha^{-1} (Beard, 1973; Lush, 1990). Regular mowing, as practiced in turf culture, increases the shoot density substantially because of enhanced tillering when compared to ungrazed grassland (Beard, 1973).

The erosion control effectiveness of turfgrass is the combined result of a high shoot density and root mass for soil surface stabilization, plus a high biomass matrix that provides resistance to lateral surface water flow, thus slowing otherwise potentially erosive water velocities. Therefore, perennial turfgrasses offer one of the most cost-efficient methods to control wind and water erosion of soil. Such control is very important in eliminating dust and mud problems around homes, factories, schools, and businesses. When this major erosion control benefit is combined with the ground water recharge, organic chemical decomposition, and carbon storage benefits discussed in the next three sections, the resultant relatively stable turfgrass ecosystem is quite effective in soil and water preservation, as well as in restoration. This restoration of environmentally damaged areas via perennial grasses encompasses highly eroded landscapes, burned-over land, garbage dumps, mining operations, and forestry harvesting.

Ground Water Recharge and Surface Water Quality. One of the key mechanisms by which turfgrasses preserve water is their superior capability to essentially trap and hold runoff, which results in more water infiltrating and filtering through the soil-turfgrass ecosystem. A mowed turfgrass possesses a leaf and stem biomass ranging from 1,000 to 30,000 kg ha^{-1}, depending on the grass species, season, and cultural regime (Lush, 1990). This biomass is composed of a matrix of relatively fine-textured stems and narrow leaves with numerous, random open spaces. The matrix is porous in terms of the water infiltration capability. Turfgrass ecosystems often support abundant populations of earthworms (*Lumbricidae*) (200 to 300 earthworms/m^2) (Potter *et al.*, 1985, 1990a). Earthworm activity increases the amount of macropore space within the soil, which results in higher soil water infiltration rates and water-retention capacity (Lee, 1985). Studies in Maryland conducted on the same research site have shown that surface-water runoff losses from conventionally cultivated tobacco (Nicotiana tabacum L.) averaged 6.7 mm ha^{-1} $month^{-1}$ during the tobacco-growing season (May-September), whereas the surface-water runoff loss from perennial turfgrass plots averaged 0.6 mm ha^{-1} $month^{-1}$ (Angle, 1985; Gross *et al.*, 1990). Surface runoff losses of total N and total P for tobacco were 2.34 and 0.48 kg ha^{-1} $month^{-1}$, respectively, during the tobacco-growing season. Losses for the same parameters from turf averaged 0.012 and 0.002 kg ha^{-1} $month^{-1}$, respectively. Other studies have shown a similar ability of a turf or grass cover to reduce runoff and therefore enhance soil water infiltration and ground water recharge (Bennett, 1939; Gross *et al.*, 1991; Jean and Juang, 1979; Morton *et al.*, 1988; Watschke and Mumma, 1989). Finally, the reduced runoff volume, due to a turfgrass cover, may decrease the storm-water management requirements for urban tract development (Schuyler, 1987).

Organic Chemical Decomposition. The runoff water that occurs from impervious surfaces in urban areas carries many pollutants. Turfgrass areas are a good location for the catchment and filtration of polluted runoff water, especially if proper landscape designs are used (Klein, 1991; Schuyler, 1987). It is significant that a large population of diverse soil microflora and microfauna is supported by this same soil-turfgrass ecosystem. The microflora constitute the largest proportion of the decomposer biomass of most soils, with the bacterial biomass generally ranging from 30 to 300 g m^{-2}, fungi ranging from 50 to 500 g m^{-2}, and actinomycetes probably encompassing similar ranges of biomass in many soils (Alexander, 1977). Soil invertebrate decomposer biomass ranges from 1 to 200 g m^{-2}, with the higher value occurring in soils dominated by earthworms (Curry, 1986). Though soil animals play an important part in the decomposition process, only 10% or less of the CO_2 produced during decomposition has been attributed to them (Peterson and Luxton, 1982).

The bacterial population in the moist litter, clippings, and thatch of a turf is commonly in the order of 10^9 organisms cm^{-2} of litter surface (Clark and Paul, 1970). These organisms offer one of the most active biological systems for the degradation of trapped organic chemicals and pesticides. The average microbial biomass pool is reported to be 700, 850, and 1,090 kg C ha^{-1} for arable, forest, and grassland systems, respectively (Smith and Paul, 1990). A microbial biomass of 1,200 kg C ha^{-1} has been reported for grasslands in the United States (Smith and Paul, 1988). Microbial biomass values of mowed turfgrasses are not available, but are probably even higher due to (a) the high carbon biomass contained in senescing leaves and clippings that accumulate near the soil surface and (b) a more favorable moisture regime due to irrigation (Smith and Paul, 1990).

The turfgrass ecosystem also supports a diverse community of non-pest invertebrates (Potter, 1992). For example, a *Poa pratensis* - *Festuca rubra* polystand in New Jersey supported 83 different taxa of invertebrates including insects, mites, nematodes, annelids, gastropods, and other groups (Streu, 1973). Similarly, dozens of species of *Staphylinidae* (rove beetles), *Carabidae* (ground beetles), *Formicidae* (ants), *Araneae* (spiders), and other groups of invertebrates have been recovered from turfgrass sites (Arnold and Potter, 1987; Cockerfield and Potter; 1983; 1984; 1985). Earthworms (*Lumbricidae*), oribatid mites (*Cryptostigmata*), Collembola, and other invertebrates also are abundant in turfgrass soils (Arnold and Potter, 1987; Potter *et al.*, 1985; Potter *et al.*, 1990a,b; Vavrek and Niemczyk, 1990).

Carbon Storage. An extremely important function of the turfgrass-soil complex is the conversion of carbon dioxide emissions. The extensive, fibrous root system contributes substantially to soil improvement through organic matter additions derived from conversions of atmospheric carbon dioxide via photosynthesis. Actually, a high proportion of the world's most fertile and productive soils was developed under a vegetative cover of grass (Gould, 1968). The root depth potential ranges from 0.5 to 3 m, depending on the turfgrass species, extent of defoliation, and soil/environmental conditions. Generally, the C_4 warm-season turfgrasses produce a deeper, more extensive root system than the C_3 cool-season species

(Beard, 1989b). More work has been reported on the rooting characteristics of Kentucky bluegrass, *Poa pratensis*, than any other species. The root system biomass of a *P. pratensis* lawn is in the range of 11,000 to 16,100 kg ha^{-1} (Boeker, 1974; Falk, 1976). Within the upper 15 cm soil surface there are approximately 122,000 roots and 6.1 x 10^7 root hairs per liter of soil, with a combined length of over 74 km and a surface area of about 2.6 m^2 (Dittmer, 1938). Falk (1976) estimated that the annual root system turnover rate was 42% for a lawn. Utilizing Falk's estimate, the amount of root biomass in the upper 5.2 cm of soil annually converted to litter, and eventually to soil organic matter, would be approximately 6,761 kg ha^{-1}. The annual below-ground net productivity in the upper 25.4 cm of soil for a native prairie was reported to be 4,200 kg ha^{-1} (Dahlman and Kucera, 1965). For a lawn, 66% of the annual net productivity of plant biomass is below ground (Falk, 1967). This is because the net effect of mowing turfgrasses is to concentrate energies into increased vegetative growth, as opposed to reproductive processes, and to form a canopy of numerous dense, short, rapid growing plants with a fibrous root system. Range lands generally show decreased productivity from mowing since most grass species in this ecosystem maintain elevated meristematic crowns.

Heat Dissipation - Temperature Moderation. The overall temperature of urban areas may be as much as 5 to 7°C warmer than that of nearby rural areas. Through the cooling process of transpiration, turfgrasses dissipate high levels of radiant heat in urban areas. For example, infrared thermometer measurements made at 1:00 p.m. in College Station, Texas revealed that a green, actively transpiring <u>Cynodon</u> turf sustained a surface temperature of

31 ° C, while adjacent bare soil was 39 ° C; a brown, dormant turf was 52 ° C; and a synthetic turf surface was 70 ° C (Table 3) (Beard and Johns, 1985). The transpirational cooling effect of green turfs and landscapes can save energy by reductions in the energy input required for mechanical cooling the interiors of adjacent homes and buildings (Johns and Beard, 1985).

An additional asset of a turf/ecosystem is the relatively low total energy input requirements for maintenance compared to other landscape types. Of typical landscapes used in Florida (shrub and tree species that were not selected on the basis of drought or disease resistance), a lawn is the least energy intensive at 31.5 MJ m^{-2} yr^{-1}, followed by 5-yr-old trees at 87.5 MJ m^{-2} yr^{-1}, and then by shrubs at 114.8 MJ m^{-2} yr^{-1} (Parker, 1982). Similarly, Busey and Parker (1992) reported that the annual hours required for turf maintenance was 1.0 h 1000 ft^{-2}, while 11.5 h 1000 ft^{-2} was required for shrub beds. These energy inputs for maintenance could be significantly reduced by proper selection of low-energy input, sustainable species and cultivars of turfgrasses, trees, and shrubs.

Noise Abatement and Glare Reduction. The surface characteristics of turfgrasses function in noise abatement as well as in multi-directional light reflection which reduces glare. Studies have shown that turfgrass surfaces absorb harsh sounds significantly better than hard surfaces such as pavement, gravel, or bare ground (Cook and Van Haverbake, 1971; Robinette, 1972). These benefits are maximized by an integrated landscape of turfgrass, trees, and shrubs. Unfortunately, the proper use of turfgrasses, trees, and shrubs in concert to maximize noise abatement has received little attention within the scientific community.

Decreased Noxious Pests, Allergy-Related Pollens, and Human Disease Exposure. Closely mowed residential lawns reduce the numbers of nuisance pests such as snakes, rodents, mosquitoes, ticks, and chiggers. As undesirable small animals seek haven in taller grasses, flowers, and shrubs at locations more distant from the house, they also are less likely to invade the house.

Allergy-related pollens can cause human discomfort and potentially serious health concerns to susceptible individuals. Dense lawns typically are void of the many weedy species that often produce allergy-related pollens. In addition, most turfgrasses that are mowed regularly at a low height tend to remain vegetative with minimal floral development and thus have reduced pollen production. However, the best solution for those who enjoy outdoor gardening activities is to select turfgrass species/cultivars that do not form flowers nor the resultant allergy-related pollen. The turf cultural practices employed also influence flower and pollen production.

Exposure to a number of serious human diseases is facilitated by key insect vectors such as mosquitos and ticks. A closely mowed lawn around residences offers a less favorable habitat for unwanted nuisance insects and disease vectors (Clopton and Gold, 1992). Chigger mite population densities were found to be highest at the ecotone, transition area between a lawn and adjacent vegetation, and neighboring 600 mm of unmowed tall grass beyond the mowed turf. This is attributed to the distinct decrease in temperature and solar radiation at the ecotone. Of special concern is Lyme disease, which is spread by a tick commonly found in unmowed tall grass and woodland-shrub habitats.

Safety In Vehicle Operation/Equipment Longevity. Roadside turfgrasses aid in highway safety, as well as erosion control, by serving as a stabilized zone for emergency stoppage of vehicles (Beard, 1973). Mowed roadside turfs also enhance line-of-sight visibility and views of animal hazards, which are vital factors for operators of fast-moving vehicles. Turfgrasses also are utilized for soil and dust stabilization around airfield runways in order to prolong the operating life of engines, while turfgrasses are used on smaller airstrips as a low-cost means to stabilize the runway surface (Beard, 1973).

Security For Vital Installations and Lower Fire Hazard. Expanses of green, low-growing turfs in the landscape provide a high visibility zone that discourages unwanted intruders and vandals. Such turfs offer a low-cost approach that is a viable security measure, especially around sensitive military and police installations. Also, due to their low fuel value, properly positioned green, low-growing turfs function as firebreaks that significantly lower the fire hazard, especially for homes adjacent to extensive woodland/brush areas (Youngner, 1970).

Wildlife Habitat. The ever-increasing human population of the world results in a continuous increase in land area devoted to urban development. The impact on the wildlife species normally found in such areas is of concern. Certainly, proper planning of appropriate landscapes around homes, businesses, industrial complexes, and public buildings can greatly enhance the potential to support a representative wildlife community that residents may enjoy. A diverse range of wildlife can be achieved by an integrated landscape composed of turfgrass, tree, shrub, and water features, such as that found on a golf course (Green and

Marshall, 1987; Maffei, 1978). Ponds, lakes, and wetlands are very desirable features as utilized in parks and golf courses because they create additional aquatic habitats. A study of golf courses and parks in Cincinnati, Ohio has shown conclusively that passerine birds benefit from golf courses, even to the extent that golf courses may be described as bird sanctuaries (Andrew, 1987). Considerable pre-construction planning of golf courses, parks, and recreational areas is needed to address the impact on natural habitat. Properly designed golf courses can maintain and even promote plant and animal diversity, natural habitat, and wetlands when compared to traditional agriculture and urban residential usage (Love, 1992). Typically, 1.7 times more area is utilized for natural habitats such as roughs than to the combined area utilized for greens, tees, and fairways. This "naturalization" style of design is unquestionably conducive to both golf recreation and wildlife management.

TURFGRASS RECREATIONAL BENEFITS

Turfs provide a low-cost, safe recreational surface. Many outdoor sports and recreational activities utilize turfgrasses, including archery, badminton, baseball, cricket, croquet, field hockey, football, golf, hiking, horse racing, horseshoes, lawn bowling, lawn tennis, lacrosse, polo, rugby, shooting, skiing, soccer, softball, track and field, and volleyball.

Both the enjoyment and the benefits of improved physical and mental health derived from recreation and leisure activities on turfs are vital to contemporary society, especially in densely populated urban areas. Community pride and interest can be derived from quality sports fields and parks. Also, spectators derive entertainment from sporting competitions played on turfs.

Turfgrasses provide a unique, low-cost cushioning effect that reduces injuries to the participants, particularly in the more active contact sports like football, rugby, and soccer (Gramckow, 1966) Harper et al. (1984) reported in a study of 12 Pennsylvania high school football programs that 21% of injuries were classified as either definitely or possibly field related. Surface hardness measurements obtained with a Clegg decelerometer illustrate the substantial benefit of a properly-managed, quality turf in reducing the hardness of sports fields (Table 4) (Rogers and Waddington, 1992; 1990; Rogers *et al.*, 1988). Turfs are resilient and feel good to walk on. This resiliency protects the legs of participants, whether running or walking.

Home lawn owners derive the benefits of both physical exercise and therapeutic relaxation from the stresses of the work place via activities involved in the actual care and grooming of lawns. Many people find lawn maintenance an excellent opportunity to enjoy reasonable exercise and a healthy mental diversion.

TURFGRASS AESTHETIC BENEFITS

Francis Bacon, during the Renaissance in England, wrote that next to the house there is to be a lawn, with an avenue of trees in the middle, and covered shady walks on either side. "Nothing is more pleasant to the eye, than green grass kept finely shorn" (Gothein, 1979). Respondents to a Harris/Life survey reported that one of the things 95% of the respondents wanted most around them was "green grass and trees" (Life, 1971). Turfgrasses provide beauty and attractiveness that enhance the quality-of-life for human activities. Their aesthetic benefits are magnified when combined within an integrated landscape of trees, shrubs, and flowers. A turfgrass has numerous, important mental therapeutic benefits in addition to being attractive. These important dimensions that contribute to our quality of life are too often overlooked.

Improves Mental Health Via a Positive Therapeutic Impact. Most city dwellers attach considerable importance to urban parks and forests with views of grass, trees, and open space (Ulrich, 1986). Cities can be very dismal without green turfgrasses in parks, beside boulevards, and surrounding homes, schools, businesses, and the workplace. The result is a loss of productivity, more susceptibility to anxieties, and mental disease. For example, an outdoor view contributes to more rapid recovery for hospital patients (Ulrich, 1984). R. Kaplan and F. Kaplan (1989) addressed the role of nature, including parks, woodland areas, and large landscape sites in contributing to a person's quality-of-life within urban areas. The role encompasses aesthetics, i.e. appreciation of natural beauty, as well as the opportunity to use nature facilities in recreational activities. They also reported an increased sense of residential neighborhood satisfaction and of general well-being when there was a nearby nature landscape. Finally, personal satisfaction improved if the individuals were actually involved in gardening activities such as care of the landscape.

Contributes to Social Harmony and Improved Productivity. How we use vegetations, such as turfgrasses, in our surroundings is basic to social stability and harmony. Ugliness is costly. A turfed landscape area surrounding a factory or business is an asset in conveying a favorable "we care" impression to employees and the general public. These employees have lower levels of perceived job stress (Kaplan and Kaplan, 1989). Recent research demonstrates that visual encounters with outdoor landscapes and vegetation can be linked to health and in turn can be related to the economic benefits of visual quality (Ulrich, 1986). The clean, cool, natural green of turfgrasses provides a pleasant environment in which to live, work, and play. Such aesthetic values are of increasing importance to the human spirit and the mental health of citizens because of a rapid-paced lifestyle and increasing urbanization.

CONTEMPORARY ISSUES

For many centuries people have been willing to devote time and resources to enhance their quality-of-life and recreational opportunities through the use of turfgrasses (Beard, 1989a). Also, for many centuries turfgrasses have played a vital role in protecting our environment, long before it became an issue of major national and international importance to modern societies. In recent national headlines, there have been allegations that turfgrass culture adversely affects the environment. It is important to address these allegations and to identify those that can be supported by sound scientific data in order to make the adjustments needed to eliminate or minimize the problem. At the same time it is necessary to nullify those unfounded allegations that are based on non-germane, pseudoscientific information.

WATER CONSERVATION

Certainly the conservation of water has become an issue, not only in the arid western parts of the United States, but also in many densely populated eastern urban areas that do not have adequate reservoir supplies as a contingency when extended droughts occur. Considering all our uses for water in the United States, the average person directly or indirectly uses between 6,813 and 7,570 L d^{-1} (1,800 and 2,000 gallons per day which is more than applying one inch of water over a 10,000 ft^2 lawn each day of the year) (Rossillon, 1985). Industry accounts for 43% of the use, agricultural irrigation for 47%, and domestic use for cooking, bathing, sanitation, drinking, lawn sprinkling, etc. for the remaining 10%. Decisions concerning the most effective programs to reduce water utilization should consider these percentages. A primary concern that is seldom mentioned is the actual water leakage loss rate of municipal water distribution systems. For example, it was estimated that $7.6x10^8$ L (200 million gallons) leak from the New York City's water system each day (Miller, 1979).

Certain groups are actively promoting the reduction of turfgrass areas and their replacement with trees and shrubs as an urban water conservation measure. Statements have been made in widely distributed non-scientific publications such as "all turfgrasses are higher water users than trees and shrubs." There is no published scientific data available to support this allegation. In fact, the limited experimental data available suggest the opposite position.

Very few of the many hundreds of tree and shrub species/cultivars have actually been quantitatively assessed for their evapotranspiration rates. In contrast, a major portion of the turfgrass species/cultivars have been assessed for their evapotranspiration rates (Beard, 1990). There are *Cynodon* cultivars with evapotranspiration rates of less than 3 mm d^{-1}, whose evapotranspiration rates are 50% lower during dry-down periods between irrigations and/or rain. If one compares the evapotranspiration studies that are available, typically trees and shrubs are found to be higher water users than turfgrasses on a per unit land area basis (D. Devitt, 1992, personal communication). This is based on the sound premise that the evapotranspiration rate increases with leaf area when under a positive water balance (Johns *et al.*, 1983; Kim and Beard, 1987). Note that the major grasslands of the world are located in the semiarid regions, whereas the major forests of the world are located in the higher rainfall areas.

Much confusion has arisen from the "low water use landscape plant lists" that have been widely distributed. The lists are based on the incorrect assumption that those plants capable of surviving in arid regions are low water users, when these plants typically are only drought resistant. When these species are placed in an urban landscape with drip or other forms of irrigation, many become high water users. This occurs because the respective physiological mechanisms controlling evapotranspiration and drought resistance are distinctly different and can not be directly correlated within a plant species/cultivar (Beard, 1989b).

For unirrigated landscape sites, detailed assessments have been conducted of drought resistance and dehydration avoidance for many turfgrass species/cultivars (Sifers *et al.*, 1990). The results have shown that a number of turfgrass genotypes possess superior dehydration avoidance and can remain green for 158 d in a high sand root zone without irrigation under the hot summer conditions in College Station, Texas. Comparable detailed studies of dehydration avoidance and drought resistance among tree and shrub species/cultivars are lacking.

When turfed areas are irrigated, the adjacent trees and shrubs also are being irrigated as a result of the multitude of shallow tree and shrub roots that concentrate under the irrigated turf area (Whitcomb and Roberts, 1973). Thus, when a home owner is irrigating the lawn, most of the adjacent trees and shrubs also are being irrigated.

Numerous turfgrass species are capable of ceasing growth, entering dormancy, and turning brown during summer drought stress, but they readily recover once rainfall occurs

(Sifers *et al.*, 1990). Some people incorrectly assume that turfgrasses must be kept green throughout the summer period to survive, and thus will irrigate. Many trees drop their leaves during summer drought stress or during the winter period when only brown bark remains. What then is wrong with a tan to golden-brown turf during summer droughts, if one chooses not to irrigate?

Some advocates propose the replacement of turfgrasses with a mulch cover and then planting landscape shrubs within the mulched area as a water conservation measure. Mulches do reduce evaporation of moisture from the soil. However, the presence of a mulch increases the radiant energy load on the under side of deciduous shrubs and trees, which have a majority of their stomata on the under sides of the leaves. This in turn substantially increases the evapotranspiration rate. Detailed studies revealed that crape myrtle (*Lagerstroemia indica* L.) grown on a mulched surface used 0.63 to 1.25 kg m^{-2} d^{-1} more water than those located in a bare soil, and 0.83 to 1.09 kg m^{-2} d^{-1} more water than crape myrtle located in a bermudagrass (*Cynodon* spp.) turf (Zajicek and Heilman, 1991). Further, crape myrtle located on bare soil used 0.2 kg m^{-2} d^{-1} more water than when growing in a bermudagrass turf. Sensible heat and long wave radiation from the mulched area increased plant temperatures and thus the leaf air vapor pressure deficit and associated transpiration rate.

In summary, there is no valid scientific basis for water conservation strategies or legislation requiring extensive use of trees and shrubs in lieu of turfed areas. Rather the proper strategy based on good science is the use of appropriate low-water-use turfgrasses, trees, and shrubs for moderate-to-low irrigated landscapes and similarly to select appropriate dehydration-avoidant and drought-resistant turfgrasses, trees, and shrubs for nonirrigated landscape areas. The main culprit in excessive landscape water use in most situations is the human factor. The waste of water results from improper irrigation practices and poor landscape designs rather than any one major group of landscape plant materials.

What is the future? Great natural genetic diversity exists among the turfgrass genotypes in terms of both low evapotranspiration rates and superior dehydration avoidance/drought resistance (Beard, 1989b). Applying appropriate breeding techniques should achieve even lower water use rates among the currently used turfgrass species. There is also one caution as we strive for plant materials with low evapotransporation rates. One must avoid a narrow, single-issue emphasis that ignores the potential effects of a lowered evapotranspiration rate on the total urban ecosystem. Urban areas already suffer substantially higher temperatures than adjacent rural areas. Lowering the evapotranspiration rate through plant material selection and judicious irrigation will reduce transpirational cooling and increase heat loads on residences and buildings, thereby increasing energy requirements for mechanical cooling. Depending on the relative costs and availability of water versus energy, it may be wise in certain urban areas not to strive for the lowest possible water-using landscapes. Here again, detailed scientific investigations of a very sophisticated nature will be required to developed appropriate definitive strategies that take into consideration the total effects on all components within the urban ecosystem. Also, more turfgrass areas can be irrigated with reclaimed waste water. This practice has been successfully studied for turfs (Anderson *et al.*, 1981a,b; Dudeck *et al.*, 1979; Hayes *et* *al.*, 1990a,b). In this age of conservation and recycling, irrigating turf and landscape sites with recycled water has considerable merit.

GROUND WATER AND SURFACE WATER QUALITY PRESERVATION

Ten percent of the turfgrass areas in the United States receive a higher intensity of culture that involves fertilization plus one or more pesticides. Appropriate questions must be addressed concerning the potential for these chemicals to enter our ground water by downward leaching or our surface water via runoff following intense precipitation.

Pesticides. As discussed earlier, the long-term, biologically active ecosystem that develops in turfed areas possesses a multiplicity of diverse soil microflora and microfauna that have excellent capabilities in the degradation of organic pollutants, including pesticides. A turf is one of the best vegetative ecosystems known for the entrapment and degradation of organic compounds.

The potential of turfgrass pesticides to contaminate surface or ground waters has not been studied extensively. Most studies have shown either directly or indirectly that when proper turfgrass management practices are followed, pesticide movement into surface or ground water is negligible (Branham and Wehner, 1985; Cohen *et al.*, 1990; Gold *et al.*, 1988; Niemczyk and Krueger, 1987; Rhodes and Long, 1974; Sears *et al.*, 1987; Watschke and Mumma, 1989). One reason there is negligible movement of pesticides into surface or ground waters is that most turfgrasses develop a 6- to 9-mm deep thatch layer just below the soil surface which serves as an entrapment and degradation site for pesticides. These studies also suggest that excellent degradation conditions exist in the soil-turfgrass ecosystem, especially during favorable temperature and moisture conditions. However, water pollution may have been a problem on turfgrass sites with a prolonged usage of mercurial fungicides (Fushtey and Frank, 1981), with the use of tricalcium arsenate on sandy sites (Duble *et al.*, 1978) and with the use of dacthal (USEPA, 1990; 1992). Fortunately, these materials are either no longer used on turf or probably will no longer be registered for turf use.

In terms of the net effect of pesticide usage on drinking water, the U.S. Environmental Protection Agency (EPA) completed its 5-yr National Survey of Pesticides in drinking water wells in 1990 (USEPA, 1990; 1992). The EPA sampled approximately 1,300 community water system (CWS) wells and rural domestic wells for the presence of 101 pesticides, 25 pesticide degradates, and nitrate. The EPA estimated that at most, 0.8% of the CWS wells and 0.6 % of rural domestic wells nationwide contain at least one pesticide above the respective Health Advisory Levels or Maximum Contaminant Levels. Recent reports also indicate that pesticides are not a major source of nonpoint pollution that affects surface waters (Carey, 1991). It was estimated that pesticides account for 3% and less than 1% of all nonpoint pollution sources in affected rivers and lakes, respectively, in the United States.

There have been instances where significant deaths of animals, such as geese and fish, have occurred as a result of pesticide applications to turf areas. Typically, these deaths have been associated with either intentionally high application rates or application by improperly trained and unlicensed practitioners. This dimension is the one aspect of most concern in terms of environmental protection. It emphasizes the need for thorough, quality training and licensing programs to prevent misuse of otherwise safe pesticides.

Integrated pest management (IPM) concepts, which have been recently reviewed (Balogh *et al.*, 1992; Bruneau *et al.*, 1992; USEPA, 1989), have been an important component of turfgrass culture for a long time. For example, 90 percent of all potential weed problems are controlled via regular mowing. Also, the best approach to minimizing disease and insect problems is providing a turf, soil, and cultural environment that maximizes turfgrass plant health. Even under these conditions, threats to plant health may occur as a result of extraordinary intensities of disease or insect activity. The pesticides registered for control of these problem diseases and insects have negligible effects on both ground and surface water quality when properly applied to the turfgrass ecosystem due to its high organic chemical degradation capability. Biological control approaches hold promise for the future. Continued research and development of biological controls for problem pests of turf need to be aggressively pursued.

Fertilizers. First it should be noted that the perennial turfgrasses have an extensive, fibrous root system that tends to dominate the upper 20 to 30 cm of the soil profile. This root system has an abundance of root hairs distributed along the full length of the roots (Green *et al.*, 1991). These root hairs are highly efficient in the uptake of applied nutrients. Second, as previously mentioned the turfgrass ecosystem forms a very dense above-ground biomass that reduces runoff and thus allows time for soil infiltration of water. Consequently, fertilization of turfgrasses, according to established cultural strategies, presents a negligible potential for nutrient elements to pass through the root zone into the ground water or be transported via runoff water into surface waters. This has been confirmed by a number of studies or reviews (Cohen *et al.*, 1990; Gold *et al.*, 1990; Gross *et al.*, 1990; Morton *et al.*, 1988; Petrovic, 1990; Watschke and Mumma, 1989). Comparatively less NO_3 leaching occurs from turfgrasses than from row crop agriculture (Gold *et al.*, 1990). In terms of the net effect of nitrogen fertilizer use and other factors contributing to water pollution from nitrogen, the EPA estimated that only 1.2% of community water system wells and 2.4% of rural domestic wells nationwide contain nitrate exceeding 10 mg L^{-1}, which is the Maximum Contaminant Level (USEPA, 1990, 1992).

Fertilizer application during a time of the year when the turfgrass is dormant or nongrowing is a potential negative situation and is ill-advised from an agronomic standpoint. The efficient nutrient uptake system of the roots is less operative, and thus fertilization should not be practiced during dormant periods. Another potential negative situation may occur during the process of applying fertilizer, if some material gets on sidewalks, driveways, and streets, where it may be washed into the sewer system and eventually out into rivers and lakes. Obviously, the individual applying the fertilizer must be educated as to the need to apply all fertilizer to the target turf area only. In addition, fertilizer spreaders can be obtained with appropriate protective edging devices to avoid throwing or dropping fertilizer onto nontarget areas. When fertilizer is applied, it is best followed by a light irrigation to move the particles into the soil, thereby minimizing the potential of nutrients entering lateral surface water flow. On the other hand, excessive irrigation may cause problems on coarse sandy soils. Excessive application rates of watersoluble nitrogen fertilizers on turfgrasses followed by overwatering on sandy soils can cause nitrate contamination of ground water (Brown *et al.*, 1982; Snyder *et al.*, 1984).

Trends in turfgrass fertilization have been toward lower nitrogen application rates. The highest rates were used during the 1960's; with the rates now used on professional turf areas having been reduced to one-third of those formerly used. In addition, the use of slow-release nitrogen carriers has increased. In fact, the turfgrass industry has been a leader in the development of slow-release nutrient carriers, which offer increased environmental protection.

For the future, emphasis is needed on breeding turfgrasses with improved tolerance to nitrogen stress. It is also critical to educate the general public that the darkest green turf, which many people strive for, is in fact not the healthiest turf. A medium green turf with a moderate growth rate will have the deepest root system with less thatching, reduced disease and insect problems, and increased tolerance to environmental stresses such as heat, drought, cold, and wear (Beard, 1973).

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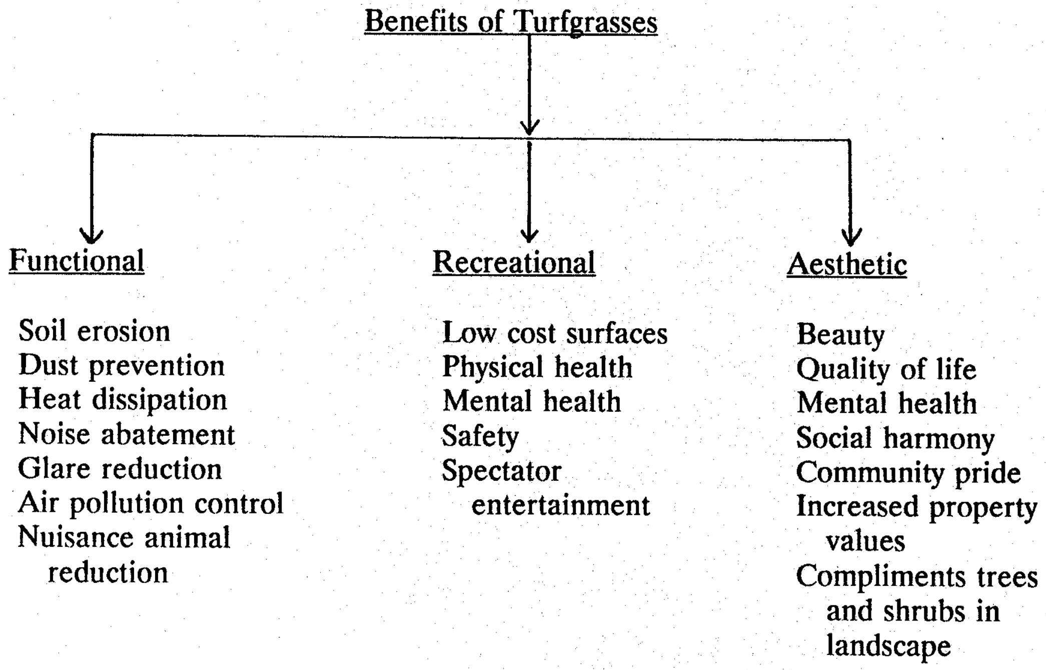

Figure 1. Diagrammatic summary of benefits derived from turfs.

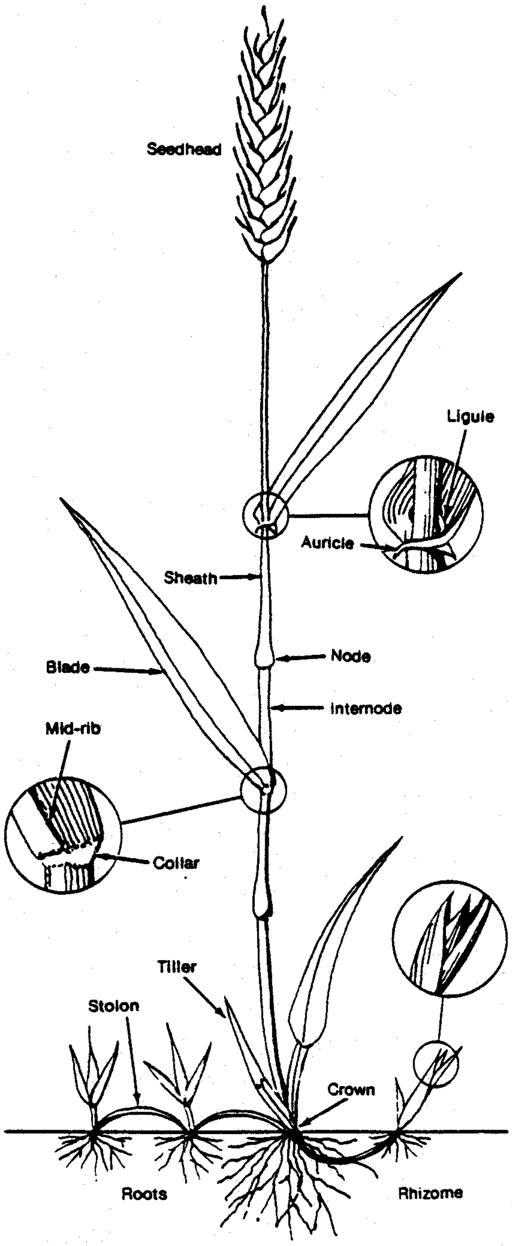

Figure 2. The turfgrass plant.

Table 1. History of turf use.

Century	Activity	Century	Activity
11th	Landscape designs utilizing lawn-like areas	16	Soccer played on turfed central parks
12th	Lawns composed of low-growing grasses inter-planted with flowers Sodding described in a Japanese gardening book	17th	First significant gardening books
13th	Sport of bowls played on turfs	18th	First commercial production of sod Tennis played on turfed areas
14th	Turfed lawns manually mowed in Japan	19th	Lawn mower invented First turfgrass research publications
15th	Golf played on turfs in Scotland Towns and villages utilized a turfed central park called a green or common.	20th	Development of the modern turfgrass industry and university research

Table 2. Evolution of turfgrass research since 1945.

Time period	Key areas of research emphases and achievements
1945-55	- Selective broadleaf weed control: phenoxy-herbicides. - Insecticide development of efficacy and persistence.
1950-60	- Equipment: powered coring, slicing, spiking, and vertical cutting. - Mowing practices. - Culture of turfgrass communities: mixtures and blends.
1955-65	- Preemergence weed control through selective herbicides. - Turf-type fertilizer ratios and formulations. - Warm-season turfgrass cultivar development: bermudagrasses and zoysiagrasses.
1960-70	- Root zone modification, USGA Green Section Method. - Roadside establishment: improved mulching methods.
1965-75	- Cool-season turfgrass cultivar development through breeding: Kentucky bluegrasses and perennial ryegrasses. - Sod production cultural practices.
1970-80	- Turfgrass disease characterizations plus systemic fungicide programs. - New turfgrass nutritional practices, emphasizing potassium and iron plus fall fertilization.
1975-85	- Growth and physiology of turfgrasses in relation to environmental stress tolerances: cold, heat, drought, wear, and shade.
1980-90	- Development of cultural practices and cultivars that conserve water, energy, and nutrient resources.

Table 3. Temperature comparisons on a selected day in August in College Station, Texas.

Type of Surface	Maximum Daytime Surface Temperature	Minimum Nocturnal Surface Temperature
Green growing turf	31°C (88°F)	24°C (76°F)
Dry bare soil	39°C (102°F)	26°C (78°F)
Brown dormant turf	52°C (126°F)	27°C (79°F)
Dry synthetic turf	70°C (158°F)	29°C (84°F)

Table 4. Impact values for high school fields *vs.* impact values for other surfaces (from Rogers et al., 1988).

Surface	Hammer 0.5 kg	Hammer 2.25 kg
	g_{max}	
High school fields	50-286[z]	33-167
Artificial turf	109-172	60-91
Frozen practice field	404	303
Tiled, concrete basement floor	1,440	1,280
Carpet and pad on tiled concrete floor	260	190
Carpet and pad on hardwood floor	86	134

g_{max} = maximum deceleration (harder surfaces have greater g_{max} values).

[z] Good maintenance practices and good field conditions were generally associated with lower impact values, which indicated less hardness. Factors affecting hardness were soil bulk density, soil moisture, and turf cover.