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The Role of Turfgrasses in Environmental Protection and Their Benefits to Humans

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ABSTRACT

Turfgrasses have been utilized by humans to enhance their environment for more than 10 centuries. The complexity and comprehensiveness of these environmental benefits that improve our quality-of-life are just now being quantitatively documented through research. Turfgrass benefits may be divided into (i) functional, (ii) recreational, and (iii) aesthetic components. Specific functional benefits include: excellent soil erosion control and dust stabilization thereby protecting a vital soil resource; improved recharge and quality protection of groundwater, plus flood control; enhanced entrapment and biodegradation of synthetic organic compounds; soil improvement that includes CO_2 conversion; accelerated restoration of disturbed soils; substantial urban beat dissipation-temperature moderation; reduced noise, glare, and visual pollution problems; decreased noxious pests and allergy-related pollens; safety in vehicle operation on roadsides and engine longevity on airfields; lowered fire hazard via open, green turfed firebreaks; and improved security of sensitive installations provided by high visibility zones. The recreational benefits include a low-cost surface for outdoor sport and leisure activities enhanced physical health of participants, and a unique low-cost cushion against personal impact injuries. The aesthetic benefits include enhanced beauty and attractiveness; a complimentary relationship to the total landscape ecosystem of flowers, shrubs and trees; improved mental health with a positive therapeutic impact, social harmony and stability; improved work productivity; and an overall better quality-of-life, especially in densely populated urban areas.

The Role of Turfgrasses in Environmental Protection and Their Benefits to Humans

James B. Beard and Robert L. Green

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 modem societies.

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 surpasses all other genera. 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.

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 *(Zea mays* L.), all members of the grass family, serve as food for humans and animals. A host of grazing ruminant animals use grasses as their major food source as forage, pasture, and prepared feeds. Bamboo *(Bambusa* spp., *Dendrocalamus* spp., and *Phyllostachys* spp.) is a major building material. Also, grasses of all types represent a large source of biomass for production of methanol, an alternate energy source.

The turfgrass species now in use evolved during the past 50 million years and they have been cultured by humans to provide an enhanced environment and quality-of-life for >10 centuries (Beard, 1973). The modem 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 USA, including labor but excluding capital expenses, was conservatively estimated to be $25 billion (Cockerham and Gibeault, 1985). This economic impact has increased substantially during the past 10 yr. to $45 billion. This 1993 value was based on the 1985 data with adjustments for population growth and inflation. Also, the fixed assets of turf installations are valued at many times that of the annual maintenance expenditures.

The functional, recreational, and aesthetic contributions of turfgrasses than enhance the quality-of-life for humans often are overlooked and seldom addressed in the scientific literature. Our purpose is to document the beneficial contributions of turfgrasses as summarized in (Fig. 1).

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TURFGRASS FUNCTIONAL BENEFITS

Soil Erosion Control and Dust Stabilization

Turfgrasses are relatively inexpensive, durable groundcovers that protect our valuable, nonrenewable soil resource from water and wind erosion. 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 USA; and 57 and 12%, respectively, of the non-point surface-water pollution affecting the 3.3 million hectares of lakes in the USA. 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 USA was 9184 kg ha^{-1} (U.S. Department of Agriculture, 1989).

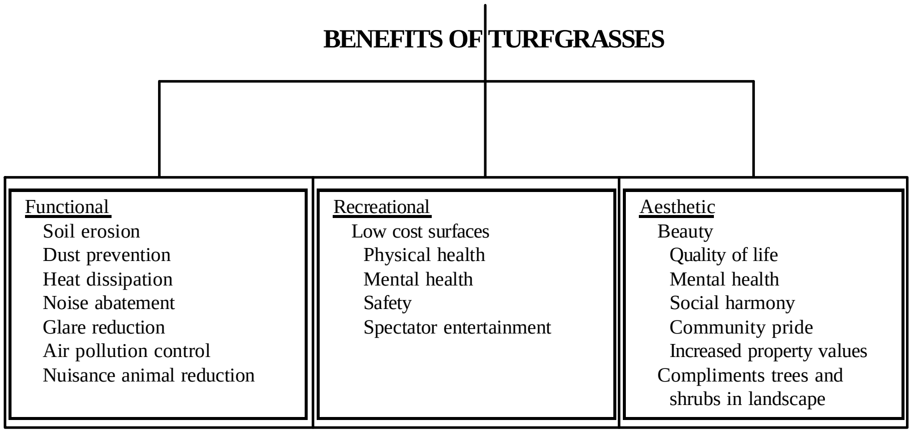

Fig. 1. Diagrammatic summary of benefits derived from turfs.

Gross et al. (1991) reported sediment losses of ~ 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 generally is 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 grasses to function as vegetative filter strips that greatly reduce the quantity of sediment transported into surface streams and rivers is well documented, especially when positioned downslope of cropland, mines, and animal production facilities (Barfield and Albrecht, 1982; Dillaha et al., 1988; U.S. Environmental Protection Agency, 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 per hectare (Beard, 1973; Lush, 1990). Regular mowing, as practiced in turf culture, increases the shoot density substantially because of enhanced tillering when compared with ungrazed grasslands (Beard, 1973). Putting and bowling greens mowed at a 4-mm height possess up to 66 billion shoots ha^{-1}.

The erosion control effectiveness of turfgrass is the combined result of a high shoot density and root mass for surface soil 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 water and wind 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 groundwater recharge, organic chemical decomposition, and soil improvement benefits discussed in the next three sections, the resultant relatively stable turfgrass ecosystem is quite effective in soil and water preservation.

Groundwater Recharge and Surface Water Quality

One of the key mechanisms by which turfgrasses preserve water is their superior capability to 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 canopy matrix is porous in terms of the water infiltration capability.

Studies in Maryland conducted on the same research site have shown that surface-water runoff losses from a cultivated tobacco *(Nicotiana tabacum* L.) site averaged 6.7 mm ha^{-1} 4 wk^{-1} during the tobacco-growing season (May-September); whereas, the surface-water runoff loss from perennial turfgrass averaged only 0.6 mm ha^{-1} 4 wk^{-1} (Angle, 1985; Gross et al., 1990). Surface runoff losses of total N and P for tobacco were 2.34 and 0.48 kg ha^{-1} 4 wk^{-1}, respectively. Losses of N and P from the turf averaged only 0.012 and 0.002 kg ha^{-1} 4 wk^{-1}, respectively. Other studies have shown a similar ability of a turfgrass cover to reduce runoff, and therefore enhance soil water infiltration and groundwater recharge (Bennett, 1939; Gross et al., 1991; Jean and Juang, 1979; Morton et al., 1988; Watschke and Mumma, 1989). Finally, the reduced runoff volume from a turfgrass cover offers the potential to decrease the storm-water management requirements and costly structures used in urban development (Schuyler, 1987). Turfgrass ecosystems can support abundant populations of earthworms *(Lumbricidae)* of from 200 to 300 m^{-2} (Potter et al., 1985, 1990a). Earthworm activity increases the amount of macropore space within the soil, that results in higher soil water infiltration rates and water-retention capacity (Lee, 1985).

Organic Chemical Decomposition

The runoff water and sediment that occurs from impervious surfaces in urban areas carries many pollutants, (Schuyler, 1987) including metals such as Pb, Cd, Cu, and Zn; hydrocarbon compounds as from oil, grease and fuels; and household and industrial hazardous wastes such as waste oils, paint thinners, organic preservations, and solvents. Turfgrass areas can be designed for the catchment and filtration of these polluted runoff waters (Schuyler, 1987). It is significant that large populations of diverse soil microflora and microfauna are supported by this same soil-turfgrass ecosystem. Microflora constitute the largest proportion of the decomposer biomass of most soils. The bacterial biomass component ranges from 30 to 300 g m^{-2}, and fungi from 50 to 500 g m^{-2}, with actinomycetes probably in a similar range (Alexander, 1977). Soil invertebrate decomposer biomass ranges from 1 to 200 g m^{-2}, with the higher values 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, grass clippings, and thatch of a turf commonly is 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 1090 kg C ha^{-1} for arable, forest, and grassland systems, respectively (Smith and Paul, 1990). A microbial biomass of 1200 kg C ha^{-1} has been reported for grasslands in the USA (Smith and Paul, 1988). Microbial biomass values of mowed turfgrasses are not yet available, but are probably even higher due to the high C biomass contained in the senescent leaves and grass clippings that accumulate near the soil surface and to a more favorable soil moisture regime due to irrigation (Smith and Paul, 1990).

The turfgrass ecosystem also supports a diverse community of nonpest invertebrates. For example, a Kentucky bluegrass *(Poa pratensis* L.)-red fescue *(Festuca rubra* L.) polystand in New Jersey supported 83 different taxa of invertebrates including insects, mites *(Acarina* spp.), nematodes *(Nematoda* spp.), annelids *(Annelida* spp.), gastro*pods (Gastropoda* spp.), and other groups (Streu, 1973). Similarly, dozens of species of rove beetles, *(Staphylinidae*), ground beetles *(Carabidae), ants* (*Formicidae*), spiders *(Araneae),* and other groups of invertebrates have been recovered from turfgrass sites (Arnold and Potter, 1987; Cockfield and Potter; 1983, 1984, 1985). Earthworms, oribatid mites *(Cryptostigmata),* Collembola, and other invertebrates also are abundant in turfgrass soils (Arnold and Potter, 1987; Potter et al., 1985, 1990a,b; Vavrek and Niemczyk, 1990).

There also is the gaseous dimension of atmospheric pollution control. Carbon monoxide concentrations >50 μL often occur in urban environments, especially near roadsides (Jaffe, 1968). Gladon et al. (1993) reported that certain turfgrasses, such as tall rescue *(Festuca arundinacea* Schreber), may be useful as an absorber of CO from the urban environment.

Soil Improvement and Restoration

An extremely important function of turfgrasses is soil improvement through organic matter additions derived from the turnover of roots and other plant tissues that are synthesized in part from atmospheric CO_2 via photosynthesis. A high proportion of the world's most fertile soils has been 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, 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 than any other species. The root system biomass of a Kentucky bluegrass lawn is in the range of 11,000 to 16,100 kg ha^{-1} (Boeker, 1974; Falk, 1976). In the upper 150 mm of the soil there are ˜ 122,000 roots and 6.1X 10^7 root hairs per liter of soil, with a combined length of >74 km and a surface area of ˜ 2.6 m^2 (Dittmer, 1938).

Falk (1976) estimated that the annual root system turnover rate was 42% for a lawn. Using Falk's estimate, 6761 kg of root biomass per hectare would be turned over into the soil each year. This estimate is low because it did not account for root secretions, death and decay of fine roots and root hairs, and consumption of roots by soil animals. The amount of root biomass annually produced and turned over into the soil, or root net productivity, for a defoliated grassland is higher than the amount reported for ungrazed prairie ecosystem (Dahlman and Kucera, 1965; Sims and Singh, 1971, 1978). Similarly, the net effect of regular mowing on prostrate growing turfgrasses would be 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. Also, many prairie lands in the USA generally show decreased productivity under regular defoliation, as by mowing, since most native grass species found in these ecosystems form meristematic crowns that are elevated higher above the soil and where removal is more likely when compared with turfgrass species. Dahlman and Kucera (1965) estimated the time required for a central Missouri prairie to reach 99% soil organic matter equilibrium to be 110, 420, and 590 yr for the A_1, A_2, and B_2 soil horizons, respectively.

Accelerated soil restoration of environmentally damaged areas by planting perennial grasses is employed effectively on highly eroded rural landscapes, burned-over lands, garbage dumps, mining operations, and steep timber harvest areas. These areas may then be developed as parks, golf courses, sports field complexes, and recreational areas.

Heat Dissipation-Temperature Moderation

The overall temperature of urban areas may be as much as 5 to 7^{o}C warmer than that of nearby rural areas. Through the cooling process of transpiration, turfgrasses dissipate high levels of radiant heat in urban areas. Maximum daily canopy temperatures of a green, growing *Cynodon* turf was found to be 21^{o}C cooler than a brown dormant turf and 39 'C cooler than a synthetic surface (Table 1; Beard and Johns, 1985). The transpirational cooling effect of green turfs and landscapes can save energy by reductions in the energy input required for interior mechanical cooling of adjacent homes and buildings (Johns and Beard, 1985).

An additional asset of a turfgrass ecosystem is the lower total energy input requirements for maintenance compared with other landscape types. A comparison of typical landscapes used in Florida revealed a lawn was 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 1.076 h 100 m^{-2}, while 12.37 h 100 m^{2} was required for shrub beds, which seem to be low values. Energy inputs for maintenance could be reduced by proper selection of resource efficient, 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 that 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 turfgrasses, 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 *(Ophidia* spp.), rodents *(Rodentia), mosquitoes (Culicidae* spp.), ticks *(Ixodoidea* spp.; *Acari* order), and chiggers *(Trombiculidae* spp.*; Acari* order). 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 and 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. Of current concern is Lyme disease, which is spread by a tick commonly found in unmowed tall grass and woodland-shrub habitats. A closely mowed lawn around residences offers a less favorable habitat for unwanted nuisance insects and disease vectors (Clopton and Gold, 1993). Chigger mite (*T. irritens)* population densities were found to be highest at the ecotone or transition area of neighboring 600-

mm tall grass beyond the mowed turf. This is attributed to the distinct decrease in temperature and solar radiation at the ecotone.

Table 1. Temperature comparisons of four types of surfaces on August 20 in College Station, TX.

Type of surface	Maximum daytime surface temperature	Minimum nocturnal surface temperature
Green growing *Cyodon* turf	31°C	24°C
Dry bare soil	39°C	26°C
Brown summer-dormant *Cynodon* turf	52°C	27°C
Dry synthetic turf	70°C	29°C

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 enhance line-of-sight visibility and views of signs and animal hazards, which are vital factors for operators of fast-moving vehicles. Turfgrasses are used for soil and dust stabilization around airport runways and taxiways to prolong the operating life of airplane engines (Beard, 1973). Furthermore, turfgrasses are used on small airstrips as a low-cost means to stabilize the runway surface.

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, the low fuel value of green, prostrate-growing turfs serves a valuable function as a firebreak that significantly lowers the fire hazard if properly positioned (Youngner, 1970). This attribute is especially important for homes and buildings adjacent to extensive woodland or brush areas.

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 enhance the potential to support a representative wildlife community that residents may enjoy. A diverse wildlife population can be achieved by an integrated landscape composed of turfgrass, tree, shrub, and water features, such as that found on golf courses (Green and Marshall, 1987; Maffei, 1978). A study of golf courses and parks in Cincinnati, OH, 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). Ponds, lakes, and wetlands are very desirable features as used in parks and golf courses because they create aquatic habitats, as well as diversity in visual landscape aesthetics. Considerable preconstruction planning of golf courses, parks, and recreational areas is needed to address their impact on natural habitats. Properly designed urban landscape green areas such as golf courses and parks can maintain and even promote plant and animal diversity, natural habitats, and wetlands when compared to intensive agriculture and urban residential usage. A naturalized style of golf course design is unquestionably conducive to both golf reaction and wildlife management. Typically, 1.7 times more area on a golf course is used for natural habitats such as roughs, woodlands, and water features than the combined area devoted to greens, tees, and fairways.

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 when compared with poorly or nonturfed soils, particularly in the more active contact sports like football, rugby, and soccer (Gramckow, 1968). In a study of 12 Pennsylvania high school football programs Harper et al. (1984) reported that 21% of injuries were classified as either definitely or possibly field related. Surface hardness measurements obtained with a Clegg impact soil tester (Lafayette Instrument Co., Lafayette, IN) illustrate the substantial benefit of a properly managed, quality turf in reducing the hardness of sports fields (Table 2; Beard and Sifers, 1993, p. 40; Rogers et al., 1988; Rogers and Waddington, 1990, 1992). Turfs are resilient and pleasant to walk on. This resiliency can help to protect the legs of participants, whether running or walking.

Table 2. Impact absorption values for high school athletic fields versus other surfaces (Rogers et al., 1988).

	Impact hammer weight	
Type of surface	0.5 kg	2.25 kg
	------------------- ^{g}max† -------------------	
High school athletic fields	50-286‡	33-167
Artificial turf	109-172	60-91
Frozen practice athletic field	404	303
Tiled, concrete basement floor	1440	1280
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).

‡ Good maintenance practices and field conditions generally were associated with lower impact values that indicated less hardness

Home lawn owners derive the benefits of both physical exercise and therapeutic relaxation from the stresses of the work place through activities involved in the 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. 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 (Hooper, 1970). 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 turf 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 can be a loss of productivity, more susceptibility to anxieties, and mental disease. For example, an outdoor view contributed to more rapid recovery for hospital patients (Ulrich, 1984). Kaplan and 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 encompassed the opportunity to use nature facilities in recreational activities as well as aesthetics, i.e., the appreciation of natural beauty. 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 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 plan, 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 rapid paced lifestyles and increasing urbanization.

CONTEMPORARY ISSUES

In recent national headlines, there have been allegations that turfgrass culture has a major role adversely affecting 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 any potential problem. At the same time it is necessary to nullify those unfounded allegations that are based on speculative pseudo-scientific information.

Water Conservation

Conservation of water has become an issue, not only in the arid regions of the USA, 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 USA, the average person directly or indirectly uses between 6,813 and 7,570 L d^{1} (Rossillon, 1985). To put in perspective, this is more than applying 25 mm of water across a 929 m^{-2} lawn each day for a year. Industry accounts for 43% of our water use, agricultural irrigation for 47%, and domestic use for cooking, bathing, sanitation, drinking, and landscape irrigation for the remaining 10%. Decisions concerning the most effective programs to reduce water use should consider these data. A primary concern that is seldom mentioned is the actual water leakage loss rate of municipal water distribution systems.

The original xeriscape group and others have actively promoted the reduction of turfgrass areas and their replacement with trees and shrubs as an urban water conservation measure (Beard, 1993). Statements have been made in widely distributed nonscientific publications such as all turfgrasses are higher water users than trees and shrubs. There are 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. There are *Cynodon* cultivars with evapotranspiration rates of < 3 mm d^{1}, whose evapotranspiration rates are 50% lower during dry-down periods between irrigation or rain (Beard, 1990). 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, 1993, 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 from the xeriscape groups 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 can become high water users. This occurs because the physiological mechanisms controlling evapotranspiration and drought resistance are distinctly different and can not be directly correlated within a plant species or cultivar (Beard, 1989b).

For unirrigated landscape sites, detailed assessments have been conducted of drought resistance and dehydration avoidance for many turfgrass species and 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, TX. Comparable detailed studies of dehydration avoidance and drought resistance among tree and shrub species 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 homeowner 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? If water conservation is the goal, then a dormant turf uses little water whereas certain trees and shrubs may continue to remove water from lower soil depths.

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. Some 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 undersides of the leaves. This in turn substantially increases the evapotranspiration rate. For example, 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 turfgrasses. 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 cause for 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 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 and other cultivars.

There is one caution as we strive for low evapotranspiration 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 interior mechanical cooling. Depending on the relative costs and availability of water vs. energy, it may be wise in certain urban areas not to strive for the lowest possible water-using landscapes. Here again, detailed scientific investigations will be required to develop appropriate definitive strategies that take into consideration the total effects on all components within the urban ecosystem. Furthermore, turfgrass areas can be irrigated with reclaimed wastewater. This practice has been successfully evaluated 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.

Groundwater and Surface Water Quality Preservation

Ten percent of the turfgrass areas in the USA receive a higher intensity of culture that involves fertilization. Appropriate questions must be addressed concerning the potential for these chemicals to enter groundwater by downward leaching or surface water via runoff following intense precipitation.

First it has been noted previously that the perennial turfgrasses have an extensive, fibrous root system that tends to dominate the upper 200 to 300 mm 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). Second, the turfgrass ecosystem forms a very dense aboveground 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 groundwater or be transported by 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). Turfgrass root systems are highly efficient in the uptake of applied nutrients. Comparatively less $N0_3$ leaching occurs from turfgrasses than from row crop agriculture (Gold et al., 1990). In terms of the net effect of N fertilizer use and other factors contributing to water pollution from N, the USEPA estimated that only 1.2% of community water system wells and 2.4% of rural domestic wells nationwide contain NO_3 exceeding 10 mg L^{-1}, which is the Maximum Contaminant Level (U.S. Environmental Protection Agency, 1990, 1992).

Fertilizer application during a time of the year when the turfgrass is dormant or nongrowing is a potentially negative situation. This is because the normally efficient nutrient uptake system of the roots is less operative (Petrovic, 1990). Another potentially negative situation may occur during the process of applying fertilizer. For example, if material gets on sidewalks, driveways, and streets, it may be washed into the sewer system and eventually out into rivers and lakes. Obviously, the individual applying the fertilizer must be informed 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 course sandy soils. Excessive application rates of water-soluble N fertilizers on turfgrasses followed by over-watering on sandy soils can cause NO_3 contamination of groundwater (Brown et al., 1982; Snyder et al., 1984).

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

For the future, the breeding of turfgrasses with improved tolerance to N stress should be emphasized. It also is 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).

REFERENCES

Alexander, M. 1977. Introduction to soil microbiology. 2nd ed. John Wiley &, Sons, New York.

Anderson, E.L., I.L. Pepper, and W.R. Kneebone. 1981a. Reclamation of wastewater with a soil-turf filter: I. Removal of nitrogen. J. Water Pollut. Control Fed. 53:1402-1407.

Anderson, E.L., I.L. Pepper, W.R. Kneebone, and R.J. Drake. 1981b. Reclamation of wastewater with a soil-turf filter: II. Removal of phosphorus, boron, sodium and chlorine. J. Water Pollut. Control Fed. 53:1408-1412.

Andrew, N.J. 1987. Wildlife and related values of park golf course ecosystems. Res. Project Rep. Hamilton County Park District, Cincinnati, OH.

Angle, J.S. 1985. Effect of cropping practices on sediment and nutrient losses from tobacco. Tob. Sci. 29:107-110.

Arnold, T.B., and D.A. Potter. 1987. Impact of a high-maintenance lawncare program on non-target invertebrates in Kentucky bluegrass turf. Environ. Entomol. 16:100-105.

Barfield, B.J., and S.C. Albrecht. 1982. Use of a vegetative filter zone to control fine-grained sediments from surface mines. p. 481-490. *In* Proc. symposium on surface mining, hydrology, sedimentology and reclamation. Univ. of Kentucky, Lexington, KY. 5-10 Dec. 1982.

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Englewood Cliffs, NJ.

Beard, J.B. 1989a. The role of Grarnineae in enhancing man's quality of life. p. 1-9. In Symp. Proc. Nat. Comm. Agric. Sci., Tokyo. July 1989. Japanese Sci. Council, Tokyo.

Beard, J.V. 1989b. Turfgrass water stress: Drought resistance components, physiological mechanisms, and species-genotype diversity. P. 23-28. *In* H. Takatoh (ed.) Proc. 6th Int. Turfgrass Res. Conf., Tokyo. July 1989. Japanese Soc. Turfgrass Sci., Tokyo.

Beard, J.B. 1990. Genotype diversity in evapotranspiration rates within seven major turfgrass species. P. 40-42. *In* Texas Turfgrass Research – 1990. Texas Agric. Exp. Stn. PR-4750. College Station.

Beard, J.B. 1993. The xeriscaping concept: what about turfgrasses. Int. Turfgrass Soc. Res. J. 7:87 – 98.

Beard, J.B., and D. Johns. 1985. The comparative heat dissipation from three typical urban surfaces: Asphalt, concrete, and a bermudagrass turf. P. 125-133. *In* Texas turfgrass res. – 1985. Texas Agric. Exp. Stn. PR-4329. College Station.

Beard, J.B., and S.I. Sifers. 1993. Stabilization and enhancement of sand-modified root zones for high traffic sports turfs with mesh elements. Texas Agric. Exp. Stn. Bull. B-1710.

Bennett, H.H. 1939. Soil conservation. McGraw-Hill Book Co., New York.

Boeker, P. 1974. Root development of selected turfgrass species and cultivars. P. 55-61. *In* E.C. Roberts (ed.) Proc. 2nd Int. Turfgrass Res. Conf., Blacksburg, VA. June 1973. ASA and CSSA, Madison, WI.

Brown, K.W., J.C. Thomas, and R.L. Duble. 1982. Nitrogen source effect on nitrate and ammonium leaching and runoff losses from greens. Agron. J. 74:947-950.

Busey, Pl, and J.H. Parker. 1992. Energy conservation and efficient turfgrass maintenance. Pl 473-500. *In* D.V. Waddington et al. (ed.) Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI.

Clark, F.E., and E.A. Paul. 1970. The microflora of grassland. Adv. Agron. 22:375-435.

Clopton, R.E., and R.E. Gold. 1993. Distribution, seasonal and diurnal activity patterns of *Eutrombicula alfreddugesi* (Acari: Trombiculidae) in a forest edge ecosystem. J. Med. Entomol. 30:47-53.

Cockerham, S.T. , and V.A. Gibeault. 1985. The size, scope, and importance of the turfgrass industry, p. 7-12. *In* V.A. Gibeault and S.T. Cockerham (ed.) Turfgrass water conservation. Univ. of California, Div. Of Agric. And Natural Resources, Publ. No. 21405, Riverside, CA.

Cockfield, S.D., and D.A. Potter. 1983. Short-term effects of insecticidal applications on predaceous arthropods and oribatid mites in Kentucky bluegrass turf. Environ. Entomol. 12:1260-1264.

Cockfield, S.D., and D.A. Potter. 1984. Predation on sod webworm (*Lepidoptera: Pyralidae)* eggs as affected by chlorpyrifos application to Kentucky bluegrass turf. J. Econ. Entomol. 77:1542-1544.

Cockfield, S.D., and D.A. Potter. 1985. Predatory arthropods in high- and low-maintenance turfgrass. Can. Entomol. 117:423-429.

Cohen, S.Z., S. Nickerson, R. Maxey, A. Dupuy, Jr., and J.A. Senita. 1990. A groundwater monitoring study for pesticides and nitrates associated with golf courses on Cape Cod. Groundwater Monit. Rev. (winter): 160-173.

Cook, D.I., and D.F. Van Haverbeke. 1971. Trees and shrubs for noise abatement. Nebraska Agric. Exp. Stn. Res. Bull. 246, Lincoln.

Curry, J.P. 1986. Effects of management on soil decomposers and decomposition processes in grassland. P. 349-399. *In* M.J. Mitchell and J.P. Nakus (ed.) Microfloral and faunal interactions in natural and agroecosystems. Dordrecht, Boston.

Dahlman, R.C., and C.L. Kucera. 1965. Root productivity and turnover in native prairie. Ecology. 46:84-89.

Dillaha, T.A., J.H. Sherrard, D. Lee, S. Mostaghimi, and V.O. Shanholtz. 1988. Evaluation of vegetative filter strips as a best management practice for feed lots. J. Water Pollut. Control Fed. 60:1231-1238.

Dittmer, H.J. 1938. A quantitative study of the subterranean members of three field grasses. Am. J. Bot. 25:654-657.

Dudeck, A.E., C.E. Donoho, A.J. Turgeon, P.L. Heinzen, and G.E. Stout. 1979. A literature review on sewage utilization for turfgrass purposes with annotated bibliography. Univ. Florida, Inst. Of Food and Agric. Sci. Misc. Publ. 1979-1, Gainesville, FL.

Falk, J.H. 1976. Energetics of a suburban lawn ecosystem. Ecology. 57:141-150.

Gladon, R.J., D.J. Brahm, and N.E. Christians. 1993. Carbon monoxide absorption and release by C_3 and C_4 turfgrasses in light and dark. Int. Turfgrass Soc. Res. J. 7:649-656.

Gold, A.J., W.R. DeRagon, W.M. Sullivan, and J.L. Lemunyon. 1990. Nitrate-nitrogen losses to groundwater from rural and suburban land uses. J. Soil Water Conserv. 45:305-310.

Gould, F.W. 1968. Grass systematics. McGraw-Hill, New York.

Gramckow, J. 1968. Athletic field quality studies. Cal-Turf Inc., Camarillo, CA.

Green, B.H. and I.C. Marshall. 1987. An assessment of the role of golf courses in Kent, England, in protecting wildlife and landscapes. Landscape Urban Planning. 14:143-154.

Green, R.L., J.B. Beard, and M.J. Oprisko. 1991. Root hairs and root lengths in nine warm-season turfgrass genotypes. J. Am. Soc. Hortic. Sci. 116:965-969.

Gross, C.M., J.S. Angle, R.L. Hill, and M.S. Welterlen. 1991. Runoff and sediment losses from tall fescue under simulated rainfall. J. Environ. Qual. 20:604-607.

Gross, C.M., J.S. Angle, and M.S. Welterlen. 1990. Nutrient and sediment losses from turfgrass. J. Environ. Qual. 19:663-668.

Harper, J.C., C.A. Morehouse, D.V. Waddington, and W.E. Buckley. 1984. Turf management, athletic-field conditions, and injuries in high school football. Pennsylvania Agric. Exp. Stn. Prog. Rep. 384. University Park.

Hayes, A.R., C.F. Mancino, W.Y. Forden, D.M. Kopec, and I.L. Pepper. 1990a. Irrigation of turfgrass with secondary sewage effluent: II. Turf quality. Agron. J. 82:943-946.

Hayes, A.R., C.F. Mancino, and I.L. Pepper. 1990b. Irrigation of turfgrass with secondary sewage effluent: I. Soil and leachate water quality. Agron. J. 82:939-943.

Hooper, B. 1970. A life poll by Louis Harris. The real change has just begun. Life 68(1):102-106.

Jaffe, L.S. 1968. Ambient carbon monoxide and its fate in the atmosphere. J. Air Pollut. Control Assoc. 18:534-540.

Jean, S. and T. Juang. 1979. Effect of bahiagrass mulching and covering on soil physical properties and losses of water and soil of slopeland (First report). J. Agric. Assoc. China. 105:57-66.

Johns, D., and J.B. Beard. 1985. A quantitative assessment of the benefits from irrigated turf on environmental cooling and energy saving in urban areas. P. 134-142. *In* Texas Turfgrass Research – 1985. Texas Agric. Exp. Stn. PR-4330. College Station.

Johns, D., J.B. Beard, and C.H.M. van Bavel. 1983. Resistance to evapotranspiration from a St. Augustinegrass turf canopy. Agron. J. 75:419-422.

Kaplan, R. and S. Kaplan. 1989. The experience of nature. Cambridge Univ. Press, New York.

Kim, K.W., and J.B. Beard. 1987. Comparative turfgrass evapotranspiration rates and associated plant morphological characteristics. Crop Sci. 28:328-331.

Lee, K.E. 1985. Earthworms. Their ecology and relationships with soil and land use. Academic Press, New South Wales, Australia.

Lush, W.M. 1990. Turf growth and performance evaluation based on turf biomass and tiller density. Agron. J. 82:505-511.

Maffei, E.J. 1978. Golf courses as wildlife habitat. Trans. Northeast. Sect. Wildl. Soc. 35:120-129.

Manzel, R.G. 1991. Long term research on water and environmental quality. Agron. J. 83:44-49.

Morton, T.G., A.J. Gold, and W.M. Sullivan. 1988. Influence of over-watering and fertilization on nitrogen losses from home lawns. J. Environ. Qual. 17:124-130.

Parker, J.H. 1982. An energy and ecological analysis of alternate residential landscapes. J. Environ. Syst. 11:271-288.

Peterson, H., and M. Luxton. 1982. A comparative analysis of soil fauna populations and their role in decomposition processes. Oikos. 93:297-388.

Petrovic, A.M. 1990. The fate of nitrogenous fertilizers applied to turfgrass. J. Environ. Qual. 19:1-4.

Potter, D.A., B.L. Bridges, and F.C. Gordon. 1985. Effect of N fertilization on earthworm and microarthropod populations in Kentucky bluegrass turf. Agron. J. 77:367-372.

Potter, D.A., A.J. Powell, and M.S. Smith. 1990a. Degradation of turfgrass thatch by earthworms (Oligochaeta: Lumbricidae) and other soil invertebrates. J. Econ. Entomol. 83:205-211.

Potter, D.A., M.C. Buxton, C.T. Redmond, C.G. Patterson, and A.J. Powell. 1990b. Toxicity of pesticides to earthworms (Oligochaeta: Lumbricidae) and effect on thatch degradation in Kentucky bluegrass turf. J. Econ. Entomol. 83:2362-2369.

Robinette, G.O. 1972. Plants, people, and environmental quality. U.S. Dep. Interior, National Park Service, and Am. Soc. Land. Archit. Foundation, Washington, DC.

Rogers, J.N., III, and D.V. Waddington. 1990. Effects of management practices on impact absorption and shear resistance in natural turf. P. 136-146. *In* R.C. Schmidt et al. (ed.) Natural and artificial playing fields: Characteristics and safety features. ASTM STP 1073. ASTM, Philadelphia, PA.

Rogers, J.N., III and D.V. Waddington. 1992. Impact absorption characteristics on turf and soil surfaces. Agron. J. 84:203-209.

Rogers, J.N., III, D.V. Waddington, and J.C. Harper II. 1988. Relationships between athletic field hardness and traction, vegetation, soil properties and maintenance practices. Pennsylvania Agric. Exp. Stn. Prog. Rep. 393, University Park.

Rossillion, J.P. 1985. Water: Whose is it and who gets it. P. 13-20. *In* V.A. Gibeault and S.T. Cockerham (ed.) Turfgrass water conservation. Univ. of California, Div. Of Agric. And Natural Resources Publ. 21405. Riverside.

Schuyler, T. 1987. Controlling urban runoff: A practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments, Washington, DC.

Sifers, S.I., J.B. Beard, and M.H. Hall. 1990. Comparative dehydration avoidance and drought resistance among major warm-season turfgrass species and cultivars. P. 37-40. *In* Texas turfgrass res. – 19909. Texas Agric. Exp. Stn. PR-4749. College Station.

Sims, P.L., and J.S. Singh. 1071. Herbage dynamics and net primary production in certain ungrazed and grazed grasslands in North America. P. 59-123. *In* N.R. French (ed.) Preliminary analysis of structure and function in grasslands. Range Sci. Dep. Sci. Series. No. 10. Colorado State Univ., Fort Collins.

Sims, P.L. and J.S. Singh. 1978. The structure and function of ten western North American grasslands. III. Net primary production, turnover and efficiencies of energy capture and water use. J. Ecol. 66:573-597.

Smith, J.L. and E.A. Paul. 1988. The role of soil type and vegetation on microbial biomass and activity. P. 460-466. *In* F. Megusar and M. Gantar (ed.) Perspectives in microbial ecology. Slovene Soc. For Microbiology, Ljubljana, Yugoslavia.

Smith, J.L. and E.A. Paul. 1990. The significance of soil microbial biomass estimations. P. 357-396. *In* J.M. Bollag and G. Stotzky (ed.) Soil biochemistry. Col. 6. Marcel Dekker, New York.

Snyder, G.H., B.J. Augustin, and J.M. Davidson. 1984. Moisture sensor-controlled irrigation for reducing N leaching in bermudagrass turf. Agron. J. 76:964-969.

Streu, H.T. 1973. The turfgrass ecosystem: impact of pesticides. Bull. Entomol. Soc. Am. 19:89-90.

Ulrich, R.S. 1984. View through a window may influence recovery from surgery. Science. (Washington, DC) 224:420-421.

Ulrich, R.S. 1986. Human responses to vegetation and landscapes. Landscape Urban Planning. 13:29-44.

U.S. Department of Agriculture – Soil Conservation Service. 1989. Summary report 1987 national resources inventory. Statistical Bull. No.790. U.S. Gov. Print. Office, Washington, DC.

U.S. Environmental Protection Agency. 1976. Erosion and sediment control, surface mining in the Eastern U.S. Vol. 1. Planning. USEPA 625/3-76-006. U.S. Gov. Print. Office, Washington, DC.

U.S. Environmental Protection Agency. 1990. National survey of pesticides in drinking water wells. Phase I report. USEPA 570/9-90-015. U.S. Gov. Print. Office, Washington, DC.

U.S. Environmental Protection Agency. 1992. Another look: National survey of pesticides in drinking water wells. Phase II report. USEPA 579/09-91-020. U.S. Gov. Print. Office, Washington, DC.

Vavrek, R.C., and H.D. Niemczyk. 1990. The impact of isofenphos on non-target invertebrates in turfgrass. Environ. Entomol. 19:1572-1577.

Watschke, T.L., and R.O. Mumma. 1989. The effect of nutrients and pesticides applied to turf on the quality of runoff and percolating water. Pennsylvania State Univ. Environmental Resources Res. Inst. ER-8904, University Park.

Watson, J.R. 1985. Water resources in the United States. P. 19-36. *In* V.A. Gibeault and S.T. Cockerham (ed.) Turfgrass water conservation. Univ. of California, Div. of Agric. and Natural Resources, Publ. No. 21405, Riverside.

Whitcomb, C.E., and E.C. Roberts. 1973. Competition between established tree roots and newly seeded Kentucky bluegrass. Agron. J. 65:126-129.

Young, R.A., T. Huntrods, and W. Anderson. 1980. Effectiveness of vegetative buffer strips in controlling pollution from feedlot runoff. J. Environ. Qual. 9:483-487.

Younger, V.B. 1970. Landscaping to protect homes from wildfires. California Turfgrass Culture. 20(4):28-32.

Zajicek, J.M., and J.L. Heilman. 1991. Transpiration by crape myrtle cultivars surrounded by mulch, soil, and turfgrass surfaces. Hort-Science. 26:1207-1210.