

**Literature Review and
Environmental, Social,
Economic and Health
Benefits of the Australian
Turf and Golf Industries**

Peter McMaugh
Turfgrass Scientific Services Pty
Limited

Project Number: TU07034

TU07034

This report is published by Horticulture Australia Ltd to pass on information concerning horticultural research and development undertaken for the turf and nursery industry.

The research contained in this report was funded by Horticulture Australia Ltd with the financial support of Australian Golf Course Superintendents Association and the turf industry.

All expressions of opinion are not to be regarded as expressing the opinion of Horticulture Australia Ltd or any authority of the Australian Government.

The Company and the Australian Government accept no responsibility for any of the opinions or the accuracy of the information contained in this report and readers should rely upon their own enquiries in making decisions concerning their own interests.

ISBN 0734122446

Published and distributed by:
Horticulture Australia Ltd
Level 7
179 Elizabeth Street
Sydney NSW 2000
Telephone: (02) 8295 2300
Fax: (02) 8295 2399

© Copyright 2010



Know-how for Horticulture™

Environmental, Social, and Health Benefits of Turfgrass

- A Literature Review

Francis. R. Higginson and Peter. E. McMaugh*

Turfgrass Scientific Services Pty Ltd, 14 Carolyn Avenue, Carlingford NSW 2118, Australia.

*Corresponding author. Email: higginr@activ8.net.au

Abstract. The initial study of environmental, social and health benefits of turfgrass was published by JB Beard & RL Green in 1994 (23). This literature review is aimed at bringing that study up to date, expanding on its base, and attempting to relate the findings within the context of the Australian turfgrass industry. With recent severe water shortages and the fear of climate change, the general public within Australia and the USA is developing a negative environmental image for turfgrass (115). This is because turfgrass requires to be maintained regularly, involving mowing, fertilising and watering. These three practices utilise water, a limited resource, create greenhouse emissions (from petrol mowers), and expose the environment to possible chemical pollution from fertiliser and pesticide usage.

Areas specifically targeted for review include potentially adverse environmental impacts of growing turfgrass, such as soil erosion, sediment movement, and contamination of surrounding areas with fertiliser and pesticide leachates; aesthetic, social and health benefits of growing turfgrass; water usage by turfgrass; heat sink effects of turf use; carbon sequestration capacity of turfgrass; and turf's use on sporting fields, with special reference to surface quality and heat stress.

Since 1994, there have been major developments in most areas reviewed, but particularly in the management of pesticide and nutrient leaching from turfgrass (41) and in water usage by turfgrass (25). A major research program funded by the United States Golf Association, and undertaken within twelve universities across the United States, has significantly improved the knowledge and management of pesticide and nutrient movement from turfgrass environments to the extent that the problem is now a readily manageable one (41). This information is directly relevant and transferable within the Australian context.

In the area of water usage by turfgrasses, there have been vast improvements, both within Australia and the USA, in the selection and breeding of new varieties and types of turfgrass with drought avoidance or drought tolerant characteristics. The use of these new varieties, in conjunction with improved irrigation technologies that apply water only when it is required by use of in-situ soil moisture monitoring systems, has led to savings of up to 40% in water usage by sports fields in both Queensland and the Australian Capital Territory (1; 48).

Both within Australia and overseas, there has been a considerable increase since 1994 in the amount of research undertaken by social and health scientists in assessing the value and benefits derived from urban green space in improving the public health and mental wellbeing of city dwellers (87; 111). There is a lack of specific research related to the role that turfgrass plays within urban green space, but this is generally implied within the overall context of the research. Turfgrass, as an integral component of the park landscape, must play a major role in these health benefits.

Research on heat amelioration effects and on carbon sequestration by turfgrasses has not developed as much as the three previous fields. Enough is known, however, to make intelligent estimates of benefits provided by turfgrasses in these two areas. More research is needed in both areas. Most estimates indicate that grasses can be considerable sinks for storing carbon (113) but if these grasses require to be managed, as turfgrasses generally do, then the benefits of carbon sequestration by turf are partially nullified by the management processes, particularly mowing, fertilising and irrigating (96) which generate carbon emissions.

Research on the use of turf on sports fields has progressed significantly in recent years. The selection and improvement in turfgrass varieties used for amenity purposes has increased the opportunity for improved performance with reduced usage of water. As well, in the USA, new agrichemicals being used with increased specificity at lowered rates of active ingredients are enabling turfgrass systems to be maintained in a more effective manner without contamination of groundwater (39). In Australia in recent years, the number of new agrichemical introductions has been low. Those that have been introduced have relied on new active ingredients with much safer chemistry. The regulatory authorities have actively encouraged a safer, environmentally friendly approach by phasing out many less desirable, older products.

Despite these improvements, community concerns over shortages of water and contamination of natural resources has led to restrictions on the management tools available to turf professionals. Such restrictions have raised the option that turf for sports purposes be replaced with artificial or alternative landscapes to

reduce inputs of water and chemicals. The newer generation of synthetic turfs (termed the “third generation”) are far superior to previous types (58). One of the major advantages of synthetic over natural turf is the greater wear resistance of synthetics, enabling more intensive use (82). One very significant area where synthetic surfaces have not made up ground on natural turf is temperature. On a hot summer day, unshaded synthetic turf absorbs sunlight and becomes much hotter than natural turf. Excessive heat on players then becomes a workplace health and safety issue (58). Furthermore, the cost of installing and managing artificial turf surfaces far exceeds natural grass playing fields (59).

In summary, claims that turfgrass utilises excessive water and contaminates the environment with chemical residues are difficult to justify when one considers the amount of progress in these two areas illustrated in published scientific literature. The turfgrass industry has responded very positively to overcome these perceived negative environmental impacts. Together with the very positive benefits to public health and mental wellbeing of greenspace and turfgrass demonstrated by social and health scientists, and the very positive heat amelioration effects of turfgrass in the urban environment, the turfgrass industry in Australia is in a strong position to respond to any negative environmental criticisms that it may receive. Furthermore, the overall carbon sequestration potential of turfgrass and related greenspace is another environmental benefit that can be utilised by the industry in a positive manner.

Introduction. It is common knowledge that the general public is becoming very much more aware of environmental issues. With recent severe water shortages and the fear of climate change, the general public within Australia and

the USA is developing a negative environmental image for turfgrass (115). This view is well illustrated by Walsh (134) where he states, 'the first principle of waterwise gardening is to reduce the amount of lawn. Lawns soak up enormous amounts of water. Lawns use more water per square metre than any other part of the garden. In some parts of Australia, up to 90% of the water used in gardens is applied to lawns.' He goes on further in stating, 'Let's look at the front lawn... A majority of homes have most of the front of the property given over to grass. This serves very little function except perhaps to show off the house, some specimen trees and a fringe of garden beds. In some circumstances, it is really used as a car park. It is never used for entertaining or for children's play. Basically, such a lawn does not justify its existence. It would be best removed...' (134). He says a lot more negative things about side lawns and backyard lawns.

Another example of an attack on lawns has recently been published by Haeg (66). Haeg states, 'There are 12 million hectares of lawn in the US. That's 12 million hectares of carefully tended, mown, watered – and largely useless – space. And of that massive swathe of unused greenery, the worst offender... is the front lawn. The front lawn is so deeply embedded in our national psyche that we don't really see it any more...Why is it there? Or rather, why is nothing there?' (66).

Unsubstantiated statements similar to the examples above are common in gardening books, magazines, newspapers and television programs, and they can only have a negative impact on the image of turfgrass. A review of the scientific literature is needed so that the turfgrass industry can be informed on just where it stands from an environmental and ecological point of view.

Many of the solutions to turf's perceived "negative environmental impact" exist already, but aren't being publicised effectively by the Industry. For example, simply by selecting slow-growing, drought-hardy lawn varieties can lead to a significant reduction in the need for mowing, fertilising and watering. Furthermore, as backyards in Australian city homes continue to become very much smaller or non-existent, the demand for petrol lawn mowers should decline. Hand-pushed mowers should be sufficient for most modern situations but are not being marketed in a positive manner, or even being marketed at all within Australia. Hand-pushed mowers, or reel mowers as they are currently called, are being successfully marketed within the USA (49).

Methodology. The methodology employed in this study is a detailed literature review using internet and library searches. The following areas were examined:

1. The environmental benefits of turfgrass as part of the total landscape in an urban green space;
2. Potentially adverse environmental impacts of growing turfgrass, such as soil erosion, sediment movement, and contamination of surrounding areas with fertiliser and pesticide leachates;
3. Aesthetic, social and health benefits of growing turfgrass;
4. Water usage by turfgrass, including the need to emphasise the selection of particular varieties for different climatic areas;
5. Heat amelioration effects of turf use with reference to the energy balance between turf and its replacement competitors in an urban environment;

6. Carbon sequestration capacity of turfgrass, and greenhouse gas emissions related to turfgrass use and maintenance; and
7. Research in relation to turf's use on sporting fields, with special reference to surface quality and heat stress.

The Environmental Benefits of Turfgrass. The seminal study of the environmental benefits of turfgrass was conducted by Beard in the early 1990's (23). This study seeks to evaluate Beard's results in the context of the Australian environment, and to build on that base.

Beard (20) provides a useful summary of the major functional, recreational and aesthetic benefits to the environment derived from utilising turfgrasses. These are:

Functional.

- Soil erosion control
- Dust prevention
- Rain water entrapment and ground water recharge
- Solar heat dissipation
- Glare reduction
- Noise abatement
- Organic chemical/pollutant entrapment and degradation
- Air pollution control
- Nuisance animal/pest reduction
- Fire prevention
- Security/visibility
- Environmental protection

Recreational.

- Low cost surfaces
- Physical health
- Mental health
- Safety cushion
- Spectator entertainment

Aesthetic.

- Beauty
- Quality of life
- Mental health
- Social harmony
- Community pride
- Increased property values
- Compliments trees and shrubs in the landscape.

Beard & Green (23) expand on these environmental benefits in more detail and cite research documenting the non-referenced statements presented above. Beard (22) presents similar information to Beard & Green (23) but is specifically related to golf course turfs and their environment. Beard (24) is a recent update relating to golf course environments and was partially supported by the United States Golf Association.

Potentially Adverse Environmental Impacts of Growing Turfgrass.

The management of turfgrass systems in urban areas generally require:

- Exposure of bare soil surfaces;

- Exposure of areas with disturbed soil structure;
- Vegetation planting, upkeep and maintenance;
- Irrigation;
- Pest management, and
- Fertilization.

These practices can intensify potentially adverse environmental effects, such as soil erosion, sediment and run-off water movement, losses of applied chemicals and nutrients, contamination of groundwater, leaching of pesticides and fertilizers, disturbance of adjacent ecosystems, and impacts on non-target plants and animals (9; 115).

The golf course industry has responded to the above issues in a very positive way. Environmental management programs for golf courses have become common practice in recent years (5; 52; 53).

Sediment and Nutrient Export. Although there can be potential environmental risks associated with turfgrass management, the overall benefits of turfgrass should not be underestimated. Healthy turfgrass provides considerable benefit to land surfaces in urban environments by providing resistance to insect and weed infestation (14). Its dense root system also enables an efficient use of applied nutrients and water, which in turn limits the need for unnecessary irrigation, fertilizer and pesticide applications (18). Furthermore, it has a major influence in minimising diffuse pollution by sediments, pesticides and nutrients in surface waters (107). Research on various land use types compared with turfgrass indicates that sediment and nutrient losses from urban and turfgrass systems is

considerably less than losses from agricultural and forest systems (see Table 1, derived from 81).

Table 1: Estimated Annual Contributions to Surface Waters from Selected Non-point or Diffuse Sources – Average load in million tonnes per year.

Source	Sediment	Nitrogen (N)	Phosphorus (P)
Cropland	1870	4.3	1.56
Pasture and Rangeland	1220	2.5	1.08
Forest	256	0.4	0.09
Urban, including Turfgrass	20	0.2	0.02

An Australian study measured soil and nutrient movement from four turf farms in the Wyong region of NSW (92). As expected, soil movement was greatest in the period shortly after turf harvest and on land of steeper slope. Measured soil movement averaged 0.61 tonnes/ha/year, with a range from 0.04 to 2.13 tonnes/ha/year. Overall, the soil movement figures were greater than those reported for well managed permanent pastures (62) but were small when compared with irrigated crops grown under conventional tillage. The results are similar to those measured in overseas studies (63).

This above study (92) also reported nutrient loads in runoff from turf farms. Results were as follows (in kg/ha/year): total phosphorus 1.1; nitrate nitrogen 1.4; sulfate 10.1; calcium 6.7; magnesium 2.6; sodium 7.6; potassium 5.9. These results are intermediate between values recorded in the literature for intensive cropping systems and perennial pasture.

Another Australian study looked at irrigation and fertiliser regimes on nitrogen (N) leaching from couch grass sod (*Cynodon dactylon*) in sandy soils of Western Australia (11; 12). This study concluded that N leaching from couch grass production on sandy soils will be low if irrigation regimes supply sufficient water for turfgrass growth without causing excess water to move beyond the rooting zone. Under well-managed irrigation regimes (ie. 70% replacement of pan evaporation), they expect N leaching to be low for all fertiliser types as long as N is applied at a rate and frequency that matches turfgrass requirements. The risk of N leaching is greatest during the establishment of turfgrass, especially if this coincides with high rainfall. Higher irrigation rates (ie. 140% replacement of pan evaporation) can be detrimental by enabling N leaching, and by decreasing root growth of the couch

grass sod by up to 30%. Although there is an obvious direct relevance of this research to the Western Australian turfgrass industry, the study has considerable relevance to a large part of the Australian turf industry because of the importance of couch grass within the Australian context. This is particularly so within urban areas, such as sports fields, bowling greens, and golf greens where a similar sand-based growth medium to that of the standard USGA green (124) is utilised. These sand-based growth media would be expected to perform similarly to Western Australia's natural sandy soils.

Cisar (39) also reports on techniques being used within the USA to reduce nutrient leaching from sand-based soils. For modern sports play, turfgrass is often grown on coarse-textured soils such as sands that require routine application of nutrients from fertilisers, particularly nitrogen and phosphorus. Strategies used to reduce N and P leaching include regulations that limit the amounts of N and P applied, management systems that minimise off-site losses, and the use of slow or controlled release fertilisers. Other techniques used include applying lower rates of fertiliser frequently through the irrigation system ("fertigation") and/or adjusting irrigation rates to replace only the amount of water used in evapotranspiration.

Surface run-off is important in transporting both dissolved chemicals and suspended sediment from turfgrass systems to surface waters. Although the volume of surface run-off and sediment loss from turfgrass systems is relatively low compared to other management systems (see Table 2, derived from 64), the volume of run-off from bare soil on turfgrass construction sites is considerably higher (19.2 vs. <1 tonnes/ha per year of sediment) (44).

These results clearly demonstrate the effectiveness of turfgrass in minimising sediment movement from catchments to adjacent waterways. As nutrients such as nitrogen and phosphorus, and other contaminants such as pesticides, are transported primarily in association with eroded sediment (72), then turfgrass is highly effective in minimising their movement as well.

Table 2: Average Annual Sediment Losses from Selected soils and slopes under Different Management Conditions - Sediment Loss in tonnes/ha/year .

Soil Texture/ % Slope	Fallow	Cropping	Rotation	Turfgrass
Loam/4	102.8	48.7	6.7	0.7
Silt Loam/8	278.6	211.2	28.2	0.7
Silt Loam/16	375.2	84.1	62.5	<0.25
Fine Sandy Loam/8	50.1	69.4	13.6	<0.25
SandyClayLoam/10	159.8	63.7	26.7	<0.25

In an Australian context, there are a plethora of models and techniques existing to estimate the export of suspended solids and nutrients from catchments (51). Despite this, very few studies on nutrient generation rates have been completed in Australia since 1995-96. One such study (6) derived phosphorus export rates for sub-catchments of the Hawkesbury-Nepean River in Western Sydney. The phosphorus loads estimated for different land uses are summarised in Table 3.

Table 3: Phosphorus (P) Transport Rates from Various Land Uses in a Temperate Climate (6).

Land Use	Phosphorus (kg/ha/yr)
Market Garden	15.3
Intensive Dairy	16.4
Extensive Dairy	1.9-2.5
Semi-improved pasture/ Hobby Farm	0.8
Unimproved	0.3

Turfgrass is not specifically listed as a land use type in this study, however, it is reasonable to assume that it will behave similarly to semi-improved pasture/hobby farms or to extensive dairy pasture. The result is a ten to twenty-fold reduction in nutrient loss when compared to other land use activities.

Table 2 above also gives a clear indication of the effect of slope on sediment loss, particularly in the case of bare fallow systems and rotational farming. The effect of slope on sediment loss from turfgrass systems was minimal in this study, probably reflecting the dense sward of protective vegetation that turfgrass is generally able to provide when managed correctly.

Nutrient and Pesticide Export. Easton *et al.* (50) looked at nutrient and pesticide losses from a small hillside seeded to turfgrass. The aim was to examine the relationship between runoff, hillslope hydraulics, and turfgrass growth. The research was conducted on a 6 to 8% hillslope on a sandy loam soil seeded to 80% kentucky bluegrass and 20% perennial ryegrass. The results indicate that it is imperative to assess site suitability prior to applying nutrients and pesticides. Certain areas simply pose a higher risk to ground and surface water contamination. In this study, upper slope areas produced less runoff, and subsequently lower mass losses of nutrients and pesticides, when compared with lower slope areas which generally produced greater runoff, and as a result greater mass losses of applied compounds. This was due to the compounding effects of lower soil infiltration and hydraulic conductivity on the lower slopes due to a finer textured soil, and a higher average soil moisture content. The higher overall water content at the bottom of the slope, due to runoff contributed from the upper slope areas,

decreased infiltration rates and therefore increased runoff and leachate levels. Overall, in this study, pesticide losses were low. No compound had more than 0.5% of the applied amount lost in runoff. Nitrate and Ammonium concentrations in the runoff were also low but at levels that could possibly pose a threat to aquatic organisms in some circumstances. Phosphate levels in runoff were lower than contaminant levels set by the EPA.

The above study (50) clearly demonstrates that it is best to avoid nutrient and pesticide applications in areas close to water bodies, and/or at the bottom of slopes having a long expanse of upslope area to contribute to the overall runoff volume.

In 1990, the United States Golf Association (132) began funding an environmental research program to quantify and document the impact of turfgrass management on the environment. The major objective was to understand and quantify the degradation and fate of turfgrass pesticides and fertilisers so as to be able to accurately predict or simulate their environmental impacts. Research programs were established at 12 universities within the USA. The results of this research program were published (41) by the American Chemical Society. Among the topics of the 26 papers are:

- turfgrass benefits and the golf environment (24);
- groundwater contamination potential of pesticides and fertilisers used on golf courses (32);
- potential movement of nutrients and pesticides following application to golf courses (122);
- surface runoff of selected pesticides applied to turfgrasses (135; 136);

- mobility and persistence of pesticides applied to a USGA green (124; 40);
- environmental fates of fungicides in the turfgrass environment (123);
- the effect of salinity on nitrate leaching (31);
- best management practices to reduce pesticide and nutrient runoff from turf (7); and
- microbial strategies for the control of turfgrass diseases (101).

Results from the above study (132) reported for fertilisers suggest a very strong trend exists between the rate of nitrogen application and leaching losses of nitrogen as nitrate. The relationship between soil type and subsurface loss of nitrogen agrees closely with previous research conducted on both turf and agricultural systems. Regardless of the turf cover used, runoff concentrations of applied nitrogen did not appear to be different for different species of turfgrass. Results reported are consistent with those of other researchers, namely that runoff decreases with an increasing amount of soil vegetative cover. Turfgrass, due to its dense surface vegetative cover, not only attenuates surface losses of water but reduces the potential for surface and subsurface losses of nitrogen as well because of its dense surface layer and its underlying dense thatch layer. Phosphate concentrations in leachate never exceeded the irrigation water content of 1 to 2.5 mg/L. This is not surprising given the high affinity of phosphate for soil particle surfaces, which effectively decreases leaching potential (132). Loss of phosphate in both agricultural and turfgrass systems usually occurs through sediment loss and transport during construction or turf establishment (72; 133).

A study by Pennsylvania State University (135) examined the potential effects of turf on the amount of runoff and on the quality of the runoff water. The study

compared three treatments; a sodded turf (sod), a seeded turf (classic) and a contractor-applied turf (contract). All plots were maintained equally and uniformly irrigated with a controlled system. The amount of runoff from each plot was measured and samples were chemically analysed for nutrients and pesticides. The results clearly indicate that the sodded turf proved to be 15 times more effective than either of the seeded plots at controlling runoff (see Chart I in 135). When the runoff water was analysed, researchers found almost no detectable amounts of the eight pesticides and nutrients that had been applied to the turf (see Chart II in 135).

Another major study (124) looked at the mobility and persistence of turfgrass pesticides applied to a United States Golf Association (USGA) -type green. Because water percolation can be much more appreciable in a coarse-textured man-made rooting media, leaching of pesticides from a USGA green is an obvious area for investigation. In the above study, two commonly used herbicides were investigated, namely Dicamba and 2,4-D. The results indicate that, although only 10% as much Dicamba as 2,4-D was applied, nearly 65% as much Dicamba was recovered in the percolate water over a 2-month period following application. Clearly, Dicamba was much more mobile than 2,4-D in the USGA green. Nevertheless, the average concentrations of both herbicides in the percolate were well below Maximum Contaminant Levels set by USA authorities (2.6 and 1.2 micrograms per litre compared to 70 micrograms per litre). Clearly, herbicide leaching from turfgrass grown on an ideal drainage media (such as that of a standard USGA green) indicates that herbicide leaching under normal turfgrass circumstances is not likely to be a major environmental problem.

Under Australian conditions, there has been limited research undertaken of the fate and behaviour of pesticides applied to turfgrass. One study (13) indicated that some pesticides do have a leaching potential from turfgrass under average rainfall conditions of Sydney and Brisbane, although the amount of leaching measured was relatively small and well below contaminant levels set by Australian authorities (4). The above study also showed that absorption of commonly used pesticides under Australian turf was greater in the thatch than in the rooting medium, and column leaching studies showed that Dicamba had the greatest potential for leaching and Chlorpyrifos had the lowest. These results are consistent with those reported in the USA (132).

Another approach not discussed above is to consider using non-chemical control of either weed or insect pests (93; 109) as a means of minimising or avoiding leaching of pesticide residues to the environment. Little research directly related to turfgrass appears to have been done in this field in Australia, although the use of "bioherbicides" and "biological insecticides" have been introduced in some Australian crops, particularly cotton. The sales of biological insecticides constituted less than 0.1% of the estimated US turfgrass insecticide market in 1998. Few professional turfgrass managers use such products because they are viewed as less reliable and more costly than conventional insecticides (109). The emergence and use of biotechnology, and particularly the use of genetically-modified organisms, has mostly met with a strong negative response from the general public, and these areas may need to be treated with due caution by the turfgrass industry. Nevertheless, they should be considered when appropriate as part of a holistic or integrated approach to pest management.

Aesthetic, Social and Health Benefits of Turfgrass. There are many keen gardeners and garden-lovers in Australia that gain great pleasure and enjoyment from a beautiful lawn as a back-drop and framework to a garden. The social and health benefits of this pleasure, particularly to older generations, are immense (127). As well, lawns are places where children and pets can play, and these beneficial social aspects of turfgrass use are of considerable importance to the average lawn owner.

50% of the average backyard in Australian cities that was once turfed is now being landscaped, with the emphasis being on entertainment and outdoor living space, such as barbeques, courtyards and pools. This reduction in turfed area reflects an expansion of landscaped garden space where the lawn is more commonly being used as just part of the overall garden design, and not the prominent feature that it once used to be. The benefits of local parks and gardens for passive recreation are immense, commonly being used to walk the dog, have family picnics, kick a ball with one's mates, or simply just to relax, go for a walk and enjoy the scenery.

Health and Wellbeing. Parks and nature are currently undervalued as a means of improving and maintaining health. Most people are aware of the health benefits of sport and recreation, although the range of other health and wellbeing benefits arising from contact with parks and nature are not as well known (90). Contact with the natural world (through active interaction or even passive contemplation) has the ability to affect human health and wellbeing in countless positive ways. There are immediate and long-term favourable, emotional and

physiological changes proceeding from contact with nature through animals, gardens, natural landscapes, and wilderness (90).

The Parks Forum (the peak body for park management agencies within Australia and New Zealand) has established a National Coordination Group for a 'Healthy parks, healthy people' message (90). The significance of this message is to communicate the many health and wellbeing benefits available from humans interacting with nature in park settings, and the implications of this for public health in general. For this Forum and its member agencies to be able to increase their understanding of the 'Healthy parks, healthy people' message, and for them to be able to communicate it to governments and the community at large, it is essential that up-to-date information about the importance of parks and nature for human health and wellbeing be available. To enable this, a joint initiative between Parks Victoria and the NiCHE (Nature in Community Health and Environment) Research Group at Deakin University has revised and updated an earlier literature review (88) to provide key information about the 'Healthy parks, healthy people' message. (90). This review cites Australian Government claims that the World Bank and the World Health Organisation predict that cardiovascular disease and poor mental health are likely to be the two biggest contributors to human disease by the year 2020. Evidence cited in the review shows that parks and nature can be a significant contributor to reducing premature death and disease in these two fields. Promising evidence is also emerging that positive influences from park environments, and associated flora and fauna, enhance human wellbeing in relation to other health issues. The authors conclude that parks are one of our most vital health influences, and suggest that both the health and

parks/environment sectors need to act more proactively in collaboration to enrich the role that parks play in improving and sustaining the nation's health.

A significant amount of psychological, social and behavioural research indicates that the availability of accessible and attractive green spaces is an integral part of urban quality of life (67). Research using various psychophysiological and health measurements in natural and urban field settings from 112 randomly chosen young adults clearly demonstrate that regular access to restorative environments, such as greenspace, can interrupt processes that negatively affect health and wellbeing. For urban populations in particular, easy pedestrian and visual access to natural settings produced preventative benefits (67).

Beard and Green (23) report on research which 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 (131). 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 mind and the mental health of citizens in an urban environment (33; 45; 54).

A recent study (71) surveyed 221 residents in public and private housing in inner Sydney and Melbourne, and suburban Parramatta in Sydney's west. Henderson-Wilson found that among those things that influenced health and wellbeing, access to green open spaces and a body of water were paramount. Henderson-Wilson reports that high-rise residents feel a much better quality of life if they can get involved in community gardens or simply just take a stroll in the park. Exposure to nature has been found to enhance psychological wellbeing, to

increase immunity to disease and to improve productivity, while isolation from nature has been linked with depression. Henderson-Wilson reports that, since 1996, medium to high-density housing has spread strongly in Australia's big cities. People are moving away from the traditional house with a backyard, and that's limiting the opportunity for people to be close to nature. The onus now is on urban planners and developers to have green spaces, including community gardens, in their developments and to ensure that parks and lakes are nearby. Having nature within a five-minute walk, or under 500m away, positively helped people's health and wellbeing.

Some recent research (43; 69; 88; 139) demonstrates that contact with companion animals (eg: walking the dog) has multiple positive physiological and psychological effects on human health including: decreasing blood pressure, heart rate and cholesterol; reducing anxiety and stress and providing protection against stress-related diseases; provision of companionship and kinship; and the opportunity to nurture. All of these factors improve quality of life and enhance health and wellbeing. Parks are important in providing a setting for pet-owners to interact both with their pet and with other pet-owners and park users, which can positively influence the social aspects of health. In addition, parks are essential in the preservation of habitat for native wildlife, as well as providing people with the opportunity to observe or encounter animals in their natural environment (88).

Maller *et al.* (88; 89) conclude that, 'There is a clear message for park managers to join public health fora, as not only do parks protect the essential systems of life and biodiversity, but they also are a fundamental setting for health promotion and the creation of wellbeing that to date has not been recognised.' The

extent to which turfgrass in parks contributes to these areas awaits specific investigation, although it can be reasonably implied that turfgrass, as an integral component of the park landscape, must play a major role in these health benefits.

As well as the above research, there are many other examples of similar findings from overseas. A United Kingdom study (111) concludes that regular contact with nature and green space enhances mental health and positively influences psychological wellbeing. The study also indicates that participating in regular physical activity generates many physical and psychological health benefits. They state that levels of physical activity have dramatically declined over recent decades and consequently health has suffered, such as obesity, coronary heart disease and type II diabetes. Therefore, the authors have hypothesised that there may be a synergistic benefit in adopting physical activities whilst at the same time being directly exposed to nature. They have called this 'green exercise' (110).

Other European studies support their findings. In Sweden, a study was conducted of 953 individuals suffering from different stress-related illnesses, such as burnout syndrome, insomnia, fatigue, depression and feelings of panic (60). This study found that there were statistically significant relationships between the use of urban open green spaces and self-reported experiences of stress. The results suggest that the more often a person visits urban open green spaces, the less often he or she will report stress-related illnesses. The same pattern is shown when time spent per week in urban open green spaces is measured. The distance to public urban open green spaces seems to be of decisive importance, as is access to a garden. These findings are similar to that of Australian studies (71).

It is generally recognised that greenery filled public areas provide a comfortable and pleasant living environment for urban residents. A Japanese study (127) concluded that living in areas with walkable green spaces positively influenced the longevity of urban senior citizens. "Walkable green spaces" are defined in this study as greenery filled public areas that are nearby and easy to walk in, such as parks and tree-lined streets. The authors analysed the survival of 3144 senior citizens in Tokyo and concluded that, after controlling the effects of the citizen's age, sex, marital status, and socio-economic status, the factor of walkable green spaces near their residence showed significant predictive value for the survival of urban senior citizens over the following five years ($p < 0.01$).

Other studies have looked at the influence of inner city environments on young children, and the effect of green spaces on their development. Taylor *et al.* (129) examined young children growing up in the inner city, and whether a barren inner-city neighbourhood space compromises the everyday activities and experiences necessary for their healthy development. The authors observed sixty four urban public housing outdoor spaces (27 low vegetation; 37 high vegetation) on four separate occasions, and recorded that, overall, inner-city children's everyday activities and access to adults appeared remarkably healthy. Of the 262 children observed, most (73%) were involved in some sort of play, and most groups of children (87%) were supervised to some degree. In relatively barren spaces, however, the picture was considerably less optimistic. Levels of play and access to adults were approximately half as much as those found in spaces with more trees and grass, and the incidence of creative play was significantly lower in barren spaces than in relatively green spaces. They conclude that trees and grass

may foster everyday activities and experiences that are important in children's development. Another study (108) concludes that a view of leafy green spaces whilst studying or doing homework may also help inner-city children become more academically successful through increased concentration and self-discipline.

The nearby natural environment plays a far more significant role in the wellbeing of children residing in poor urban environments than has previously been recognised. A study at the University of Michigan (137) measured the linkage between the naturalness or restorativeness of the home environment and the cognitive functioning of low-income urban children. Objective measures of naturalness were employed, along with a standardised instrument measuring the children's cognitive functioning, both before and after relocation. Results indicate that children whose homes improved the most in terms of greenness following relocation also tended to have the highest levels of cognitive functioning following the move.

Another study at the University of Michigan (138) collected data from 337 rural children about 9 years of age. The aim of the study was to examine whether vegetation near the residential environment might buffer or moderate the impact of stressful life events on children's psychological wellbeing. Results indicate that the impact of life stress was lower among children with high levels of nearby nature than among those with little nearby nature. Wells & Evans (138) state that it is reasonable to expect that green natural settings preferred by children would also have a beneficial effect on children's wellbeing. Other research involving children supports this view. Children apparently function better cognitively and

emotionally in 'green environments' than those without (137), and have more creative play in 'green areas' (129).

A Netherlands study came to a similar conclusion (86). The objective of this study was to investigate the strength of the relationship between the amount of green space in people's living environment and their perceived general health. They conclude that the percentage of green space inside a one kilometre and a three kilometre radius had a significant relationship to perceived general health. The relationship was generally present at all degrees of urbanity, but somewhat stronger for lower socio-economic groups. Elderly, youth, and secondary educated people in large cities seem to benefit more from presence of green areas in their living environment than other groups in large cities.

Public aesthetic preferences. A different perspective of parks and green spaces is their aesthetic value rather than their health or wellbeing value. In this perspective, a recent Australian study looked at public aesthetic preferences in urban parks and the efficient use of water (28). This study employed landscape visual assessment methods, web-based surveys and verbal rating scale techniques to measure public perceptions and preferences for various park environments. This study identified three dimensions underlying participants' judgements of park landscapes, namely:

- Vegetation type (ie, native/indigenous versus exotic) and degree of perceived naturalness,
- Vegetation density and spatial organisation, and
- Presence of water.

Two predominant sub-groups within the public were identified, namely those preferring densely forested, natural looking landscapes that are dominated by native/indigenous vegetation, and those preferring more formal, picturesque-style landscapes dominated by lush exotic types of vegetation. Turfgrass or lawn plays a prominent role in the second landscape type. For sub-group1 (ie: the nature lovers), aesthetic preferences increase linearly, and inversely with decreases in perceived landscape water use. In contrast, for sub-group 2 (ie: the exotic lovers), aesthetic preferences seem to increase with increases in perceived landscape water use, suggesting a preference for lush environments regardless of the environmental cost in terms of water resources to maintain such landscapes.

The results obtained from this study seem to infer that native/indigenous vegetated, self-sustained landscapes (n=66) are more preferred than some more formal landscapes planted with exotic water-hungry vegetation (n=49). Nevertheless, the consensus on these environments is not absolute as these two groups accounted for only 45% of the total variance in the data set. Bitar argues that, when variations in preferences emerge from within a given population, the obvious reaction by designers, managers and planners of public parks, should be to provide a variety of types of environments to meet these preferences. Users can then select those that best appeal to their individual preferences.

Examination of the respondents' sociodemographic background showed that the majority (67%) of respondents associated with the "native lovers" group were in direct contact with the natural environment through their occupation. In contrast, the majority (64%) of respondents associated with the "exotic lovers" group did not come in direct contact with the natural environment through their

occupation. These findings suggest that an environmental background/education might play a significant role in shaping people's perceptions/preferences for ecological or sustainable landscapes in spite of aesthetic values.

Some conclusions from this research are that conservation of remnant indigenous bushlands in a city is important. Such remnant bushlands that were designed as reserves were found to be not only highly preferred with respect to aesthetic appreciation but also to use much less water than do the more English-style, picturesque gardens. This native-exotic variance may be reflecting more of a socio-cultural aspect developing within the Australian population in recent years. The severity of native vegetation loss, land degradation, drought and associated environmental/socio-economic problems have become disturbingly evident of late, such that new values and perceptions are emerging among both urban and rural Australians. There has been a shift away from Eurocentric attitudes and a greater concern for indigenous cultural/environmental values and ethics, particularly with respect to creating a sense of national identity and community belonging (28).

The implications of this research to the Australian turfgrass industry are not as damning as might first be perceived. Even though there is an apparent drift towards "native lovers" as compared to "exotic lovers" in preferences for parks and gardens, the population tested was only small (n=148). "Native lovers" comprised 45% of the population and "exotic lovers" 33%. The message to the turfgrass industry is that there is still a large proportion of the population that prefers European-type gardens comprising rolling lawns and trees, but that this group appears to be declining within the Australian context, particularly when water conservation issues are considered. Furthermore, this study did not include sports

fields and parks designed for “active” forms of recreation, an area where turfgrass is still very much the preferred option when compared to its competitors, such as artificial turf and hard-surface areas (eg: asphalt, etc.).

Water Usage by Turfgrass. Water quantity and quality are now major global environmental issues. As a consequence, the demand for more water-efficient turfgrasses will continue to grow. So will the demand for turfgrasses with other reduced input requirements, such as a low stress tolerance to water quality, pH extremes, low nutrient requirements, and reduced pesticide requirements. Multiple environmental stress screening processes for new turfgrass varieties are now being commonly used.

Considerable political pressure has been developing in the USA to minimise water use in the urban environment. This concept, termed the “Xeriscape” concept, aimed to reduce water usage by as much as 30% by promoting water conservation. One guideline was to “limit lawn area” , stating that turfgrass is the number one consumer of water in the landscape, and that trees and shrubs be promoted as replacements for turfgrass. Similar statements and concepts have been published in Australia (134). Beard (21) argues that the xeriscape concept is not based on sound scientific principles, and that more science has been published on the water usage rates and drought tolerance or drought avoidance of turfgrasses than on any other group of garden trees and shrubs.

Irrigation Technology. A study undertaken in residential landscapes (104) supports the view of Beard (21). This study investigated the water use rates of two contrasting residential landscapes, a monoculture of St. Augustine grass (*Stenotaphrum secundatum* cv. 'Floratum') turfgrass lawn, and an alternative

presumed resource-conservative ornamental mixed-species landscape. The researchers found that, while irrigation requirements during the establishment phase were greater for the turfgrass landscape, less irrigation was needed for a mature lawn landscape compared to one of native and presumably drought-tolerant plants with an expanding canopy. In year four, the mature turfgrass landscape required less than two-thirds of the irrigation that the mixed-species landscape required.

The “negative environmental image” of turfgrass being a major user of water still persists. The general consumer perception is that turf uses huge volumes of water and ties up resources. This has led to a reduction in the use of turf for the residential market. Furthermore, Governments, via Regional Water Boards, are strongly promoting a “water wise” policy, and this has been misinterpreted by consumers because of publication in the media and in books of scientifically unsupported statements (134).

Another recent stocktake report on the turfgrass industry (80) reaches a similar conclusion. It states that there is a strong public misconception that turf and green space are high water users and “legitimately” the first target in water restrictions. The reality is, according to the report, that the industry has a positive story to communicate about the availability of new turf varieties that use less water, and about the industry’s success in improving water use efficiency in turf production and maintenance.

Turf is used as a ground cover worldwide for utility, recreational and aesthetic purposes. Despite this fact, the turf industry is hindered by a strong public misconception that turf and green space in urban environments are “water

wasters". This misconception is reinforced by statements from some government spokespersons and media personalities that lawns should be removed as a water saving action (80).

A research project in Western Australia (105) evaluated a soil moisture sensor-controlled irrigation system for improving water use in turf. The cumulative volume of water applied at two sites to areas controlled by the soil moisture sensor was 25% less in summer than areas irrigated according to current recommendations of WA Water Corporation (during times without water restrictions). Use of the soil moisture sensor-controlled system saved 100 L of water from leaching per square metre during a summer period (November to April) of 154 days. This project effectively demonstrates the value of utilising some form of soil moisture sensor to control irrigation of turfgrasses.

Another positive response by the Australian industry to environmental criticism has been in Canberra where the ACTEW Corporation has recently commenced a turf and irrigation research project that seeks to develop best practice watering regimes and to benchmark water use requirements for turf, in particular in large open spaces (1). Since 2006, the research site has been planted with five different varieties of turf, cross-laid with different sprinkler and drip irrigation systems. The project is attempting to determine the most efficient way to keep large grassed areas, such as schools and parks, alive and healthy through more sustainable water use.

Results for the first full year (2007) of operation have been very promising (1), achieving an approximate 40% saving in water use. For an average-sized football field, this would equate to a saving of approximately 2.5 megalitres for the

year. The lack of rain throughout the year, also one of the hottest years on record for the ACT, resulted in an increase in water demand by both cool and warm season grasses by over 50%. This resulted in major reductions to watering schedules that pushed many of the turf varieties to the limit. The result was significant water savings along with many other learning outcomes, such as the importance of monitoring soil moisture, the benefits of "cyclic watering", and the testing of which turfgrass varieties can survive with the least amount of water. "Cyclic watering" is defined as a watering method that applies water for a very short time, then allows that water to soak in before watering resumes. The benefits are that it does not cause excessive pooling or run-off.

Five different turfgrass varieties, selected on the basis of their drought tolerance, were compared in the above trial (1). The warm season grasses, namely Sir Walter Buffalo and Transcontinental Couch, performed very well with irrigation at 40% of evaporation. These grasses survived at an even lower watering rate of 25-30% of evaporation later in the season. In contrast, the cool season grasses, namely the fescues, Rhizomatous Tall and Premium Tall, needed double the amount of water to survive.

Similar research as that of ACTEW has been conducted by DPI&F's Redlands Research Station on soil-based community sports fields in Brisbane (48). Their results show that savings in water use on community sports fields are still possible without compromising turf quality or playability. Under normal frequent irrigation scheduling, the average field uses about 5ML/ha. Strategic weekly irrigation (applied only when no rain had fallen in the previous week and soil surface moisture content was rapidly declining) still maintained good turf quality and a safe

playing surface, but on average required less than half the irrigation water (About 2.4ML/ha).

By comparison, tree crops such as Citrus typically require 5.0 to 7.5 ML/ha (48). More studies within Australia of the kind described above are needed to help get the message across to the public that turf is not a high water user, but rather a sustainable and environmentally-friendly option as demand pressure on urban water supplies increases.

Irrigation scheduling techniques are an obvious important means of addressing water conservation. A study undertaken within the Sydney Metropolitan Area of irrigation systems used on home lawns and gardens (87) clearly showed that, for irrigating lawns, fixed sprinkler irrigation systems with automatic controllers apply less water than those with either tap timers or no controllers at all. The study concluded, however, that there are relatively few well-designed irrigation systems in operation in home gardens, and that maintenance of such systems is often neglected.

As well as irrigation scheduling, water conservation can also be achieved by the introduction of subsurface micro-irrigation systems, such as drip irrigation or the Australian-patented KISSS capillary subsurface irrigation system. The KISSS technology utilises conventional drip irrigation techniques together with special polyester geotextile materials and polyethylene to spread water underground in an even and efficient manner. It is reported to be a significant improvement on drip irrigation in that it uses capillary flow to enable the soil to absorb the water at its own rate, and help prevent subsequent run-off and deep profile percolation (65).

However, such systems sometimes fail in extreme climates when capillary flow cannot keep up with evaporation.

Within the USA, similar public criticism of turfgrass being a high water user has been aired. To counteract this, and to scientifically examine the facts presented on both sides of the argument, the Council for Agricultural Science and Technology hosted a workshop in 2006 (35). This workshop provided an opportunity for researchers, scientists, environmentalists and water specialists to join together to discuss the issues facing the turfgrass industry. The publication arising from this workshop (25) is an outstanding contribution to the field of water quality and quantity issues affecting turfgrass in an urban environment. The major issues discussed in this book, some of which have been included in an Interpretive Summary (35), have been summarised below because they are of direct relevance to the Australian context:

- Water availability and conservation are a priority for the turfgrass industry. The first step is to select the correct turfgrass for the climate in which it will be grown. During the last 30 years, turfgrass scientists have determined the water use rates for all major turfgrass species. Turfgrasses can survive on much lower amounts of water than most people realise, and several turfgrass species have good drought resistance. Turfgrasses with deep, extensive root systems, coupled with decreased water use, are more drought resistant and have a greater water conservation potential. Water usage rates vary with species and cultivars, as documented by extensive research (17; 55; 74). Selecting low water use and/or drought-resistant turfgrass species and cultivars is a primary means of decreasing water needs.

- Plant selection and landscape design are key factors in urban landscape water conservation. Although water usage rates for turfgrasses have been extensively reported, far less is known about the actual water use of ornamental plants, especially large trees, and even less about other shrubs and species used in mixed landscape designs. There are perhaps 12 major turfgrass species used extensively in urban landscapes throughout the USA and Australia, whereas the number of ornamental species may exceed several thousand. It may be that this paucity of research on ornamentals and total landscape water use, compared with research that has enabled the precision irrigation of turfgrass, has led to restrictions on turfgrass or its removal in many water conservation programs (25).
- Specific cultural practices can be used to decrease water use and enhance drought resistance in urban landscapes, including mowing height and frequency, turfgrass nutrition and turfgrass irrigation. Secondary practices, such as soil cultivation, topdressing, wetting agents, plant growth regulators and pest management, also influence potential water conservation.
- The use of alternative water for irrigation is another means of conserving potable water in both high rainfall areas, and in regions of recurring drought. In dry regions of the country, and in highly populated metropolitan areas where water is limited, irrigation with municipal recycled water, untreated household grey water, or other low quality water is a viable means of coping with potable water shortages.

- Important aspects of any irrigation system design include efficient and uniform water application, regardless of the type of water applied, and filtration of suspended matter content in recycled and brackish waters. Additionally, groundwater quality monitoring programs may be required. Sites irrigated with recycled water may be required to protect adjacent properties or bodies of water from irrigation runoff or overspray.
- Beyond water conservation, extensive turfgrass use requires attention to pesticides and fertilisers and their potential for leaching and runoff. Turfgrass managers must adopt practices that decrease the potential for pesticide and nutrient leaching that can harm groundwater and surface water supplies.
- Most pesticides currently used in turfgrass present relatively low risks of significant groundwater contamination. A healthy turfgrass provides considerable protection against leaching because of high levels of organic matter and associated microbial activity, serving to immobilize and degrade applied pesticides and nitrates.
- Nitrate leaching may present problems in some segments of the turfgrass industry where nitrogen fertilisation rates have not been lowered to account for turfgrass age and clippings return.
- Mathematical models used to predict the off-site transport of turfgrass chemicals to water resources are important tools for risk assessment and management, but there are concerns about the reliability of some model applications. Most of these models have not been designed specifically for turfgrass, and the unique aspects of turfgrass relative to row crops should be incorporated into model algorithms and designs.

- Perceived environmental problems must not be addressed in isolation, but in terms of all of the interrelationships and with all stakeholders associated with these landscapes. The ultimate goal is to provide quality urban areas for activities and recreation while conserving and protecting our water resources and supplies.

The use of alternative waters for irrigation of turfgrass has been extensively practised in Australia as well. One such example (95) illustrates the effectiveness of utilising recycled water on turfgrass and provides specific recommendations for the use of recycled water in parks and gardens. Alternative sources of water can include rainwater, stormwater, greywater, recycled water and bore water. In Queensland, 15-20% of treated effluent is used for irrigation compared with 11-14% nationally, and 60% in California. In 1999 in Queensland, about 75 golf courses used treated effluent accounting for about 45% of the municipal wastewater being recycled. There were also approximately 60 other schemes irrigating sports fields, parks and gardens (95).

Breeding and Selection of Turfgrass Varieties. There has been considerable research within the USA over the past 30 years to seek species and cultivars of turfgrass that are drought tolerant. Beard (17) has published comprehensive reviews of research carried out on water use rates and water stress of turfgrasses. Kim and Beard (79) studied the comparative evapotranspiration (ET) rates and associated morphological characters of 11 warm-season turfgrasses representing 9 species. Significant differences in ET rates were found both among

and between 10 warm-season turfgrass species (128) encouraging selection and genetic development for drought tolerance and other physiological characteristics.

The typical turfgrass plant has a water content that ranges from 75 to 85% by weight. A 10% reduction in water content from 75 to 65% within a short time may be lethal (15). Only a very small proportion (about 3%) of the water absorbed by a turfgrass plant is actually utilised in physiological and growth processes (21). By far the major portion of this water is transpired from the turfgrass surfaces into the surrounding atmosphere. This transpired water is not necessarily considered a loss as the transpiration stream can be important in cooling aboveground tissues during periods of heat stress.

The term evapotranspiration (ET) combines the evaporation processes that occur from the soil with the transpiration rate occurring from the growing plants. ET rates are a means of assessing the relative efficiency of various turfgrass varieties in utilising the available water. A classification of evapotranspiration rates is presented in Beard (15).

A turfgrass cultivar possessing a low ET rate is not necessarily drought tolerant, however such a cultivar is better able to delay the onset of drought stress. The situation is complicated by the fact that ET rates for a cultivar can be altered substantially by any changes in cultural practices or environmental conditions that may alter the canopy density, leaf area, leaf orientation, or vertical leaf extension rate. As a consequence, it is important to conduct comparative ET rate studies at the interspecies level in a controlled, stress-free environment. Sufficient basic information is available from such studies to conclude that specific species and cultivars can be selected with lower ET rates, thus enabling the

selection of turfgrasses that will contribute to water conservation strategies. This process can also assist in the breeding of water-conserving turfgrass varieties (15).

The interest in breeding and selecting turfgrasses with drought tolerance is still active within the USA. One such example (37) is to evaluate turfgrass performance in relation to a San Antonio Water System conservation program that will maintain a list of turfgrasses that have demonstrated summer dormancy capabilities. Summer dormancy in the Northern Hemisphere is defined as the ability of turfgrass to survive without water for a period of sixty consecutive days between the months of May through to September. SAWS has decreed that all turfgrass within their area of jurisdiction established after January 1, 2007, shall have summer dormancy capabilities.

Development of drought-tolerant turfgrasses is also very active within the Australian context. A Queensland team (48) has recently begun to develop more drought-tolerant turfgrass cultivars for a range of uses. Over the next four years, this project will focus on collecting and evaluating Australian *Cynodon* genotypes for turf quality and drought tolerance.

While large differences in drought tolerance are found among species, differences within species also occur, which help to maximise water savings. Drought tolerance, however, is not the only attribute to be considered when selecting a turfgrass. Some 25% of turfgrass sites, for example, are affected by shade, where the most drought-tolerant species – green and blue couch (*Cynodon dactylon* and *Digitaria didactyla* respectively) – do not perform well. Buffalo grass (*Stenotaphrum secundatum*), manila grass (*Zoysia matrella*) and sweet smothergrass (*Dactyloctenium australe*) grow much better than green and blue

couch under shade, and maintain green healthy turf much longer than they would in full sunlight (48).

The selection of grasses with lower ET rates is only one tool available in conserving water use. Turfgrass management, including the manipulation of the primary cultural practices of mowing, fertilising and irrigating, very much contributes to the overall water use efficiency of the sward. Turfgrass managers interested in conserving water should mow high and frequently, fertilise to meet nutritional needs only, and irrigate infrequently based on the use of soil moisture sensing devices rather than on set time schedules (120). Another study reported by Beard (16) reviews the effects of plant growth and cultural practices on ET rate, and reports nitrogen levels and mowing heights that maximise water conservation.

An example of turfgrass water efficiency is reported by Short and Colmer (121). They report that warm season grasses can maintain acceptable growth and colour with only 50-60% of available water. These same grasses had 50-60% of their roots in the top 10cm of soil while less efficient grasses had 86% of their roots in the top 10cms. The ability of cultivars to explore a greater soil depth can obviously assist their water use efficiency.

The importance of the grass root system in dehydration avoidance and drought resistance is clearly demonstrated in a study by Beard & Sifers (26). This study investigated the genetic diversity in drought resistance among genotypes of *Cynodon* and *Zoysia* species. Among the 26 *Cynodon* genotypes tested, substantial genetic diversity was detected and those with the shorter root systems tended to have poorer dehydration avoidance and poorer drought resistance. Among the 9 *Zoysia* grasses tested, the genetic diversity was much narrower and all had much

poorer dehydration avoidance than the *Cynodon* species, attributed primarily to a very limited root system and a higher evapotranspiration rate. Obviously, the genetic potential for producing a much greater root depth, density and biomass is a trait well worth selecting for when seeking drought resistance or dehydration avoidance in turfgrasses.

Another study (73) further emphasises the importance of root systems in facilitating turfgrass breeding for drought resistance. This experiment investigated root activity and spatial distribution in relation to drought resistance for four warm-season turfgrass species. The results show that root spatial distribution and activity to surface soil drying varied with grass species and genotypes. Superior drought resistance was associated with enhanced root growth at deeper soil layers and maintenance of root activity when drought occurred in the upper soil profile. Root length per unit root mass was less clearly related to drought resistance. Differences in these characteristics among turfgrasses could serve as selection criteria for improving drought resistance.

Although the selection and breeding of turfgrass varieties with particular genetic traits (such as drought resistance) is active within the USA, there is some concern about the genetic diversity of existing collections of USA turfgrass species (100). Turfgrass germplasm collection and genetic improvement is in its infancy compared to that of other, more traditional crops. For example, world germplasm collections of major crops such as wheat, corn and rice contain accessions numbering in the hundreds of thousands each, while the USA collection of the same crops boasts accession numbers of at least 20,000 each. This compares with existing collections of USA turfgrass species which contain only 434 accessions of

Kentucky bluegrass (*Poa pratensis*), the most widely used species for turf in the USA, 347 accessions of Bermudagrass (*Cynodon dactylon*), the most important turfgrass in the Southern USA, and only 49 accessions of creeping bentgrass (*Agrostis palustris*), the grass found on more than 16,000 golf courses within the States (100). The turfgrass germplasm collection within Australia is almost certainly going to be as limited in its genetic diversity. For example, a range of warm-season turfgrasses being evaluated under Queensland conditions (47) comprise an accession of 137 different cultivars or experimental lines. Although there may be some limitation in genetic diversity, this collection at Redlands Research Station in Brisbane is rated as the most comprehensive living collection of warm-season turfgrasses in the world (84).

Most turf and amenity grass breeding programs within the USA are being conducted by private breeders where the main emphasis in the program is in making a profit. Private breeding programs for turf and amenity grasses in the USA are about five times greater than efforts devoted to forage grasses (83). A similar trend is beginning to happen in Australia where government or institutional breeding programs are being phased out due to a lack of resources. This trend is not necessarily a bad thing for the turfgrass industry as it encourages private entrepreneurs to produce specialised grasses for particular purposes. There will, however, be an inevitable increase in cost to the end consumer.

Aldous (3) provides a good summary of the size and extent of the Australian (and New Zealand) turfgrass industry, and lists the most important species currently being utilised, as well as some new species being considered as future

possibilities. The extent of breeding and selection within Australia is adequately summarised (3).

Martin (91) has reviewed the potential of Australian native grasses for use as managed turf. He points out that, as greater demands are placed on turf for high performance under increasingly difficult environmental conditions, opportunities are opening up for the addition of new species to the list and/or the transfer of unusual adaptive traits found in some native grasses to traditional turf species. He concludes that most of the Australian native species thought to have some turf potential (eg. *Microlaena stipoides*, *Sporobolus virginicus*, *Agrostis aemula* complex and *Austrodanthonia*) would not repay the effort required to make them commercially acceptable as recreational turfgrasses. They may, however, have an important role to play in environmental turf plantings such as landscaping, where tolerance to human traffic is not a major requirement.

Within Australia, as well as selecting and breeding turfgrasses for adverse environments such as drought tolerance and shading, there is a considerable need for the evaluation of grasses for their suitability as salt tolerant turf or as amenity grasses for urban landscaping in salt-affected areas. Researchers in Queensland (85) are looking at this need and describe a range of adaptations by different plants to salinity and associated soil problems, such as salt-induced 'drought' effects. They then consider how this range of plant material might be managed effectively in a whole of landscape approach, highlighting some current and potential species for productive, amenity and environmental roles within such systems.

From a turfgrass point of view, there are some promising salt tolerant species being investigated, including the use in parts of southern Australia of seashore paspalum (*Paspalum vaginatum*) on salt-affected golf courses. The North Melbourne Institute of TAFE, in conjunction with QDPI, are investigating the adaptation and management of seashore paspalum on golf courses within Victoria. Other potential turfgrasses include marine couch (*Sporobolus virginicus*) which has a higher salt tolerance than seashore paspalum, and is already present to a limited extent on saline sections of golf courses and urban parkland. Some promising lines of marine couch are under investigation by turf researchers at QDPI (85).

As well, some genotypes of the widely-used buffalo grass (*Stenotaphrum secundatum*) are also salt tolerant, and naturalised plants are commonly present on sand dunes near coastal communities throughout southern Australia. In the future, greater use may be made of *Zoysia* species, particularly in northern Australia. These again show a wide range of salt tolerance (85).

Besides selection and breeding, another approach attempted in avoiding drought with turfgrasses has been the use of high water absorbency hydrogels, such as polyacrylamides (PAM) or cross-linked polyacrylamides (CLP), as soil amendments. Industry has promoted the usage of hydrogels, PAM or CLP, as soil water conservation amendments and as reservoirs for plant available water that may be helpful in alleviating plant stress during periods of drought. Unfortunately, research to date seems to indicate that, even though the products are very good at absorbing water, the water absorbed is not readily available to the growing plant (61). This study used CLP banded at the recommended rate and at 20 times

this rate to test the robustness of CLP in enhancing drought tolerance in legumes, however, the addition of CLP did not sustain yields with reduced irrigation levels.

Other research has shown that hydrogels do not work well in clay soils and that fertiliser salts and saline soils decrease the water uptake and holding capacity of PAM hydrogels. Positively charged ions such as potassium, calcium, magnesium and iron decrease water absorption by PAM hydrogels by as much as 90% (36). The available evidence seems to indicate that hydrogels, although widely recommended by the industry, have a very limited role to play in water conservation for the turfgrass industry except possibly in sandy soils with low organic matter concentrations (106).

Energy Saving and Heat Amelioration Effects of using Turfgrass. The overall temperature of urban areas may be as much as 5 to 7 degrees C. warmer than nearby rural areas. Turfgrasses can serve in dissipating the high heat loads generated in urban areas through the cooling process of evaporation. Furthermore, the cooling effect of irrigated turf and landscapes can result in energy savings via reducing energy inputs required for mechanical cooling (21).

A study by Beard (19) gives an example of the unique cooling effect of turfgrass in dissipating heat energy and therefore enhancing the comfort of people in highly populated urban areas. The study consistently demonstrates that actively growing turfgrass can reduce surface temperatures by 10-20 degrees F (5-10 degrees C) in comparison to bare soil and by 50-70 degrees F (30-40 degrees C) in comparison to synthetic turf surfaces (see Table 4, adapted from 19). Hardscapes (such as cement, asphalt and stone surfaces) also act as heat absorbers with surfaces much hotter than turf (34).

Urban green spaces can change the climate by increasing urban surface albedo (54). Surface albedo is the extent to which a surface reflects radiation. Low albedo materials, such as asphalt, absorb more radiation and therefore heat up. Increasing vegetation cover around buildings increases surface albedo and assists radiation (ie. heat) reflection. Urban vegetation also has a positive impact through the cooling process of evapotranspiration. Combining these two processes can have a cooling effect of between 2 – 8 degrees C (54).

Table 4: Surface temperatures in degrees Centigrade of some commonly used surfaces (19).

Type of Surface	Surface Temp.	Above Surface	Nocturnal Temp.
Green, Irrigated Turf	31	32	24
Synthetic Turf, Dry	70	36	29
Brown, Dormant Turf	52	35	26
Bare Soil, Dry	39	33	26

Landscape architects have generally recognised the positive environmental benefits of turfgrass. Rogers (117), a member of the American Society of Landscape Architects, states that turfgrass, when properly planned and efficiently managed in a multi-use landscape, can provide a very real asset to the environment. While eye-pleasing and inviting, the grasses exchange carbon dioxide for oxygen in the atmosphere, they trap particulate matter, cool surrounding areas, control erosion and even provide access for turf-filtered groundwater recharge.

While hardscapes (concrete, specialty rock or paving) and semi-hardscapes (crushed stone, scattered boulders) can also be aesthetically pleasing, they can be environmentally damaging. Such designs can seal sections of the earth surface and can become heat sinks, absorbing large amounts of energy and then radiating that heat energy back into the surrounding area. Furthermore, such hard-surfaced areas can create storm water overflows when it rains which can lead to local flooding problems. While these forms of landscaping require minimal inputs for maintenance, such as water or fuel, their inert state fails to provide as many positive environmental benefits as turfgrass (117).

Turfgrass is able to soften the harshness of the built-up environment. More green space, including turfgrass, within cities and towns greatly improves the urban environment visually and aurally which leads to improved comfort and health (physical and mental) for users and residents. Apart from aesthetics, turf improves visual comfort through glare reduction and aural comfort through noise absorption (80).

Turfgrasses contribute, as a component of urban vegetation, to the mitigation of the urban heat island effect. A study conducted in an irrigated urban

park in suburban Sacramento, CA (125), observed surface energy balance at three sites extending from the edge of the park to its centre along a transect aligned with the prevailing wind. Results show that the daily and daytime total evaporation from the park is more than 300% that from the integrated suburban area, and more than 130% that from a nearby irrigated rural grass site. The evaporation rate is a major factor in reducing air temperature, thus the urban park was much cooler than the surrounding urban area, and even cooler than a nearby rural grass site.

In France and Spain, new tram lines have been installed that are beautifying cities by creating greenbelts rather than taking them away. By installing turfgrass between and surrounding the actual tram lines, these cities are not only solving traffic congestion but are also solving noise pollution and creating an environment that looks a lot nicer, but also has a considerable cooling effect on ambient temperatures (75).

The use of turfgrass and other green space to cool and enhance urban environments is also occurring in architecture where "green" buildings are becoming increasingly popular across the USA, Europe and parts of Asia (116). Such buildings incorporate plantings of vegetation, such as the use of turfgrass as roofing material, garden rooftops, multi-levelled terraced gardens, lush foliage draping exterior walls, and vast, internal hanging gardens. These "living" buildings, as some call them, have been credited with emitting far fewer greenhouse gases than their vegetation-free counterparts, as well as insulating against heat and cold, and better at absorbing street and urban noises.

The Carbon Sequestration Capacity of Turfgrass. Australian soils are generally, on World standards, very low in carbon. The usual range for organic carbon content in Australian soils is between 1 and 5% (42). Some unusual and rare soils, such as Alpine Humus soils, can accumulate up to 12% but most Australian soils are exposed to high temperatures and dry conditions which limit carbon accumulation. The effects of living organisms on soil organic matter and carbon are substantial. Of these, vegetation is the primary source of soil organic matter and thus the major influencing factor on the amount present.

Grasses in general, and particularly turfgrasses, develop a dense root mass and an organic thatch layer that is ideal for storage of carbon in soils. The extensive fibrous root system of turfgrasses contributes substantially to soil restoration and improvement through organic matter and carbon additions (21).

When people think 'carbon' they usually think 'trees', but in reality 82% of carbon in the terrestrial biosphere is in the soil (77). Healthy grasslands may contain over 100 times more carbon in the soil than on it, making a well managed perennial grass ley the quickest and most effective way to restore degraded land (77).

A study of historic soil testing records in Colorado, (113) estimates that golf course greens and fairways alone can sequester carbon (C) at average rates approaching 0.9 and 1 tonne per hectare per year, respectively. They concluded that C sequestration in turf soils occurs at a significant rate that is comparable to that reported for USA land that has been placed in the United States Department of Agriculture (USDA) Conservation Reserve Program (56).

The above researchers report on historic data that indicates a strong pattern of soil organic matter response to decades of turfgrass culture. Total C sequestration continued for up to about 31 years in fairways and 45 years in putting greens. The most rapid increase occurred during the first 25 to 30 years after turfgrass establishment. A further paper by the same research team (10) using CENTURY model simulations near Denver and Fort Collins indicate that turfgrass systems can serve as a C sink following establishment. Model estimates are that 23 to 32 Mg/ha (tonnes/ha) soil organic carbon were sequestered in the 0 to 20cm below the soil surface after about 30 years. These results compare very favourably with those estimated above from soil testing records (113). They conclude that this research indicates that turfgrass systems serve as a sink for atmospheric C for approximately 30 to 40 years after establishment at approximately 0.9 to 1.2 Mg/ha/yr.

By extrapolating from published data on root dry matter under turfgrass swards, it is possible to obtain another estimate of the role that turf plays in carbon storage within soils (29; 30). These authors report root dry matter from 0 to 20cms under various turfgrass swards grown in the Rhine Valley, Germany. The results indicate that up to 11% of a cubic metre of topsoil can be comprised of organic matter derived from root material. This represents a very substantial addition of carbon to the soil, approximately 4.5% by weight in the top 20cm. Results are summarised in Table 5 below:

Table 5: Results from Boeker & Von Boberfeld (30) summarised below*

Soil depth	Root Dry Matter	Organic Matter	Organic Matter	Organic Carbon
Cm.	Gm/1000 sq.cm.	% by volume	% by weight	% by weight
0-5	110	11	7.81	4.45
5-10	3.5	0.35	0.25	0.14
10-15	2.0	0.2	0.14	0.08
15-20	1.0	0.1	0.07	0.04

***Assumes a soil bulk density of 1.4 gm/cubic cm, and an average C content in organic matter of 57% (68).**

As these results were collected at two or three sampling dates, it is possible to estimate the rate of carbon sequestration. Averaging all of the Rhine Valley data in Table 6 provides a carbon sequestration rate of about 2.2 tonnes/ha/year. This is about twice the rate reported by Qian & Follett (113) for Denver and Fort Collins, Colorado. There is considerable variation in the Rhine Valley data which appears to be very much species related. Results are compared in Table 6 below:

Table 6: Estimates of Carbon Sequestration Rates by various Authors.

Authors	Results reported	Organic Matter	Carbon
		Tonnes/ha/yr	Tonnes/ha/yr
Qian & Follett	Soil test results	1.6–2.1	0.9 – 1.2
Bandaranayake <i>et al.</i>	Century Model		
Boeker & Von Boberfeld	Poa/Festuca	3.2	1.8
Boeker, 1974	Agrostis/Table 1	0.7	0.4
Boeker, 1974	Festuca/ Table 3	4.6	2.6
Boeker, 1974	Lolium/Phleum/ Poa/ Table 5	3.8	2.2
Boeker, 1974	Festuca/Table 7	5.4	3.1
Boeker, 1974	Festuca/ Table 8	6.5	3.7
Boeker, 1974	Lolium/ Table 9	2.4	1.4

Carbon soil storage could provide turfgrass growers with additional income via carbon credit trading schemes. Such schemes pay participants carbon credits for activities that reduce levels of atmospheric carbon dioxide. In Australia, the National Australia Bank has established a nabCapital Carbon Solutions Group to identify opportunities in the evolving carbon finance market, and it has indicated that it is keen to assist clients to take advantage of new markets that are emerging (80).

A study in the USA (102) states that there are an estimated 40 million acres (ie: 16.2 million hectares) of tended lawns in the USA, making turfgrass one of their largest crops and one that has a significant and positive impact on their economy, health and environment. It adds that lush lawns are a "sink" for carbon dioxide, pulling in greenhouse gases out of the atmosphere as they grow. It is estimated that 2% of the US land surface covered by lawns could account for about 5% of the carbon dioxide absorbed by all plants.

In another estimate from the USA (78), urban turf is estimated to cover 20 million hectares. Using Qian & Follett's (113) estimate above of carbon being sequestered under turf at about 1 tonne/ha/year, US urban turf would be responsible for carbon storage of about 20 million tonnes/year. This figure compares favourably with a gross carbon sequestration rate of 22.8 million tonnes/year by urban trees in the USA (103).

Another study of carbon storage and flux in urban residential greenspace (76) reports much lower rates of carbon sequestration than those reported above. Total net annual carbon inputs from grass and other herbaceous plants were estimated to be between 0.2 and 0.3 tonnes/ha/year, whereas trees and shrubs

contributed between 5 and 8 tonnes/ha/year. This study, conducted in north-west Chicago, indicates that great variations in carbon sequestration rates are to be expected due to variations in temperature and other climatic conditions.

The above study (76) makes another important observation, namely that although urban greenspace helps reduce atmospheric carbon, it also contributes to carbon emissions through the consumption of energy for landscape management activities, such as mowing, pruning, irrigation and fertilisation. These activities can generate carbon either directly or indirectly. Direct release occurs when, for example, gasoline is used to mow grass or electricity is used to pump water. Indirect release occurs when the material or equipment used for maintenance requires energy in its manufacture or installation.

Jo & McPherson (76) estimate that the annual carbon generation from using gasoline as the power source for mowing is about 0.15 tonnes/ha/year (14.58 g/sq m/year), which is equivalent to 60% of the amount estimated to have been sequestered. The loss of carbon to the atmosphere via mowing is therefore a substantial component and, combined with carbon release from irrigation pumps and pruning activities, nullifies the carbon storage capacity of grasses and herbaceous plants in urban greenspace. They conclude that the estimation of landscape carbon inputs and outputs for the study area indicated that soils and woody plants were carbon sinks, while grass was a net carbon source because of maintenance requirements, particularly mowing.

There is great variability in the available data on whether turfgrass is a sink for carbon, or whether its maintenance nullifies the sink effect. Milesi *et al.* (96) report that the cost in carbon emissions due to fertilisation and operation of

mowing equipment ranges from 15 to 35% of the sequestration. They state that, for turfgrass, the gross soil carbon sequestration potential has to be discounted by the carbon emissions involved. At least two of the sources of emissions can be quantified in their model, namely emissions associated with N fertilisation (10% of the C sequestration potential), and emissions deriving from the operation of lawn mowers (between 5 and 25% depending upon management scenarios). Further reductions in the C sequestration potential that cannot be accounted for in their model are connected with irrigation practices, especially where pumping is involved, and with the disposal of lawn clippings in landfills (96).

Another study, commissioned by the lawn mower industry sector (Outdoor Power Equipment Institute Inc. or OPEI), indicates that responsibly-managed lawns can reduce the carbon footprint from turfgrass (118). This study states that perennial managed grassland systems, such as turfgrass with minimal disturbance (ie. residential lawns, golf courses, parks, etc.) sequester the greatest amounts of carbon because their roots are able to grow deeper and access more carbon. It also states that, for an average managed lawn, turfgrass captures four times the amount of carbon from the air than the carbon output of a typical mower; and that for a well-managed lawn, turfgrass captures five to seven times the amount of carbon than the carbon output of mowing. These figures are substantially different than those of Jo & McPherson (76) and Milesi *et al.* (96) quoted above. Little data has been presented in the paper (118) to support such claims, although the author makes the very good point that the largest amount of carbon intake occurs with the recycling of nitrogen contained in grass clippings. He advocates that grass clippings should be left on the ground to break down and recycle, and also

advocates responsible watering as part of good lawn management. In other words, his proposed model for good lawn management minimises carbon loss from irrigation systems (not estimated above) and from emissions associated with N fertilisation (estimated at 10% by Milesi *et al.* 2005). The author concludes that the carbon sequestration of turfgrasses can be maximised by measures such as, cutting regularly and at the appropriate height, feeding with nutrients left by grass clippings, watering in a responsible way, and not disturbing grass at the root zone. This conclusion appears to be justifiable from available evidence but may not suit the management regimes of many turfgrass professionals. The utilisation of “mulching mowers” may well fit with this management scenario, but this needs more research to validate it.

An Australian study at the University of Newcastle (112) measured the amount of emissions from lawn mowers in use within Australia. It did not calculate carbon emissions as a percentage of C sequestration potential, but concluded that lawn-mowers, when compared to transport sources in the Newcastle region, contribute 5.2 and 11.6% of carbon monoxide (CO) and NMHC (non methane hydrocarbons) emissions respectively. This compares favourably with data from North America that estimates the contribution of lawn mowers to total hydrocarbon emissions to be as high as 13% (140). The above study (112) also demonstrated that lawn-mowers with two-stroke engines emit hydrocarbons at an average rate in excess of seven times the rate of emission from lawn-mowers with four-stroke engines at the power setting typical of that determined from field observations of mowing habits.

Sullivan & Parr (126) have reported that some grass plants can store carbon dioxide for thousands of years. Grasses, such as wheat and sorghum, are capable of storing large amounts of carbon in microscopic balls of silica, termed phytoliths, that form around a plant's cells as they draw the mineral from the soil. When the plant dies, these phytoliths enter the soil and lock up carbon (termed "silica occluded carbon") for potentially thousands of years. There is an obvious potential for long-term future research into this area to breed or select suitable turfgrasses that are capable of producing phytoliths.

The enormity of the climate change problem means that anything good for the environment is welcome news. The huge tracts of land occupied by gardens, including turfgrasses, throughout Australia has a positive environmental effect because they store carbon. Because gardens act as carbon sinks, their numbers should be increasing rather than decreasing. Governments serious about alleviating the effects of climate change should be subsidising gardeners so they can maintain their lawns and garden beds. Homeowners should be encouraged to create gardens rather than cover their backyards with paving tiles. Even lawns consume carbon dioxide. While homeowners are encouraged by some to remove lawns and replace them with paving because lawns consume water, it should be remembered that masonry prevents the exchange between living matter and the soil. Carbon sequestration cannot occur without a gaseous exchange between the atmosphere, living plants and the soil environment. Gardeners are being penalised with water use restrictions when in fact they are a very important consumer of carbon dioxide.

The sheer size of the amateur garden industry within Australia needs to be considered within this context. There are 640 registered clubs within the ambit of

Garden Clubs of Australia Inc. This represents about 60,000 members or 0.3% of the Australian population. When one considers that only keen gardeners join their local Garden Club, there would be a much larger proportion of the population actively practising “gardening” as a regular pursuit. The Nursery and Garden Industry of Australia Ltd (NGIA) estimates that there are 7 million households with about 2 million active gardeners within Australia, or 10% of the population. The amount of carbon being stored in gardens served by 10% of the population is not being considered by current carbon accounting schemes.

Unfortunately, current carbon accounting schemes, such as the Kyoto Protocol, measure only livestock methane emissions and tree clearing and do not take into account carbon accumulation on the properties producing those emissions (97). As a consequence, the amount of carbon being stored in grass, woodland or soil is not being fully accounted for. This may soon change as the Australian Government is expected to announce a new emissions trading scheme later this year (99). A new proposal for funding by MLA (97) aims to establish a property-scale carbon budget that will allow landholders to estimate the carbon accumulation in vegetation and soil. This budget, when released, would also be useful for turfgrass producers, golf clubs, gardeners, and other large turf areas such as sporting fields.

According to the Australian Greenhouse Office’s latest data (2), agriculture is the second largest source of gross greenhouse gas (GHG) emissions in Australia – still a long way behind electricity production (16% versus 50% of total emissions). More importantly, agriculture is the only sector that has significantly reduced net GHG emissions since 1990, the base year for GHG emissions reporting under the

Kyoto agreement. All other sectors have significantly increased emissions over this period, due to rapidly increasing use of fossil fuels for manufacturing, cars, air conditioning, plasma TVs and other luxury items to fuel the consumer lifestyle that Australians currently enjoy (98).

Turfgrass Utilisation in Sports and Sporting Fields. Many social and sporting events take place on lawns or turfgrass, such as Bowls, Golf, Cricket, Horse Racing, Football, Rugby, Hockey, Croquet and Tennis. The role that a good quality turfgrass plays in the success, enjoyment and safety of these sports is of great importance, and is a very positive aspect of turfgrass use in the urban landscape from social, health and environmental points of view.

A dense, vigorous sward of turf (often as a monoculture) is the key goal of turfgrass systems used in sport. To achieve this is an extremely challenging task for turf managers, requiring the use of pesticides, fertilisers, and water to provide aesthetic, safe, and performance-acceptable venues. To provide modern playing conditions, certain management practices such as mowing have been intensified to achieve the desired condition. For example, modern golf course greens are mowed at a height of 2-3 mm and are designed to receive 50% of the play even though the total green area makes up less than 3% of the total playing area of a golf course. Even under intensive management, the goal of turf sport management is becoming more sustainable as turfgrass scientists and managers have identified management systems that are more efficient and requiring fewer inputs (39).

The selection and improvement in turfgrass varieties used for amenity purposes has increased the opportunity for improved performance with reduced usage of water. As well, new agrichemicals being used with increased specificity at

lowered rates of active ingredients are enabling turfgrass systems to be maintained in a more sustainable manner (39).

Despite these improvements, community concerns over shortages of water and contamination of natural resources has led to restrictions on the management tools available to turf professionals. Such restrictions have raised the option that turf for sports purposes be replaced with artificial or alternative landscapes to reduce inputs of water and chemicals. Recent advances in synthetic turf surfaces, coupled with aggressive promotion of new synthetic turf products, have enabled manufacturers to make inroads into markets that were the exclusive domain of natural turf. Modern synthetic turf products feel, look and play much better than their older predecessors. One of the major advantages of synthetic over natural turf is the greater wear resistance of synthetics, enabling more intensive use (82).

One very significant area where synthetic surfaces have not made up ground on natural turf is temperature. On a hot summer day, unshaded synthetic turf absorbs sunlight and becomes much hotter than natural turf. Excessive heat on players then becomes a workplace health and safety issue (82).

The level of replacement of natural turf with synthetics is dependant upon the particular sport in question, the environment, and the intensity of use. At the elite level in many sports, there has been increased pressure for the removal of the natural variation inherent in turfgrass surfaces. With the high levels of prize money available, highly professional elite players will not accept that a tournament may be won or lost by a bad bounce. This is especially so in tennis and hockey where synthetic surfaces at elite levels are now *de rigueur*. These synthetic surfaces, however, come at a cost at several levels. Not only is the cost of installation

extremely high, but the promised life span and low costs of maintenance of these facilities have often been greatly exaggerated by their manufacturers. The real experience at the majority of venues has been, even though this is improving with the third generation products, a costly and disappointing failure.

The reality also for elite hockey synthetic surfaces is that they have to be water-filled during the game to control both heat stress on the players and for ball control on the surface. This clearly negates one of the most important benefits claimed (ie. about saving water).

Tennis as a professional sport has mostly neglected natural turf as a surface, and now utilises almost entirely (except for Wimbledon) artificial surfaces. There is considerable evidence that this has led to greater heat stress for the players and an increase in sporting injuries, particularly involving ankles, lower-back pain and feet. At domestic and non-professional levels in tennis, the proportion of hard courts to natural turf courts within Australia has always been very high, and the trend has been much more towards replacement of hard courts with sand-filled, synthetic grass courts. These have proved to be a disaster for many social players who have declined to use these courts on hot days.

A study (34) in the USA compared surface temperatures of a range of sports field surfaces commonly used in the USA (Table 7, derived from 34). This study was implemented by Brigham Young University (BYU) after observing exceedingly hot temperatures from synthetic turf surfaces, including a case where one coach received blisters on his feet through his tennis shoes. BYU has set 120 degrees F (49 degrees C) as the maximum safe temperature that a playing surface can

reach, since temperatures in excess of this can cause skin injury in less than 10 minutes.

Table 7: Average surface temperatures of playing fields measured between 7am and 7pm (34).

Surface	Average Surface Temperature	Highest Temperature
	Degrees C	Degrees C
Soccer (artificial turf)	47	69
Football (artificial turf)	47	69
Natural Grass	26	31
Concrete	34	
Asphalt	43	
Bare Soil	37	

Further to this, observations by a turfgrass specialist at the University of Missouri (57) explain that many ankle and foot injuries are due to greater levels of torque, velocity and traction found in association with artificial turf surfaces. His observations show that the potential pressure on joints and bones is increased from the inability of a fully-planted, cleat-wearing foot to divot or twist out, an action that releases force. He noted that while some might see divots or ripped-out grass from a natural grass surface as “damage”, it is actually a healthy sign indicating that the surface is doing its job of yielding to the athlete’s impact, therefore being less likely to cause an injury.

Fresenburg & Adamson (58) have stated that the new generations of synthetic turf are as safe, or even safer than natural grass. They have tracked playing field injuries at Texas High Schools for eight years and have concluded that athletes tend to suffer injuries at roughly the same frequency on natural and synthetic turfs, but different surfaces tend to result in different types of injuries. There is more torque, more velocity and more traction on artificial turfs that can lead to more muscle strains and spasms. Natural grass, on the other hand, has its own hazards, such as slippery mud, unseen potholes, and possibly harder surfaces in arid areas.

The newer generation of synthetic turfs (termed the “third generation”) are far superior to previous types, such as the former industry standard, AstroTurf (58). This is described as basically a carpet pad laid over concrete. Newer versions have considerably longer pile and are being built over surfaces in-filled with recycled rubber pellets and other materials that make for softer falls, mimicking natural grass and soil playing conditions. According to Fresenburg (58), all of the rubber

and plastic materials amplify sunlight to cause near unbearable temperatures at certain times of the day. He has measured, on a 98 degrees F (37 degrees C) day at University of Missouri's Faurot Field, the surface temperature on synthetic grass to be 173 degrees F (78 degrees C), compared to nearby natural grass where the temperature was measured at 105 degrees F (41 degrees C).

The use of artificial turf for professional soccer within the United Kingdom has been limited, except at training grounds. It has only been used at a senior professional level on four grounds (8). These authors undertook a detailed comparison of playing performance of new "third generation" artificial grass with natural turf used for soccer. They concluded that, in general terms, the best of the artificial turf surfaces gave comparable performance to good quality natural turfgrass. In the USA, limited data available suggests that the new configuration of synthetic turf surfaces perform much better than older versions, having lower surface hardness, better traction and being less abrasive (94). Their main problem is that when exposed to sunlight, synthetic turf systems heat up much faster than natural turfgrass. Research is currently underway to determine if the surface temperatures of infill synthetic turf systems can be effectively cooled by irrigation (94). Irrigating synthetic turf, however, negates a large reason for using them in the first place, namely to minimise maintenance costs and to preserve diminishing resources, such as water.

There has been considerable community backlash against the use of synthetic turf surfaces, both in the USA and in Great Britain. The Professional Footballers' Association in the UK are quoted as recognising the worth of synthetic pitches for development purposes but echo the views of the United European

Football Association who question whether there is any need to change from grass. They consider that there is a place for quality synthetic surfaces, especially at school and community levels, and in countries where it is impossible to achieve good grass, but would always support natural pitches where possible. In the USA, there have been attempts politically to prevent further installation of synthetic or artificial turf until a study is completed of potential adverse environmental and public health impacts of such material. The major concern appears to be that synthetic turf has been found to contain hazardous contaminants, including lead, arsenic, cadmium and chromium, and may not be an appropriate replacement for natural materials in all settings, but particularly concerning the safety of children in schools.

A recent study (46) reviews the potential health and safety risks from synthetic turf fields containing crumb rubber infill. This very comprehensive review did not find any reason for undue concern about the use of crumb rubber and any possible chemical contaminants contained therein. It concludes that the main health concern of synthetic turf sports fields is related to heat. It states that synthetic turf materials have shown significant temperature increases at the surface of the field and in ambient air above the playing field as compared to other surfaces, such as grass and asphalt. Elevated surface temperatures of synthetic turf may result in heat-related injuries associated with direct contact, such as burns and blisters, and may contribute to heat stress, particularly with children who are less able to adapt to temperature changes when humidity is high (46).

Despite these findings, the New Jersey Department of Health and Senior Services has issued a recent warning about the potential exposure to lead in

artificial turf (70). This report indicates that some fields tested with elevated lead in either dust and/or turf fibre samples were weathered and visibly dusty. It concludes that fields that are old ,that are used frequently, and that are exposed to the weather break down to dust, and these dust particles are a potential lead exposure risk. It also reports that the risk of lead exposure from new fields is low, particularly where the turf fibres are still intact and the lead is unlikely to be available for harmful exposure. As well, recent legal action has taken place in California where the Center for Environmental Health has found high levels of lead in artificial turf. The controversy concerning lead and other metal contamination from artificial turf surfaces is just beginning within the USA.

According to Fresenburg (59), synthetic turfgrass costs far exceed natural grass playing fields. Fresenburg calculated the costs of four field options: a regular native soil based grass field; a six-inch sand-capped natural grass field; a basic infill synthetic grass field; and a premium infill synthetic grass field. In a 16-year study, the annual average cost for each field type was as follows:

Natural soil-based field	\$33,522
Sand-capped grass field	\$49,318
Basic synthetic field	\$65,846
Premium synthetic field	\$109,013

Fresenburg (59) states that there is a national trend towards high schools, parks and recreation departments installing synthetic fields. Often the low cost of maintenance is the reason cited for such investments. However, the above costs indicate that this is not justifiably the case. The fact that they can stage more

events is the probable reason, as no natural field can ever stand the same amount of use as a synthetic field.

There are many variations of equine-based sports that utilise large areas of natural grass for their recreational pursuits. Examples are horse racing, polo, polocrosse and gymkhanas. Only small sections of horse sports, such as dressage and some pony clubs, use synthetic substitutes based mainly on reinforced sand. Recreational horse riding is a popular pursuit where suitable facilities exist, but as with other natural turfgrass areas, overuse of the facilities is a constant problem which drives the providers of such facilities to look for natural turf substitutes.

This is also a problem in the professional horse racing industry where there is an increasing use of synthetic tracks for training and, in some countries, for racing. The replacement for natural turf in these cases is mainly sand bound with oil or polymers (38), and sometimes reinforced with all types of fibres or shredded rubber. The lack of virtually no replicated and/or scientifically-validated data to support the installation of such non-guaranteed surfaces has caused millions of dollars to be wasted by the horse racing industry within Australia.

Race courses, however, have other benefits than just providing a venue for equine sports. They provide large areas of grass which, in turn, provides a constant area for carbon sequestration. Race courses also provide the venues for passive spectator enjoyment of horse racing as a social pastime. The value of spectator participation in sports, such as horse racing and football, has not been evaluated in a communal health benefit sense and is an area which deserves to be studied in much greater depth.

Golf courses and natural parklands provide the largest areas of open green space in most towns and cities. This is especially so in Australia where the availability of land has been relatively plentiful. These large open vistas provide social and health benefits not only to those who participate in the sports but also to those who live adjacent to these facilities and can enjoy their benefits in a passive way. There have been no specific studies of the health benefits directly attributable to playing golf, and this also deserves a scientific investigation.

Golf courses also provide one of the best opportunities for the clean-up of surface water run off from urban streets and hardscape areas, and there are numerous studies to show the effectiveness of cleaning water supplies by passing them through golf courses (27; 119).

The value of these large green spaces as carbon sinks with their combination of trees and turf cannot be underestimated in an urban environment. Very many golf courses in Australia have in recent years become very aware of their critical role as natural sanctuaries for wildlife in the urban environment (5). Many clubs have been accredited through the world-wide Audubon Society Wildlife Sanctuary Accreditation Scheme, and many more are in the process of gaining accreditation.

The Golf Industry has also instituted programs of environmental accreditation (5; 52; 53), and the importance of this aspect of their existence is recognised by an annual awards process. The detailed role and value of golf courses in environmental importance has not been evaluated in a thorough manner, and is certainly worthy of a much more intensive study.

Currently many clubs are using recycled water from sewage treatment works and sewage mining to recycle large volumes of water, and this is a trend that will become increasingly important in the future (114; 130).

There must be some concern that in some cities changing demographics are seeing some smaller inner city golf facilities being surrendered to urban development. The loss of large areas of green space in these situations needs careful review in terms of the social health benefits for these areas.

Bowling Clubs and their sport of Lawn Bowls has always been a traditional turf sport. It has also been generally seen as a sport for the older, aging sector of the population. Many bowling greens are established on communal parklands and provide an extra dimension to the green space in these areas. With a changing demographic, there has been a strong push from synthetic turf manufacturers to replace natural turf on bowling greens. This has largely resulted in a number of serious failures of the synthetic greens to live up to the manufacturer's promises. The heat factor associated with synthetic turf, described earlier, is especially significant for the health of older participants in lawn bowls, and has had severe adverse impacts on their enjoyment of the game.

Acknowledgements. We gratefully acknowledge assistance provided by Horticulture Australia Limited (HAL) and their support for this project.

We also gratefully acknowledge collaboration and valuable assistance provided by Associate Professor Mardie Townsend from the School of Health and Social Development, Deakin University, particularly in relation to the Section on Health and Wellbeing. We must also acknowledge Professor James Beard from

Texas A&M University who gratefully agreed to review this document in its entirety.

Literature cited.

1. ACTEW, 2008. Grass Roots – First year outcomes. From 'Grass Roots Live', a web-based portal. See www.actew.com.au/grassroots.
2. AGO, 2005. Climate Change in Rural and Regional Australia. Australian Greenhouse Office, Department of the Environment and Heritage. Canberra, ACT, Australia.
3. Aldous, D. 2000. Advances in Turfgrass Science and Management in Australasia. *Diversity* 16: 51-52.
4. ANZECC, 1992. Australian Water Quality Guidelines for Fresh and Marine Waters. Australian and New Zealand Environment and Conservation Council, Melbourne, Australia.
5. Australian Golf Union, 1998. Environmental Strategy for Australian Golf Courses. Published by AGU, ATRI and HRDC, April, 1998.
6. Baginska, B., Cornish, P.S., Hollinger, E., Kuczera, G. and Jones, D. 1998. Nutrient export from rural land in the Hawkesbury-Nepean Catchment. Proceedings of the 9th Australian Agronomy Conference, Wagga Wagga, 753-756.
7. Baird, J.H., Basta, N.T., Huhnke, R.L., Johnson, G.V., Payton, M.E., Storm, D.E., Wilson, C.A., Smolen, M.D., Martin, D.L. and Cole, J.T. 2000. Best management practices to reduce pesticide and nutrient runoff from turf. In ACS Symposium No.743 : Fate and Management of Turfgrass Chemicals. Clark, J.M. and Kenna, M.P. eds. American Chemical Society, 2000.

8. Baker, S.W. and Woollacott, A.R. 2005. Comparison of the playing performance of 'third generation' artificial grass with natural turf used for professional soccer. *International Turfgrass Society Research Journal* 10:15-26.
9. Balogh, J.C. and Walker, W.J., eds. 1992. *Golf Course Management and Construction: Environmental Issues*. 951 pp. Lewis Publishers, Michigan, USA.
10. Bandaranayake, W., Qian, Y., Parton, W., Ojima, D. and Follett, R. 2003. Estimation of Soil Organic Carbon Changes in Turfgrass Systems Using the CENTURY Model. *Agronomy Journal*. 95: 558-563.
11. Barton, L., Wan, G.G.Y., and Colmer, T.D. 2006a. Turfgrass (*Cynodon dactylon* L.) sod production on sandy soils: I. Effects of irrigation and fertiliser regimes on growth and quality. *Plant and Soil*. 284:129-145.
12. Barton, L., Wan, G.G.Y., and Colmer, T.D. 2006b. Turfgrass (*Cynodon dactylon* L.) sod production on sandy soils: II. Effects of irrigation and fertiliser regimes on N leaching. *Plant and Soil*. 284:147-164.
13. Baskaran, S., Kookana, R.S. and Naidu, R. 1997. Sorption and Movement of Some Pesticides Through Turf Profiles Under Australian Conditions. *International Turfgrass Society Research Journal*. 8, Part 1:151-166.
14. Beard, J. B. 1982. *Turf Management for Golf Courses*. Macmillan Publishing Co., New York, USA.
15. Beard, J. B. 1985. An Assessment of Water Use by Turfgrasses. In Gibeault, V. and Cockerham, S. eds. 1985. *Turfgrass Water Conservation*. Division of Agriculture and Natural Resources, University of California, Oakland, Ca, USA.
16. Beard, J. B. 1988. Controlling Turfgrass Water Use Rates. *New Zealand Turf Management Journal*. 2 (2):12.

17. Beard, J. B. 1989a. Turfgrass Water Stress: Drought Resistance Components, Physiological Mechanisms and Species-Genotype Diversity. Proc. Int. Turfgrass Conf., Japan. 6:23-28.
18. Beard, J. B. 1989b. Science shows turf can save water resources. Turf. Environ. 1(1):5.
19. Beard, J. B. 1990. Science Shows Turf Can Save Water Resources. Journal of Environmental Turfgrass 2(1):6.
20. Beard, J. B. 1992b. The Evolution of Turfgrass Sod. In Turfgrass: Nature's Constant Benediction. pp.9-16. (American Sod Producers Association).
21. Beard, J. B. 1993. The Xeriscaping Concept: What About Turfgrasses. International Turfgrass Society Research Journal. 7:87-98.
22. Beard, J. B. 1994. Environmental protection and beneficial contributions of golf course turfs. Pp. 399-408 in Science and Golf II: Proceedings of the World Scientific Congress of Golf. Cochran, A.J. and Farrally, M.R. eds. E. and F.N. Spon, London.
23. Beard, J. B. and Green, R. L. 1994. The role of turfgrasses in environmental protection and their benefits to humans. J. Environ. Qual. 23(3):452-460.
24. Beard, J. B. 2000. Turfgrass benefits and the golf environment. Pp. 36-44 in ACS Symposium No.743 : Fate and Management of Turfgrass Chemicals. Clark, J.M. and Kenna, M.P. eds. Published by American Chemical Society.
25. Beard, J. B. and Kenna, M. P. eds. 2008. Water Quality and Quantity Issues for Turfgrasses in Urban Landscapes. Council for Agricultural Science and Technology Special Publication No.27, Ames, Iowa, USA. 298pp.

26. Beard, J. B. and Sifers, S.I. 1997. Genetic Diversity in Dehydration Avoidance and Drought Resistance within the Cynodon and Zoysia Species. *International Turfgrass Society Research Journal*. 8:603-610.
27. Beehag, G.W. 1996. Implementation of a Pollutant Monitoring Program. Pp 98-115 in *Proceedings of Environmental Issues for Turf: A Symposium*. Australian Turfgrass Research Institute, Concord West, NSW, Australia.
28. Bitar, H. 2004. Public Aesthetic Preferences and Efficient Water Use in Urban Parks. Melbourne University PhD Thesis, January 2004.
29. Boeker, P. 1974. Root Development of Selected Turfgrass species and Cultivars. *Proceedings of the 2nd International Turfgrass Research Conference*. Pp.55-61.
30. Boeker, P. and Von Boberfield, O. 1974. Influence of various fertilizers on root development in a turfgrass mixture. *Proceedings of the 2nd International Turfgrass Research Conference*. Pp.99-103.
31. Bowman, D.C., Devitt, D.A. and Miller, W.W. 2000. The effect of salinity on nitrate leaching from tall fescue turfgrass. *ACS Symposium No.743 : Fate and Management of Turfgrass Chemicals*. Clark, J.M. and Kenna, M.P. Published by American Chemical Society.
32. Branham, B.E., Miltner, E.D., Rieke, P.E., Zabik, M.J. and Ellis, B.G. 2000. Groundwater contamination potential of pesticides and fertilizers used on golf courses. In *ACS Symposium No.743: Fate and Management of Turfgrass Chemicals*. Clark, J.M. and Kenna, M.P. Published by American Chemical Society.

33. Burls, A. 2007. People and green spaces: promoting public health and mental well-being through ecotherapy. *Journal of Public Mental Health*. 6 (3) :24 – 39.
34. BYU, 2002. Synthetic Surface Heat Studies - A Case Study at Brigham Young University. By Williams, C.F. and Pulley, G.E. in *Facts about Artificial Turf and Natural Grass*. Turfgrass Resource Center, East Dundee, Illinois. March, 2007.
35. CAST, 2008. Water Quality and Quantity Issues for Turfgrasses in Urban Landscapes. Proceedings of the Workshop on Water Quality and Quantity Issues for Turfgrasses in Urban Landscapes. Las Vegas, Nevada, Jan. 2006. Published by the Council for Agricultural Science and Technology, Special Publication No.27, 2008. Beard J.B. and Kenna, M.P. eds.
36. Chalker-Scott, L. 2001. The Myth of Polyacrylamide Hydrogels. Puyallup Research and Extension Center, Washington State University, USA.
37. Chalmers, D.R. 2006. Evaluation of Sixty-Day Drought Survival in San Antonio of Established Turfgrass Species and Cultivars: Year 1. A December 2006 Progress Report to the San Antonio Water System and the Turfgrass Producers of Texas. Texas A&M University System.
38. Chivers, I. 1996. Environmental Issues for Horse Racing. Pp 297-305 in *Proceedings of Environmental Issues for Turf: A Symposium*. Australian Turfgrass Research Institute, Concord West, NSW, Australia.
39. Cisar, J. L. 2004. Managing Turf Sustainably. Proc. Of the 4th International Crop Science Congress. Brisbane, Aust. 9pp.
40. Cisar, J. L. and Snyder, G.H. 2000. Mobility and persistence of pesticides applied to a US Golf Association green: Pesticides in percolate, thatch, soil, and clippings and approaches to reduce Fenamiphos and Fenamiphos metabolite

- leaching. ACS Symposium No.743 : Fate and Management of Turfgrass Chemicals. Clark, J. M. and Kenna, M. P. eds. Published by American Chemical Society.
41. Clark, J. M. and Kenna, M.P. eds. 2000. ACS Symposium No.743 : Fate and Management of Turfgrass Chemicals. Published by the American Chemical Society, Washington, DC. February,2000. 480ps.
42. CSIRO. 1983. Soils – An Australian Viewpoint. 928pp. CSIRO/Academic Press.
43. Cutt, H., Giles Corti, B., Knuiman, M., Timperio, A., and Bull, F. 2008. Understanding dog owners' increased levels of physical activity: Results from RESIDE. American Journal of Public Health. 98 (1):66-69.
44. Daniel, T.C., McGuire, P. E., Stoffel, D. and Miller, B. 1979. Sediment and Nutrient Yield from Residential Construction Sites. J. Environ. Qual. 8(3):304-308.
45. De Hollander, A. E. M. and Staatsen, B.A. M. 2003. Health, environment and quality of life: an epidemiological perspective on urban development. Landscape and Urban Planning. 65:53–62.
46. Denly, E., Rutkowski, K. and Vetrano, K. M. 2008. A Review of the Potential Health and Safety Risks from Synthetic Turf Fields containing Crumb Rubber Infill. Prepared for New York City Department of Health and Mental Hygiene, New York, USA. May, 2008. 200pp.
47. DPI&F Queensland. 2005. Reference plots of warm-season turfgrass cultivars. By Redlands Research Station of the Department of Primary Industries and Fisheries, Cleveland, Queensland, May 2005.

48. DPI&F Queensland. 2008. Drought Tolerant Turf. By Redlands Research Station of the Department of Primary Industries and Fisheries, Cleveland, Queensland, March 2008.
49. Eartheasy.com. 2007. Natural Lawn Care.
http://eartheasy.com/grow_lawn_care.htm, 19/06/2007.
50. Easton, Z. M., Petrovic, A. M., Lisk, D. J. and Larsson-Kovach, I. M. 2005. Hillslope position effect on nutrient and pesticide runoff from turfgrass. International Turfgrass Society Research Journal. 10, Part 1:121-129.
51. EPA of NSW, 1999. Review of Techniques to Estimate Catchment Exports. Technical Report No.99/73, Environment Protection Authority of NSW, Sydney, NSW, Australia.
52. European Golf Association, 1995. An Environmental Strategy for Golf in Europe. Compiled by D. Stubbs for Ecology Unit, European Golf Association.
53. European Golf Association, 1996. An Environmental Management Programme for Golf Courses – Report on Pilot Project. Compiled by D. Stubbs for Ecology Unit, European Golf Association.
54. Fam, D., Mosley, E., Lopes, A., Mathieson, I., Morison, J. and Connellan, G. 2008. Irrigation of Urban Green Spaces: a review of the Environmental, Social and Economic Benefits. Cooperative Research Centre for Irrigation Futures. Technical Report No. 04/08. April, 2008.
55. Feldhake, C. M., Danielson, R. E. and Butler, J.D. 1983. Turfgrass Evaporation. 1. Factors influencing rate in urban environments. Agronomy.Journal. 75:824-830.

56. Follett, R., Samson-Liebig, S.E., Kimble, J.M., Pruessner, E.G. and Waltman, S.W. 2001. Carbon Sequestration under the CRP in the Historic Grassland Soils in the USA. P.27-40 in Lal, R. and McSweeney, K. eds. Soil Carbon Sequestration and the Greenhouse Effect. SSSA Spec. Publ. 57. SSSA, Madison, WI.
57. Fresenburg, B. 2005. Synthetic Turfgrass Costs Far Exceed Natural Grass Playing Fields. Ph.D. thesis, University of Missouri. Reported in 'Facts about Artificial Turf and Natural Grass.' Turfgrass Resource Center, East Dundee, Illinois. March, 2007.
58. Fresenburg, B. and Adamson, C. 2005. Synthetic Turf Playing Fields Present Unique Dangers. Applied Turfgrass Science. EZ Search, Posted 3 November 2005. 2pp.
59. Fresenburg, B. 2006. Artificial Turf and Artificial Cost. International Turfgrass. (Newsletter of the International Turfgrass Society, July 2006). 1p.
60. Grahn, P. and Stigsdotter, U.A. 2003. Landscape planning and stress. Urban Forestry & Urban Greening. 2:1-18.
61. Green, C. H. 2004. Water Release from Cross-linked Polyacrylamide. Hydrology Days. 2004:253-260.
62. Greenhill, N. B., Peverill, K. I. and Douglas, L. A. 1983. Surface runoff from sloping fertilised perennial pastures in Victoria, Australia. New Zealand Journal of Agricultural Research. 26:227-231.
63. Gross, C. M., Angle, J. S. and Welterlen, M. S. 1990. Nutrient and Sediment Losses from Turfgrass. J. Environ. Qual. 19(4):663-668.

64. Gross, C. M., Angle, J. S., Hill, R. L. and Welterlen, M. S. 1991. Runoff and sediment losses from tall fescue under simulated rainfall. *J. Environ. Qual.* 20:604-607.
65. Gudsell, D. 2008. Next Generation Irrigation – Better than Drip. *Golf & Sports Turf Australia.* 16 (1):6.
66. Haeg, F. 2008. *Edible Estates: Attack on the Front Lawn.* Metropolis Books. D.A.P., New York. 128pp.
67. Hartig, T., Evans, G.W., Lamner, L.D., Davis, D. S. and Garling, T. 2003. Tracking restoration in natural and urban field settings. *Journal of Environmental Psychology.* 23: 109-123.
68. Hazelton, P. A. and Murphy, B. W. 1992. *What Do All the Numbers Mean? – A Guide for the Interpretation of Soil Test Results.* Department of Conservation and Land Management, Sydney, Australia.
69. Headey, B. 2003. Pet ownership: good for health? *Medical Journal of Australia.* 179: 460-461.
70. Health Alert Network. 2008. *Potential Exposure to Lead in Artificial Turf: Public Health Issues, Actions and Recommendations.* Health Alert Network Press Release of June 18th, 2008.
71. Henderson-Wilson, C. 2008. PhD Thesis from Deakin University, School of Health and Social Development, 2006. *Living High but Healthy: High-Rise Housing, Nature, Health and Wellbeing.* Article in "The Australian", 2008.
72. Higginson, F. R. and McMaugh, P. E. 2007. *The Optimal Use of Turf in Minimising Soil Erosion on Construction Sites.* Project TU06018, Horticulture Australia Limited, Sydney, Australia. 26pp.

73. Huang, B., Duncan, R. R. and Carrow, R. N. 1997. Root Spatial Distribution and Activity of Four Turfgrass Species in Response to Localised Drought Stress. *International Turfgrass Society Research Journal*. 8:681-690.
74. Huang, B. and Fry, J. D. 1999. Turfgrass Evaporation. Pp. 317-334. In Kirkham, M. B. ed. *Water Use in Crop Production*. Food Products Press, New York.
75. Hunter Headlines. 2007. Making Cities Green: European Tramways Add Turf. *Irrigation News and Insights*. 15:1-4. Hunter Industries Inc., California, USA.
76. Jo, Hyun-Kil and McPherson, E. G. 1995. Carbon Storage and Flux in Urban Residential Greenspace. *Journal of Environmental Management*. 45:109-133.
77. Jones, C. 2007. Australian Soil Carbon Accreditation Scheme. In *Managing the Carbon Cycle*. Katanning Workshop, 21-22 March, 2007.
78. Kent, S. 2007. Carbon Sequestration in Urban Turf Soils. ASA-CSSA-SSSA International Annual Meetings (Nov. 4-8) New Orleans, Louisiana, USA.
79. Kim, K. S. and Beard, J. B. 1988. Comparative Turfgrass Evapotranspiration Rates and Associated Plant Morphological Characteristics. *Crop Sci*. 28:328-331.
80. Kiri-ganai Research Pty Ltd, 2007. Australian Turf Industry Stocktake Project. 89pp., Canberra, ACT, Australia.
81. Koehler, F. A. et al. 1982. Best Management Practices for Agricultural Nonpoint Source Control. II Commercial Fertilizer & III Sediment. North Carolina Agricultural Extension Service, NC, USA.
82. Loch, D. S. pers.com. Synthetic Turf – Strengths and Weaknesses. Undated. 1p.

83. Loch, D. S. 1998. The Samuel and Eileen Gluyas Churchill Fellowship to study the effects of Plant Breeder's Rights on the breeding of new cultivars of herbage species. Report to the Winston Churchill Memorial Trust of Australia. May, 1998.
84. Loch, D. S. 2008. Choosing a Green Couch Cultivar: Factors to Consider. Department of Primary Industries and Fisheries, Queensland. Draft Report, 2008. 11pp.
85. Loch, D. S., Barrett-Lennard, E. and Truong, P. 2003. Role of salt tolerant plants for production, prevention of salinity and amenity values. In Proceedings of the 9th National Dryland Salinity Program's Productive Use and Rehabilitation of Saline Land (PUR\$) Conference. Yeppoon, Qld., 2003.
86. Maas, J., Verheij, R. A., Groenewegen, P. P., de Vries, S. and Spreeuweberg, P. 2006. Green space, urbanity, and health: how strong is the relation? *Journal of Epidemiology and Community Health*. 60:587-592.
87. Maheshwari, B. 2006. The Efficiency and Audit of Residential Irrigation Systems in the Sydney Metropolitan Area. Cooperative Research Centre for Irrigation Futures. Technical Report No. 01/06.
88. Maller, C., Townsend, M., Brown, P. and St. Leger, L. 2002. Healthy Parks Healthy People – The Health Benefits of Contact with Nature in a Park Context – A Review of Current Literature. Deakin University and Parks Victoria. Social and Mental Health Priority Area Occasional Paper Series 1. 86pp.
89. Maller, C., Townsend, M., Pryor, A., Brown, P. and St. Leger, L. 2006. Healthy Nature Healthy People: 'Contact with Nature' as an upstream health promotion intervention for populations. *Health Promotion International*. 21:45-54.

90. Maller, C., Townsend, M., St. Leger, L., Henderson-Wilson, C., Pryor, A., Prosser, L. and Moore, M. 2008. Healthy parks, healthy people – The health benefits of contact with nature in a park context – A review of relevant literature. Deakin University and Parks Victoria. 2nd Edition. March, 2008. 96pp. Melbourne, Australia.
91. Martin, P. M. 2004. The potential of native grasses for use as managed turf. In Proceedings of the 4th International Crop Science Congress. Brisbane, Australia. 26 Sep to 10 Oct, 2004. 17pp.
92. Martin, P. M. and Aragao, S. 1996. Soil and nutrient movement in runoff water from turf farms in the Wyong region of NSW. pp 155-163 in Proceedings of Environmental Issues for Turf: A Symposium. Australian Turfgrass Research Institute, Concord West, NSW, Australia.
93. McCarty, L. B. and Tucker, B. J. 2005. Prospects for managing turf weeds without protective chemicals. International Turfgrass Society Research Journal. 10 (Part 1) : 34-41.
94. McNitt, A. S. 2005. Synthetic turf in the USA – Trends and Issues. International Turfgrass Society Research Journal. 10 (Part 1):27-33.
95. Menzells, C., Broomhall, P. and Gash, M. 2006. Irrigating turfgrasses with recycled water. In Irrigation 2005. Townsville, Qld, Australia (Irrigation Association of Australia).
96. Milesi, C., Elvidge, C. D., Dietz, J. B., Tuttle, T., Nemani, R. R. and Running, S. W. 2005. Mapping and Modeling the Biogeochemical Cycling of Turf Grasses in the United States. Environmental Management. 36 (3):426-438.

97. MLA. 2008a. Carbon Storage in the Grassy Woodlands. Feedback. Published by Meat and Livestock Australia, North Sydney, NSW. March, 2008.
98. MLA. 2008b. Agriculture leads in Greenhouse Reduction. Feedback. Published by Meat and Livestock Australia, North Sydney, NSW. April, 2008.
99. MLA. 2008c. Trading Greenhouse Emissions. Feedback. Published by Meat and Livestock Australia, North Sydney, NSW. June/July 2008. p.20.
100. Morris, K. N. and Hossain, A. H. 2000. As the Demand for Turfgrass Grows, So Must Turfgrass Germplasm Collection and Evaluation. *Diversity*. 16(1 & 2):15-17.
101. Nelson, E. B. and Craft, C. M. 2000. Microbial strategies for the biological control of turfgrass diseases. ACS Symposium No.743 : Fate and Management of Turfgrass Chemicals. Clark, J. M. and Kenna, M. P. eds. Published by American Chemical Society in 2000.
102. Novak, J. 2006. Overview of the Turfgrass Sod and Green Industry. *International Turfgrass Society Newsletter*. July, 2006.
103. Nowak, D. J. and Crane, D.E. 2002. Carbon Storage and Sequestration by Urban Trees in the USA. *Environmental Pollution*. 116 (3):381-389.
104. Park, D. M., Cisar, J. L., Snyder, G. H., Erickson, J. E., Daroub, S. H. and Williams, K.E. 2005. Comparison of actual and predicted water budgets from two contrasting residential landscapes in southern Florida. *International Turfgrass Society Research Journal*.10. Part 2:885-889.
105. Pathan, S. M., Barton, L. and Colmer, T. D. 2003. Evaluation of a soil moisture sensor to reduce water and nutrient leaching in turf. Project TU02006, Horticulture Australia Limited, Sydney, Australia.

106. Peterson, D. 2002. Hydrophilic Polymers – Effects and Uses in the Landscape. Restoration and Reclamation Review.,14pp., Student On-Line Journal. Dept. of Horticultural Science, University of Minnesota, USA.
107. Petrovic, A. M. and Easton, Z. M. 2005. The role of turfgrass management in the water quality of urban environments. International Turfgrass Society Research Journal. 10 (Part 1):55-69.
108. Potera, C. 2003. Green spaces raise chances of success. Environmental Health Perspectives. 111 (13):A694.
109. Potter, D. E. 2005. Prospects for managing destructive turfgrass insects without protective chemicals. International Turfgrass Society Research Journal.10 (Part 1) : 42-54.
110. Pretty, J., Peacock, J., Sellens, M. and Griffin, M. 2005. The mental and physical health outcomes of green exercise. International Journal of Environmental Health Research.15 (5):319-337.
111. Pretty, J., Peacock, J., Hine, R., Sellens, M., South, N. and Griffin, M. 2007. Green exercise in the UK countryside: Effects on health and psychological well-being, and implications for policy and planning. Journal of Environmental Planning and Management. 50 (2):211-231.
112. Priest, M. W., Williams, D. J. and Bridgman, H.A. 2000. Emissions from in-use Lawn Mowers in Australia. Atmospheric Environment. 34 (4):657-664.
113. Qian, Y. and Follett, R. F. 2002. Assessing Soil Carbon Sequestration in Turfgrass Systems Using Long-Term Soil Testing Data. Agronomy. Journal. 94 (4) 930-935.

114. Richardson, G. 1996. Sewer Mining; an Alternative Water Source. pp 216-223 in Proceedings of Environmental Issues for Turf: A Symposium, Australian Turfgrass Research Institute, Concord West, NSW, Australia.
115. Robbins, P. and Sharp, J. 2003. Producing and consuming Chemicals: The moral economy of the American lawn. *Economic Geography*.79:425-451.
116. Roehr, D. and Laurenz, J. 2008. Living Skins: Environmental benefits of green envelopes in the city context. *Transactions of the Wessex Institute of Technology*. eLibrary, July 2008, 10pp. Also published in *Eco-Architecture II: Harmonisation between Architecture and Nature*. Broadbent, G. and Brebbia, C. A. eds. 368pp. 2008.
117. Rogers, W. 1991. Turf's Role in Today's Multi-use Landscape Designs – An Architect's Viewpoint. *Journal of Environmental Turfgrass*. 3 (1): 3.
118. Sahu, R. 2008. Technical Assessment of the Carbon Sequestration Potential of Managed Turfgrass in the United States. Research report presented to the Green Industry & Equipment EXPO, Louisville, Kentucky. Organised by the Outdoor Power Equipment Institute Inc. (OPEI), Alexandria, VA, USA.
119. Scaife, D. 1996. Camden Lakeside Country Club – A Case Study in Environmental Management. pp 291-296 in Proceedings of Environmental Issues for Turf: A Symposium. Australian Turfgrass Research Institute, Concord West, NSW, Australia.
120. Shearman, R. C. 1985. Turfgrass Culture and Water Use. In Gibeault, V. and Cockerham, S. eds. *Turfgrass Water Conservation*. Division of Agriculture and Natural Resources, University of California, Oakland, Ca, USA.

121. Short, D. and Colmer, T. 1999. Update on WA water use study: a comparison of eleven turfgrass genotypes during the summer in Perth. *Australian Turfgrass Management*. 1 (5), Oct-Nov 1999.
122. Shuman, L. M., Smith, A. E. and Bridges, D. C. 2000. Potential movement of nutrients and pesticides following application to golf courses. *ACS Symposium No.743 : Fate and Management of Turfgrass Chemicals*. Clark, J. M. and Kenna, M.P. eds. American Chemical Society. 2000.
123. Sigler, W. V., Taylor, C. H., Throssell, C. S., Bischoff, M. and Turco, R. F. 2000. Environmental fates of fungicides in the turfgrass environment. *ACS Symposium No.743 : Fate and Management of Turfgrass Chemicals*. Clark, J. M. and Kenna, M. P. eds. American Chemical Society. 2000.
124. Snyder, G. H. and Cisar, J. L. 1997. Mobility and Persistence of Turfgrass Pesticides in a USGA-type Green. IV. Dicamba and 2,4-D. *International Turfgrass Society Research Journal*. 8 (1):205-211.
125. Spronken-Smith, R. A., Oke, T. R. and Lowry, W. P. 2000. Advection and the Surface Energy Balance Across an Irrigated Urban Park. *International Journal of Climatology*. 20 (9):1033-1047.
126. Sullivan, L. and Parr, G. 2008. Plantstones could help lock away carbon. Reported in *New Scientist* No. 2637. 07 January 2008. p.9.
127. Takano, T., Nakamura, K. and Watanabe, M. 2002. Urban residential environments and senior citizens' longevity in megacity areas: the importance of walkable green spaces. *Journal of Epidemiology and Community Health*. 56:913-918.

128. Taliaferro, C. M. and McMaugh, P. E. 1993. Developments in Warm-Season Turfgrass Breeding/Genetics. *International Turfgrass Society Research Journal*. 7:14-25.
129. Taylor, A. F., Wiley, A., Kuo, F. E. and Sullivan, W. C. 1998. Growing up in the inner city: Green spaces as places to grow. *Environment and Behaviour*. 30 (1):3-27.
130. Thomson, A. and Beer, I. 1996. Irrigating Turf with Effluent – Case Histories. pp 191-206 in *Proceedings of Environmental Issues for Turf: A Symposium*. Australian Turfgrass Research Institute, Concord West, NSW, Australia.
131. Ulrich, R. S. 1986. Human Responses to Vegetation and Landscapes. *Landscape Urban Planning*. 13:29-44.
132. USGA. 1994. USGA Environmental Research Program – Pesticide and Nutrient Fate – 1991-1993 Summary. By United States Golf Association, New Jersey, USA. 438pp.
133. USGA. 2001. Turfgrass and Environmental Research Executive Summary. By United States Golf Association, New Jersey, USA.
134. Walsh, K. 2005. *Waterwise Gardening*. 3rd Edition. 176pp. Reed New Holland, Sydney, Australia.
135. Watschke, T. L. 1990. Turfgrasses Can Safely Clean Our Water Supplies. *Journal of Environmental Turfgrass*. 2 (1):1.
136. Watschke, T. L., Mumma, R.O., Linde, D. T., Borger, J. A. And Hamilton, G.W. 2000. Surface runoff of selected pesticides applied to turfgrasses. ACS Symposium No.743 : Fate and Management of Turfgrass Chemicals. Clark, J. M. and Kenna, M. P. eds. American Chemical Society. 2000.

137. Wells, N. M. 2000. At Home with Nature: effects of "greenness" on children's cognitive functioning. *Environment and Behaviour*. 32(6):775-795.
138. Wells, N. M. and Evans, G. W. 2003. Nearby Nature: a buffer of life stress among rural children. *Environment and Behaviour*. 35(3):311-330.
139. Wood, L., Giles Corti, B. and Bulsara, M. 2005. The Pet connection: Pets as a conduit for social capital? *Social Science and Medicine*. 61(6):1159-1173.
140. Yumlu, S. V. 1994. Lawn Mower Use and Emissions in Canada. Report EPS 5/AP/6 for the Environment Protection Service, Canada.