An Environmental Assessment of the Australian Turf Industry –

Milestone 102 Literature Survey

Hort. Innovation project no. TU16000

Spread of Turf grower in Australia

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Infotech Research

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Introduction

This is a report on the data that is available to the turf industry from all sources about its environmental performance and best practice. This study has attempted to cover the full lifecycle of turf from growing to installation and maintenance of turf over its lifespan.

The open literature and reference agencies were surveyed for information on the efficiencies of various systems and technologies of turf growing.

Horticulture Innovation Australia (Hort Innovation) has provided a set of relevant project reports that have been examined. We have also been referred to other academic and commercial reports with relevance to this topic. We examined irrigation efficiency studies that have included turf growers. Our literature search has extended to overseas turf/sod farming practice efficiencies, especially in relation to water and energy.

Universities and suppliers to the industry have been approached as has the Australian Bureau of Agriculture and Resource Economics and Sciences (ABARES), the Australian Bureau of Statistics (ABS) and the various state departments of agriculture for irrigation and land management issues. The Australian Golf Course Superintendents' Association (AGCSCA) has also been approached for golf course maintenance data.

Background

The turfgrass industry occupies a special niche in Australian agriculture. Turf is a non-food intensive horticulture product that services high profile applications such as golf courses, sporting fields and feature gardens, as well as domestic lawns. The ABS does not have a separate classification for turfgrass and reports on the general category: *Nurseries, cut flowers and cultivated turf.* The ABS valued this category at $832.8m in the year ending June 30, 2015. This figure grew by 13.2% from the previous year and represented 5.5% of the total value of irrigated agricultural production (Gross Value of Irrigated Agricultural Production, 2014-2015).

The peak industry body for turf is Turf Australia, which advises that there are 4,400 ha of turf under cultivation at any one time in Australia worth $300m at the farm gate. This is produced by 250 businesses across Australia. Turf Australia states that the installation and maintenance market is worth approximately $500m pa and services some 10,000 turf installations in Australia (Turf Producers Australia, 2016).

Turf Australia suggests that growing is split as follows: 38% in Queensland, 33% in NSW, 15% in Victoria, 11% in Western Australia, with the remaining 3% split between the other states and territories.

Defining the scope

The journey of turf from seed to installed lawn, or active sporting field, requires the application of technologies as well as the impact of solar energy, nutrients and water to the growing grass. Maintenance of turf installations requires adequate watering and fertilisation through its lifespan. All of the material inputs and outputs as wastes have an impact through resource depletion, pollution of the environment or both.

This study has chosen the following *key environmental performance factors* (KEPIs) to establish benchmarks with which to gauge the performance of the industry.

Environmental impact	Applicability to turf	Financial significance	Risk to grower	Risk to environment	KEPI for grower
Energy resource use	Yes	Yes			Yes
Greenhouse emissions	Yes	No		Yes	Yes
Carbon sequestration	Yes	Possible		No	Yes
Water resource use	Yes	Yes	Yes	Yes	Yes
Surface water pollution	Yes	Yes	Yes	Yes	Yes
Surface water eutrophication	Yes	Possible	Yes	Yes	Yes
Ground water loss	Possible	Possible	Yes	Yes	Yes
Soil loss / erosion	Possible	Possible	Yes	Yes	Yes
Soil contamination	Possible	Yes	Yes	Yes	Yes
Land contamination	Possible	Yes		Yes	Yes

Table 1. Environmental Aspects of turfgrass

Each of the environmental impacts has been studied to find existing information on grower performance. Information sources used have included:

- Published literature
- Industry guidelines
- Industry suppliers
- Industry bodies
- Academics and researchers.

Information has been sought primarily for Australian industry performance data with some examination of published information from the US and Canada and European turfgrass producers.

Environmental impacts of turfgrass

Australian turf growers have in some respects, a harsher set of conditions in which to grow turf than in the US and Europe. The climate is generally dryer and soils are often poorer, with less nutrients. What they do have in Australia is an abundance of sun, so the addition of nutrients and irrigation can lead to productive turfgrass propagation.

The key to successful and sustainable turfgrass propagation is to minimise the risks associated with losses of soil, water and nutrients to the wider environment, while maintaining optimal turf growth conditions. Much effort has been placed in assisting growers with systems, guidelines and management systems to achieve optimal outputs.

The state departments of agriculture, water authorities and researchers have teamed up to produce guidelines for turf growers on best practice turf production and maintenance. These guidelines relate to the key efficiency factors of water use, fertiliser use and carbon sequestration and are available from Victoria (Connellan, 2002), NSW (Sydney Water, 2011), WA (Swan River Trust, 2014) and Queensland (Roche, 2010).

The first article to comprehensively examine the environmental benefits of turf for human health was written by Beard and Green (Green, 1994). It examined the functional, recreational and aesthetic aspects of turfgrass. Hort Innovation has been instrumental in funding investigations into the environmental benefits of turfgrass with the work of Peter McMaugh (McMaugh, 2010). McMaugh's work considered water and energy consumption, as well as the benefits of carbon sequestration from turf. Soil movement and nutrient flows were also covered in this report. McMaugh and Higginson later looked at soil movement and nutrient flows in another Hort Innovation funded project to identify the benefits of turf in controlling erosion on building sites (Higginson, 2007). This article was a precursor to the development of a standard for turf use.

Erosion control is one of the most topical issues for turf and is the subject of a recent draft Australian Standard: DR AS 5181:2016 ***Use and installation of turf as an erosion, nutrient and sediment control measure*** (Standards Australia, 2016).

The overall conclusion drawn by Beard and Green and other researchers was that turf as a product, produced many positive aspects to enhance the environment as well as the health and wellbeing of those who enjoyed it in recreational and contemplative activities. This has been amplified by McMaugh and extended by others to include its positive impact on Global Warming through net carbon sequestration of 50 to 200 $g/m^2/y$ (Zirkle, 2011).

Lifecycle approach to turf and the environment

Most environmentally focussed studies have been directed at turfgrass installations and their maintenance. Very little had been undertaken, until recently, to investigate the environmental impacts of turf grower operations. This is an important aspect of the investigation of lifecycle impacts of turf.

A number of studies of turf grower operations have been undertaken recently. In 2015 a study of 16 NSW turf growers undertaken by Mick Battam, pointed out that approximately 13 tonne of soil was removed per ha. with the product turf when it was harvested.

Turf Queensland has undertaken some turf farm investigations to assess water efficiency, energy efficiency and nutrient losses (Turf Queensland, 2015). The University of Western Australia has established a turf research program that has published work on turf grower material efficiencies in sandy soils encountered in WA (Colmer, 2009; Barton, 2012).

No literature was found that covered the full lifecycle of turfgrass itself. A study from the University of South Australia in 2007 compared natural and synthetic turf surfaces impacts (Walker, 2007). The conclusion was not particularly clear from the information presented. The Department of Sports and Recreation WA extended the investigation regarding turf use on sports fields (Dep. of Sport & Rec. WA, 2011) with a conclusion that lifecycle costs for natural turf were considerably lower than the synthetic equivalent for most types of sporting applications.

Carbon Dioxide and Global Warming

When considering the global warming potential of turfgrass, lifecycle impacts need to be quantified. In most cases the impacts of installations have been considered in isolation so that a full account of the turf lifecycle is not produced.

The carbon and nutrient cycle associated with turfgrass involves the movement of carbon and nitrogen through the plant zone. The chemicals that are potentially volatile can contribute to global warming, while photosynthesis and respiration move carbon dioxide in and out of the plant. These should be considered to determine the global warming potential of the turf. The key gases in turf are carbon dioxide, nitrous oxide, ammonia and methane. Carbon dioxide is sequestered as organic carbon by the plant. Organic carbon can be stored by the plant in its root matter and in the leaf structure. Soil carbon can build up over 30+ years (Qian, 2002) at a rate of about 1T/ha.y.

The net impact on global warming is the difference between the carbon sequestered by the turfgrass and the Greenhouse Gas (GHG) emissions derived from the soil and maintenance operations. The net benefit of turfgrass installations as lawns was estimated to be between 25 and 127 grams of carbon per m^2 per year (Zirkle, 2011). This is approximately three times the negative impact associated mainly by emissions from mowing operations.

The net global warming savings per year of a well kept lawn is equivalent to approximately the same area of mature forest (Australia's Chief Scientist, 2009).

Carbon sequestration

The process of photosynthesis results in vegetation growth, thus locking in the carbon to a biological system. When turf grows the roots and leaves form and hold the carbon in their structure. The maintenance stage of turf in which the grass structure is maintained by mowing, leaves the root structure as the predominant means of further carbon sequestration.

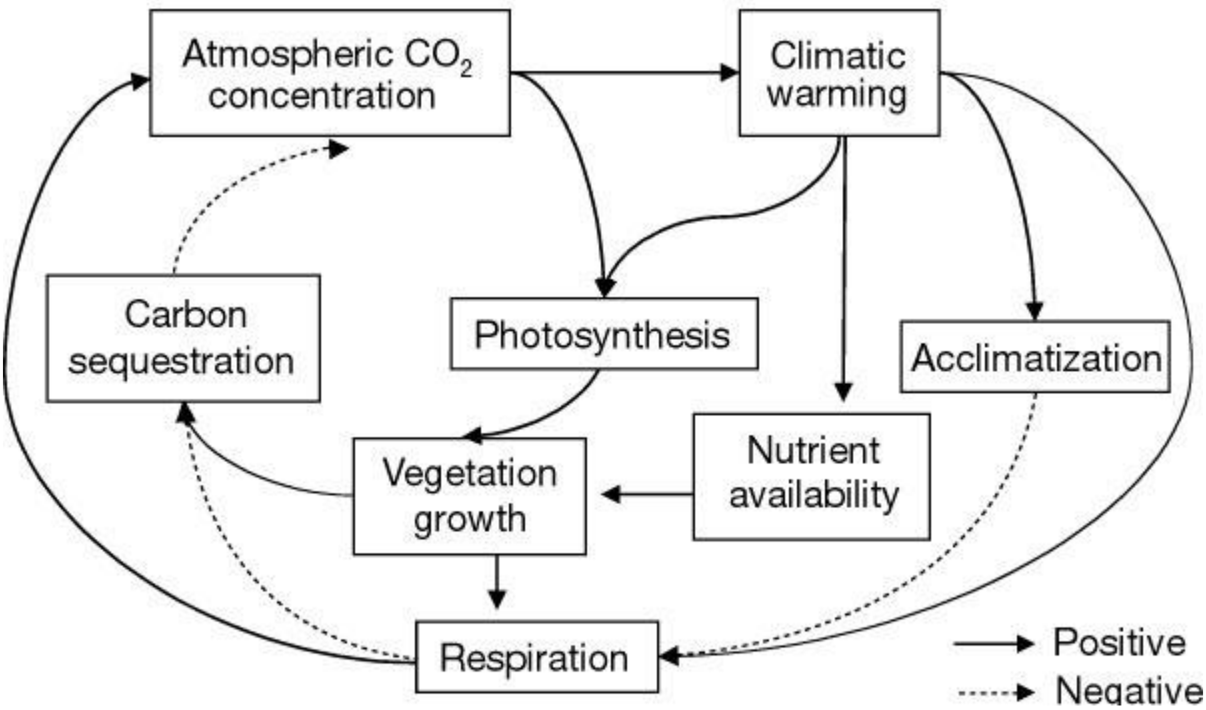

Diagram 1. The Carbon Cycle for turfgrass
Taken from: Yiqi Luo, Shiqiang Wan, Dafeng Hui and Linda L. Wallace *Nature* **413**, 622-625(11 October 2001)

No studies were found that looked at carbon sequestration at the turf farm itself. This is likely to be at a higher rate than the maintenance stage of established turf installations, as the leaf structure is forming above ground as well as the root structure.

Considering the wide variation in methods of carbon sequestration that included longitudinal measurements, historical assessments, modelling and direct carbon flux measurements the results were in fair agreement (summarised in Table 2). There were also variations in the sequestration calculation that was either a gross carbon accumulation, or a net calculation in which Greenhouse emissions from maintenance activities, notably carbon emissions from mowing equipment, were considered. An allowance for soil emissions of other Greenhouse gases such as nitrous oxide, methane and carbon monoxide are also required to gain a reliable net carbon sequestration result.

In a recent study by Baird, carbon fluxes were measured for turf plots under deficit and normal irrigation regimes to determine annual carbon uptake by the turf (Baird, 2013). The impact of the irrigation regime on carbon sequestration was not consistent with different turf species, but was up to 40% higher for the deficit irrigation tests.

Turfgrass Carbon Sequestration research

Authors	Ref year	Application	Method		Carbon[1]		CO_2(eq)[2]	
					g/m2-y	T/ha-y	T/ha-y	
Zirkle, Lai and Augustin	2011	Lawns (US)	modelled	net carbon[3]	46 - 127	0.46 - 1.27	1.69 - 4.66	Soil only
Jenerette and Baird	2013	Golf course turf	measured	gross carbon[4]	268 - 384	2.68 - 3.84	9.84 - 14.1	whole plant
Qian and Follet	2002	Golf course fairways	measured		90 - 120	0.9 - 1.2	3.30 - 4.40	Soil only
Livesley, Ossola, Threlfall, Hahs & Williams	2016	Golf course fairways	measured	gross carbon	20	0.2	0.7	Soil only

Table 2. Carbon sequestration by turfgrass

These authors drew several interesting conclusions about impacts of environmental conditions on carbon sequestration rates:

- Lawns are net sinks for atmospheric carbon dioxide even in cases where minimal maintenance is undertaken
- Fertilisation positively affected turf growth and the sequestration rate
- Fertilisation also increased the emission of Greenhouse gases such as nitrous oxide, but generally at much lower rates than to carbon sequestration
- The use of pesticides increases Greenhouse emissions (from a lifecycle perspective) due to the high raw material embodied energy of these chemicals
- Direct Greenhouse gas emissions from motor mowers contributed the largest emission counter to turf sequestration
- Livesley et.al. demonstrated that carbon concentrations were highest in the soils under tree canopies and these soils contained a higher carbon to nitrogen ratios than grassed areas. They concluded that a tree canopy can buffer any nitrogen losses from turf areas and potentially prevent bacterial and algal blooms from nutrient losses to waterways.

[1] Carbon is measured as carbon atoms rather than as carbon dioxide molecules that are 3.67 times heavier (CO2 eq = 3.67 x C)
[2] $CO_{2(eq)}$ is the agreed factor used to measure Greenhouse or global warming potential (1 gram of CO_2 = 1 gram of $CO_{2(eq)}$, 1 gram of N_2O = ~ 300 gram of $CO_{2(eq)}$)
[3] Net carbon is a term that takes into account the Greenhouse Gas emissions that oppose the absorption of carbon dioxide from the atmosphere by the plant.
[4] Gross carbon sequestration is the measurement of the amount of carbon absorbed by the plant and does not subtract the various Greenhouse Gas emissions in associated processes.

These studies confirm the ability of turfgrass to sequester carbon in plant matter, particularly roots that can extend to 150 mm depth in the soil.

Organic carbon in the first 50 mm may be 4 to 5% of the total dry soil composition and this represent 94% of the total root matter in the soil. In area terms, dry root matter is distributed at 1.2 kg/m of turf area (Boeker, 1974).

Atmospheric emissions

Greenhouse gases absorb heat in the atmosphere and interfere with night time cooling of the atmosphere leading to global warming. While the debate rages around the edges of this effect, the central principles of global warming have been established for many years. Some molecules absorb heat more effectively than others and have differing levels of impact on global warming.

The key gases with global warming potential in an agricultural context are carbon dioxide, nitrous oxide, methane and other volatile methanic hydrocarbons.

Gas species	Global Warming potential $CO_{2(eq)}$	Atmospheric Abundance in the Troposphere (PPM)[5]	Percentage of Global Warming Impact
Carbon Dioxide (CO_2)	1.0	400	57%
Nitrous Oxide (N_2O)	298	0.3	6%
Methane (CH_4)	34	1.8	15%
Refrigerant gases	,000's	PPT	10%
Ozone[5]	,000's	Stratosphere[6]	12%

Table 3. Greenhouse Gas summary (Blasing, 2016)

The Greenhouse Gas missing from the list in Table 3 is water vapour. This is a very effective Greenhouse Gas but is not persistent in the atmosphere, unlike the other gases in the table. Water vapour concentrations vary greatly but are currently estimated to average 5,000 ppm. Blasing notes that the water vapour concentrations will rise with global warming.

Nitrous Oxide

Nitrous Oxide, N2O, is formed by denitrifying bacteria that reduce nitrate to nitrous oxide and elemental nitrogen gas, N_2. This causes a loss of nitrogen to the soil and a loss of nutrient for plants.

The nitrogen cycle for turf growing is given in Diagram 2.

[5] Ozone is generated as a result of atmospheric pollution in the troposphere, but has a short half-life, while it is continuously regenerated in the stratosphere.
[6] The Troposphere is the main layer of the atmosphere at the earth's surface, the Stratosphere is above the Troposphere where the ozone layer resides. Ozone is in a state of flux as it is destroyed by UV radiation and then reforms continuously to provide UV protection at the earth's surface.

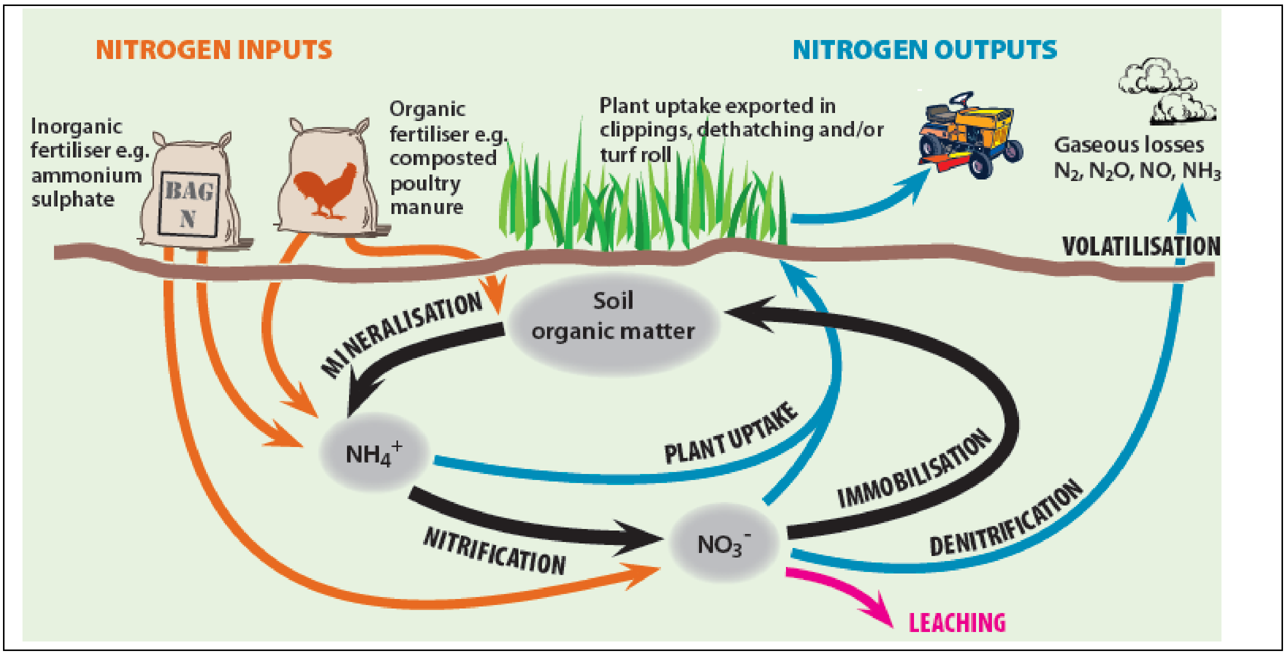

Diagram 2. The Nitrogen Cycle for turf (adapted from McLaren and Cameron (Cameron, 1996) by University of Western Australia Turf Research Programme)

Nitrogen fertilisers are applied to enhance plant growth. Nitrogen is lost from turf in grass clippings, in the product turf roll and to the atmosphere as nitrogen gas or nitrous oxide. Broad estimates give the loss of N to nitrogen gas and nitrous oxide is globally about 2.5% of the nitrogen applied. Australian agriculture is more efficient at a N loss to atmosphere of about 1.5%, of which the nitrous oxide may be one third (Grace, 2014).

The objective of fertilisation is to provide adequate nutrients to the plant at the same time to minimise losses to the atmosphere and losses from N leaching away from the plant root zone. Nitrous oxide is a particular case in which conditions that favour denitrifying bacteria will lead to greater N losses.

Nitrous oxide emissions from turf have been modelled for various cultivars of turfgrass under different soil types (Y. Zhang, 2014). The DAYCENT model was compared with measurements by Kaye (Kaye, 2004) with satisfactory results (agreement within 8%). Fluxes of N_2O between 2 and 2.5 kg N/ha.y were calculated for a fertiliser application rate of 150 kg N/ha.y (1.7% N lost as N_2O).

With constant fertilisation rates of 150 kg N/ha.y the emission rate of N_2O was modelled to rise over 50 years to approximately double that of early years. There was some dependence on irrigation rates from 60%[7] to 100% of pan evaporation. The authors concluded that there was reason to reduce the rate of fertilisation as the turf matures to approximately 50%. This modelled to reduce the N_2O emissions by 40% over the lifetime of the turf installation.

This work has led to the publication of guidelines to minimise the loss of N in fertilisers as nitrous oxide (Long, 2015). The essential features of these guidelines that may apply to turf are:

- N_2O losses are highest in water logged soils where anaerobic conditions can prevail
- N2O emissions can vary from less than 1 to over 30 kg N_2O-N/ha.y (0.1-3 g N_2O-N/m^2.y)

[7] PET Precipitation Evapotranspiration rate

- Fertiliser applications should be avoided when conditions are wet and warm (>15°C)
- The use of animal green manures can increase microbial activity and N_2O emissions
- Application of fertilisers should coincide with plant uptake / growth as much as possible
- The inhibition of nitrification will reduce N_2O production
- Consider the use of controlled release fertilisers when the potential for N_2O emissions is high.

Nitrogen utilisation efficiency, NUE, is suggested as a key management measure for fertiliser management. (NUE = N in product / N in fertiliser applied x 100%) A NUE of 35% is considered good in intensive pasture for animal grazing. Golf course nitrogen studies (Hedlund, 2005) gave a NUE between 15 and 102%. Leaching losses of mineralised N between 0.3 and 15% of fertilisation were measured.

Ammonia

Ammonium sulphate is a commonly used fertiliser in which the ammonium ion, NH_4^+, is the active nutrient component. Ammonium ion can be neutralised to form ammonia, NH_3, a volatile gas that can be lost to the atmosphere. Bacterial action on urea can also produce ammonia leading to N losses to the atmosphere.

If alkaline soil conditions are encountered (pH > 8) NH_4^+ will convert to NH_3. This is very unlikely, however the conversion of urea to NH_3 may occur at neutral to alkaline soil conditions. Losses of N due to volatilisation have been measured in field experiments by Walker and Branham from 9 to 41%. More volatilisation occurs under dryer and hotter conditions (Walker W. a., 1992).

It should be noted that ammonia is not a Greenhouse Gas and will not affect global warming potential of the turfgrass installation.

Methanic gases

Methane is produced by anaerobic bacterial action on biodegradable organic matter. On the other hand, methane, can be oxidised to carbon dioxide by aerobic bacteria. Studies on soil-atmosphere exchange of methane have shown that turfgrass can act to remove atmospheric methane (Kaye, 2004). These researchers found all soils were net methane sinks with native grasslands consuming 0.3 g C (in CH_4)/m^2.y (3 kg C/ha.y).

Gillette et.al. studied methane fluxes from a golf course fairway and rough, that was poorly drained, and found net methane emissions of 0.055 and 0.036 g C (in CH_4)/m^2.y (K.L. Gillette, 2014). This reduced to values of 0.038 and 0.001 g C/m^2.y the following year after drainage was improved. This confirmed the need of anaerobic conditions associated with water logging contributing to the production of methane in soils.

Nevertheless, the production or consumption of methane as a contributor to net Greenhouse Gas emissions or savings is relatively minor, varying from slightly negative 13.6 g $CO_{2(eq)}$/m^2.y to positive 2.5 g $CO_{2(eq)}$/m^2.y.

Energy

Two operations dominate energy use in turfgrass production and maintenance: mowing and irrigation. Mowing energy has been assessed for urban mowing petrol at 14 g (fuel)/m^2.y by Jo and McPherson (McPherson, 1995) this produced 113.2 g/m^2.y of grass clippings. This may be a worst case scenario as turf growers and organisations maintaining open greenspaces will use more efficient equipment. However, they will mow the turfgrass more frequently.

Turf mowing at a golf course was recorded at 1.56 ha/h (AGCSA, 2012) with a fuel consumption rate of 7.5 L/h the fuel use was 0.36 g/m^2 with 72 mowings per year, the consumption is 26 g (fuel)/m^2.y. The conversion from fuel to direct emission of exhaust carbon dioxide is 3.67 g of CO_2 per g of fuel.

Irrigation energy is the product of the irrigation efficiency and the volume of water irrigated. Turf farm studies, undertaken by Turf Queensland, produced irrigation pump efficiencies between 275 and 323 kWh/ML pumped (C.Carson, 2015) using pivot irrigators. This compared to assessments of vegetable grower irrigation efficiency measurements that ranged from 202 to 460 kWh/ML (Cumming, 2014).

Maintenance irrigation water usage depends on the climatic conditions and the varieties of turfgrass, but may be 600 L/m^2.y for sports fields. This gives an irrigation energy consumption of 0.18 kWh/m^2.y (0.65 MJ/m^2.y) at 300 kWh/ML irrigated.

Application of energy	**Area**	**MJ/m^2.y**	**g $CO_{2(eq)}$/m^2.y**
Mowing	Golf Course	1.2[8]	95
Irrigating	Turf Farm	0.65	211
Total		1.85	306

Table 4. Estimates of Energy use and energy related GHG emissions of turf

Irrigation may be twice the greenhouse Gas source of mowing. There are significant uncertainties and variations in energy calculations, which depend on the situation under study and need to be determined when the application is known.

This data is still useful in gaining an understanding of the net Greenhouse impacts of turfgrass in growing and installation stages.

Net Greenhouse impact/carbon sequestration

Emission factor	Net C sequestration g $CO_{2(eq)}$/m^2.y	Reference used	Year	
Photosynthesis	1,190	Jenerette and Baird	2013	
Nitrous Oxide	- 68	Zhang	2014	
Methane	13.6	Kaye	2004	
Mowing (fuels)	- 95	AGCSA	2012	
Irrigation (elec. pumps)	- 211	Carson	2015	
Net sequestration	830			

Table 5. Indicative net sequestration of carbon dioxide by turfgrass

[8] The energy intensity of diesel fuel is 38.6 MJ/L (density 0.85 kg/L)

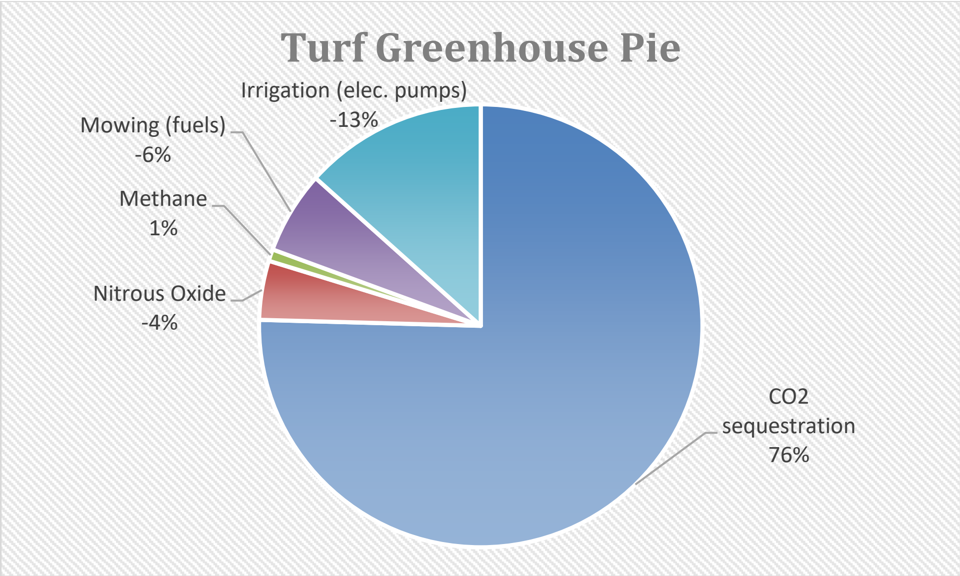

Figure 1. Greenhouse segments for turfgrass

These aspects of turf growing and maintenance are dominated by the carbon sequestration of the turf itself in photosynthesis. This impact can be diminished over the lifespan of the turfgrass if fertiliser is continually applied at a constant rate. The nitrous oxide emissions rise over time to levels that can challenge sequestration by the plants (Y. Zhang, 2014). The rate of nitrous oxide emission growth can be accelerated by increasing fertilisation rates and irrigation of the turfgrass to produce waterlogging.

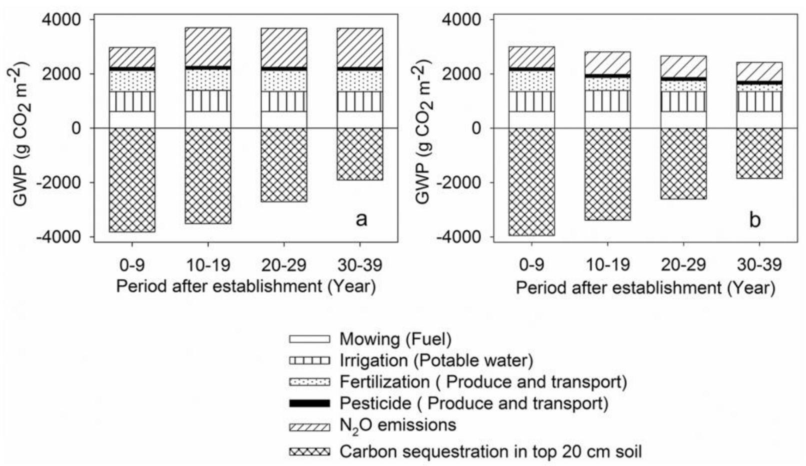

Figure 2. Net global warming impacts - taken from (Zhang, 2014)

Zhang et.al. predict a loss of carbon sequestration over decades with potential loss of sequestration potential after 30 to 40 years of turf life. They suggest that these impacts can be ameliorated with the gradual reduction in fertilisation rates for mature turfgrass.

Soil and Erosion

Soil migration through erosion is a critical function leading to loss of top soil and the nutrients that it carries. This requires a rain event, or over irrigation that result in runoff from the site that carries the soil in the form of suspended particles.

Turfgrass has a role to play in the control of erosion that has been recognised by the industry and has resulted in the development of an Australian Standard for the use of turf as an erosion, nutrient and sediment control measure at present in a draft form (***DR AS 5181:2016 – Use and Installation of turf as an erosion, nutrient and sediment control measure***). Much of the work and detail of the standard was based on studies conducted at a demonstration facility at Cleveland, Queensland (Pearce, 2013).

The effect of turfgrass is two-fold with the root structure assisting in holding the soil together, preventing suspension of the surface soil in the storm water and the leaf structure above ground interfering with the surface water flow, reducing flow rates and trapping soil particles and nutrients.

Erosion of soils is a major issue for agriculture across the globe with billions of tonnes of top soil lost to rivers and the seas each year. Urban runoff, including turfgrass, contributes less than 1% of this loss and turf itself has a role to play in preventing much greater losses (McMaugh P. , 2010). In a study of runoff from rural land in the Hawkesbury Nepean catchment (B. Baginska, 1998) nutrient export rates of 200 kg N/ ha.y and 15 kg P/ha.y were found from market gardens, down to 4N and 2P kg/ha.y from unimproved pasture. This nutrient export is deposited in the Hawkesbury River with outcomes that include blue-green algae outbreaks and eutrophication that compromised the river ecosystems health.

Nutrient and soil losses are costly to agriculture with 1 tonne of N in fertiliser costing more than $1,000 (Grace, 2014), so the loss of 200 kg N/ha.y represents a loss of at least $200/ha.y to the farmer.

Turf Queensland has published findings from a turf farm in the hinterland of the Gold Coast where bare earth (harvested areas), sprigged turfgrass (newly sewn) and full sod (mature turf) turf strips were compared in their ability to retain soil and nutrients from stormwater runoff (Carson, 2011). This study collected sediment from runoff after rain storms.

After waiting for significant rain storms that produced runoff, Carson found that full sod sloped turf areas was over 100 times more effective in retaining soils.

	Bare earth	Sprigged area	Full sod
Slope	7.3°	6.4°	7.5°
Cumulative soil loss (tonne/ha.)	60.5	35.8	0.55
Nitrate / Nitrite in runoff water (grab only)	2.5 mg/L	2.4 mg/L	1.3 mg/L
Phosphorus in sediment estimated from cumulative total	9.1 kg/h	3.2 kg/h	0.1 kg/h

Table 6. Comparative soil/nutrient losses due to erosion (Carson, 2011)

These results demonstrated the effectiveness of turfgrass in preventing soil and nutrient losses from land during a storm event as well as the concern that bare ground after turf harvesting is at risk of soil losses.

Turf farm studies have estimated soil losses from turf farms in the range 0.04 to 2.13 tonne/ha.y (averaging 0.61 tonne/ha.y). This is above unimproved pasture but well below other forms of intensive horticulture (McMaugh P. , 2010). The variation in performance indicates a range of different circumstances faced by turf growers and the range in conservative management practices of turf farmers.

Leaching of nutrients from turfgrass depends on several factors, the most important being the fertiliser application rate and the irrigation regime. The use of control release fertilisers, fertigation systems and irrigation based on replacement of water lost as evapotranspiration are all valuable to reduce losses.

The effectiveness of planting turfgrass buffer strips was compared to prairie grass buffer strips in Wisconsin USA and turf showed to be at least twice as effective in retaining soil solids and phosphorus during the periods in which the ground was not frozen (K. Steinke, 2008).

Soil contamination

Soil contamination can arise from the legacy of former activities on the land, in which cases the occupier must understand the hazards associated with the contamination and manage these risks accordingly.

Contamination issues that can arise include:

Contamination	**Sources**	**Risks**	**Management**
Heavy metals Antimony, Lead, Cadmium, Copper, Mercury…	- natural to area - fill materials - industrial activities - fly ash, mining wastes	Toxicity - Human contact - ecosystems	Clean up Removal of contaminated soil
Oils	- spillage - old machinery	Toxicity - soils Odour	Clean up Removal of contaminated soil
Pesticides	- spillage - used containers	Toxicity - Human contact	Destruction incineration removal
Asbestos	- building wastes - fill materials	Toxicity chronic - Human contact	Encapsulation Removal
Pathogens	- putrescible wastes - sewerage solids (biosolids) - septic tank wastes	Toxicity acute - Human contact	Disinfection

Table 7. Contamination issues

Water

Water sources used by turf farmers include irrigation water sourced from rivers and metered to the property, town water supplied by municipal authorities, recycled water also supplied by municipal authorities (usually Class C water), ground water (from bores) and surface water collected in dams.

The critical factor in sourcing irrigation water is its quality. Acidic pH may result in rusting irrigation infrastructure and the leaching of toxic metals like aluminium into the water. Alkaline water can result in scaling up of irrigation equipment and loss of mineral nutrients in the irrigation water (Brunton, 2011). Metal contamination can have toxic effects on the turf growth and may contaminate the soil. Saline water can have toxic effects on the turf and can build up in the soil yielding it infertile. Organic contamination can cause eutrophication, odour and anaerobic soils. Nutrients in the water can be beneficial if they are suitable for the turf to use and at a level that suits the plant growth stage.

The average turf farm consumes 6.5 ML/ha.y (Turf Queensland, 2013), but the irrigation water requirements depend on the stage of growth of the turf, the climatic conditions (rainfall and evapotranspiration), the turf growth cycle and the time of year.

Turf installations likewise vary in their demand for irrigation water. Sports fields require a high level of irrigation as they are generally based on well drained soil bases with underlying drainage systems. Average water usage for sports fields is 600 $L/m^2.y$ (60 ML/ha.y) (Dep. of Sport & Rec. WA, 2011). Golf courses have environmental conservation protocols and water efficiency is a core objective. Golf courses usually water twice per week during the hotter months and when the turf is growing. The application is from 3.8 to 5.08 cm/week (Aliance for Water Efficiency, 2016) (over 30 weeks/y gives 11.4 to 15.2 ML/ha.y). Domestic lawns require approximately 2.5 cm of water per week during the hotter months (Today's homeowner, 2016) that calculates out to 7.5 ML/ha.y. This coincides with Barton's base water needs for turf installations in WA (Barton, 2012).

These usage estimates assume optimal irrigation that supplies sufficient water to keep water to the roots of the plant. This can be calculated for the specific plant (Connellan, 2002)

Water use = Evaporation (mm) x Crop factor (F)

Plant	Crop factor (deficit irrigation)	Crop factor (optimal – high growth)
Turf (cool season varieties)	0.65	0.85
Turf (warm season varieties)	0.25	0.7

Table 8. Irrigation crop factors

It can be concluded from the crop factors that the choice of turf variety can have a significant impact on watering requirements. Warm season turf varieties such as Buffalo, Couch and Kikuyu can offer water savings over cool season varieties such as Tall Fescue and Ryegrass.

Water usage efficiency has been defined as Gross Ecosystem Production / Evapotranspiration (WUE = GEP/ET). This was examined by Jenerette and Baird for the USGA (Baird, 2013) for several turfgrass varieties with results between 1.5 and 4 for WUE. The GEP varied for these varieties between 8.5 and 12 $ugCO_2\text{-}C/m^2.s$ = 268 to 378 g $CO_2\text{-}C/m^2.y$.

Researchers have come up with a list of irrigation water efficiency improvement measures that can be considered by turf farmers and for turf maintenance alike.

Water saving options:

1. Deficit irrigation (Barton, 2012) (may be practised for a period)
2. Warm season turf species can tolerate less water and more deficit irrigation

3. Planned irrigation frequency based on rain and climatic conditions
4. Use irrigation systems with high application efficiencies (drip, or sprinklers)
5. Use of soil wetting agents where hydrophobicity occurs
6. Subsurface irrigation systems
7. Optimise the surface coverage of the irrigation system
8. Fertigation systems
9. Recovery of stormwater for irrigation
10. Use of grey water
11. Use of recycled water
12. Establish a mowing height that maximises water retention (reduces ET)
13. Use of a soil moisture sensor to control irrigation frequency and period

The suitability of these options depends on the circumstances of the turf farm or turf installation including the climatic conditions and the soil types.

Nutrients

Turfgrass plants rely on the availability of nutrients essential to their growth. These nutrients are supplied through the soil and through the leaf structure and are applied as fertiliser directly to the soil or through irrigation water in the fertigation process. The turf industry has provided training services, which include information about fertilisation practices that protect the environment while providing ideal turfgrass growing conditions. (Ellis, 2012) This has also been undertaken through the Australian Golf Environmental Initiative for turf installation maintenance (AGCSA, 2010).

While turfgrasses and all other plants require a range of micronutrients and macronutrients. The macronutrients required are the focus of environmental considerations as they have the potential to impact the environment. These are nitrogen which is taken up by plants as nitrate ($NO3^-$), phosphorus available to the plants as phosphate ($PO4^{3-}$), as well as potassium, calcium, magnesium and sulphur in smaller quantities.

The water soluble nitrate (also nitrite NO_2^- and ammonium ion NH_4^+) and phosphate can move with the water flow. If these species pass the plant root zone or run off in the surface water, they can impact the external environment negatively. The key issue with both nitrogen and phosphorus pollution is their nutrient qualities causing bacterial and algal blooms in water bodies, with a potential for loss of oxygen and bad effects on the ecosystems. Agricultural fertiliser use is also significant in depleting finite resources affecting global sustainability.

The objective of turf growers and turf managers alike is to maximise the efficiency of fertiliser application, while minimising nutrient losses to the environment from the plant root zone.

Nitrogen

Nitrogen is essential in many parts of plants. It can be applied to turf in a mineralised or an organic form, a common rapid effect form is ammonium nitrate. This is water soluble and readily absorbed by the turf plants. However, it can be lost through irrigation surface runoff and it can also be lost through leaching of irrigation water below the root zone to groundwater systems. Organic forms of nitrogen can be applied, such as urea and animal manures. These rely on bacterial action to mineralise the nitrogen for plant uptake.

Bacterial action can reduce nitrate to nitrogen and nitrous oxide gases in anaerobic (water logged conditions) as previously discussed (Kaye, 2004). Nitrogen will also be lost with sediment from erosion that may be water borne or air borne.

Studies examining nitrogen losses in leachate from established turfgrass grass plots show little loss of nitrate/ammonium nitrogen. A study by Hesketh estimated approximately 100% retention of applied nitrogen from clippings analysis and a leachate with a nitrate concentration of less than 1 mg/L at fertiliser application rates of 78 and 144 kg N/ha.y (Hesketh, 1995). They detected some nitrate in leachate at a concentration of 4-14 mg/L at a fertiliser application rate of 288 kg N/ha.y.

A Florida study of turfgrass (St.Augustinegrass) compared it with a mixed species of native shrubs and grasses. Both plots were fertilised at a rate of 300 N kg/ha.y. These plots showed no surface runoff of nitrogen and a leachate loss of 4.1 N kg/ha.y for the turfgrass plot and 48.3 N kg/ha.y for the mixed species plot (Erickson, 2001). The concentration of nitrate in leachate from the turfgrass plot was always < 0.4 mg/L and had a mean concentration < 0.2 mg/L while the mixed species averaging 1.46 mg/L.

Phosphorus

Phosphorus is also an essential and widely spread element in all plants. Like nitrogen it is taken up by plants through its available water soluble form of phosphate. Unlike nitrogen it does not form volatile compounds and does not volatilise, however, the other transport mechanisms do apply. Phosphorus transport models predict that most of the phosphorus will be carried by solids / sediments with water borne sediment being the prime phosphorus transport mechanism (USDA, 2006).

Phosphorus losses	All crops (US) Lb/acre.y	kg P /ha.y
Wind borne sediment	0.1-1.8	0.1-2.0
Water borne sediment	0.5-3.4	0.6-3.8
Surface runoff	0.1-0.9	0.1-1.0
Leachate	0.0-0.2	0.0-0.2
Total P loss ave.	2.2	2.5

Table 9. Phosphorus losses across all crops (USDA)

Grass/hay production had the lowest total phosphorus loss rate at 1.1 kg P/ha.y. The application rate estimated over grasses was 5 kg/ha.y, giving a loss percentage of 22% mainly through waterborne sediment losses.

A study of transport of phosphorus in turfgrass (Petrovic, 2008) indicated that P inputs range from 2 to 10 kg/ha.y and the outputs of P in clippings ranging from 0.4 to 7.5 kg/ha.y. Leaching of P varied from inconsequential to severe depending on the timing of rain events and their coincidence with fertilisation events. P leaching losses from mineral soils of 0.2 to 0.7 kg/ha.y were considered to be similar to surface runoff losses. They also concluded that P losses from erosion and sediment borne P were low from turfgrass.

Sediment linked losses of phosphorus account for up to 80% of the total losses in agriculture, which can be linked to the loss of soil from agriculture. Turfgrass installations will have a very low soil loss as long as the turf cover is maintained, but this is not necessarily the case in turf farming at the seeding stage of the growing cycle when the ground is bare. There is a significant risk of phosphorus and general nutrient losses to surface water systems at the start of the turf growing cycle.

Surface water pollution

Surface water pollution is the result of contamination in surface water runoff from a turf installation. The risk of contamination of runoff water is highest when a rain event immediately follows fertilisation, or the rain event causes soil erosion and sediment is swept into a receiving water body.

A significant risk of surface water pollution is from the leaching of nutrients and chemicals applied to the turf laterally through the subsurface soil to an adjacent water body.

No details of studies were found to evaluate the risk of surface water pollution from turf farms situated near rivers and creeks.

It should be noted that pesticides are formulated to be hydrophobic and as such will attach to solids in preference to dissolving in water. This property gives them a persistence where they are applied so that they are not easily washed off the plant and can act to protect it for a suitable length of time. Pesticides are less likely to pollute surface of groundwater systems than are soluble nutrients.

Ground water pollution

Groundwater pollution is linked with leachate from the turf and is more problematic in loosely structured and sandy soils.

In general groundwater has shown increases in nitrate of 0.1-1.9 mg/L (Hallberg, 1987). This is attributable in the main to fertiliser use in agriculture. Pesticide levels have also increased to low ug/L concentrations again due to agricultural use. The allocation of groundwater pollution causes to specific farming activities is problematic due to movement of soluble species such as nitrate through water bodies and the movements of groundwaters themselves.

No direct studies of the effects of turf farms or installations on groundwater were found.

Modelling of nutrient flows

There is a wide array of computerised cropping system models that have been developed to estimate the flow of nutrients through soil, water, air and biomass in agricultural systems. The most important factors in a model for this project will be an estimated level of erosion, nutrient export rates, greenhouse gas emission fluxes, evapotranspiration, nutrient leaching and changes in soil organic carbon (SOC).

The most commonly used agricultural models are: EPIC, DSSAT and APSIM.

Other common models are: AnnAGNPS, STICS, WOFOST, ORYZA, CROPSYST, RZWQM, IMPACT, SWAP and DayCENT.

Review of models

Agricultural Production Systems sIMulator (APSIM)

APSIM is a modular modelling framework that has been developed by the CSIRO and QDAF in **Australia**. APISM contains modules to estimate water balance, N and P transformations, soil pH, erosion in range of cropping environments, including **pasture**. AgPasture is a module within the APSIM framework that has been well validated in Australia. APSIM is a modern model with a wealth of current support material.

A study on grain yields in Australia by Goode et al., (2016) found that APSIM could adequately model changes in SOC, and that most of the discrepancies could be attributed to data collection errors.

Romera et al., (2017) used APSIM to accurately model nitrogen leaching in New Zealand, with an R^2 of 0.9 and a root mean squared prediction error of 0.1.

Environmental Policy Integrated Climate (EPIC) Model

The Environmental Policy Integrated Climate (EPIC) is a field-scale biogeochemical process model developed by the United States Department of Agriculture (USDA) to represent plant growth, soil hydrology, and soil heat budgets for multiple soil layers of variable thickness, multiple vegetative systems, and crop management practices (Cooter et al., 2012).

EPIC model is able to calculate soil erosion from wind and rain, and nutrient flows such as leaching through soil, gas fluxes and sequestration of soil. EPIC already includes tools to analyse carbon and nitrogen in the soil.

Decision Support System for Agrotechnology Transfer (DSSAT)

The DSSAT model requires daily weather data, soil surface and profile information, and detailed crop management as input. Simulations are initiated either at planting or prior to planting through the simulation of a bare fallow period. Simulations are conducted at a daily step and at the end of the day the plant and soil water, nitrogen and carbon balances are updated, as well as the crop's vegetative and reproductive development stage. There are modules for a wide variety of crops, however **turf or pasture is not included**, so the applicability of this model is poor. This model incorporates the CENTURY model.

Annualized Agricultural Non-Point Source Model (AnnAGNPS)

AnnAGNPS is a hydrological model developed by the USDA with collaboration from the US Geological Service and Natural Resource Conservation Service to monitor water, sediment and nutrient flows. Required input parameters for the model are climate, watershed physical information and land management operations. Input parameters can be estimated using PEST.

AnnAGNPS was applied to the prediction of export of nitrogen and phosphorus from Currency Creek, a small experimental catchment within the Hawkesbury–Nepean drainage basin of the Sydney Region, using version 2 of the software in 2001 (version 5 is now available). The catchment is 255 ha in area and has experienced extensive soil erosion and losses of nutrients from intensive vegetable cultivation, irrigated dairy pasture and poultry farms.

Li et al., (2015) compared predicted and observed annual runoff during the validation period (2011–2013) and produced an R^2 value of 0.97.

Simulateur mulTIdisciplinaire pour les Cultures Standard (STICS)

STICS was developed at INRA in France and simulates crop growth as well as soil, water and nitrogen balances driven by daily climatic data.

WOrld FOod STudies (WOFOST)

WOFOST is a simulation model for the quantitative analysis of the growth and production of annual field crops. The model estimates evapotranspiration and water balance and is mainly used to predict the maximum attainable performance of a crop.

ORYZA

ORYZA is a model that simulates the growth of rice and incorporates a water and nutrient balance (Wopereis et al 1996).

Cropping Systems Simulation Model (**CROPSYST**)

CropSyst was developed by Washington State University in USA and simulates soil, water and nitrogen budgets, crop growth and development, crop yield, residue production and decomposition, soil erosion by water, and salinity (Stöckle et al 2003).

Root Zone Water Quality Model (RZWQM)

RZWQM simulates the growth of the plant and the movement of water, nutrients and pesticides over, within and below the crop root zone of a unit area, however the model does not include factors above the surface.

International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT)

IMPACT is used to analyse long-term food security. (Robinson et al., 2015).

Soil, Water, Atmosphere and Plant (SWAP)

SWAP was developed in the Netherlands to simulate transport of water, nutrients and heat throughout the soil profile (Van Dam et al., 2008).

DAYCENT

DAYCENT is an adaption of the CENTURY model

A study (Wang et al., 2017) found that DAYCENT accurately modelled SOC and CO_2 emissions, with a coefficient of determination of 0.75 and 0.97 respectively, however modelled N_2O emissions were significantly underestimated. DAYCENT was used in another study (Cooter et al., 2012) where significant correlation was achieved between modelled and measured N_2O emissions, but there were still concerns over accuracy of results. Cooter et al (2009) deemed that modelled and measured SOC correlated well, and that soil nitrate was significantly under estimated.

The APSIM model is a very suitable for estimating the nutrient flows that occur during turf production. APSIM is capable of calculating N_2O and CO_2 fluxes, changes in SOC, N and P leaching, and water balances. The APSIM model has been developed and validated in Australian conditions, it is up-to-date, frequently cited in very recent publications, and uniquely, has a specific module for pasture which likely could be adapted for turf production systems.

AnnAGNPS is very capable in estimating sediment runoff specifically, and could be used in conjunction with APSIM, if required.

Conclusions

The focus of most research has been the effective maintenance of turfgrass installations under different applications. Some work has been done on turf growing in relation to the potential for soil erosion from the growing sites (B. Baginska, 1998). Benchmarks for energy use and GHG emissions are not available for growers, but data is available with modelling of nutrient movement for installations. This will aid this work on turf lifecycle impacts and provide a platform for grower and installation measurements.

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