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A model of greenhouse gas emissions from the management of turf on two golf courses

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ABSTRACT

An estimated 32,000 golf courses worldwide (approximately 25,600 km^2), provide ecosystem goods and services and support an industry contributing over $124 billion globally. Golf courses can impact positively on local biodiversity however their role in the global carbon cycle is not clearly understood. To explore this relationship, the balance between plant–soil system sequestration and greenhouse gas emissions from turf management on golf courses was modelled. Input data were derived from published studies of emissions from agriculture and turfgrass management. Two UK case studies of golf course type were used, a Links course (coastal, medium intensity management, within coastal dune grasses) and a Parkland course (inland, high intensity management, within woodland).

Playing surfaces of both golf courses were marginal net sources of greenhouse gas emissions due to maintenance (Links 0.4 ± 0.1 Mg CO_2e $ha^{-1}y^{-1}$; Parkland 0.7 ± 0.2 Mg CO_2e $ha^{-1}y^{-1}$). A significant proportion of emissions were from the use of nitrogen fertiliser, especially on tees and greens such that 3% of the golf course area contributed 16% of total greenhouse gas emissions. The area of trees on a golf course was important in determining whole-course emission balance. On the Parkland course, emissions from maintenance were offset by sequestration from trees which comprised 48% of total area, resulting in a net balance of -4.3 ± 0.9 Mg CO_{2e} $ha^{-1}y^{-1}$. On the Links course, the proportion of trees was much lower (2%) and sequestration from links grassland resulted in a net balance of 0.0 ± 0.2 Mg CO_{2e} $ha^{-1}y^{-1}$. Recommendations for golf course management and design include the reduction of nitrogen fertiliser, improved operational efficiency when mowing, the inclusion of appropriate tree-planting and the scaling of component areas to maximise golf course sequestration capacity. The findings are transferrable to the management and design of urban parks and gardens, which range between fairways and greens in intensity of management.

1. Introduction

In the UK and Ireland alone there are approximately 3000 golf courses serving an estimated 1.5 million associated golfers (KPMG, 2008). With the number of golf courses worldwide exceeding 32,000 (Tanner and Gange, 2005) and a typical golf course area of 60–80 ha (EPA, 2009), the spatial scale of this capacity can be estimated to be in the region of 19,200–25,600 km^2 worldwide. Whilst this is relatively small compared to other land uses such as agriculture, the majority of golf courses are located on or close to, the urban fringe. Where located within urban areas, golf courses provide significant areas of amenity turf which often forms the only unsealed, photosynthetically active areas in that environment (Maas et al., 2009). Golf also has a considerable economic impact, estimated to be €53 billion in 2006 for Europe, the Middle East and Africa, and $62 billion in the USA in 2000 (KPMG, 2008), equivalent to US$124 billion, accounting for changes in inflation. This economic impact has been shown to affect land management decisions, with golf tourism providing a greater economic return per unit of irrigation water than agriculture in Spain for example (Rodriguez Diaz et al., 2007).

Golf courses provide ecosystems goods and services as defined by the Millennium Ecosystem Assessment (2005). These include support and regulation of both above and below-ground biodiversity; storing and cycling essential nutrients; and water attenuation and filtration. Golf courses have been shown to have a significant and positive impact on local biodiversity (Tanner and Gange, 2005; Tratalos et al., 2007) and the use and presence of amenity grasslands has also been shown to have a beneficial impact on human health (Mitchell and Popham, 2008). Nutrient cycling on golf courses provides the capacity to sequester atmospheric greenhouse gasses (GHG) through soil organic carbon accumulation (Milesi et al., 2005; Qian and Follett, 2002). Sequestration is offset by the direct and indirect emissions of GHG from the maintenance of the golf course, including emissions of CO_2 from maintenance equipment engines and the application of synthetic

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Notation

Parameter	Description
ρ_w	Density of water (kg m^{-3})
χ	Total greenhouse gas efflux for a particular golf course component (Mg CO_2e ha^{-1} y^{-1})
$\chi_{fairways}$	Total greenhouse gas efflux for fairways (Mg CO_2e ha^{-1} y^{-1})
χ_{greens}	Total greenhouse gas efflux for greens (Mg CO_2e ha^{-1} y^{-1})
χ_{other}	Total greenhouse gas efflux for other areas (Mg CO_2e ha^{-1} y^{-1})
χ_{rough}	Total greenhouse gas efflux for rough (Mg CO_2e ha^{-1} y^{-1})
χ_{tees}	Total greenhouse gas efflux for tees (Mg CO_2e ha^{-1} y^{-1})
χ_{trees}	Total greenhouse gas efflux for trees (Mg CO_2e ha^{-1} y^{-1})
a.i.	Active ingredient of an agrochemical
c_c	Number of oil changes per year on the agrochemical sprayer
c_F	Number of oil changes per year on the tractor used for fertiliser application
c_M	Number of oil changes per year on the mowers
A	Total area of golf course (ha)
$A_{fairways}$	Area of fairways (ha)
A_{greens}	Area of greens (ha)
A_n	Area of non-playing components of the golf course (ha)
A_{other}	Area of other parts of the golf course (ha)
A_p	Area of playing components of the golf course (ha)
A_{rough}	Area of rough (ha)
A_{tees}	Area of tees (ha)
A_{trees}	Area of trees (ha)
C_{elec}	UK standard emissions coefficient for national grid electricity production and distribution
$C_{ai(f)}$	Fungicide greenhouse gas coefficient (kg CO_2e L^{-1})
$C_{ai(h)}$	Herbicide greenhouse gas coefficient (kg CO_2e L^{-1})
$C_{ai(i)}$	Insecticide greenhouse gas coefficient (kg CO_2e L^{-1})
$C_{f(d)}$	Diesel greenhouse gas coefficient (kg CO_2e L^{-1})
$C_{f(p)}$	Petrol greenhouse gas coefficient (kg CO_2e L^{-1})
C_i	Water application (irrigation) greenhouse gas coefficient (kg CO_2e L^{-1})
C_K	Potassium fertiliser greenhouse gas coefficient (kg CO_2e kg^{-1})
C_l	Lubricant greenhouse gas coefficient (kg CO_2e L^{-1})
C_N	Nitrogen fertiliser greenhouse gas coefficient (kg CO_2e kg^{-1})
C_P	Phosphorus fertiliser greenhouse gas coefficient (kg CO_2e kg^{-1})
C_w	Water production greenhouse gas coefficient (kg CO_2e L^{-1})
E	Energy consumed by pump in irrigation water application (kWh L^{-1})
G	Acceleration due to gravity (m s^{-2})
H	Irrigation pump head (m)
M	Total greenhouse gas emissions from maintenance for a particular golf course component (Mg CO_2e ha^{-1} y^{-1})
M_A	Greenhouse gas emissions from aeration of a particular golf course component (Mg CO_2e ha^{-1} y^{-1})
M_C	Greenhouse gas emissions from agrochemical application for a particular golf course component (Mg CO_2e ha^{-1} y^{-1})
M_F	Greenhouse gas emissions from fertiliser use for a particular golf course component (Mg CO_2e ha^{-1} y^{-1})
M_I	Greenhouse gas emissions from irrigation application for a particular golf course component (Mg CO_2e ha^{-1} y^{-1})
M_M	Greenhouse gas emissions from mowing of a particular golf course component (Mg CO_2e ha^{-1} y^{-1})
M_S	Greenhouse gas emissions from the basal respiration rate of the microbial community in the soil of a particular golf course component (Mg CO_2e ha^{-1} y^{-1})
n_A	Number sprayer applications per component, per year (accounting for tank mixing)
n_F	Number of fertiliser applications per component, per year (accounting for compounds)
n_M	Number of mowing cycles per component, per year
P_e	Irrigation pump efficiency (ratio)
$Q_{ai(f)}$	Quantity of fungicide active ingredient applied (kg ha^{-1})
$Q_{ai(h)}$	Quantity of herbicide active ingredient applied (kg ha^{-1})
$Q_{ai(i)}$	Quantity of insecticide active ingredient applied (kg ha^{-1})
$Q_{f(A)}$	Quantity of fuel used in aeration (L ha^{-1})
$Q_{f(C)}$	Quantity of fuel used in application of agrochemicals (L ha^{-1})
$Q_{f(F)}$	Quantity of fuel used in application of fertilisers (L ha^{-1})
$Q_{f(M)}$	Quantity of fuel used in mowing (L ha^{-1})
Q_K	Quantity of potassium fertiliser applied as K_2O (kg ha^{-1})
$Q_{l(A)}$	Quantity of lubricant used in aeration (L ha^{-1})
$Q_{l(C)}$	Quantity of lubricant used in application of agrochemicals (L ha^{-1})
$Q_{l(F)}$	Quantity of lubricant used in application of fertilisers (L ha^{-1})
$Q_{l(M)}$	Quantity of lubricant used in mowing (L ha^{-1})
Q_N	Quantity of nitrogen fertiliser applied as N (kg ha^{-1})
Q_P	Quantity of phosphorus fertiliser applied as P_2O_5 (kg ha^{-1})
$Q_{w(C)}$	Quantity of water used in application of agrochemicals (L ha^{-1})
$Q_{w(I)}$	Quantity of water used in irrigation (L ha^{-1})
S	Total greenhouse gas sequestration for a particular golf course component (Mg CO_2e ha^{-1} y^{-1})
S_{OTHER}	Other vegetation sequestration coefficient (kg CO_2e ha^{-1})
S_{TREES}	Trees sequestration coefficient (kg CO_2e ha^{-1})
S_{TURF}	Turfgrass sequestration coefficient (kg CO_2e ha^{-1})
T	Total greenhouse gas balance from the management of the whole golf course (accounting for area)
T_n	Total greenhouse gas balance from the management of non-playing components of the whole golf course (accounting for area)
T_p	Total greenhouse gas balance from the management of playing components of the whole golf course (accounting for area)

fertilisers and agrochemicals. The accumulation of soil organic matter in managed turf grass systems has been shown to be greater than less-intensively managed grassland systems. This is due to accelerated biogeochemical cycling from clipped leaf nitrogen and nitrogen fertiliser application (Qian et al., 2003) and a sustained crop cover with less soil disturbance compared to agriculture (Pouyat et al., 2009). N_2O is a potent GHG released from the application of fertilisers and N_2O emissions from common rates of fertiliser application reduce, and could exceed, net GHG sequestration from the turf (Conant et al., 2005; Kaye et al., 2004; Townsend-Small and Czimczik, 2010). To determine whether golf courses and other managed fine turf areas are net GHG sinks or sources requires quantification of the sequestration capacity of