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Energy use and greenhouse gas emissions from turf management of two Swedish golf courses

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ABSTRACT

Turf management on golf courses entails frequent maintenance activities, such as mowing, irrigation and fertilisation, and relies on purchased inputs for optimal performance and aesthetic quality. Using life cycle assessment (LCA) methodology, this study evaluated energy use and greenhouse gas (GHG) emissions from management of two Swedish golf courses, divided into green, tee, fairway and rough, and identified options for improved management. Energy use and GHG emissions per unit area were highest for greens, followed by tees, fairways and roughs. However, when considering the entire golf course, both energy use and GHG emissions were mainly related to fairway and rough maintenance due to their larger area. Emissions of GHG for the two golf courses were 1.0 and 1.6 Mg CO_2e ha^{-1} $year^{-1}$ as an area-weighted average, while the energy use was 14 and 19 GJ ha^{-1} $year^{-1}$. Mowing was the most energy-consuming activity, contributing 21 and 27% of the primary energy use for the two golf courses. In addition, irrigation and manufacturing of mineral fertiliser and machinery resulted in considerable energy use. Mowing and emissions associated with fertilisation (manufacturing of N fertiliser and soil emissions of N_2O occurring after application) contributed most to GHG emissions. Including the estimated mean annual soil C sequestration rate for fairway and rough in the assessment considerably reduced the carbon footprint for fairway and turned the rough into a sink for GHG. Emissions of N_2O from decomposition of grass clippings may be a potential hotspot for GHG emissions, but the high spatial and temporal variability of values reported in the literature makes it difficult to estimate these emissions for specific management regimes. Lowering the application rate of N mineral fertiliser, particularly on fairways, should be a high priority for golf courses trying to reduce their carbon footprint. However, measures must be adapted to the prevailing conditions at the specific golf course and the requirements set by golfers.

1. Introduction

Mitigation of climate change and reducing the current dependency on fossil fuels are interlinked challenges shaping policies in many sectors. The European Union (EU) has committed itself to reducing greenhouse gas (GHG) emissions, increasing the share of renewable energy supply and improving energy efficiency, all by 20% by 2020 (European Commission, 2007), and this commitment requires immediate measures in all sectors of society.

There are more than 500 golf courses, occupying approximately 28,000 ha, in Sweden (Statistics Sweden, 2013). Golf is associated with several benefits, e.g. it provides recreational value for the many people who play the game, enhances local biodiversity through extensively managed roughs in areas with intensively managed agriculture (Tanner and Gange, 2005) and promotes soil carbon (C) sequestration (Qian and Follett, 2002; Selhorst and Lal, 2011). Managed turfgrass systems achieve significantly higher C sequestration than arable land and extensively managed grassland (Qian and Follett, 2012). However, turfgrass maintenance on golf courses is reliant on repeated mowing, which requires fossil energy and releases GHG emissions to the atmosphere, mainly as carbon dioxide (CO_2). High turfgrass quality also requires other maintenance practices such as irrigation, fertilisation, vertical cutting, aeration and sand dressing, all with associated environmental impacts. Furthermore, nitrogen (N) from fertilisers and plant residues enhances nitrification and denitrification, which may increase emissions of nitrous oxide (N_2O). Intensive turfgrass management combining frequent irrigation and fertilisation can

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enhance N_2O losses, particularly if water is applied immediately after fertilisation (Gu et al., 2015). However, soil N_2O production is associated with high variability depending on soil properties and management, which poses a great challenge when estimating N_2O emissions (Li et al., 2013). Emissions of N_2O are particularly worrisome since N_2O is a potent greenhouse gas with high global warming potential (GWP). The GWP of a certain gas is a measure of how much heat is trapped in the atmosphere relative to the amount of heat trapped by CO_2 over a specific time interval (IPCC, 2007). The concept of GWP for different GHG makes it possible to add them together to obtain total GWP for an entire system.

Energy use and GHG emissions are not only associated with the maintenance activities performed on the golf courses, since there are also indirect environmental burdens related to production of purchased inputs such as mineral fertilisers, fuel, machinery and transport of sand used for dressing. Life cycle assessment (LCA) is a comprehensive methodology addressing both direct and indirect energy use and emissions along the entire value chain in order to identify environmental hotspots. LCA is a commonly used standardised procedure for identifying opportunities for improved environmental performance and providing decision support for stakeholders in strategic planning and development (ISO, 2006). Carbon footprinting, a subset of a full LCA including only GHG emissions caused by a product or a service during its life cycle and summarised as CO_2-equivalents, is attracting increasing interest in the context of global warming mitigation (Röös, 2013).

A number of studies have evaluated GHG emissions from public and private lawns (e.g. Townsend-Small and Czimczik, 2010; Zirkle et al., 2011; Selhorst and Lal, 2013; Kong et al., 2014; Gu et al., 2015), while fewer studies are available for golf courses. Bartlett and James (2011) modelled GHG emissions from two golf courses in the UK and determined the balance between soil C sequestration and emissions from turf management. They assumed the same sequestration rate for the treeless components of the golf courses (green, tee, fairway and rough), independent of time since construction, mowing frequency and fertilisation rate, and found that the main contribution to GHG emissions came from mowing and production of fertilisers. Selhorst and Lal (2011) included C release due to different maintenance practices, summarised for the entire golf course, but excluded GHG emissions other than CO_2.

Depending on the prevailing climatic and edaphic conditions, turf management differs between locations. In addition, the different playable areas on a golf course are managed with differing intensity. In order to devise and implement efficient and well-adjusted measures for sustainable turf management, more knowledge is required about current energy use and GHG emissions from different components of the golf course and how these are distributed among different management activities.

The objective of the present study was thus to evaluate energy use and GHG emissions from annual management of two Swedish golf courses divided into green, tee, fairway and rough, and identify options for improved management. Particular emphasis was placed on maintenance operations and purchased inputs.

2. Material and methods

LCA methodology was used for evaluation of primary energy use and GHG emissions associated with turf management on golf courses during one year. Emissions of GHG were summarised as CO_2-equivalents (CO_2e) according to IPCC (2007), with a time horizon of 100 years. The results were presented both per hectare and for the entire courses.

Information on management practices was obtained through interviews with course managers of the golf courses. A brief description of different activities performed on the two golf courses is presented below, while a more detailed description can be found in Wesström (2015).

Table 1
Area of the different playable components included in the study, based on information provided by the golf course managers.

Course	Green (ha)	Tee (ha)	Fairway (ha)	Mowed rough (ha)	Total (ha)
Sigtuna	1.5	1.0	10	40	52.5
Uppsala	2.5	1.5	22	50	76

2.1. Description of the golf courses and their management

The golf courses included in the study are parkland courses situated in eastern Sweden. One of the golf clubs is located in the county of Uppsala and was established at its present site in 1964. It currently consists of one 18-hole course and two 9-hole courses, with a total playable area of 76 ha (Table 1). The other golf club is located outside the town Sigtuna, in between Stockholm and Uppsala. It has one 18-hole course constructed in the end of the 1960s, one 6-hole course and four practice greens. The golf courses are surrounded by a mosaic landscape characterised by agricultural land and forest. The total playable areas of the courses in Sigtuna and Uppsala were 52.5 and 76 ha, respectively (Table 1).

The golf season is approximately 26 weeks in Uppsala and 28 weeks in Sigtuna. Maintenance strategies differ considerably between the playing areas, in order to provide optimal performance and aesthetic quality for each specific area.

2.2. Application of fertiliser, pesticides, sand and water

The application rate of mineral fertilisers varies slightly between years. Sigtuna follows a specific fertiliser regime where the weekly fertilisation of greens and tees is pre-ordained. Here, we used data from 2013, which was considered to be a representative year. At Uppsala, fertiliser application is determined by the course manager and the data used in this study were representative of recent years. Fertilisers are applied manually to greens and tees on a regular basis throughout the season. Fairways are fertilised mechanically several times a year, while roughs do not receive any mineral fertiliser.

Fungicides and herbicides are occasionally used at both courses, while insecticides are not used at all. The rough in Uppsala receives herbicides once every other year.

The irrigation frequency is determined by precipitation. In general, greens, tees and fairways are irrigated approximately three times per week, while roughs are not irrigated at all. The irrigation water used in Sigtuna is pumped from a nearby lake and distributed via an underground pipe system, complemented with a hose when necessary. In Uppsala, the water is pumped from a nearby pond that also receives drainage water from the course. The amounts of water applied to the different parts of the course in this study were based on estimates by the managers, since no measured data were available. Sand for dressing is applied on greens and tees at both sites, and on fairways in Uppsala. This sand is transported 160 km to Uppsala and 50 km to Sigtuna. The amounts of mineral fertiliser, sand and pesticides applied and the volume of water used for irrigation are presented in Table 2.

2.3. Mowing and other maintenance practices

Greens are mowed seven times a week at Uppsala and five to six times a week at Sigtuna during the season. Tees and fairways are mowed three times a week at both sites during the season. Roughs are mowed once a week during the season, using a rotary mower. On all areas, seasonal mowing is complemented with some additional off-season mowing. The grass clippings from greens and tees