CRANFIELD UNIVERSITY

M. CAPLE

A PILOT STUDY INTO THE USE OF FOSSIL FUELS IN GOLF COURSE MAINTENANCE OPERATIONS UNDER SWEDISH CONDITIONS

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A Pilot Study into the Use of Fossil Fuels in Golf Course Maintenance Operations under Swedish Conditions

Supervisors: M. Dufour (Cranfield University)
K. Blombäck (SLU)

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Abstract

A method is proposed for measuring fuel consumption of golf course maintenance machinery within this study, in response to growing industry concerns to rising fuel prices and greenhouse gas emissions. The aim of this method is for its implementation as a maintenance optimisation tool to allow measurement, prediction and ultimate reduction in fuel consumption in maintenance.

Volumetric fuel consumption was recorded for various operations by refilling fuel tanks back to the same levels prior to operations being performed. Results were presented initially in the primary unit of fuel consumption per cycle. A cycle was identified as the work required to perform an operation on a particular feature type, and which did not change in its nature between cycles. This *in-situ* method allowed fuel consumption measurements to be replicated for the same maintenance operations. Four secondary units to portray fuel consumption were created, one being area mown per litre of fuel, which allowed fuel consumption to be normalised by area and compared across golf courses.

Key maintenance cycles were assessed on three different golf courses in Sweden. From the data collected, it was determined that rough mowing typically consumed the greatest amount of fuel per cycle and fairway mowing the greatest amount per year. Fairway mowing was also found to be the most fuel efficient operation. On the main test site, 86% of yearly diesel consumption was accounted for by operations that could be categorised into cycles.

The proposed method was determined to be feasible for extended use due to its simplicity and ease of repetition. Normalisation of the data allows for further research to be undertaken into identifying inefficient operations and seeking methods to reduce fuel consumption. Further research should be undertaken over a whole golfing season to determine the accuracy for mean fuel consumption per cycle and to enable sporadic and smaller operations to be measured on an individual basis. The affect that distance travelled by machines between features has on cycle fuel consumption is the main recommendation for further adaptation of the method.

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Abbreviations

CO_2 Carbon Dioxide

EEA European Environment Agency

EIA Energy Information Administration

GHG Greenhouse Gases

g/km Grammes per Kilometre

HP Horsepower

IPCC Intergovernmental Panel on Climate Change

kW Kilowatt

m^2 Squared Metre

M/C Main Golf Course

mg/km Milligrammes per Kilometre

ml Millilitre

NEAA Netherlands Environmental Assessment Agency

NOx Nitrogen Oxide

Ped Pedestrian Mower

R-o Ride-on Mower

S/C Short Golf Course

SEPA Swedish Environmental Protection Agency

W/G With Groomers

Wo/G Without Groomers

1. Introduction

1.1 Golf Course Maintenance

Performing golf course maintenance operations is vitally important in order for golf courses to be well presented at all possible times. Surface playability and aesthetics are both vital characteristics required of a golf course, and no other sport requires as much effective maintenance than golf (Beard, 1982). Machinery for use on golf courses has improved continuously over the last few decades, allowing for optimum productivity and quality of finish, as well as reduced man-hour requirements. With increasing fuel costs and environmental concerns regarding greenhouse gas emissions, the fuel efficiency and emissions of machines is rapidly becoming an area of interest and research.

1.2 Fuel Prices

Prices of fuel have risen sharply as crude oil prices have climbed. The cost of a barrel of crude oil has risen 440 % from September 2003 to May 2008 (Figure 1.1) and prices do not look likely to fall again in the foreseeable future (BBC, 2008)

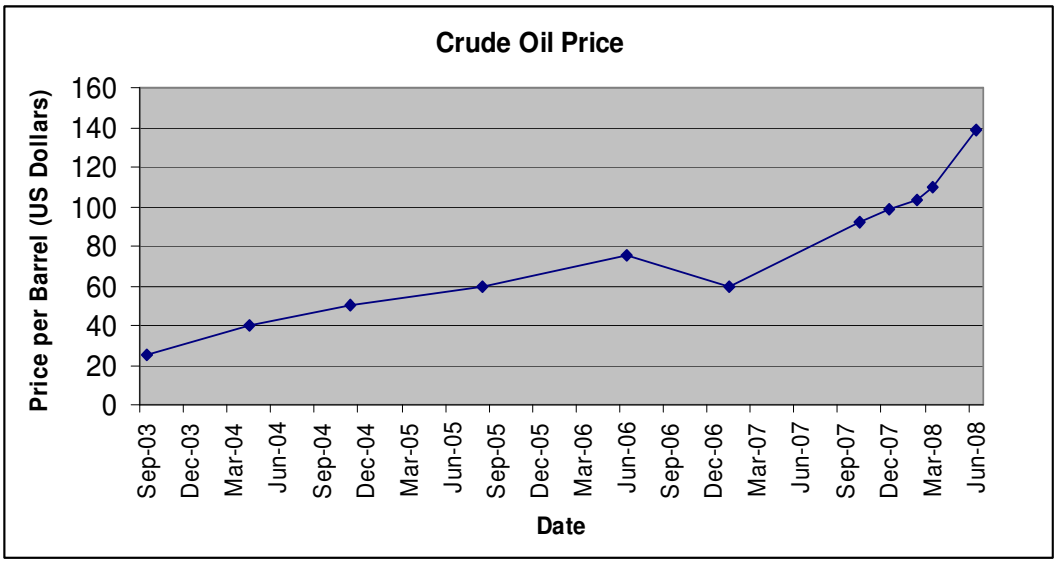


Figure 1.1 Price per barrel of crude oil (EIA, 2008)

In recent years, the industry movement towards alternatively fuelled maintenance machines was due primarily to environmental concerns for gaseous emissions and noise reduction issues. The desire to reduce fuel costs was a third priority behind these two (Lanier, 2005 quoted in Skernivitz, 2005). The stance the golf maintenance industry has taken has now changed it seems, as the major current issue for golf course managers regarding fossil fuel use is the financial costs (Melka, 2008 quoted in Pioppi, 2008). The golf industry, like many others, was not expecting the price of fuel to rise so sharply in the last two years, and golf course managers are seeking ways to reduce fuel costs (Melka, 2008 quoted in Pioppi, 2008).

With the increase in fuel costs, golf course managers have seen their fuel bills rise in recent years. Motyka (2008 quoted in Pioppi, 2008) has stated that his fuel bill had risen 60 % from 2004 to 2007. Barth (pers. comm., 2008) reported that the fuel bill for 2006 at Fullerö Golfklubb in Västerås, Sweden, had risen 57 % higher than that of 2004 (Figure 1.2). There are split opinions in the golf industry as to whether golf clubs should pass the financial increases of fuel and energy bills onto the golfers by higher golf prices, or whether doing this will decrease the revenue further by pricing people out of playing golf (Pioppi, 2008).

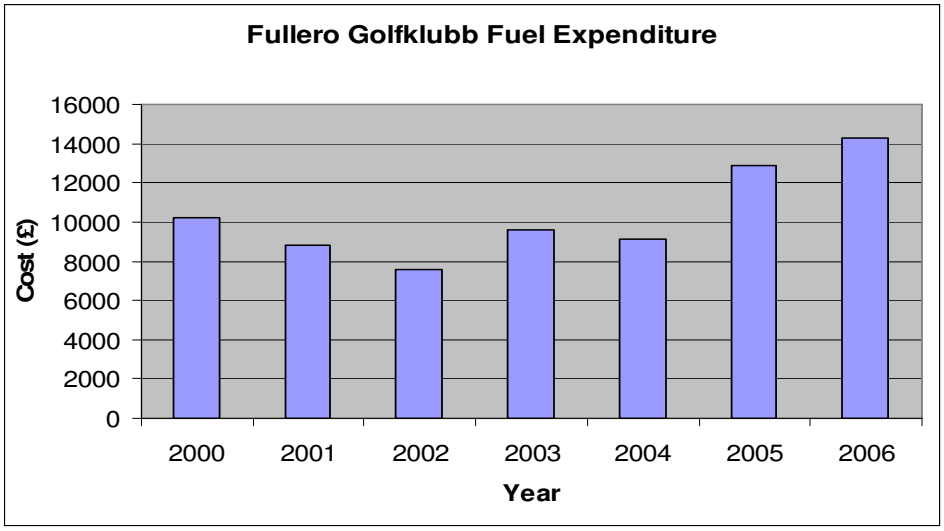


Figure 1.2 Golf course maintenance fuel expenditure 2000–2006 at Fullerö Golfklubb

1.3 Reducing Fossil Fuel Consumption

The use of fossil fuels for maintenance machinery in golf has financial and environmental impacts. Beard (2004) identified that energy conservation in turfgrass management, especially in terms of combustion engine use, should be one of the most prioritised areas for further research and expenditure in future years. Literature has been found that suggests methods of reducing fuel consumption. These can be categorised into three main areas:

1. Maintenance Procedures

- Reducing the amount of maintenance cycles (Watson, 1976)
- Reducing inputs of fertiliser and water (Brede, 2000)
- Use of plant growth regulators (Frabotta, 2008)
- Selection of the shortest traffic routes (Watson, 1976)
- Maintaining machines correctly (Steinegger *et al,* 1983)
- Use of grass species that demand less mowing (Brede, 2000)
- Operator training for efficient operation of machines (Watson, 1976)
- Combining maintenance operations (Hartwiger, 2007)

2. Size of Golf Course Features

- Reducing the size/number of intensively managed golf course features (greens, tees, fairways, surrounds) (O'Brien, 1997)
- Increasing the size of low-maintenance areas such as long roughs (Steele, 2006)

3. Machinery Selection

- Selection of fuel efficient machines (Watson, 1976)
- Selecting machines with lower horsepower ratings (Thomas, 1980)
- Use of alternative fuel-powered machines (Aylward, 2006)

1.4 Measuring Fuel Consumption

To reduce the amount of fuel being used on a golf course, it is first necessary to quantify the amount being used for the various maintenance operations being undertaken. With this knowledge, prioritising of operations can take place, where the cost of an operation can be weighed up against its benefit. Having a method in place to record fuel consumption for different operations can also help identify fuel efficient machinery, maintenance techniques and operator competence.

There have been very few reports of fuel consumption data for golf maintenance operations, and none that specifically intended to compare fuel use of the different operations. Those that have been found will be discussed later. More importantly, there is not an accepted method of measuring fuel consumption or a unit of presenting the results, which is critical to implementing a strategy to reduce fuel consumption.

1.5 Research Aim and Objectives

Aim

The aim of this research is a pilot study to perform fuel consumption measurements on different maintenance operations on golf courses in Sweden.

Objectives

1. Develop a suitable method and unit of measurement for recording fuel consumption on golf courses. The method must be simple and appropriate so that greenkeepers on any golf course can repeat the method regularly.
2. Test the method by performing measurements on different maintenance operations and on different golf courses.
3. Evaluate the accuracy and suitability of the method for highlighting the most fuel-consuming operations and for future use as an optimisation tool on golf courses.

An analysis of fuel consumption methods from other industries such as agriculture will be undertaken, as well an exploration into the factors that affect fuel consumption for machinery. This will enable objective 1 to be met, where a suitable golf course specific method of fuel consumption will be proposed. Objective 2 will be satisfied by implementing the method on three different golf courses in Sweden, while objective 3 will be met by considering limiting factors to the method and for its use on a larger scale.

2. Literature Review

2.1 Golf in Sweden

Sweden has over 450 golf courses and an estimated 540,000 people are members of golf clubs (KPMG, 2007). The typical golf season in Sweden runs from mid April to early November, as golf is unplayable during the winter period due to the cold climate and snow cover. There are on average 234 playable golf days in the year on golf courses in Northern Europe, and the average rounds per year experienced at a Swedish golf club is 22,000 (KPMG, 2007), equating to around 94 rounds of golf per day.

2.2 Fossil Fuels and Greenhouse Gases

2.2.1 Fossil Fuels

Fossil fuels are carbon-based fuel sources which are used mainly to produce energy when oxidised (during the combustion process). The three main fossil fuels are crude oil, coal and gas (Shafiee & Topal, 2007). Diesel and petrol are produced from crude oil via distillation, and reserves of this resource are thought to be limited. The exact amount of years left of extraction is uncertain (Dow & Downing, 2006). An estimated 86 % of world energy production came from the burning of fossil fuels in 2005 (EIA, 2007). Fossil fuel combustion is the most preferred and widely used form of energy production worldwide as it is relatively cheap, easy to transport and easily combusted (Quadrelli & Peterson, 2007).

2.2.2 Greenhouse Gases

The greatest implication with the burning of fossil fuels is the emission of greenhouse gases (GHGs). These gases reduce the amount of heat from the earth escaping into the atmosphere, and increased levels of these gases results in global temperature increases, by attributing to the natural greenhouse effect (Quadrelli & Peterson, 2007). The major GHGs which are emitted from fossil fuel burning activities are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Other major gases emitted by fossil fuels are nitrogen oxide (NOx) and carbon monoxide (CO), as well as volatile organic

compounds (VOCs). These all have increased concentrations of tropospheric ozone (O_3), which is a strong greenhouse gas (Claussen *et al*, 2001).

Almost 80 % of anthropogenic (human produced) greenhouse gas emissions are caused by fossil fuel combustion (IPCC, 2001). The largest contributor to the greenhouse effect and climate change is CO_2 (Siddiq, 1996). Emissions of CO_2 from the combustion of fossil fuels was estimated to have risen 28 % in the period 1990-2004 (NEAA, 2007)

In Sweden, 65.7 million tonnes of greenhouse gases were emitted in 2006 (Figure 2.1), which is 8.7 % lower than 1990 levels (SEPA, 2007). This is an equivalent to 5.7 tonnes per person per year. This figure is low compared to countries such as USA, Canada and Australia, where figures are around 20 tonnes per person. The average emissions per person for a developing country are around 2 tonnes per year (SEPA, 2007).

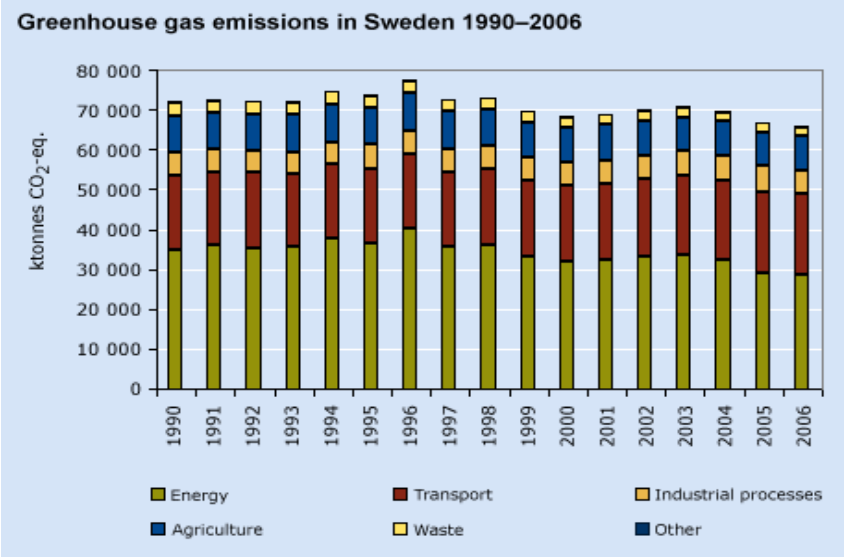


Figure 2.1 Sources of Swedish greenhouse gas emissions (SEPA, 2007)

The European Union has pledged to jointly reduce CO_2 emissions from the member states by 8 % of 1990 levels by 2012, in accordance with the Kyoto Protocol (European Commission, 2006). Sweden has the potential to increase its CO_2 emissions by 4 % in

the period 2008-2012 due to the burden-sharing approach of the European Commission (Table 2.1).

Table 2.1 CO_2 emissions (million tonnes equivalent) of selected EU-15 states, from base year 1990 to 2012 targets (EEA, 2007)

Country	Base Year 1990 (million tones)	2005 (million tonnes)	Change Base Year - 2005	Targets 2008 - 2012 under Kyoto Protocol and EU Burden Sharing
Sweden	72.3	57	-7.40%	4.00%
United Kingdom	746	657.4	-15.70%	-12.50%
Germany	1253.3	1001.5	-18.70%	-21.00%
Denmark	69	63.9	-7.80%	-21.00%
Finland	76.8	69.3	-2.60%	0.00%

Sweden has low CO_2 emissions compared to other countries as a large proportion of its electricity is produced from hydro and nuclear power, and a national move towards the use of biofuels for vehicles (SEPA, 2007).

2.3 Fuel Consumption Research for the Golf Industry

The data that is available on golf course maintenance machinery and fuel consumption in the golf industry is discussed in this section. Much of the literature found concentrates on mowers. Typical factors which effect fuel consumption in combustion engine machines are engine speed and engine load.

2.3.1 Golf Course Machinery

Although every golf club is unique in respect to its geographical and landscape layout, typical machinery fleets will comprise of the following type of powered machinery:

- Tractors of varied sizes and power
- Ride-on mowers of varied sizes and type

- Utility vehicles of different size
- Pedestrian mowers of varied type
- Hand powered units of varied size and type
- Powered and non-powered implements

(Beard, 1982)

Powered machinery will range in size and power potential depending on the specific job it is designed to perform. The vast majority of golf course machinery is powered by combustion engines that run on fossil fuels of diesel and petrol (Skernivitz, 2005). Although a large variety of maintenance operations take place on a golf course, the operation that is performed most frequently is mowing (Adams & Gibbs, 1994), especially during the grass growing season. In Sweden this would typically be between the period of mid May and mid October (Paulsson pers. comm., 2008).

2.3.2 Pedestrian Mowers

A major problem that has been identified when trying to calculate fuel consumption in mowers is the difference between fuel consumption for field tests and that for artificial laboratory tests at set power ratios. Any calculations for fuel consumption are difficult unless mowers have been operated as they would be for mowing operations. Priest *et al* (2000) calculated fuel consumption at different engine power loads, as well as in-field mowing operations (Table 2.2).

Table 2.2 Average fuel consumption rates (ml/min) for two-stroke and four-stroke lawnmowers in the field and under different test loads for in-use mowers (Priest et al, 2000)

	Field Tests	Standardised Tests			
Load (kW)		**0.12**	**0.72-0.92**	**1.12**	**1.32-1.62**
Two-stroke	20.36	13.45	20.4	21.07	22.54
Four-stroke	12.19	8.67	12.74	15.16	19.26

Fuel consumption was calculated volumetrically in this study by using a graduated burette and timing the rate of consumption. Table 2.2 also identifies that two-stroke mowers consume more fuel than four-stroke mowers, under all power loads applied during the tests. Two-stroke engines typically consume more fuel as they combust fuel and creates power twice as fast as four-stroke engines. Two stroke engines are common in small maintenance machines and some mowers used on golf courses as they are capable of high power outputs and are relatively lightweight (Nesbitt, 2000).

Pedestrian mowers used to mow golf greens require more expenditure in man hours and therefore wage costs to complete the operation compared to the more efficient ride-on mower. However, it is accepted that using hand mowers will reduce cost expenditure in fuel. Piller (1994) reported that pedestrian mowers consumed 4.4 litres of fuel to mow 18 golf greens; a figure which he believed was around half the amount that would be required for a ride-on triplex greens mower.

2.3.3 Ride-on Mowers

The most relevant information that has been found for fuel consumption data for different operations is calculations compiled by the course manager at Fullerö GolfKlubb, Västerås, Sweden (Table 2.3).

Table 2.3 Estimated fuel use for mowing operations at Fullerö Golfklubb in 2006 (Barth pers. comm., 2008)

Machine	Mowing Area	Fuel Consumption Per Hour (Litres)	Time Per Operation (Hours)	Total Fuel Consumed (Litres)
Jacobsen G-Plex III	Greens	2	4	8
Ransomes T-Plex 185	Tees	2	5	10
Jacobsen 305	Fairway	4	7	28
Jacobsen AR-250	Semi-Rough	5	11	55
Jacobsen HR-6010	Rough	5	20	100

The figures represent rough estimates of fuel consumption per operation. The method for measuring was by filling the machines from fuel tanks and estimating the fuel needed to refill the tank. This was thought to be accurate to the nearest litre (Barth pers. comm., 2008). The Course Manager originally compiled these figures as part of a larger collection of data to present the golf club members with financial costs for each operation. Total costs per operation were calculated from total fuel consumption, wages, maintenance costs and lease costs. The research indicates that golf course managers may have some knowledge of fuel consumption for the golf courses they manage. However, whilst they may have the incentive to collect data very little has been published.

Fuel consumption of golf course mowers will increase with the engine load and power. Ride-on mowers used on golf courses can range from around 17 HP (12.7 kW) for greens mowers to 60 HP (44.8 kW) or more for large ride-on rough mowers (Jacobsen, 2008; John Deere, 2008; Toro, 2008). Mowers with higher HP or kW ratings will typically burn more fuel than less powerful mowers during normal operation (Thomas, 1980). Small engine machines such as mowers have been estimated to be operated at 90 % or more of peak output for the majority of operational use (Nesbitt, 1994). HP is increased as a necessity when the size of the mower increases and the intended height of cut increases. Rotary mowers with high HP ratings are typically used for mowing golf course roughs as they possess the ability to cut thicker, longer grass than a cylinder mower. However, it is acknowledged that rotary mowers can use up to 50 % more fuel than cylinder mowers under the same conditions (Thomas, 1980). This is due to the scissor action of a cylinder mower being more energy efficient than the mode of action of a rotary. Mower selection for each area to be mowed is therefore critical for reductions in fuel consumption.

The number of blades on a cylinder mower will also have an affect on fuel consumption. Watson (1976) reported that five bladed cylinder mowers will use between 8 to 12 % less fuel than a six bladed mower due to the smaller amount of energy required to mow with less blades.

2.3.4 Tractors

Due to the extensive use of tractors on golf courses for maintenance operations such as aeration, topdressing and general loading, it is worth considering research findings on their performance. Fuel consumption can be optimised with the correct operation of a tractor. Tractor engine load, speed and gear selection is critical.

Fuel consumption is regarded to be at its lowest on a tractor at an engine speed approximately 60-80 % of the nominal speed, and operating in the highest gear possible for the work being undertaken, in order to maintain high engine load (Zoerb & Kushwaha, 1983). Tractors are more fuel efficient when they are operating at full load (Hansson *et al,* 1999). Matching implement size to tractor power is also vitally important to conserve fuel. Agricultural engineers can predict fuel consumption and tractor power size requirements by assessing the draught and power requirements of the specific tillage implements and the soil type present (Serrano *et al,* 2007). On-board tractor microcomputers are available that monitor tractor performance and recommend the optimal gear and throttle setting to operate at maximum fuel efficiency. Fuel consumption can be reduced by between 11.3 and 20.0 % when these microcomputers are used (Grogan *et al,* 1987). Additionally, research has found that fuel consumption is at its lowest when tractors are operating at their optimal tractive performances (Jenane *et al*, 1996). This data originates from agricultural-based research. There has been no literature found for matching implement, speed and gear requirements for different tractor sizes in golf course maintenance, in respect to identifying fuel efficiency in various operations. Since an average golf course covers around 60 hectares (Adams & Gibbs, 1994), this may be an area which needs further research in order for efficient fuel consumption operations with tractors to be identified.

2.4 Fuel Type

2.4.1 Diesel versus Petrol

The majority of golf maintenance mowers are fuelled by diesel. The number of petrol-fuelled mowers operated has declined rapidly in recent years with the increase in fuel prices. Mower manufacturers sell less petrol mowers than diesel mowers due to the

greater fuel efficiency that diesel fuel provides and some machine models are now not available with petrol engines. Diesel has a greater energy density than petrol and is around 20 to 25 % more efficient in operation compared to the same size petrol engine (Watson, 1976).

Diesel is heavily used in some industries due to the lower rate of tax added. 'Agricultural' diesel is fuel that is specifically intended for use in farm machinery, construction machinery and boats. In some countries, it can also be used in golf course maintenance machinery. The low rate of tax makes it more affordable for golf course maintenance.

Agricultural diesel prices have risen sharply with the price of crude oil. The commercial purchase price has risen 71 % from June 2007 to June 2008, and as much as 382 % since 2002 in the UK (The Times, 2008). Lower taxed diesel is not available for use on golf courses in Sweden unless the golf club becomes tax registered. It is often not financially rewarding for many golf clubs to do this, so it results in the golf club paying the same price for a litre of fuel for maintenance as what is sold in fuel garages for vehicle use.

2.4.2 Alternative Fuels/Hybrids

Alternative fuels such as electricity and biofuels have increasingly been used to operate maintenance machinery in the last decade, and golf machinery manufacturers have been pioneering them for more widespread use in the golf maintenance industry. Biofuels of biodiesel and ethanol are becoming more widespread in their use as they are produced from renewable resources such as oilseed rape, waste food oils and corn and barley (Ostmeyer, 2007). This makes them much more environmentally friendly than fossil fuel combustion. It is approximately 20 % cheaper to run machines on biofuels, depending on the blend mix with regular fossil fuel (Beardall, 2008). Two of the major manufacturers of golf course mowers, Toro and John Deere, have been pursuing biofuel research in the last couple of years, and both are ensuring that the majority of mowers manufactured in 2008 are capable of at least 10 % biofuel blends (Ostmeyer, 2007).

There are issues with biofuels that need addressing before widespread use of the fuels is possible. The consistency of the material for the production of the fuel, as well as universal agreement upon the blend percentages with fossil diesel and petrol requires further research and clarification (Finamore, 2007 quoted in Ostmeyer, 2007). There have also been operational problems reported such as the fuel gelling in cold weather, blocking of filters and increased seal and gasket failure in machines fuelled on biofuels (Finamore, quoted in Ostmeyer, 2007). Increased use of this fuel may also pose production problems. The land and the crops that are used to produce the fuels are primarily used for human and animal food production, so it remains to be seen whether biofuels are a viable source for widespread use in mowers in the future (Peters and Thielmann, 2008).

Electric mowers from Jacobsen have been in production for around 15 years and do not require the use of fossil fuels to operate. Although the production of the electric required to power the batteries in the mowers is generated by burning fossil fuels, the efficiency in producing this electricity is greater and emits far less gaseous emissions. Using electric mowers is cheaper than using combustion engine mowers. Whurr (2000) estimated that using an electric mower instead of a combustion engine mower could save up to $1000 (approximately £500) per year in maintenance and operational costs, the biggest saving coming from reduced fuel costs. Weeks (2006, quoted in McCormick, 2006) has stated that charging the battery on the Jacobsen ride-on E-Plex II greensmower consumes around 50 cents (approximately £0.25) worth of electricity. Weeks compares this to approximately three gallons of fossil fuel needed to power a combustion engine mower for the same amount of run-time. Calculations he made were that yearly power costs for the electric mower was $150 (approximately £75), compared to around $4,500 (approximately £2250) for fossil fuel.

Electric mowers have not been widely accepted in the golf maintenance industry due to potential power problems. Lead batteries do not possess the same amount of condensed power as fossil fuels and this is the major flaw in this energy source. Although improvements have been made, performance is not comparable to combustion engine mowers and accessories such as grooming and verticutting units are not yet possible on electric mowers (McCormick, 2006).

John Deere manufactured a Hybrid 2500E ride-on greensmower which has posed a solution to reduced power on electric mowers. The mower operates on a traditional combustion engine, but the reel-drive cutting units are powered by electricity. This enables the mower to be operated at reduced engine power (McCormick, 2006). Fuel consumption has been calculated to be reduced by up to 30 % for this mower (Blais, 2008).

With the problems identified with alternative fuel machinery, it seems unlikely that fossil fuel combustion engines will be fully replaced within the next 20 years on golf courses (Aldridge, 2008 quoted in Pioppi, 2008).

2.5 Fuel Consumption Research from Other Industries

In order for a suitable method of measuring fuel consumption in golf course maintenance operations to be selected, it is important to analyse the techniques used in more researched industries, and the units that are used for portraying fuel consumption.

2.5.1 Transport/Combustion Engines

Fuel efficiency in transport is measured as the ratio between distance traveled and the input of fuel. These tests are portrayed in units of litres per 100 kilometres (l/100km), which is common in Europe, and miles per gallon (mpg), which is used in the US and UK. Units for fuel consumption and efficiency in transport, like many industries, are commonly measured in volumetric form. Fuel consumption can also be portrayed gravimetrically, where the amount of fuel an engine uses is calculated in weight (Bachman *et al,* 2006). Fuel consumption can be calculated for combustion engine machines by the carbon balance method. This method measures the amount of carbon-containing compounds that is present within the emissions from the engine. The carbon within the liquid hydrocarbon fuel will be exactly equal to the concentration of carbon that is emitted from the exhaust. Accurate calculations of the amount of fuel the engine has combusted can then be calculated. Using this method, fuel consumption of

combustion engine machines can be calculated at different speeds and loads (Bachman *et al,* 2006).

2.5.2 Agriculture

The main objective for arable farming is to maximise crop production and minimise crop production costs. This area has been extensively researched for intensive agriculture for decades. Reference data from the mid 1970s can be found that details energy consumption for different farming operations. Dalgard *et al* (2001) suggested a model that inventoried all energy use in the production of crops, including all direct energy inputs (diesel consumption and irrigation energy requirements) and indirect energy inputs (production of fertilisers and pesticides). The energy consumption was calculated per hectare and per tonne of production. The common unit for fuel consumption in agriculture is litres of fuel used per hectare (Dovgan, 1989).

2.5.3 Forestry

The forestry industry like the agricultural industry is more developed with its research on fuel consumption for machinery and operations in the aim of lowering production costs. Fuel consumption inventories of forestry practices have been compiled, and results have been portrayed in litres of diesel consumption per tree (Gasslander *et al,* 1979). For this method, every operation from tree felling to hauling the timber is required to have the fuel consumption recorded.

Sundberg (1982) identified that by measuring fuel consumption against operational practices in forestry, the lowest cost per unit of produce can be identified, and labour-machine optimal ratios could be determined. This method had the advantage of grouping together vastly different machines and gauging their fuel consumption and cost per unit of production. The unit used was litres of fuel used per cubic metre of wood. The financial cost of using each machine per hour was also calculated. This involved adding the calculated costs of capital expenditure per hour of use and operational costs per hour of use (including fuel costs) together.

Sundberg (1986) proposed a method of costing forestry machinery based on fuel consumption. It was identified that fuel consumption and cost of fuel heavily influences the factors that condition work practices. The cost of fuel per year was calculated for a machine as a percentage, against the initial purchase price and yearly maintenance costs. This work identified that fuel consumption of a machine was a viable parameter for calculating capital cost of machinery and forecasting future development of machinery and operational practices.

2.6 Fuel Consumption Research in Sweden

Recent research in Sweden regarding fuel consumption has concentrated on the large non-road mobile machinery sector. This is machinery used in non-road industries with a rated engine power above 37 kW (49.62 HP). Machines with this power rating and above include agricultural and forestry machines, tractors and various types of construction equipment. The average fuel consumption for this type of machinery was calculated at 3,700 litres per machine per year in Sweden (Lindgren, 2007). This research did not include large ride-on mowers with a HP above 49.62.

Lindgren (2007) calculated emissions and fuel consumption for the whole large non-road machinery sector across Sweden. The method used for calculating total fuel consumption involves equating factors such as annual hours of use, number of machines, rated power, average annual load factor and fuel consumption per hour. In order for this research to accurately calculate national fuel consumption, data was needed for fuel consumption for each type of machine.

There is little data on the fuel consumption and emissions of small off-road vehicles with a rated power below 37 kW (Lindgren pers. comm., 2008). This type of machinery would include most golf course maintenance machines and other domestic and commercial machinery. Research is currently being undertaken by the Swedish Road Administration to calculate national fuel consumption and emissions from this type of

machinery, but more data is needed on fuel consumption for different types of machinery such as ride-on mowers (Lindgren pers. comm., 2008).

2.7 Summary

After analysing literature, research and information from the golf course maintenance industry, it is clear that research into fuel consumption for maintenance operations has been limited compared to other industries such as transport, agriculture and forestry. The main presumption for this reason is that fuel has been relatively affordable in the past for golf courses. Although literature has been found stating the effect that increased HP has on fuel consumption, these statements have not been investigated by *in-situ* testing on golf courses in order to identify the most suitable fuel efficient machinery and operations. Due to this, a repeatable method for measuring fuel consumption needs to be developed first, before researching other effects such as HP and machine design on fuel consumption.

By analysing consumption methods and units from both the golf maintenance industry and from other comparative industries and machinery, a suitable method for measuring fuel consumption has been identified, with justification for the method included as part of the discussion section:

- Fuel consumption will be measured volumetrically, being the most practical form of measurement *in-situ* on a golf course and for a study this size. Units used will be litres.
- The primary unit of measurement for portrayal of fuel consumption has been decided as a cycle of maintenance. Fuel consumption can be portrayed as litres of fuel consumed per cycle.
- A secondary unit of measurement for portrayal of fuel consumption will be area. The total area of each feature type will calculated, if possible, so that fuel consumption can also be normalised by unit area. A feature has been defined as the different playing surfaces on a golf course, e.g. greens, tees, fairways.

- Fuel consumption measurements will be recorded for different operations on three different golf courses. The fuel consumption of these operations will be listed in an inventory.

3. Materials and Method

3.1 Overview

Data collection was conducted during the months of June and July 2008, on three different golf courses around the Uppsala region in central Sweden.

3.2 Study Sites

Vassunda Golfklubb

Vassunda Golfklubb was used as the main golf club for fuel consumption recordings, where as many operations as possible were tested, due to the willingness of the staff to participate. The club is an 18-hole parkland golf club situated 23 kilometres south of Uppsala. Data collection on this golf course was carried out solely by the greenstaff during the period between 16th June and 18th July.

Fullerö GolfKlubb

Fullerö Golfklubb is situated just outside the city of Västerås, 70 kilometres from Uppsala. It possesses a main 18-hole course and a short 9-hole par three course within its parkland setting. The data collected originates from the main 18-hole golf course. Data collection on this course was carried out solely by the greenstaff between 24th June and 17th July.

Upsala GolfKlubb

Upsala Golfklubb was established in 1937, and moved to its current parkland location to the west of the city of Uppsala in 1964. The club has 18 main holes in play, with nine other main holes under reconstruction. It also possesses a shorter nine-hole golf course. The data collected varied from operations performed on all 27 holes (main course and short course) and those that were performed separately on either the short

course or main course. Data collection at this golf course was carried out solely by the author during the period between 30th June and 25th July.

3.3 Experimental Design

Fuel measurements were conducted on machines that performed a predefined cycle of maintenance that was not subject to severe alteration throughout the golf season. A cycle of maintenance was defined as the work required completing a whole golf course operation on a particular feature type, e.g. mowing of all the greens or raking all of the bunkers. A feature was defined as a recognised playing area on a golf course, e.g. greens, tees, fairways, bunkers. This *in-situ* approach allowed consistent fuel consumption data to be collected and replicated on the same operations.

The machines that were to be subjected to fuel consumption measurements were inventoried, with machine make and model, purpose, age, power (HP) and fuel type listed. If the machines had specific numbers designated by the golf club then they were also recorded. Other more specific details such as height of cut or working hours of the machinery were not deemed necessary for this pilot study.

3.3.1 Machine/Operation Selection

All machines selected were required to possess fossil fuel combustion engines. Fuel measurements were taken from as many different maintenance machines as possible at Vassunda. This approach depended entirely upon the nature and type of operations being carried out during the testing period. Fuel measurements were collected for all mowing operations, topdressing, aeration and verticutting of the greens, fairway fertilisation, bunker raking and driving range ball pick-up (Table 3.1). Operations which were concentrated upon at Fullerö and Upsala were mowing cycles, as data for these golf courses was collected in order to confirm the proposed method. Greens, tees and fairway mowing were collected at both of these golf clubs (Tables 3.2 and 3.3). It was not possible to collect data for rough mowing at Upsala due to the lack of full cycles of this operation being performed during the testing periods. Some replicates for rough mowing were collected at Fullerö.

Maintenance operations which differed in their nature of work within each frequency were not recorded. For instance, trim mowing is carried out regularly on golf courses, but very often the location and amount of work undertaken differs greatly, meaning that these types of operations did not meet the criteria for a defined maintenance cycle. Machines such as utility vehicles were not included in the study, as they are often used for multiple tasks which also cannot be regarded as definitive cycles. The majority of data collection was performed on mowers, as this type of machine is used more regularly than any other type of machine, and often performs the same task each time it is used. Tables 3.1 to 3.3 list the relevant cycles of maintenance on the feature types which were the subject of data collection at the different study sites

Table 3.1 Details of maintenance cycles that provided data at Vassunda Golfklubb

Vassunda		
Feature	**Operation**	**Powered Machinery Required**
Greens	Mowing	Ride-on Triplex Mower
	Topdressing	Large Tractor
	Verticutting (Double Pass)	Ride-on Triplex Mower
	Cross Tining	Large Tractor
Tees	Mowing	Ride-on Triplex Mower
Greens Collars/Aprons	Mowing	Ride-on Triplex Mower
Fairways	Mowing	Ride-on Five-unit Mower
	Fertilising	
Semi Rough	Mowing	Ride-on Rotary Mower
Landscape Areas	Mowing	Ride-on Front Deck Rotary
Long Rough	Mowing	Ride-on Rotary Mower
Bunkers	Raking	Ride-on Bunker Rake

Table 3.2 Details of maintenance cycles that provided data at Fullerö Golfklubb

Fullerö		
Feature	**Operation**	**Powered Machinery Required**
Greens	Mowing	Ride-on Triplex Mower
Greens Surrounds	Mowing	Ride-on Triplex Mower
Greens Aprons	Mowing	Ride-on Triplex Mower
Tees	Mowing	Ride-on Triplex Mower
Fairways	Mowing	Ride-on Five-unit Mower
Semi Rough	Mowing	Ride-on Rotary Mower
Long Rough	Mowing	Ride-on Rotary Mower
Bunkers	Raking	Ride-on Bunker Rake

Table 3.3 Details of maintenance cycles that provided data at Upsala Golfklubb

Upsala		
Feature	**Operation**	**Powered Machinery Required**
Greens	Mowing Verticutting (Double Pass)	Three pedestrian Mowers and/or Ride-on Triplex Mower Ride-on Triplex Mower
Tees	Mowing	Ride-on Triplex Mower
Greens Collars/Aprons	Mowing	Ride-on Triplex Mower
Fairways	Mowing	Ride-on Seven-unit Mowers

3.3.2 Feature Selection

The selection of features that were included in the data collection was dependant upon the operational cycles that were conducted within the testing period. The three main feature areas on a golf course (greens, tees and fairways) were included for mowing

cycles on all three golf courses. Other smaller features such as greens collars/aprons and bunkers were included where possible and where operational cycles were performed allowing data to be collected.

3.4 Data Collection

3.4.1 Fuel Measurement

Fuel consumption was measured volumetrically. The method used was to ensure the machinery fuel tanks were full prior to maintenance cycles being undertaken. On all machinery, the fuel tank was classified as full when either the fuel level was at the marked recommended fill level position or at the bottom of the fuel filling spout if no level was marked. The greenstaff were instructed to complete the cycle of maintenance in the same manner as would normally be expected and the amount of fuel which was required to refill the fuel tanks to the full level after completion of the cycle was recorded in litres, to the nearest 100 ml. This level of precision was used as it was determined that it would provide data that was accurate enough in ratio to the total amount of fuel that would be recorded.

Fueling equipment that was already present at the golf clubs or that was cheap to purchase was used. All golf clubs possessed fueling equipment for large ride-on machinery that could measure the amount of fuel needed to refill the machines to the nearest 100 ml. At two of the golf courses (Vassunda and Upsala), the fuel tank had reel meters on the pumps, which indicated the amount of fuel that the pump dispensed in litres. At Vassunda Golfklubb, estimations of fuel dispensed could be made to the nearest 100 ml by judging the degree to which the single litre reel meter had rotated (Figure 3.1). At Upsala Golfklubb, the reel meter had increments of 100 ml marked clearly, so actual fuel dispensed data could be obtained (Figure 3.2). Due to the use of pedestrian mowers for greens mowing at Upsala, a plastic one-litre measuring jug with 100ml graduations pre-marked was purchased to measure the amount of petrol that was required to refill the fuel tanks (Figure 3.3).

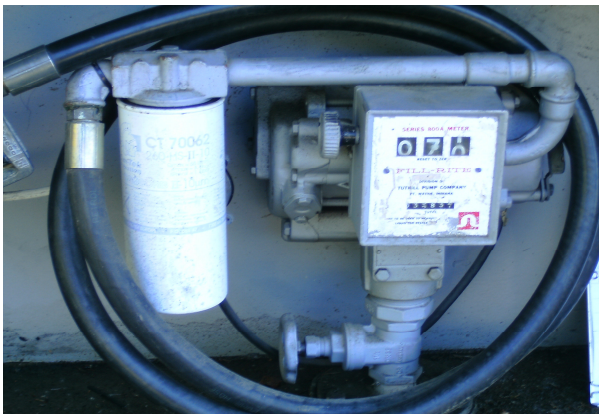


Figure 3.1 Fuel reel meter on fuel tank pump at Vassunda Golfklubb (The gauge shows 70.4 litres)

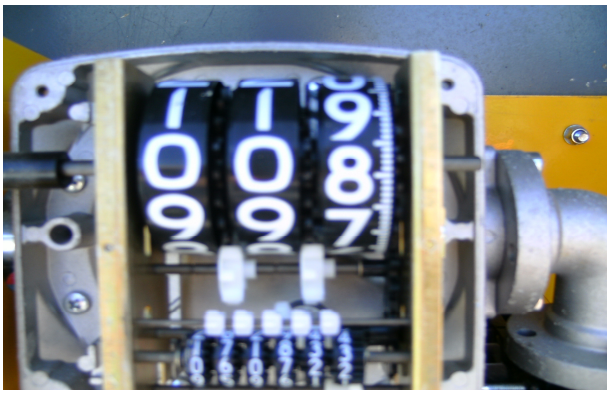


Figure 3.2 Fuel reel meter with 100 ml increment markings on fuel tank at Upsala Golfklubb



Figure 3.3 One-litre measuring jug used to collect data for pedestrian mowers at Upsala Golfklubb (note 100 ml graduations)

At Fullerö Golfklubb, the method for filling machines with fuel was by using ten-litre plastic containers which had 500 ml increments marked on the side (Figure 3.4). Estimates to the nearest 100 ml could be made by judging the location of the fuel level between the relevant two 500 ml markings.



Figure 3.4 Ten-litre fuel containers used to fill machinery with fuel at Fullerö Golfklubb

3.4.2 Repeat Measurements

Data collection for mowing cycles of greens, tees and fairways were more readily available than other maintenance cycles, as these operations were carried out seven, three and three times weekly respectively on each golf course during the grass growing season. It was decided that three replicates of each of these cycles would be collected as a minimum. This number was regarded as suitable for a mean fuel consumption figure to be collected for this pilot study, and one that did not cause inconvenience to the greenstaff at the golf clubs.

Obtaining sufficient number of replicates for certain operations was difficult due to the infrequency of their implementation and the short testing period. Operations such as topdressing, aeration and fertilising were only recorded on one occasion at Vassunda Golfklubb and only on one feature type each time. The number of replicates collected also depended heavily on the climatic conditions encountered during the testing periods. Data collection on operations such as rough mowing could only be collected when conditions were correct for the grass to grow sufficiently to warrant mowing.

3.4.3 Total Annual Fuel Consumption

Yearly fuel consumption data for all the maintenance equipment at each golf club was collected in order to estimate percentage distribution of fuel consumption for each operation separately. The unit required for this data was litres. This data was freely available for diesel and petrol separately at Vassunda and Fullerö, as it was part of the yearly records for the maintenance budget. Consumption data from year 2007 was collected at Vassunda and data from year 2005 from Fullerö. This data was not collected from Upsala as total fuel consumption data was only available in monetary units. The total cost of fuel which was available was also only from financial years when all 36 golf holes were maintained.

3.4.4 Maintenance Cycles per Year

The total number of maintenance cycles per year was collected for all the operations with which data collection was performed. At Vassunda Golfklubb, each time an operation is performed it is recorded on a Microsoft Office Excel spreadsheet. This method for recording operations allowed historical data from 2006 and 2007 to be viewed, as well as operations to collection date in 2008. Operations per year were not recorded at Upsala Golfklubb, and only annual man-hours per operation were recorded at Fullerö Golfklubb. Man-hour information is not useful for the method implemented for this study, as fuel consumption per cycle is being recorded, and not fuel consumption per hour. Man-hour figures also include time taken to prepare and clean machinery for each operation, leaving a larger margin for error when attempting to calculate number of yearly operations.

Due to the aforementioned problems, only estimates of total maintenance cycles per year were recorded for Fullerö and Upsala. This was calculated by multiplying the number of cycles performed each week by the number of weeks in the main grass growing season (mid-May to mid-October), with a small number added for the periods before and after these dates. This is the most accurate method for calculating cycles per year that was available for this study, and details of the estimates can be found in Appendix A.

3.4.5 Number of Features

Data for the number of each feature at each golf course was collected. This data was easily collected as the golf course managers had knowledge of these figures. This information was inventoried along with feature area for all three golf courses (Table 3.4).

Table 3.4 Example feature number and area inventory form

Feature	Number	Area (m²)
Greens		
Tees		
Fairways		
Collars and Aprons		

3.4.6 Area of Features

The area of the different golf course features was collected where possible. The features collected were greens, tees and fairways on all courses. Other features such as greens collars and aprons were also collected where possible and necessary. Area of roughs were not calculated due to the difficulty involved in accurately estimating area for a feature which often possesses such irregular shapes and which is sporadic in its positioning.

At Vassunda, the area of each green and tee was provided by Strokesaver®, a company who specialise in providing course information booklets of distance and area by the use of GPS technology. Information on area for fairways and greens collars/aprons was provided as an estimate from the assistant golf course manager. At Fullerö and Upsala, all of the data for feature area was provided from estimates by the course managers. Supervisory personnel are often required to possess knowledge of total feature size when ordering and applying materials such as fertiliser, irrigation and topdressing, so the data provided was regarded as relatively accurate and the best available for a study of this size.

3.5 Data Analysis

3.5.1 Data Presentation

The study aims to present fuel consumption in the following five units:

1. Fuel consumption per cycle for each operation (litres/cycle)
2. Yearly fuel consumption of each operation (litres)
3. Percentage distribution of total annual fuel consumption for each operation (%)
4. Fuel consumption per feature of each mowing operation (litres)
5. Area mown per unit of fuel for each operation (squared metres/litre)

3.5.2 Statistical Analysis

1. Mean fuel consumption per cycle will be calculated for each operation. These figures will be used to calculate fuel consumption results in all four other units.
2. Fuel consumption per cycle will be normalised by unit area in order for fuel consumption to be compared across operations and golf courses (unit five).

4. Results and Discussion

The results and discussion chapter has been split into two sections. The first section is the presentation of the results, with the second section dedicated to evaluation of this cycle method undertaken.

4.1 Fuel Consumption Results

Data collection from a greater number of maintenance operations was possible at Vassunda Golfklubb as contact was made and operations were recorded earlier than at the other two clubs. Statistical information collected from Vassunda was also more accurate and detailed than at Fullerö and Upsala. This has allowed a greater extent of data analysis to be performed on the results from Vassunda, while results from Fullerö and Upsala was used more to confirm the proposed method.

4.1.1 Fuel Consumption per Cycle

Fuel consumption data for all operations from all three golf clubs are displayed in Tables 4.1 to 4.3. Specific make and model of machines have been included where there was more than one model of machine that completed the operation on a regular basis. Inventories of the relevant machinery can be found in Appendix B. Machinery which was used for each operational cycle can be found in Appendix C.

Table 4.1 Full list of fuel consumption measurements and means for different maintenance cycles at Vassunda Golfklubb

Operation	Fuel Consumption (Litres)			Mean
	Measurement 1	Measurement 2	Measurement 3	
Greens Mowing	7.3	7.5	7.5	**7.4**
Tees and Greens Approach Mowing				
John Deere 2500 (No.1)	12.5	9.5	10	**10.7**
Toro 3100	11			**11**
Fairway Mowing				
John Deere 4600 (No.1)	22	28	24	**24.7**
John Deere 4600 (No.2)	26	22	23	**23.7**
Bunker Raking	2.5	2.5	3	**2.7**
Semi Rough Mowing	70	81		**75.5**
Landscape Mowing	3.5	4		**3.8**
Mowing Around Tees	10	11		**10.5**
Long Rough Mowing	63.5			**63.5**
Driving Range Mowing	6			**6**
Greens Verticutting (2 Passes)	10			**10**
Greens Tining	33.2			**33.2**
Greens Top Dressing	9			**9**
Driving Range Ball Pick-Up	2			**2**
Fairway Fertilising	7.5			**7.5**

The range of fuel consumption figures collected across all the operations at Vassunda varied from two to 75.5 litres. The operations which consumed the least amount of fuel were driving range ball pick-up, bunker raking and landscape mowing. Long rough and semi rough mowing consumed the most fuel per cycle.

Table 4.2 Full list of fuel consumption measurements and means for different maintenance cycles at Fullerö Golfklubb

Operation	Fuel Consumption (Litres)			Mean
	Measurement 1	Measurement 2	Measurement 3	
Greens Mowing	6.5	7	7.5	**7**
Greens Surrounds Mowing	8.5	7.5	6.6	**7.5**
Tees/Collars/Aprons Mowing	10.5	9.5	9.5	**9.8**
Fairways Mowing	31	31	38	**33.3**
Semi Rough Mowing	36			**36**
Long Rough Mowing	68	56		**62**
Bunker Raking	6.5			**6.5**

Long rough mowing consumed the greatest amount of fuel per cycle at Fullerö with a mean of 62 litres. Bunker raking, greens mowing and greens surrounds all consumed the least fuel from the selected operations, as all produced mean fuel consumption figures of less than ten litres.

Table 4.3 Full list of fuel consumption measurements and means for different maintenance cycles at Upsala Golfklubb

Operation	Fuel Consumption (Litres)			Mean
	Measurement 1	Measurement 2	Measurement 3	
Greens Mowing (Main Course)				
Toro Flex 21 (No.1)	1.4	1.5	1.6	
Toro Flex 21 (No.2)	1.6	1.2	1.5	
Toro Flex 21 (No.3)	1.5			
Toro Flex 21 (No.4)		1.5	1.2	
Combined Greens (Toro)	***Total = 4.4***	***Total = 4.2***	***Total = 4.3***	**4.3**
GK VI 1962D (No.1)	8.5			**8.5**
Greens Mowing (Short Course)	3	3.3	3.1	**3.1**
Fairway Mowing (Main Course with Toro groomers on)				
Jacobsen LF 4677	29.1	3		
Toro 6700	31.75	55.6	41.2	
Combined Fairways (w groomers)	***Total = 60.85***	***Total = 58.6***	***Total = 41.2***	**53.6**
Fairway Mowing (Main Course without groomers)				
Jacobsen LF 4677	10.3			
Toro 6700	26.5			
Combined Fairways (w/o groomers)	***Total = 36.8***			**36.8**
Tees and Collars (Both Courses)				
GK VI 1962D (No.3)	7.1		10.1	
GK VI 1962D (No.5)	8.1	12.6		
Combined Tees/Collars	***Total = 15.2***			**12.63**
Greens Verticutting (2 Passes)				
14 greens	9.6			
Equivalent for 19 Greens	**13.03**			**13.03**

Greens mowing on the short course at Upsala consumed the least volume of fuel per cycle, with a mean just over three litres. Mowing fairways both with and without groomers in operation was the most fuel consuming operation tested at Upsala, although it is noted that mowing with the groomers consumed 45 % more fuel than

mowing without the groomers. Using ride-on mowers to cut the main greens also uses almost 100 % more fuel than when pedestrian mowers are used. The mean figure of 4.3 litres consumed to mow greens with pedestrian mowers at Upsala is comparable to the 4.4 litres reported by Piller (1994).

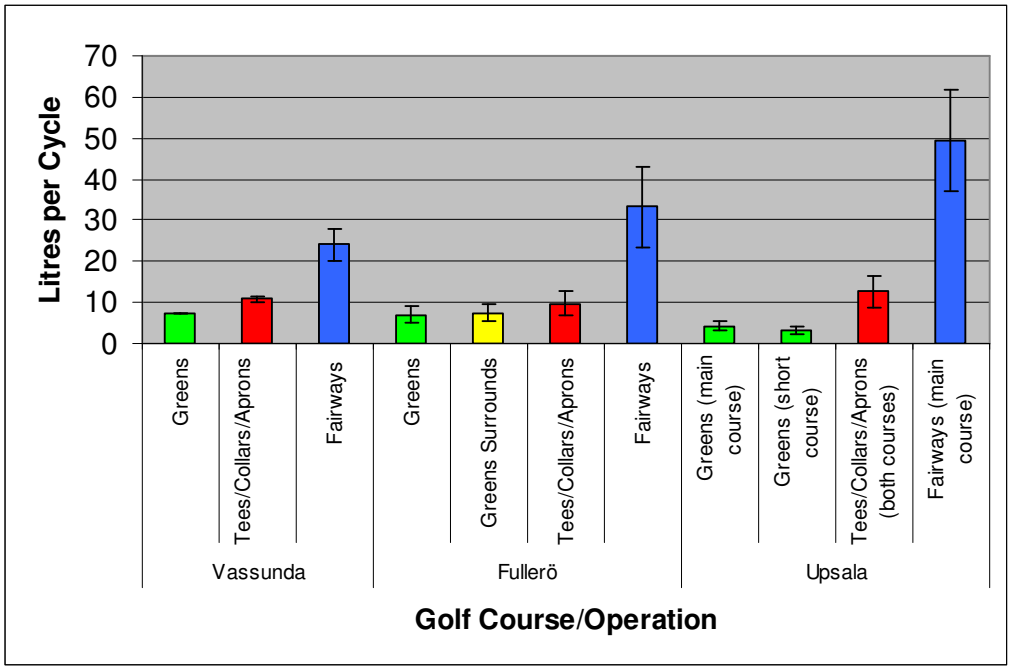


Figure 4.1 Mean fuel consumption measurements of selected mowing operations with standard error bars at Vassunda, Fullerö and Upsala Golf Clubs

The main comparable mowing operations that were recorded over all three of the golf clubs are presented in Figure 4.1. Fairway mowing consumed more fuel per cycle than mowing greens and tees/collars/aprons on all of the golf courses, although the consumption figures for the three golf courses were very different. This is to be expected due to the larger area size these features commonly possess on golf courses. It is also noted that fairways have larger standard error bars, due to the longer time taken to perform this operation than the other selected operations. There were large differences in the fuel consumption recordings for fairway mowing cycles at Upsala, indicated by the largest standard error bars in Figure 4.1. On one of the two operational

fairway mowers (Toro 6700), there were turf groomers in place that were estimated to be used on around 50 % of the fairway mowing cycles. The course manager acknowledged that using these groomers increased the fuel consumption for this machine (Paulsson pers. comm., 2008). The fairways were also mowed via a variety of techniques at Upsala. Often both fairway mowers were used to perform the cycle in order for the operation to be performed in less time. The ratio that each mower was used was not always equal. Fuel consumption data and means were collected for operations of both fairways mown with groomers and without groomers. Figures were added together and the mean calculated for the purpose of compiling Figure 4.1. The standard error for mean fuel consumption per cycle was lower for cycles that consumed less fuel, used less powerful mowers and had smaller areas to mow. For greens mowing on all of the golf courses the standard error was very low, suggesting that further replicates may yield similar data. Greens mowing consumed the least amount of fuel of the mowing operations selected on all three golf courses. At all the three golf courses, mean fuel consumption was very similar when ride-on mowers were used, with data ranging from 7 litres to 8.5 litres. This was similar to mowing cycles for tees/collars/aprons, where machinery used on all three golf courses consumed similar mean amounts of fuel to undertake these operations (9.8 to 12.6 litres).

4.1.2 Yearly Fuel Consumption of Each Operation

Yearly fuel consumption of each operation has been calculated by multiplying the mean fuel consumption figures collected for each cycle by the total yearly operations (Tables 4.4 to 4.6). The sources of origin for total yearly operations are included in the materials and methods section.

Table 4.4 Yearly fuel consumption of operations at Vassunda Golfklubb

Operation	Mean Fuel Use Per Cycle (Litres)	Total Operations (2007)	Estimated Fuel Use 2007 (Litres)
Greens Mowing	7.4	194	1441.4
Tees and Greens Approach Mowing			
John Deere 2500 (No.1)	10.7	77	821.6
Toro 3100	11.0	14	154.0
Fairway Mowing*	24.2	75	1812.0
Semi Rough Mowing	75.5	15	1132.5
Long Rough Mowing	63.5	17	1079.5
Greens Verticutting	10.0	13	130.0
Greens Tining	33.2	4	132.8
Driving Range Mowing	6.0	9	54.0
Landscape Mowing	3.8	10	37.5
Mowing Around Tees	10.5	18	189.0
Driving Range Ball Pickup	2.0	180	360.0
Bunker Raking	2.7	25	66.8
Greens Topdressing	9.0	6	54.0
Fairway Fertilising	7.5	3	22.5
		Total	**7487.5**

* The mean figure for fuel consumption of fairway mowing used in Table 4.4 was the mean of all six replicates recorded from the two different fairway mowers, as the separate number of yearly operations for each fairway mower was not recorded as part of the maintenance records at Vassunda.

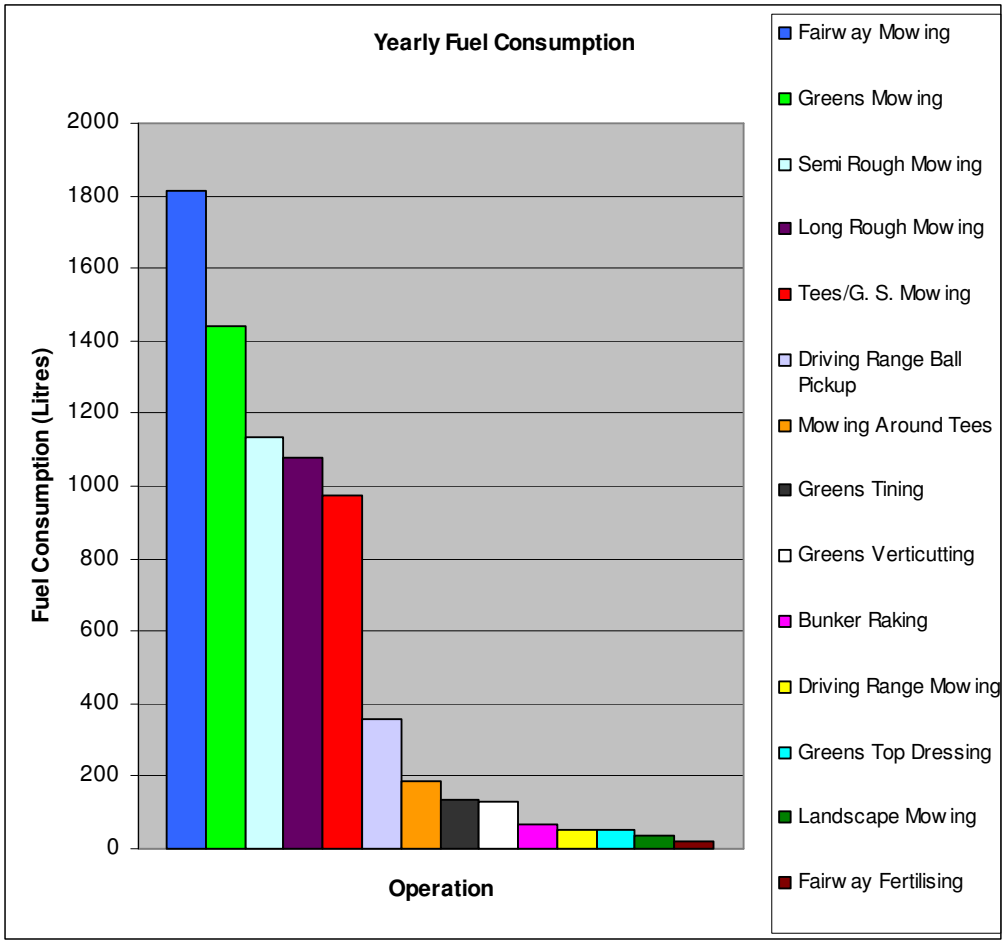


Figure 4.2 Calculated yearly fuel consumption of maintenance operations at Vassunda Golfklubb

Fuel consumption for both the John Deere 2500 and the Toro 3100 were added together to create a total yearly estimated fuel consumption for mowing tees/collars/aprons (Figure 4.2). These machines run on diesel and petrol fuels respectively. Mowing operations were the most significant consumers of fuel at Vassunda Golfklubb, with fairway mowing calculated as the operation that consumed the single greatest amount of fuel over a year, followed by greens mowing (Figure 4.2). Although both types of rough mowing consumed the greatest amount of fuel per cycle, they are only the third and fourth most fuel consuming operations over a year; this is due to the infrequency of their operations compared to greens and fairway mowing.

Table 4.5 Yearly fuel consumptions of operations at Fullerö Golfklubb

Operation	Mean Fuel Use Per Cycle (Litres)	Estimated Total Operations Per Year	Estimated Fuel Use 2007
Greens Mowing	7	160	1120
Greens Surrounds Mowing	7.5	70	527.1
Tees and Aprons Mowing	9.8	70	688.1
Fairways Mowing	33.3	70	2331
Semi Rough Mowing	36	22	792
Long Rough Mowing	62	22	1364
Bunker Raking	6.5	25	162.5
		Total	**6984.70**

Fairway mowing was also calculated as the operation which consumed the greatest amount of fuel per year at Fullerö, followed by long rough mowing and greens mowing. Long rough mowing cycles were only estimated to be performed 22 times per year, but consume more fuel per year than greens mowing, even though greens are mowed 160 times per year.

Table 4.6 Yearly Fuel Consumptions of Operations at Upsala Golfklubb

Operation	Mean Fuel Consumption Per Cycle (Litres)	Estimated Annual Operations	Estimated Annual Fuel Consumption (Litres)
Greens Mowing (Main Course with Pedestrian Mowers)	4.3	150	645
Greens Mowing (Main Course with Ride-on Mower)	8.5	10	85
Greens Mowing (Short Course)	3.1	160	500.8
Fairway Mowing (Main Course without groomers)	36.8	35	1288
Fairway Mowing (Main Course with groomers)	53.6	35	1874.3
Tees and Collars (Both Courses)	12.6	70	884.1
Greens Verticutting (2 Passes)	13	12	156
		Total	**5433.51**

Fairway mowing was calculated to consume the greatest amount of fuel per year at Upsala, similar to that of Vassunda and Fullerö although rough mowing cycles were not included. Fuel consumption for mowing the main greens with pedestrian mowers at Upsala was lower than data calculated at Vassunda and Fullerö, where ride-on mowers are used. Ride-on mowers are estimated to be used on the main course greens at Upsala only around 10 times during the year. These machines are solely used immediately after topdressing is applied to the greens (Paulsson pers. comm., 2008). Fuel consumption of fairway mowing with the use of groomers was calculated to consume almost 600 litres more fuel a year than when the groomers are not used. For the purposes of estimating yearly fuel consumption for fairway mowing at Upsala, the mean figures for cycles with both groomers on and off were used, and the estimated ratio of usage (50:50) was applied against estimated total operations (Table 4.6).

4.1.3 Percentage Distribution of Total Fuel Consumption for Each Operation

The percentage distribution of total fuel consumption for each operation has been calculated by dividing the total yearly fuel consumption per operation into the total yearly fuel consumption from the relevant year for all the maintenance machinery. This has been performed for both diesel and petrol fuel. The vast majority of operations at all three golf courses were carried out on diesel machinery. This unit was not able to be implemented for Upsala Golfklubb due to limitations previously detailed.

Table 4.7 Percentage distribution of total fuel consumption for each operation at Vassunda Golfklubb

Operation	Estimated Fuel Consumption 2007 (Litres)	Estimated Annual Fuel Consumption (% of 2007 total)	
		Diesel (8000 Litres)	Petrol (5000 Litres)
Greens Mowing	1441.4	18	
Tees/Collars/Aprons Mowing			
John Deere 2500 (No.1)	821.6	10.3	
Toro 3100	154		3.1
Fairway Mowing	1812	22.7	
Semi Rough Mowing	1132.5	14.2	
Long Rough Mowing	1079.5	13.5	
Landscape Mowing	37.5	0.5	
Mowing Around Tees	189	2.4	
Driving Range Mowing	54	0.7	
Bunker Raking	66.8		1.3
Greens Verticutting	130	1.6	
Greens Tining	132.8	1.7	
Greens Topdressing	54	0.7	
Driving Range Ball Pickup	360		7.2
Fairway Fertilising	22.5	0.3	
Total	**7487.5**	**86.3**	**11.6**

The majority of the major operations undertaken at Vassunda had fuel measurements recorded, and over 86 % of the total diesel fuel consumption has been accounted for from 2007. The remaining 14 % of fuel is consumed by operations that were not recorded. This may be due to the operations not being performed during the testing period or due to the sporadic nature and inability to be classified as cycles. Only a small percentage of the total petrol consumption has been accounted for from 2007 (12 %). Other maintenance use for petrol fuel at Vassunda is in the majority of smaller powered machines such as pedestrian rotary mowers and strimmers, although the majority of the remaining fuel consumed is expected to have been used for a company car, which is used by the supervisory members of the greenstaff.

The estimated annual fuel consumption of operations such as verticutting, fertilising and topdressing are very low, due to the infrequency these operations are typically performed. The five main mowing operations at Vassunda (greens, tees/collars/aprons, fairways semi rough and long rough) are calculated to account for over 78 % of total diesel fuel consumption per year. This suggests that mowing operations at golf clubs will consume the majority of fuel per year.

Table 4.8 Percentage distribution of total fuel consumption for each operation at Fullerö Golfklubb

Operation	Estimated Annual Fuel Consumption (Litres)	Estimated Annual Fuel Consumption (% of 2005 total)	
		Diesel (13,457 Litres)	Petrol (1,255 Litres)
Greens Mowing	1120	8.3	
Greens Surrounds Mowing	527.1	3.9	
Tees and Aprons Mowing	688.1	5.1	
Fairways Mowing	2331	17.3	
Semi Rough Mowing	792	5.9	
Long Rough Mowing	1364	10.1	
Bunker Raking	162.5		12.9
Total	**6984.7**	**50.7**	**12.9**

Only 51 % of total diesel consumption at Fullerö was accounted for. This is due in part to the lower number of operations for which data collection was conducted. The percentage of fuel consumption attributed to the main mowing operations is much lower than at Vassunda. A possible reason for this may be that the calculated yearly cycles for some of the operations such as rough mowing were calculated too low compared to the actual number of operations that were undertaken in 2005.

4.1.4 Fuel Consumption per Feature

Portrayal of fuel consumption per feature was only practical for machinery which performed operations on just a single feature type. For instance, greens and fairway

mowing cycles were possible to portray, but tees could not be included as the mowers used to perform these operations mow greens collars and aprons during the same cycle on all the golf courses. The shape and nature of collars and aprons are different compared to a tee, so this unit was not used for these mowing cycles. Details of feature numbers can be found in Appendix D.

Table 4.9 Fuel consumption per feature of mowing operations at Vassunda Golfklubb

Feature	Mean Fuel Use Per Cycle (Litres)	Total Feature Number	Fuel Use Per Feature (Litres)
Greens	7.43	21	0.35
Fairways	24.16	14	1.73

Table 4.10 Fuel consumption per feature of mowing operations at Fullerö Golfklubb

Feature	Mean Fuel Use Per Cycle (Litres)	Total Feature Number	Fuel Use Per Feature (Litres)
Greens	7.00	21	0.33
Fairways	33.30	18	1.85

Table 4.11 Fuel consumption per feature of mowing operations at Upsala Golfklubb

Feature	Mean Fuel Use Per Cycle (Litres)	Total Feature Number	Fuel Use Per Feature (Litres)
Greens M/C (Ped)	4.30	19	0.23
Greens M/C (R-o)	8.50	19	0.45
Greens S/C	3.13	9	0.35
Fairways M/C W/G	53.55	14	3.83
Fairways M/C Wo/G	36.80	14	2.63

Some of the results for fuel consumption per feature are consistent across the golf courses. This may be due to the similar type of machinery used on all the golf courses, which possess similar HP ratings, width of working cut and mode of action. Fuel consumption per green on ride-on mowers are an example of this, where figures are 0.35, 0.33 and 0.45 litres for Vassunda, Fullerö and Upsala respectively. The lowest fuel consumption per feature was recorded for greens mowing at Upsala with hand mowers, while the most was fairway mowing with the use of groomers, again at Upsala. Fuel consumption per feature for ride-on greens mowers and fairway mowers were both higher at Upsala than at the other two golf courses. The distance travelled between each feature type was not recorded within this study, but may have had an affect upon this unit for fuel consumption. An approach to measuring and assessing these distances and gauging their affect upon fuel consumption is discussed in section 4.1.5.

4.1.5 Area Mown Per Litre of Fuel

The area mown per litre of fuel has been calculated on operations for which total feature area was available. These results were calculated by dividing the total feature area (m^2) by the mean fuel consumption per cycle (litres). Unlike fuel consumption per feature, the mowers which cut the tees/collars/aprons on the golf courses was included for this unit, as data of collar and apron feature areas were also collected. Full details of feature areas for all three golf courses can be found in Appendix E.

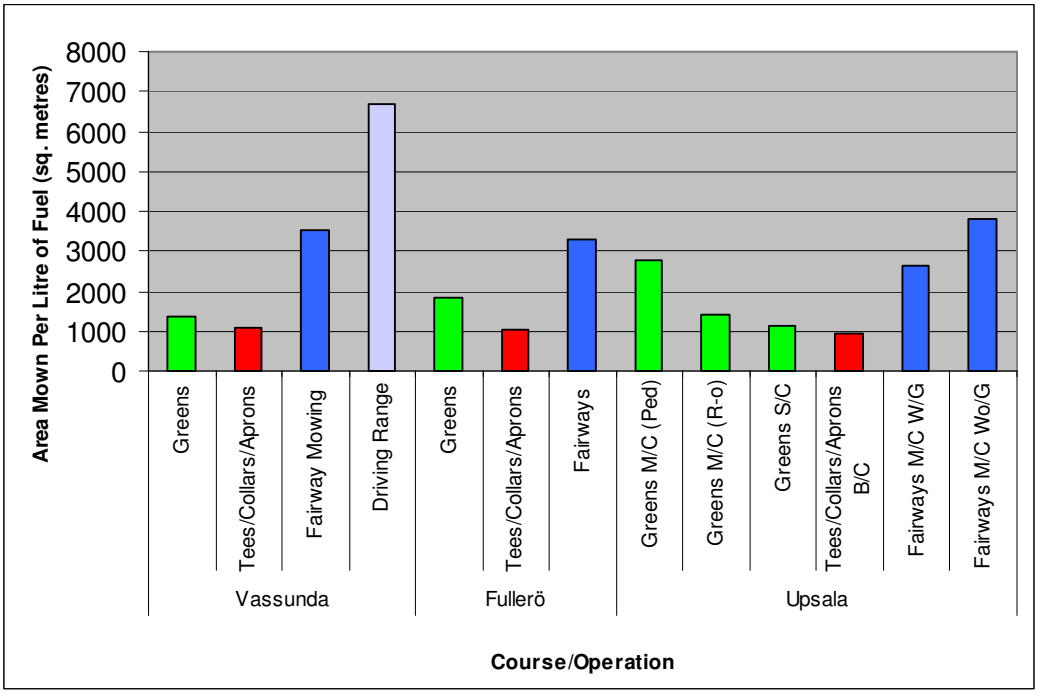


Figure 4.3 Fuel efficiency of selected mowing operations at Vassunda, Fullerö and Upsala Golf Clubs

This measurement unit allows for statistical analysis of fuel consumption to be carried out between golf courses, as the fuel consumption data has been normalised by unit area.

The most fuel efficient operation performed at all the three golf clubs was mowing of the driving range at Vassunda. This was performed with a John Deere 2130 tractor and a trailed gang mower. Excluding this operation, fairway mowing was the most fuel efficient operation of those tested, on all three golf courses. The exception to this statement is at Upsala, where mowing of the greens with pedestrian mowers was more fuel efficient than mowing the fairways with the Toro groomers in use. This is a very surprising result. Due to the more expansive area of this feature type, less machine maneuvering needed, larger mowing widths and often fewer blades per mowing unit than tees and greens mowers, fairways mowers would be expected to be more fuel efficient.

On all three golf courses the least efficient operation in terms of area mown per litre of fuel consumed was mowing the tees, collars and aprons. This may be down to the size and shape of these types of feature, where multiple passes and maneuvering of the mower are often required to mow a small area of turf. Fuel efficiency of mowing roughs is not known due to the problems with calculating area for these features.

The variations in the results of fuel efficiency for some operations across the three golf courses could be due to an extensive range of factors, e.g. machine selection, operator competency, moisture content of the turf, grass species, level of machine maintenance and more. The results have portrayed some similar data across the golf courses, suggesting that these other factors are not as prominent to fuel consumption as the area to be mowed is. One of the major variables that affects fuel consumption data for all the five proposed measurement units is the distances travelled between the different features. Normalising the data by area allows for further analysis of this variable, as well as the effect that other variables have on fuel consumption. It also eliminates area as a variable upon cycle fuel consumption. The process of normalising fuel consumption over area is therefore a benchmark to allow research into methods to reduce fuel consumption. It is important that the distance between the features is altered from being a variable to a constant. This would be achieved by measuring the total distance travelled of machinery between the features and calculating fuel consumption per unit of distance across a relevant terrain. Multiplying fuel consumption per unit of distance by the total distance travelled between features would give a figure of fuel consumption for all the travelling between the features. Subtracting fuel consumption of the distance travelled from total fuel consumption of each cycle would produce a fuel consumption figure for just the maintenance operation performed on the feature. This would also allow greater analysis of the proportion of fuel that travelling between features consumed compared to total cycle consumption. Distances between feature areas were not calculated for any of the golf courses due to the lack of an accurate and feasible method to calculate this variable for a project of this scale.

Another factor which needs to be considered when evaluating the fuel efficiency of machinery is the selection of working patterns. This area is highly researched in agriculture, where patterns for operating machinery on land are planned in order to

spend as little time as possible performing the operation and for the machinery to travel the shortest distance possible (Hunt, 2001). This reduces the fuel consumption of the operation. This approach can be adopted in the golf courses management industry, but with adaption. As aesthetics is a major aspect influencing maintenance operations, it should not be sacrificed solely for the pursuit of productivity. For instance, fairways are often mown in manners that create stripes or square effects for aesthetic purposes, even though a more fuel efficient method for mowing theses features is available. Striking a balance is essential, where less fuel efficient techniques such as double mowing or the frequent use of turf groomers are avoided, but where aesthetic appeal is still created.

4.2 Evaluation of Method and Units

4.2.1 Unit Selection

It was determined that using fuel consumed per cycle of maintenance is the most relevant unit for golf course managers. Solutions to reducing fuel consumption can be analysed using this method, by calculating the amount of fuel that can be conserved per cycle/month/year. This unit of fuel consumption is classified as the primary unit, whilst total annual fuel consumption, percentage distribution of total fuel consumption for each operation, fuel consumption per feature and area mown per litre are all regarded as secondary units. Presenting fuel consumption per cycle of maintenance, as well as the main secondary unit of consumption by area was decided upon due to their relevance in the golf maintenance industry.

Although a main reason for prompting the development of this study was due to the increasing costs of fuel, displaying golf course cycles in financial cost was not considered for this project, although it is obviously important from a business perspective. Calculating the cost of fuel required to complete a cycle is possible by multiplying litres consumed by the cost of a litre purchased. Calculating financial costs per cycle is interesting for a budgetary point of view, but it does not address environmental issues involved with fossil fuel consumption. It also stimulates ideas as

to how total operational costs can be reduced, and this may include lowering wages and reducing machinery purchases and maintenance.

Measuring fuel consumption per unit of production is a dominant feature for agriculture and forestry. For the golf industry, a unit of production would be a round of golf. Calculating fuel consumption per round can be achieved by dividing total fuel consumption for the maintenance machinery by the yearly number of rounds of golf. A figure of interest would be generated (around 0.6 litres per round of golf at the golf courses tested), but these two variables are not always dependant upon each other. For example, rounds of golf can increase or decrease by the influences of the weather and prices charged by a golf club as much as, or even more so by the amount of fuel consumed in maintenance.

4.2.2 Method Evaluation

The method used for physically measuring fuel consumption, by refilling maintenance machinery to the same fill level in the fuel tanks, possesses an obvious advantage in its simplicity. The main advantage of the whole cycle method for portraying fuel consumption is that it allows machinery of different type and function to be categorised under the same primary unit of measurement (Litres/Cycle). Portraying fuel consumption per cycle can be used on the vast majority of golf courses, achieving the main aim for this study. A limitation to this cycle method is that there may have to be added expenditure needed to purchase new fuelling equipment for accurate data to be collected. As this pilot study has shown, there are a variety of processes that can be performed in order for fuel consumption to be measured accurately to 100 millilitres. It is important that a protocol is established so that individuals who perform the fuelling procedure do so in the same manner. Deviations in opinions of these fill levels could alter consumption data by as much as a litre or more on the larger machinery. This would affect the accuracy of the primary unit and in turn affect the accuracy of the secondary units. For example, a one litre deviation of cycle fuel consumption data for mowing fairways at Vassunda would give an error range of 150 litres over a year (Table 4.12)

Table 4.12 Potential annual fuel consumption deviations for fairway mowing at Vassunda Golfklubb

	Cycle Consumption (Litres)	Yearly Consumption (Litres)
Mean (calculated)	24.2	1815
Mean (-one litre)	23.2	1737
Mean (+one litre)	25.2	1887

It is also important that the amount of fuel that is dispensed from a marked litre on the fuel tank reel meter is a litre in actual terms. This is easily measured with a one-litre jug.

The number of data replicates collected for this study was sub-optimal for some operations. The data collected was also limited in its diversity at two of the clubs. The short testing periods prevented further data collection. The accuracy of the fuel consumption results in all the secondary units entirely depended upon the accuracy of the primary unit and the statistical data that was collected. More replicates are advised to be collected in the future, across a whole year or golfing season. One way of achieving this would be to perform measurements on 25 % of cycles for operations that were performed at least once a week and for 75 % of cycles for operations that were performed less frequently. This data would then be representative of climatic conditions and other variables such as the condition of the machinery on yearly fuel consumption.

There was no difficulty in collecting the fuel consumption data. The relatively short testing period and time required for testing at three different golf clubs simultaneously was the biggest drawback to the study. Testing at the three different golf clubs was deemed necessary, as this cycle method needed to be tested at more than just the one golf club in order for its feasibility for extended use to be determined. The testing procedure did not greatly interfere with the greenstaff at the golf clubs, again adding to its advantages for further implementation.

4.2.3 Evaluation of Selected Units

Fuel Consumption per Cycle

As highlighted earlier, this method can accurately measure fuel consumption of machines or operations that perform consistent operational cycles. The calculated results at Vassunda Golfklubb have shown that the vast majority of annual diesel consumption (over 86 %) was estimated to be accounted for with operations that could be classified into cycles. Sporadic or less frequent maintenance practices can be included in this method over a larger time frame, where specific data collection can be collected with careful planning of operations and refuelling.

Fuel Consumption per Year/Percentage Distribution of Total Fuel Consumption

Calculating total fuel consumption per year of each operation and its percentage to total fuel consumption is highly dependent on the accuracy of the statistical data collected for total operations and total fuel consumption. Rough estimates of these figures will allow for comparison of operations to be made. The accuracy of this data will be relevant for golf course managers to analyse techniques employed at their respective golf clubs, suggesting these units are feasible for further use.

The five proposed units for portraying fuel consumption need to be researched further by implementing the cycle method on a larger number of golf courses (e.g. ten or more), to measure the ratio of golf courses that keep records of total operations and total fuel consumption. Two out of the three golf courses that were selected for this study did not have accurate data for total yearly operations and it was not possible to gain accurate data for total annual fuel consumption at Upsala.

An assumption that has been included for this cycle method is that the rate of fuel consumption for the machinery and each cycle is the same as the year from which total fuel consumption for all the machinery was collected. Climatic conditions and age of the machinery could affect the fuel consumption and therefore accuracy of the data. A method for avoiding this in the future would be to implement the data collection over a

whole year and collect total fuel consumption for all the machinery at the end of the year.

Fuel Consumption per Feature

A highlighted problem for calculating fuel consumption per feature is that some cycles mow more than one type of feature, e.g. mowing tees/collars/aprons. This unit is not as useful as the other four secondary units that have been developed due to this reason, but also as it highly dependent on outliers of data, e.g. one golf green being much larger/smaller than all of the rest will affect the data.

Area Mown per Litre of Fuel

One of the major limitations of presenting fuel consumption to area is the lack of a consistent means to calculate accurate feature area. However, this is not a hindrance to further implementation of this unit, as the estimates used are precise and representative of the actual feature areas on each golf course. The lack of a repeatable scientific method causes the data to be unreliable for accurate comparison between courses, but this was not the aim of this pilot study. Only greens and tees areas on one of the three golf courses were regarded to be accurate, as they were calculated by a commercial company via GPS. Using GPS or manual surveying was far too time-consuming and expensive for a project of this scale and for its intended future implementation. The use of satellite programmes such Google Earth® and computer programmes such as AutoCAD® were examined as a means to accurately calculate feature areas, but were not possible as the golf course images on the satellite programmes portrayed the golf courses under snow. These sources may be a viable and efficient process to be incorporated in further research, although estimations of feature area used in this study are sufficiently accurate for the intended use of this method.

Normalising fuel consumption of each cycle over area is an important benchmark for further research to be performed. Presenting fuel consumption in this manner allows area to be eliminated as a variable to differences in fuel consumption, both across different operations and comparing the same operations across different golf courses.

4.2.4 Wider Implications of The Cycle Method

Golf course managers can use this cycle method of measuring fuel consumption and primary unit to compare fuel consumption of different cycles, different maintenance techniques and different machinery. The method can help to evaluate any added benefits to performing operations in certain ways by weighing the benefits against the added financial and environmental costs that performing it would incur. The secondary units used in this study will undoubtedly be useful to a course manager, especially when calculating the effect that different machinery and maintenance techniques have over a year or the effect that feature area has on fuel consumption.

The cycle method can be successfully adopted when golf course managers are undertaking demonstrations of new machinery in a view to purchase. It is hoped that this method can add another factor into the decision making of machine purchases, by identifying fuel efficiency between various machines. It may also help implement Sundberg's (1986) method for costing forestry machinery based on fuel consumption, but with respect to golf machinery. Ongoing expenditure required for machinery such as fuel costs is often not considered with machinery purchases, and data on fuel consumption could be included as standard with machine specifications.

The process of auditing fuel consumption of machinery and operations outlined for this method will be extremely useful if environmental certifications or restrictions of fuel use or emissions are enforced within the golf industry. This method can be similar in principle to irrigation audits and computer data-logging, as records of fuel consumption can be compiled.

Other applications of the cycle method could include its use as a means to gauge the effect that aspects such as reduced maintenance approaches, or the incorporation of an alternatively fuelled machine into a machinery fleet would have on total fuel consumption per year for the maintenance facility.

4.3 Conclusions

The cycle method for measuring and presenting fuel consumption for different operations on golf courses is a mechanism which needs to be researched further, although it has met the aims and objectives set out in section 1. This thesis, as a pilot study into the development of the cycle method, has identified the simplicity of the method of measuring fuel consumption and the ease of its repetition. Due to the merits of the process for data collection adopted, the data collected is accurate, although there is a lack of published data to compare this work to. Greater replicates of data are needed in order for mean fuel consumption per cycle to be accurately calculated, as this figure is used to calculated data for all four secondary units. The method therefore needs to be implemented over at least one calendar year to gain a larger number of data replicates. Further research into this method needs to be performed on greater numbers of golf courses and sporadic maintenance procedures need to have fuel consumption data collected. This may allow for 100 % annual fuel consumption to be accounted for and percentage distribution to be allocated. As 86 % of diesel fuel consumption was accounted for at Vassunda Golfklubb in this pilot study, achieving the goal of near 100 % allocation should not be a difficult task. Normalisation of fuel consumption by area is an important unit and can be used in benchmarking fuel consumption across golf courses, as it allows for greater scrutiny of variables other than area to be performed.

The cycle method has highlighted that fairway mowing is the operation that consumed the greatest percentage of golf course total fuel. The method has also outlined the importance of looking at both the fuel consumption per cycle and the number of cycles per year when determining fuel consumption reduction for operations. This method has also successfully highlighted the variation in fuel consumption of different maintenance techniques. Mowing fairways with the use of the groomers at Upsala Golfklubb was estimated to consume 45 % more fuel per year than mowing fairways without these groomers. Identification of this variation is a strong advantage that this method possesses for future implementation as an optimisation tool.

5. Recommendations for Future Research

- The proposed method should be researched further by performing data collection over a whole year and all operations should have fuel consumption data collected.
- The method should be tested on larger numbers of golf courses, in different countries. This will further assess the feasibility of the fuel data collection process and availability of total fuel consumption and total operations data.
- Greater accuracy in area values should be sought. The use of satellite programmes such as Google Earth, with the aid of CAD programmes should be examined further. This will be important for greater accuracy of normalisation of fuel consumption to area, allowing comparisons of fuel consumption between golf courses to be more accurate.
- Distances travelled between each feature should be altered to a constant rather than a variable. Research into categorising machines for fuel consumption per distance should be performed and sought to be included into the method, so that both distance and area can then be eliminated as causes of varying fuel consumption data. Fuel consumption for the distances travelled between features should be neutralised if comparisons between golf courses is to be viewed extensively, as currently this method does not measure the extent to which distance travelled by machinery has on total cycle fuel consumption.
- The feasibility of categorising machines or features should be investigated. For example, a golf course with greens totalling 10,000-13,000 m^2 should expect to use between 7-8 litres of fuel to mow greens on a ride-on triplex diesel mower.
- Same-type machines from different manufacturers should be analysed for their fuel efficiency. Fuel consumption per distance or area should be adopted as a standardised unit for manufacturers to include the fuel consumption of each machine as standard within the machinery specification. This would provide the manufacturers with a further dimension of quality and performance.

- Once this method is fully established as an optimisation tool for golf course managers, emissions of golf maintenance machinery should be researched further.

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7. Appendices

Appendix A – Calculations of Operational Cycles

Growing Season in Sweden = Mid-May to Mid-October (22 weeks)

Greens mowed 7 days a week x 22 = 154, with 6 more cycles added to accommodate for cycles outside this period = **160 cycles per year**

Fairways mowed 3 days a week x 22 = 66, with 4 more cycles added to accommodate for cycles outside this period = **70 cycles per year**

Tees/Collars/Aprons mowed 3 days a week x 22 = 66, with 4 more cycles added to accommodate for cycles outside this period = **70 cycles per year**

Appendix B – Inventories of Machines Subjected to Data Collection

Table 7.1 Machine inventory from Vassunda Golfklubb

Machine	Year of Manufacture	Fuel Type	Power (HP)
John Deere 2500 (No.3)	2000	Diesel	19.6
John Deere 2500 (No.1)	2000	Diesel	19.6
Toro 3100	1998	Petrol	18
Roberine 1503	1999	Diesel	Unknown
Toro 4700	2003	Diesel	60
John Deere F935	2000	Diesel	22
John Deere 1200A	2000	Petrol	10
John Deere 3235	2000	Diesel	48.5
John Deere 3235	2000	Diesel	48.5
John Deere 4600 Tractor	2000	Diesel	43
Massey Ferguson Tractor 362	1989	Diesel	62
John Deere 2130 Tractor	1977	Diesel	75
Range Servant	Unknown	Petrol	15

Table 7.2 Machine inventory from Fullerö Golfklubb

Machine	Year of Manufacture	Fuel Type	Power (HP)
Jacobsen MK III	2007	Diesel	19
Ransomes T-Plex 185	1998	Diesel	20.9
Jacobsen MK III	2006	Diesel	19
Ransomes 305	305	Diesel	41.9
Ransomes Groom Master	1998	Petrol	19
Ransomes AR 250	2000	Diesel	42
Ransomes HR 6010	2003	Diesel	60

Table 7.3 Machine inventory from Upsala Golfklubb

Machine	Year of Manufacture	Fuel Type	Power (HP)
Toro Flex 21 (No.1)	2007	Petrol	3.7
Toro Flex 21 (No.2)	2007	Petrol	3.7
Toro Flex 21 (No.3)	2007	Petrol	3.7
Toro Flex 21 (No.4)	2007	Petrol	3.7
Jacobsen Greens King VI 1962D (No.1)	2001	Diesel	18.5
Jacobsen Greens King VI 1962D (No.3)	2001	Diesel	18.5
Jacobsen Greens King VI 1962D (No.5)	2001	Diesel	18.5
Toro 6700D	2008	Diesel	46
Jacobsen LF4677	2004	Diesel	44

Appendix C – Details of Machinery Used for Each Operation Subjected to Data Collection

Table 7.4 Operations and machinery used at Vassunda Golfklubb

Operation	Machine
Greens Mowing	John Deere 2500 (No.3)
Tees/Collars/Aprons	John Deere 2500 (No.1)
	Toro 3100
Fairway Mowing	John Deere 4600 (No.1)
	John Deere 4600 (No.2)
Semi Rough Mowing	Toro 4700
Landscape Mowing	John Deere F935
Mowing Around Tees	John Deere F935
Long Rough Mowing	Roberine 1503
Driving Range Mowing	John Deere 2130
Bunker Raking	John Deere 1200A
Greens Verticutting (2 Passes)	John Deere 2500 (No. 1)
Greens Tining	John Deere 4600 Tractor
Greens Top Dressing	Massey Ferguson 362 Tractor
Driving Range Ball Pick-Up	Range Servant
Fairway Fertilising	Massey Ferguson 362 Tractor
Greens Verticutting (2 Passes)	John Deere 2500 (No. 1)
Greens Tining	John Deere 4600 Tractor
Greens Top Dressing	Massey Ferguson 362 Tractor
Driving Range Ball Pick-Up	Range Servant
Fairway Fertilising	Massey Ferguson 362 Tractor

Table 7.5 Operations and machinery used at Fullerö Golfklubb

Operation	Machine
Greens Mowing	Jacobsen Greensplex MK III
Greens Surrounds Mowing	Ransomes T-Plex 185
Tees and Aprons Mowing	Jacobsen Greensplex MK III
Fairways Mowing	Ransomes 305
Semi Rough Mowing	Ransomes AR 250
Long Rough Mowing	Ransomes HR 6010
Bunker Raking	Ransomes Groom-Master

Table 7.6 Operations and machinery used at Upsala Golfklubb

Operation	Machine(s)
Greens Mowing (Main Course)	Toro Flex 21 (No.1)
	Toro Flex 21 (No.2)
	Toro Flex 21 (No.3)
	Toro Flex 21 (No.4)
	GK VI 1962D (No.1)
Greens Mowing (Short Course)	GK VI 1962D (No.3)
Fairway Mowing (Main Course)	Jacobsen LF4677
	Toro 6700D
Tees/Collars/Aprons (Both Courses)	GK VI 1962D (No.3)
	GK VI 1962D (No.5)
Greens Verticutting (2 Passes)	GK VI 1962D (No.3)

Appendix D – Feature Numbers and Areas

Table 7.7 Feature numbers and areas at Vassunda Golfklubb

Feature	Number	Area (m²)
Greens	18 + 3 Practice Greens	8,904 + 1,400
Tees	44	7,232
Collars/Aprons	18	4,200
Fairways	14	85,000
Semi Rough	N/A	Unknown
Rough	N/A	Unknown
Bunkers	34	N/A
Driving Range	1	40,000

Table 7.8 Feature numbers and areas at Fullerö Golfklubb

Feature	Number	Area (m²)
Greens	18 + 3 Practice Greens	13,000 in total
Greens Surrounds	18	Unknown
Tees	45	6,000
Collars/Aprons	18	4,000
Fairways	Fairway Mown Areas on all 18 holes	110,000

Table 7.9 Feature numbers and areas at Upsala Golfklubb

Feature	Number	Area (m²)
Greens (Main Course)	18 + 1 Putting green	12,000 in total
Greens (Short Course)	9	3600
Tees (Both Courses)	52	9500
Collars/Aprons (Both Courses)	27	2,500
Fairway (Main Course)	14	140,000
Fairway (Short Course)	4	30,000