Energy inputs and carbon dioxide emissions from turf maintenance equipment on a golf course in California

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Abstract: The potential negative effects of human activities on global climate have generated significant interests in recent years. Reducing or offsetting carbon dioxide (CO_2) emissions has been central to such discussion among and between state and federal regulatory agencies. Although emissions data from industrial, transportation and agronomic systems have been studied extensively, little data exists for managed ecosystems such as residential and municipal landscapes or sports turf facilities. Even though these intensively managed landscapes are a significant component of modern agriculture in the United States, very little CO_2 emission studies have been conducted on these systems. The objective of this study was to quantify energy inputs and the carbon emissions of a standard size 18-hole golf course in California's Central Valley, one of the most productive agricultural regions of the world. Carbon dioxide emissions from annual maintenance and carbon sequestered by soils and vegetation of such intensively managed ecosystems were also examined. These analyses included energy inputs required for equipment manufacturing and subsequent annual fuel consumption from the use of equipment during daily operations. Our estimates indicated that the total energy requirement for this golf course was 1149 GJ year^{-1} or 13.1 GJ ha^{-1} year^{-1}. The carbon emissions calculated utilizing these energy input estimates indicated that this site also sequesters more CO_2 than it generates during routine turfgrass maintenance operations.

Keywords: energy input, carbon emissions, carbon dioxide, golf course, carbon sequestration

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1 Introduction

As the atmospheric carbon dioxide (CO_2) concentration continues to rise there is a significant global interest to determine sources and to mitigate or offset these emissions. Houghton (2001) demonstrated that atmospheric CO_2 concentrations have increased about 30% since pre-industrial times and possibly could double or triple pre-industrial levels in this century. With this in mind, regulatory agencies have made it a priority to determine methods to reduce/offset CO_2 emissions.

There is a significant body of evidence demonstrating that anthropogenic CO_2 emissions can be mitigated by vegetation transferring atmospheric carbon dioxide to the soil (Lal, 2004). Once such vegetation is turfrgrass, which in the United States, is estimated to cover about 128,000 square kilometers, making it the single largest irrigated crop in the nation (Milesi et al., 2005). This acreage includes areas planted to turfgrass for residential, municipal and commercial lawns, roadsides and sports turf facilities. Among these, golf courses are a significant component and represent some of the most intensively managed "crops" in the nation. Furthermore, turfgrass accounts for approximately 70% of the planted area in these courses (Lyman et al., 2007).

Despite the fact that these intensively managed landscapes are a significant component of modern agriculture in the United States, very little CO_2 emission

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data have been collected from these ecosystems. In particular, it is worthwhile to quantify the CO_2 emissions from these systems in a region such as California's Central Valley which is noted as being one of the most productive agricultural regions of the world (NASS, 2011), and one of the worst air quality basins in the nation. One approach to quantifying CO_2 emissions from these turfgrass-based systems is to adopt a process-based model approach, similar to that used for ammonia emissions (NRC, 2003; EPA, 2004; Pinder et al., 2004), in which the CO2 emissions from various sources within the system are first determined and then summed in order to calculate the total amount of CO_2 emitted. For example, in applying this approach to estimate CO_2 emissions for a given piece of equipment, it would be necessary to, not only measure the emissions during its operation but also, take into consideration the energy input and CO_2 emission during the manufacturing process. Hence, in this study, the primary objective was to estimate the CO_2 emissions from the initial manufacturing of selected equipment and during routine maintenance operations for a golf course in California's Central Valley. Also, the Intergovernmental Panel on Climate Change (IPCC) (2006) has offered guidelines on estimating average carbon dioxide emissions from manufacture of all vehicle components. A secondary objective of this study was to compare the IPPC data for equipment used on the golf course with the carbon sequestration estimates from the turfgrass in an effort to determine if such sites are net source or sink for CO_2 emissions.

2 Materials and methods

2.1 Golf course maintenance equipment

The site utilized in this study was an 87.5 hectare (216 acres), 18-hole golf course. Of this total, 47 hectares (116 acres) were planted to turfgrass with 10.27 hectares (25.4 acres) for greens and 36.73 hectares (90.8 acres) for roughs and fairways. There were also 36.4 landscaped hectares (90 acres) with 18.2 hectares (45 acres) planted to woody perennial shrubs and 18.2 hectares (45 acres) planted to unmanaged grasses. The remaining 4.1 hectares (10 acres) were dedicated to other uses such as parking, cart paths, walkways, and other miscellaneous activities. Energy inputs for equipment (Table 1) used in routine maintenance operations of a golf course were calculated using data provided by the study site's superintendent and manufacturer specifications (Course Superintendent, pers. communication).

Table 1 Equipment† used for various routine maintenance operations of the golf course

	Type	Engine type	Horsepower /kW (HP)
Mowing	Toro Greensmaster 3250-D	Daihatsu DM850D	15.7 (21)
	Toro Reelmaster 5610	Kubota V1505-T	32.9 (44.2)
Edging	Toro Sand Pro 5040	Briggs and Stratton Vanguard	13.4 (18)
Brush cutter	Kawasaki	Kawasaki	0.77 (1.03)
Spray operations	Toro Multi Pro 1250	Kohler CH20	15 (20)

Note: †The equipment used in the various maintenance operations is considered representative for a golf course in California.

2.2 Energy inputs and carbon dioxide emissions from manufacturing turf grass maintenance equipment

The amount of energy sequestrated in a machine consists of the energy used to manufacture raw materials, the energy required during the manufacturing process, energy for repair and maintenance and energy required to transport it from the factory to the consumer (Bowers, 1992). There is no published data concerning energy specifically sequestered by turf maintenance equipment. For this reason, data were extrapolated from similar sized agricultural operations equipment. It was presumed that the energy used for farm manufacturing machinery, such as tractors and harvesters, was similar to the energy used for the manufacture of turfgrass maintenance equipment. Pimentel et al. (1973) estimated the energy required in the manufacturing of agricultural machinery to be 86.77 MJ kg^{-1}.

The energy for repair and maintenance was estimated to be 0.55 times the energy to manufacture the machine (Fluck, 1985). The energy sequestered for transportation and distribution was estimated to be 8.8 MJ kg^{-1} (Lower et al., 1977). The total energy sequestered in the mowing equipment (143.2 MJ kg^{-1}) was used for equipment in this study site.

Wells (2001) estimated that average CO_2 emissions from the manufacture of all vehicle components also requires input of fossil fuel energy and a subsequent average emission factor of 0.07 kg CO_2/MJ. Taking into account deficiencies into the manufacturing process he used an emission coefficient of 0.08kg CO_2 MJ^{-1}.

Golf course equipment parameters, energy coefficients and emissions rates for use during routine maintenance operations are summarized in Table 2. The energy coefficient is defined as the amount of energy ‘emitted’ from the machine per hour of operation. This energy is considered incorporated into the machine during the manufacturing process.

Table 2 Parameters of golf maintenance equipment of the golf course

	Mass/kg	Life/h	Energy coefficient/MJ • h^{-1}	Emission factor/kg CO_2 • MJ^{-1}	Emission rate/kg CO_2 • h^{-1}
Toro Greensmaster 3250-D	608	9500	9.2	0.08	0.74
Toro Reelmaster 5610	1326	9500	20	0.08	1.60
Toro Sand Pro 5040	422	9500	18	0.08	1.44
Brush cutter	5	300	2.4	0.08	0.19
Toro Multi Pro 1250	1025	9500	15.5	0.08	1.24

Note: Data were obtained from manufacturer specifications and the ARB OFFROAD (2007) model.

The golf course superintendent consulted for this study indicated that the Toro Greensmaster 3250-D (diesel) was utilized for greens mowing. This operation normally took approximately 4.5 hours to mow all greens and was conducted seven days a week year-round totaling 1,638 hours/year. It required 9 hours to cut all the tees and was conducted once per week in the winter months and 1-2 times per week in the summer months totaling 468 hours/year.

For roughs, the Toro 5610 mower was used for 16 hours to cut the course once a week during growing months totaling 624 hours/year. Eight hours per week were required to maintain collars (greens perimeter) totaling 312 hrs per year. For fairways, 11 hours per week were required only during the 9 growing months (one month twice per week and 8 months once per week) totaling 440 hrs per year.

Turfgrass edges were maintained during summer months at six hours every other week. The Toro Sand Pro 5040 was used for this purpose. Spray operations using the Toro Multi Pro 1250 were conducted on average 3 hours per week for the whole year. Brush cutters were used extensively by three employees 5 days a week on this area. Annual energy inputs and carbon dioxide emissions for the turf grass maintenance operations, excluding exhaust emissions, are summarized in Table 3.

Table 3 Energy inputs and carbon dioxide emissions for individual turfgrass maintenance operations

	Energy coefficient /MJ • h^{-1}	Annual working hours	Annual golf course aintenance energy input/MJ • $year^{-1}$	Annual CO_2 emissions /kg CO_2 • $year^{-1}$
Greensmaster 3250-D	9.2	2106	19375	1558
Reelmaster 5610	20	1376	27520	2202
Edging	18	36	648	52
Trimming	2.4	8320	19668	1581
Spray Operations	15.5	156	2418	193
Total			69629	5586

2.3 Carbon dioxide emissions and energy inputs from fuel

Equipment fuel consumption data for mowing operations were based on the superintendent’s estimated 75% load factor for the equipment used (pers. communication). Specific fuel consumption data were obtained from engine manufacturer specifications. Energy contained within one liter of diesel fuel was estimated at 47.8 MJ/L and 46.3 MJ/L for gasoline (Ortiz-Canavate and Hernandez, 1999). Emissions and energy requirements for turf maintenance operations are summarized in Table 4. The US Environmental

Protection Agency (EPA) (2005) has recommended calculations for CO_2 emissions from one gallon of fuel which includes multiplication of carbon emission values by the ratio of the molecular weight of CO_2 (44) to the molecular weight of carbon (12). By applying the IPCC (2006) guidelines which assumes full oxidation of the fuel, the calculated value for diesel fuel is 2.692 kg CO_2 l^{-1} and 2.345 kg CO_2 l^{-1} for gasoline.

Table 4 Annual carbon dioxide emissions for each maintenance operation with applied load factor of 75%

	Fuel consumption /l • hr^{-1}	Annual operation /hr	Annual fuel use /l • $year^{-1}$	Energy sequestered in fuel/MJ • l^{-1}	Total energy /MJ • $year^{-1}$	Annual CO_2 emissions /kg CO_2
Greensmaster 3250-D	3.75	2,106	7,898	47.8	377,523	21,261
Reelmaster 5610	7.11	1,376	9,784	47.8	467,676	26,338
Edging	4.37	36	158	46.3	7,316	370
Trimming	0.50	8,320	4,160	46.3	192,608	9,755
Spray operations	4.54	156	708	47.8	33,842	1,660
Total					1,078,965	59,384

3 Results and discussion

Direct plant carbon (C) sequestration occurs as plants acquire atmospheric CO_2 into plant biomass via photosynthesis (SSSA, 2001). Qian and Follett (2002) examined soils from 15 golf courses in the western United States and found that the average C sequestration rates of 0.9 and 1.0 t ha^{-1} yr^{-1} for fairways and putting greens, respectively (Table 5). Gebhart et al. (1994) examined land use change from cropland to perennial grass cover associated with the Conservation Reserve Program (CRP) and documented that for cropland converted to grassland (unmanaged grassland), soil C accumulation rates ranged from 0.028 to 0.218 tonnes of C per hectare per year (0.07 to 0.54 tonnes of C per acre per year). The golf course in this study had 18.2 hectares planted to unmanaged grass. A comprehensive literature search did not result in any reliable C sequestration rates for the 18.2 hectares planted to woody perennial shrubs grown on the golf course. However, it is widely accepted that fast growing plants will subsequently sequester C at relatively faster rates than slow growing one. In addition, C sequestration in landscapes containing maturing tree canopies and shrubs increases over time, however, little data exists for this component in established golf courses, even though there is general agreement that such tree canopies sequester significant amounts of C (Goodale et al., 2002). However, Zirkle, Lal and Augustin (2011) recently modeled C sequestration in home lawns, giving us at least baseline data for comparison of grasses managed in golf course versus home lawns. These comparisons are essential as many areas used for golf course establishment would otherwise be devoted to housing developments. The authors provided evidence that home lawns can serve as a significant carbon sink, ranging from 25 to 204 g C m^{-2} y^{-1}, depending on maintenance levels. The data from Zirkle, Lal and Augustin (2011) appear to be in accordance with the findings from the current study, although the values resulting from this study are greater. This may be due to the absence of estimates for fertilizer, pesticide and irrigation inputs in this study.

Portmess et al. (2008) indicated that the C emissions, in terms of carbon equivalents (CE), from maintenance equipment in a golf course was 26.9 t CE $year^{-1}$. The current study estimated that total CO_2 emissions from fuel consumption were 59.4 t CO_2/year or 16.2 t C/year. The difference between these data may be attributed to differences in fuel consumption. Portmess et al. (2008) used an average course and used average fuel consumption while this study used real data from one golf course in California.

Table 5 Carbon sequestration in various golf course components

	Area/ha	Carbon sequestration/t • yr^{-1}
Fairways	36.7	33.0
Greens	10.3	10.3
Unmanaged grass	18.2	0.51 to 4.0
Total	65.2	43.81 to 47.30

Note: The data were adapted from Qian and Follett (2002).

In order to convert the carbon sequestrated to CO_2, we multiplied the molecular weight of CO_2 (32+12) and divided by the molecular weight of carbon (12). The 43.81 to 47.30 tonnes of C sequestrated by the soil (Table 5) corresponds to 161 to 173 tonnes of CO_2. Total annual CO_2 emissions from equipment and maintenance operations for the single golf course examined in this study totaled 65 tonnes (Table 6). These data indicate that mowing operations accounted for 78% of total CO_2 emissions and energy consumption from this golf course.

Table 6 Annual energy and CO_2 emissions for maintenance operations

	Energy from manufacturing /MJ • year^{-1}	CO_2 emissions from manufacturing/kg CO_2 • year^{-1}	Energy from fuel /MJ • year^{-1}	CO_2 emissions from exhaust/kg CO_2	Total energy per year/MJ	Total CO_2 emissions per year/kg CO_2
Greensmaster 3250-D	19,375	1,558	377,523	21,261	396,898	22,819
Reelmaster 5610	27,520	2,202	467,676	26,338	495,196	28,540
Edging	648	52	7,316	370	7,964	422
Trimming	19,668	1,581	192,608	9,755	212,276	11,336
Spray operations	2,418	193	33,842	1,660	36,260	1,853
Total	69,629	5,586	1,078,965	59,384	1,148,594	64,970

4 Conclusions

Turf management in this selected golf course in California's Central Valley resulted in an estimated release of 65 tonnes of CO_2 per year. This same golf course sequestered an estimated equivalent of 161 to 173 tonnes of CO_2 per year. This amount does not include possible C sequestration from shrubs. Our findings suggest that for this 87.5 hectare (216 acres), 18 hole golf course there is a net annual C sequestration of 96 to 108 tonnes of CO_2 and a concurrent energy sequestration of 1,148 GJ or 13.1 GJ ha^{-1}. It should be noted that further analyses, to include other process based components (e.g. water pumping, irrigation and fertilizer use) are necessary to complete a more comprehensive estimate of the energy consumption and CO_2 emissions associated with this golf course. These preliminary data do, however, suggest careful consideration of the positive role of turfgrass in carbon sequestration and subsequent impact on global climate change.

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