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Sheep grazing in 'lawnscape' management: an emissions comparison with conventional 'lawnscape' management

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ABSTRACT
The use of sheep in lawnscape management is touted as a low-carbon alternative to conventional lawnscaping; however this claim remains unsubstantiated. While conventional lawnscaping generates greenhouse gas (GHG) emissions, primarily through fuel combustion, sheep grazing produces methane (CH_4) as well as manure which releases embodied nitrogen as nitrous oxide (N_2O) as it degrades. These gases have a carbon equivalency of 25 and 298 respectively, indicating their much greater potency as GHGs relative to carbon dioxide (CO_2). This paper is the first to critically profile and compare GHG emissions produced by grazing and conventional lawnscape management. It discusses critical factors affecting the carbon footprint of both practices, and develops a framework for evaluating lawnscape management emissions. This study finds that replacing lawnmowers and the treatment and application of compost with a grazing regime can reduce net lawnscape management emissions by 34–37%, or 980 kgCO_2e/ha/year.

KEYWORDS
Sheep grazing; landscape management; landscaping; landscape emissions; lawnmower; sustainability

1. Introduction

Public and private sector organisations are increasingly searching for ways to reduce their greenhouse gas (GHG) emissions. One possibility is to adopt more sustainable management of turfgrass 'lawnscapes'. Lawnscape management regimes vary significantly according to climatic conditions and land-use, however regular gas-powered mowing and the removal of grass clippings throughout the growing season is a common feature (Bormann, Balmori, & Geballe, 2001; Chalmers & Booze-Daniels, 2009). Regular mowing and composting of lawnscape waste, referred to in this paper as conventional lawnscape management (CLM), generates significant GHG emissions (Selhorst & Lal, 2013; Strohbach, Arnold, & Haase, 2012). While various studies have proposed incineration or anaerobic digestion as value-added alternatives for treating lawnscape waste (see Shi et al., 2013; Shi, Ge, Chang, Shao, & Tang, 2013; Springer, 2012; Triolo, Pedersen, Qu, & Sommer, 2012), both rely on the continued use of resource-intensive lawn mowers, waste collection and waste management activities.

Grazing lawnscape management (GLM), depicted in Figure 1, is a comprehensive alternative to CLM, in which herbivorous livestock, typically sheep, are used to manage turfgrass areas, replacing the need for lawnmowers and organic waste treatment. The use of sheep labour in landscape management dates back to at least the thirteenth century and was a defining feature of pre-industrial European farming (Brunt, 2007; Cunfer & Krausmann, 2009). Today GLM is used by governments and businesses around the world, and in 2013, was even promoted by a number of British politicians as a way to reduce

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Figure 1. (Left) Sheep mow the White House Lawn c. 1918. Source: The White House Historical Association, n.d. (Right) Sheep manage apartment lawnscape in Gloucestershire, UK in 2012. Source: Tomlinson (2012).

government expenditure (Holehouse, 2013). Moreover, GLM is often described as an environmental alternative to CLM (e.g., Kim, 2014; 'Paris hires munching sheep as eco lawn mowers', 2013), despite the fact that sheep produce methane (CH_4) as well as manure which releases embodied nitrogen as nitrous oxide (N_2O) as it degrades. These gases have a carbon equivalency of 25 and 298 respectively, indicating their much greater potency as GHGs relative to carbon dioxide (CO_2).

This paper is the first to profile and compare GHG emissions from CLM and GLM. It begins with an overview of CLM and the principle ways in which it generates GHG emissions, followed by a similar overview for GLM. The remainder of the paper is divided into methodology and assumptions, results, discussion and conclusion.

2. Overview of conventional lawnscape management

CLM is a resource-intensive process, requiring regular inputs of fossil fuels, water and fertiliser, as well as the removal and treatment of organic waste. This study focuses exclusively on GHG emissions generated from lawnmowers and lawn waste management, since these are the emissions sources which are effectively replaced by GLM.

2.1. Lawnmower emissions

GHG emissions from lawnmower use are substantial; in the US they release an estimated 1.8–3.7 TgCO_2e annually (Selhorst & Lal, 2013). Motorised lawn and garden equipment (LGE) can also be a significant source of emissions for large land-owning organisations. A study of the University of Central Florida for example, estimated that roughly 1200 Mg of carbon dioxide (CO_2) were emitted annually as a result of LGE use on campus (Clifford & Cooper, 2012).

Most lawnmower studies are conducted under lab conditions and express emissions as a function of time (g/h) or unit of fuel (g/l). The first such studies involving direct testing of lawnmower emissions date back to at least the mid-1970s (Hare, Springer, Oliver, & Houtman, 1973; Zinger & Hecker, 1979). In the decades since, numerous other studies have been performed (Gabele, 1997; Priest, Williams, & Bridgman, 2000; White, Carroll, Hare, & Lourenco, 1991) though these have focused on non-GHG emissions due to their human health impacts.

A few studies have instead focused on GHG emissions from lawnmowers, developing spatial emissions estimates as part of larger investigations into the carbon sequestration capacity of lawnscapes (Sahu, 2008; Selhorst & Lal, 2013; Sivaraman & Lindner, 2004; Townsend-Small & Czimczik, 2010a, 2010b). Unlike emissions per hour or unit of fuel, spatial emissions estimates require the researcher to make implicit or explicit assumptions about mowing speed and blade coverage. Thus while a spatial estimate is the established and most practical method for profiling GHG emissions from landscape management, it necessarily involves a higher degree of uncertainty than other emissions figures.

Table 1. Spatial fuel consumption (Sahu, 2008).

Machine type	Fuel consumption (l/ha)
Push mower	9.35
Ride mower	7.02

To develop a spatial lawnmower emissions estimate, it is first necessary to determine spatial fuel consumption. Previous studies have accomplished this using one of three methods. Townsend-Small and Czimczik's (2010a, 2010b) study concerning park management emissions in Irvine California, used a monthly fuel consumption rate and total park area to determine fuel consumption per hectare per year. This method elegantly avoids the need to make assumptions about lawn mowing speed and blade coverage, and thus is an ideal means of calculating spatial emissions from lawnmowers for an in-use CLM regime.

Other studies have developed spatial fuel consumption figures for lawnmowers without a case-study reference. Sivaraman and Lindner's (2004) accomplished this by making explicit assumptions about operator walking speed and blade length. Assuming no blade overlap on already mowed grass, the authors estimated an average mowing time of 5.9hr/ha. Combining this figure with hourly fuel consumption rates, they were then able to estimate fuel consumption/ha.

A third method is to use established industry figures which include implicit assumptions about mowing speed and blade coverage. Studies by Sahu (2008) and Selhorst and Lal (2013) both use this method, citing the same spatial fuel consumption figures for push and ride mowers first published by Sahu (see Table 1).

2.2. Compost emissions

Composting is often considered a GHG negative process because it can be used to divert organic waste from landfill, replace carbon-intensive peat and synthetic fertilisers, and increase carbon sequestration in soil (Boldrin, Andersen, Møller, Christensen, & Favoino, 2009; Christensen et al., 2009; Fisher, 2006). These same benefits however, have equally been attributed to the use of livestock grazing (Garnett, 2009; Hadjigeorgiou, Osoro, Fragoso de Almeida, & Molle, 2005) and so are excluded from the present study.

2.2.1. Biogenic compost emissions

Composting produces the GHGs CO_2, CH_4 and N_2O (Ermolaev, Sundberg, Pell, & Jönsson, 2014) however, while CO_2 is produced in the greatest quantity, it is considered part of the natural carbon cycle and thus climate change neutral (Andersen, Boldrin, Samuelsson, Christensen, & Scheutz, 2009; Hellebrand, 1998).[1] Biogenic compost emissions (BCEs) are dependent on a wide range of factors (feed stock and particle size, temperature, moisture content, and aeration levels) making compost management essential to minimising GHGs (Amlinger, Peyr, & Cuhls, 2008; Andersen, Boldrin, Christensen, & Scheutz, 2010; Ermolaev et al., 2014; Hellebrand, 1998). BCEs are typically expressed as a ratio of emissions output to Wet Waste (WW) input (kgCO_2e/MgWW). Table 2 presents BCE rates from a number of studies, as well as the IPCC's own default emission factor (EF) for the biological treatment of waste (Pipatti et al., 2006).

2.2.2. Compost management emissions

Compost Management Emissions (CMEs) are often excluded from compost emissions studies despite the important role of machinery in centralised composting systems (Christensen et al., 2009). Total CMEs can vary considerably depending on the management regime employed. In open compost systems, CMEs originate from fuel combustion in shredders, loaders, turning machines, while in closed systems, further indirect emissions may occur through the use of electricity in temperature regulation and air filtration (Boldrin et al., 2009). As with lawnmower emissions, CMEs are derived from fuel consumption rates, expressed in litres (diesel)/MgWW (Boldrin et al., 2009).

Table 2. Biogenic composting emissions.

Source	Compost operation	Feed stock	$kgCO_2e\ Mg^{-1}$ WW
Amlinger et al. (2008)	Backyard Composting	Organic Household Waste	76.1
	Windrow Composting	Organic Household Waste	14.4–41.2
		Garden Waste	8.6–67.9
Anderson et al. (2010)	Backyard Composting	Organic Household Waste	100–239
Andersen et al. (2009)	Windrow Composting	Garden Waste	111 ± 30
Hellebrand (1998)	Pilot	Garden Waste	143
Dong et al. (2006)	Default	Garden Waste	189.4

2.2.3. Emissions from compost use

Finally, compost also releases GHG emissions when used as fertiliser. Although the practice is atypical in CLM, compost can be an effective alternative to more conventional ammonium nitrate fertilisers (ANFs) (Zhang, Malhi, Panasuik, & Henriquez, 2010). The application of compost, if not performed manually, will require the use of landscape machinery and is therefore an important consideration when comparing CLM and GLM emissions, as the spreading of compost mirrors the equivalent process of spreading manure performed naturally by sheep. Once applied to the land, soil enhancers like manure and compost produce N_2O emissions, as stored Nitrogen (N) is exposed to the air and undergoes oxidisation (Pipatti et al., 2006). The amount of N_2O generated from N in applied compost has been measured at between 1 and 2.2% (Boldrin et al., 2009).

2.3. Carbon sequestration in turfgrass

Numerous studies have demonstrated carbon sequestration in lawnscapes, though the impact of lawnscape management remains a topic of debate. Several studies conclude that carbon sequestration rates in turfgrass exceed GHG emissions from a range of likely lawnscape management regimes (Maestas, Alexandrou, Bushoven, Goorahoo, & Adhikari, 2012; Selhorst & Lal, 2013; Zirkle & Augustin, 2011) however others (Lafond, Lalancette, Brodeur, Allaire, & Dufour-L'Arrivée, 2008; Townsend-Small & Czimczik, 2010a, 2010b) argue net carbon sequestration depends on conservative management practices. Sahu (2008) and Milesi et al. (2005) on the other hand, argue that more intensive turfgrass management can actually increase net sequestration rates despite the greater management emissions. Grassland studies have also found that management with livestock can enhance carbon sequestration rates (Allard et al., 2007; De Faccio Carvalho et al., 2010; Garnett, 2009) however, as Selhorst and Lal (2013) point out, the carbon capacity of turfgrass is not boundless; once exhausted, it will no longer serve to offset continued lawnscape management emissions. Moreover, higher management emissions mean turfgrass sequestration cannot offset GHGs from other sources, resulting in a greater opportunity cost. For these reasons, this study excludes carbon sequestration impacts.

3. Overview of grazing lawnscape management

Sheep and other ruminant livestock produce GHGs in the form of CO_2, CH_4 and N_2O, however as with composting, CO_2 emissions are considered natural and thus excluded from livestock emissions estimates (Dong et al., 2006; Herrero et al., 2011). CH_4 is primarily generated as a result of enteric fermentation during the digestive process in ruminants, though it may also arise during manure management. N_2O emissions originate from livestock manure, chiefly during storage and following its application as fertiliser (O'Mara, 2011). Livestock emissions are typically expressed as $kgCO_2e$ per weight of marketable product (meat, milk, eggs, wool) though they may also be expressed on a per head basis (Garnett, 2009), as when considering the global warming impacts of animal labour.

3.1. Enteric fermentation and the production of CH_4

The agricultural sector is estimated to produce two-thirds of annual anthropogenic CH_4 emissions (Sejian, Lal, Lakritz, & Ezeji, 2011), half of which has been attributed to enteric fermentation in ruminant livestock (Eckard, Grainger, & de Klein, 2010). Enteric fermentation is the process by which methanogens living in the digestive tract of ruminants consume a portion of the animal's feed and produce CH_4 which is then released into the atmosphere (Sun et al., 2012).

Enteric CH_4 emissions in sheep are usually measured *in vivo* using respiratory chambers (McAllister, Beauchemin, McGinn, Hao, & Robinson, 2011) and have been found to range from 12.2 to 32gCH_4/sheep/day depending on a range of variables including feed intake, grazing intensity and individual animal and breed characteristics (Savian et al., 2014). In a well-known study by Pelchen and Peters (1998), the authors reviewed 89 studies concerning enteric emissions in sheep and derived an average emissions rate of 22.15gCH_4/sheep/day. The IPCC, which distinguishes between developed and developing countries, uses a default EF for the former of 21.9gCH_4/sheep/day, drawing from previous studies and assuming an average live weight of 65 kg (Dong et al., 2006).

3.2. Manure emissions

Sheep and other ruminant livestock only consume 5–25% of the N contained in their food; what remains is excreted through faeces and urine, collectively known as manure (Eckard et al., 2010). The relatively high N content in livestock manure is what makes it a potent fertiliser, but also a major source of CO_2e, as stored N is oxidised into N_2O. The United Nations' Food and Agriculture Organisation (FAO) estimates that animal manure accounts for 5% of anthropogenic GHGs globally (FAO, 2006). The methods by which manure is stored and applied to the land are the critical factors affecting manure emissions (Dong et al., 2006). Anaerobic conditions in manure storage ponds or tanks result in the creation of CH_4, while long storage times increase N oxidisation into N_2O. Eliminating storage time and applying manure directly to the land through grazing can therefore dramatically reduce manure emissions (Gerber et al., 2013; Murphy, Crosson, O'Brien, & Schulte, 2013).

3.2.1. Pasture, range and paddock manure management

The impact of manure management systems on manure emissions is reflected in their different N_2O EFs. Sheep grazing is considered a 'pasture, range and paddock' (PRP) system in which, 'the manure from pasture and range grazing animals is allowed to lie as deposited, and is not managed' (Dong et al., 2006, p. 10.49). The PRP EF for sheep manure used by the IPCC is .01 kgN_2O/kgN (Ce Klein, Novoa, & Williams, 2006).

4. Methodology and assumptions

The comparison of CLM and GLM emissions in this study was based on a 26-week turfgrass growing season. This is in accordance with previous turfgrass studies in temperate climates (Sivaraman & Lindner, 2004), and was confirmed as appropriate for the UK through discussion with a UK-based landscape management company. All grass growth was assumed to occur during the 26-week growing season. Emissions estimates for both CLM and GLM are presented in terms of annual management emissions/ha of turfgrass. As previously stated, no transportation emissions associated with either CLM or GLM were considered due to their high variability, nor were the impacts of carbon sequestration in turfgrass. All lawn waste is assumed to be treated in an open compost system where the only CMEs are from fuel combustion. Compost emissions include those generated during compost production, and those associated with its land application as together, these stages represent a parallel and equivalent process to the digestive breakdown of organic material within sheep and the distribution of manure across the landscape.

Only N_2O emissions from applied compost and manure were included, CH_4 emissions being minor under well-aerated conditions (Ermolaev et al., 2014). Finally, all CH_4 and N_2O emissions detailed in this study were converted to CO_2e based on their respective global warming potential (GWP) over a 100-year period (25GWP for CH_4; 298 GWP for N_2O) (Forster et al., 2007).

4.1. Estimating CLM emissions

4.1.1. Mowing emissions

In the CLM regime developed for this study, mowing was assumed to occur weekly throughout the growing season in accordance with well-established mowing behaviour identified in previous studies (Alumai, Salminen, Richmond, Cardina, & Grewal, 2009; Heckman, Liu, Hill, DeMilia, & Anastasia, 2000; Sahu, 2008; Sivaraman & Lindner, 2004; Wang, Haver, & Pataki, 2013). Emissions estimates for both push and ride mowers were developed using the spatial fuel consumption figures from Sahu (2008) of 9.35 l/ha for push mowers and 7.02 l/ha for ride mowers. Fuel volume was converted into mass using a standard ratio of 1 l: .75 kg. The resulting fuel mass/ha was then multiplied by the European Environmental Agency's (EEA) Tier 1 default GHG EFs for LGE (Winther, Samaras, Zierock, & Lambrecht, 2010), presented in Table 3.

4.1.2. Compost production emissions

Emissions estimates for composting were based on an open composting system in which no heat or energy is captured during the composting process. It was assumed that all grass clipping were collected during mowing. An average annual grass clipping yield of 10 MgWW/ha was adopted from work by Springer (2012) in the US, though it should be noted that industry and council sources in the UK claim maximum grass clipping yields ranging from 16 Mg to 22 Mg/ha (Mowerpro, 2010; Mulching Magic, 2010; Redding Municipal Utilities, 2004). Though no peer-reviewed publications were found to verify these claims, they indicate the Springer figure may be a conservative one.

To determine the appropriate BCEs, the study used the IPCC's default EF of 189.6 kgCO_2e/MgWGW (wet garden waste) (Pipatti et al., 2006). CMEs were estimated using Boldrin et al.'s (2009) fuel consumption figure of 3 l diesel/MgWW for open compost systems and the EF for diesel of 2.7 kgCO_2e/l used by Fruergaard, Astrup, and Ekvall (2009).

4.1.3. Compost use emissions

Since the effort required to spread tonnes of compost evenly across a hectare makes manual labour impractical, this analysis assumed all compost would be applied using landscaping machinery and used a fuel consumption rate of 12 l diesel/ha (Dalemo et al., 1997), multiplied by the previously mentioned EF for diesel combustion (Fruergaard et al., 2009).

In order to determine N_2O emissions from applied compost, total N content first needed to be estimated. This was accomplished using the annual grass clipping estimate of 10 Mg/ha, and an average N output from composting of 6 kgN/MgWGW (Boldrin et al., 2009). This figure was then multiplied by the IPCC's default EF of .01 for the oxidisation of N into N_2O from compost (Ce Klein et al., 2006).

The most significant factors affecting total CLM emissions are lawnmower fuel consumption/ha and grass growth (kgWGW/ha). A sensitivity analysis was conducted by isolating both factors and adjusting their values ±40% while keeping the opposite factor constant. Variations in grass growth were assumed

Table 3. Lawn and garden emissions factors (Winther et al., 2010).

Engine type	Emission	EFs kg gasoline^{-1}
2 Stroke	CO_2	3.197 kg
	CH_4	2.2 g
	N_2O	.02 g
4 Stroke	CO_2	3.197 kg
	CH_4	1.95 g
	N_2O	.06 g

to have no impact on lawnmower use or compost application emissions. The analysis was performed separately for push and ride mowers.

4.2. Estimating GLM emissions

In calculating GLM emissions, this study assumed no external feed inputs would be required during grazing, and that emissions from the supply of drinking water would be negligible. Emissions estimates were based on the exclusive use of adult, non-lactating ewes based on current GLM regimes in practice (Playdon, 2014)[2] as well as recommendations made to Scottish Natural Heritage (2006).

4.2.1. Developing a grazing regime

To estimate GLM emissions, a grazing regime, expressed in 'sheep-days' (grazing days/year × sheep/ha), was developed using Scottish Blackface sheep, among the most common breed in Britain (Mavima, 2011). Annual lawn clipping waste of 10 MgWW/ha, equivalent to 3.95 MgDM (dry matter)/ha (Springer, 2012), was used as a proxy for available feed, then divided by the average voluntary daily forage intake for an adult blackface ewe of 1.4 kgDM (Forestry Commission Scotland, 2014). This produced a grazing regime of 2821 sheep days, from which GLM emissions could be estimated. While a fixed forage intake is a simplification, the advantage of using a 'sheep-days' regime directly tied to grass growth is it allows for variability in stocking rates throughout the growing season based on changing forage availability.

4.2.2. Grazing emissions

To estimate enteric emissions/ha from a grazing regime of 2821 days, the number of sheep-days was multiplied by the IPPC's Tier 1 figure for enteric sheep emissions in developed countries of 21.9gCH_4/sheep/day (Dong et al., 2006).[3] N_2O emissions from sheep manure were calculated using DEFRA's estimate for the annual N excretion per adult sheep of 8.8 kg (DEFRA, n.d.) which was multiplied by the IPCC's Tier 1 EF for PRP of .01 (Ce Klein et al., 2006). The result was then used to derive daily N_2O emissions per sheep and subsequently for 2821 sheep-days. A sensitivity analysis was performed in which daily CH_4 and N_2O emissions per sheep were isolated and adjusted ±0% while the opposite factor was held constant.

5. Results

5.1. CLM emissions profile

5.1.1. Lawnmower emissions

A complete emissions estimate for the use of both push and ride lawnmowers is presented in Table 4. The results show that CO_2 accounts for approximately 99.9% of total GHG emissions mass and 98% of total GWP. As one would expect, push mowers produce greater emissions (598.8 kgCO_2e) than ride mowers (447.2 kgCO_2e) in proportion to their different rates of fuel consumption/ha. Combining push and ride mower emissions produces an average of 521 kgCO_2e/ha/year.

Table 4. Lawnmower emissions.

Machine type	kg Gas ha^{-1}	Mowing frequency	kg Gas ha^{-1} yr^{-1}	EFs	Emissions ha^{-1} yr^{-1}	CO_2e ha^{-1} yr^{-1}	Total CO_2e ha^{-1} yr^{-1}
Push	7.01	26	182.26	CO_2	582.69 kg	582.69 kg	594.8 kg
				CH_4	355.41 g	8.89 kg	
				N_2O	10.94 g	3.26 kg	
Ride	5.27		137.02	CO_2	438.05 kg	438.05 kg	447.2 kg
				CH_4	267.19 g	6.68 kg	
				N_2O	8.22 g	2.45 kg	

5.1.2. Compost emissions

Emissions for both the production and use of compost are presented in Table 5. The results show that compost production accounts for just over 90% of total CO_2e. Biogenic emissions are the single greatest source, responsible for 96% of CO_2e during production, and 87% of total compost emissions. The second greatest source of CO_2e is N_2O resulting from N oxidisation in applied compost, which accounts for 85% of emissions from compost use but only 8% of total compost emissions.

5.1.3. Total CLM emissions

A complete emissions profile for CLM, presented in Table 6, shows that compost is responsible for the majority of CLM emissions, contributing 79% of emissions when using a push mower, and 83% when using a ride mower. Based on these findings, the average emissions output for CLM is estimated at 2707.4 kgCO_2e/ha/year.

5.2. GLM emissions profile

Total annual GHG emissions for a grazing regime of 2821 sheep-days are estimated at 1747.2 kgCO_2e/ha/year. The results, presented in Table 7, show that enteric CH_4 emissions account for 99% of total emissions mass, and 88% of total GWP.

5.3. Comparing emissions from CLM and GLM regimes

A comparison of CLM and GLM regimes used in this study, presented in Table 8, shows that GLM produces 37% less emissions/ha than CLM using a push mower and 34% less using a ride mower. Using average lawnmower emissions of 521 kgCO_2e/ha/year, Figure 2 depicts the contributions of different CLM and GLM processes to their respective carbon footprints and their net difference of 960.2 kgCO_2e/ha/year.

Table 5. Compost emissions.

Emissions sources		EFs	MgWGW ha^{-1} yr^{-1}	kgCO_2e ha^{-1} yr^{-1}	Total kgCO_2e ha^{-1} yr^{-1}
Compost production	Biogenic emissions	189.4 kgCO_2 $tWGW^{-1}$		1894	
	CME	8.1 kgCO_2e $tWGW^{-1}$	10	81	2186.4 kg CO_2e
	Application	32.4 kgCO_2 ha^{-1}		32.4	
Compost use	N Oxidisation	17.9 kg CO_2e $tWGW^{-1}$		179	

Table 6. Total CLM emissions.

Mowing regime	Machine type	Mowing emissions kgCO_2e	Compost emissions kgCO_2e	Total emissions kgCO_2e ha^{-1} yr^{-1}
	Push	594.8		2781.2
26 mows $year^{-1}$			2186.4	
	Ride	447.2		2633.6

Table 7. Total GLM emissions.

Emissions source	EFs	Sheep-days	Regime emissions	kgCO_2e	Total emissions kgCO_2e ha^{-1} yr^{-1}
Enteric emissions	21.9 gCH_4 $sheep^{-1}$ day^{-1}		61.8 kgCH_4	1544.5	
		2821			1747.2
Manure emissions	.24 gN_2O $sheep^{-1}$ day^{-1}		680.1 gN_2O	202.7	

Table 8. Emissions comparison between CLM and GLM Regimes/ha/year.

CLM	GLM	Difference	% Reduction using GLM
Push	2781.2	1034	37%
	1747.2		
Ride	2633.6	886.4	34%

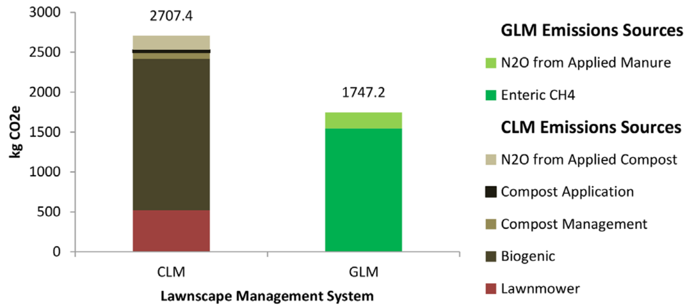

Figure 2. Emissions comparison between CLM and GLM regimes/ha/year.

5.4. Sensitivity analysis

5.4.1. Conventional lawnscape management

The results of the sensitivity analysis, presented in Figure 3, show that CLM emissions are much more sensitive to changes in grass growth than changes in lawnmower fuel consumption. This is because compost emissions make up 79–83% of total CLM emissions. The analysis also revealed that CLM emissions are slightly less sensitive to changes in fuel consumption rates when using ride mowers due to their lower rates of fuel use/ha.

5.4.2. Grazing lawnscape management

The results, presented in Figure 4, reveal GLM emissions are highly sensitive to changes in CH_4 emissions and relatively insensitive to changes in N_2O emissions. The difference is due to the much greater contribution of enteric CH_4 to total GLM GWP compared with N_2O emissions resulting from manure.

5.4.3. Sensitivity of CLM and GLM to changes in grass growth

A third and final analysis was performed to compare the sensitivity of CLM and GLM emissions to changes in grass growth. Analysis was based on the assumption that a marginal increase in grass growth would have an equal marginal impact on both kgWW/ha under CLM, and the number of sheep-days

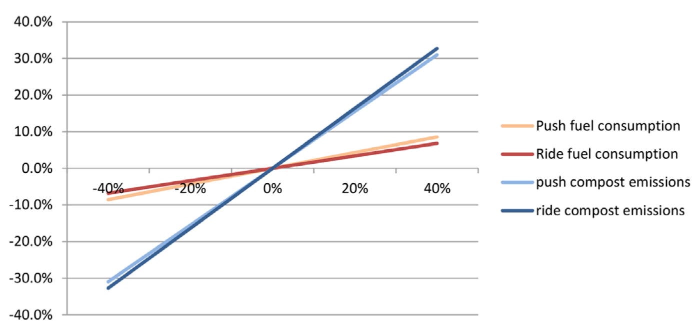

Figure 3. CLM sensitivity to changes in fuel consumption and grass growth.

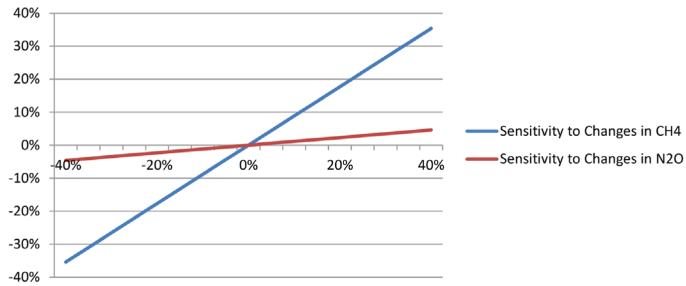

Figure 4. GLM sensitivity to changes in enteric CH_4 emissions and N_2O emissions from manure.

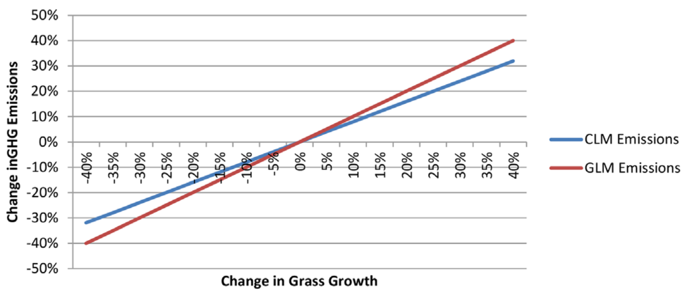

Figure 5. Sensitivity to CLM and GLM to changes in grass growth.

under GLM. The results of this analysis, shown in Figure 5, reveal that GLM emissions are slightly more sensitive to changes in grass growth since all emissions sources are directly affected by changes in sheep-days, while only some CLM emissions sources are affected by changes in WGW.

Nonetheless, the minor difference in sensitivity between the two management systems indicates that even in cases where grass growth is much higher than the 10 Mg/ha/year used in this study, GLM will continue to produce fewer GHG emissions in absolute terms. This is illustrated in Figure 6 using a 100% increase in grass growth/ha/year.

6. Discussion

6.1. Areas for future research

This study is the first to quantitatively show that GLM can reduce GHG emissions and waste generated through lawnscape management. In order to build on these findings, several areas for future research are outlined.

First, field testing of GLM relative to in-use CLM regimes is highly recommended. This will enable researchers to refine the GLM regime developed in this study based on local conditions and desired management outcomes. Moreover, field testing will allow for the inclusion of transportation emissions which, depending on the distances travelled under either management system, could be a significant contributor to their respective carbon footprints.

Second, the aim of this study was to compare CLM and GLM as lawnscape management methods, and did not consider the potential role for GLM in food production. If sheep were used exclusively for GLM, then all emissions they produce throughout the year must be attributed to that activity, irrespective of the growing season. In this study, GLM emissions would effectively double. A more likely scenario is that GLM would be integrated into the conventional sheep farming system, in which case emissions produced over the growing season would be shared between the lawnscaping service, and whatever

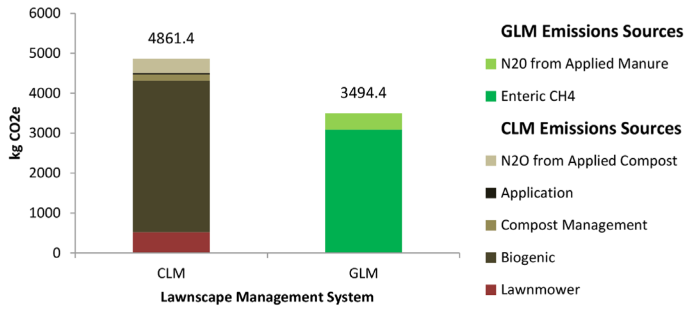

Figure 6. Emissions comparison between CLM and GLM regimes with 100% increase in grass growth (20 Mg/ha/year).

products were produced. There are a number of ways emissions can be allocated between co-products and services (see Röös, Sundberg, & Hansson, 2014), including according to their relative market value. For example, if the value of sheep products produced over the growing season is equal to the value of the GLM service provided, then emissions can be split evenly (873.6 kgCO_2e each). Determining the appropriate share of emissions between products and service is beyond the scope of this paper, but it is clear that any overlap with conventional farming will result in a lower carbon footprint for GLM.

Finally, future research should develop evaluation criteria and use this with land-use data to identify the amount of land suitable for GLM at a regional or national level in order to estimate carbon savings opportunities on a larger scale.

6.2. GLM and resource efficiency

The reduction in CO_2e that can be achieved through GLM is the result of correcting inefficiencies in conventional agriculture and landscape management. By using waste, energy and land more efficiently, GLM is an innovative way for organisations to reduce their GHG emissions and achieve greater resource efficiency.

6.2.1. Waste efficiency

Although manure and organic landscape waste can both provide valuable soil improving products, their means of production are often expensive, energy intensive and inefficient. The large volume of manure resulting from intensive livestock farming releases enormous amounts of GHG emissions due to anaerobic storage conditions, but also requires huge financial and energy investment to store, treat, transport and apply (McAllister et al., 2011; Murphy et al., 2013). The same is true for the collection, processing and redistribution of organic waste as compost (Christensen et al., 2009).

In contrast, GLM manages livestock and landscape waste at the point of production without the need for large financial and energy inputs. This process not only returns stored N directly to the soil from which it originates without the need for transportation and treatment, but also adds value to organic waste by harnessing its stored energy as feedstock. This is particularly important in the light of a growing human population and greater demand for food (McMichael, Powles, Butler, & Uauy, 2007) since organic landscape waste can offset the use of cereal crops in livestock farming, estimated at 30–40% of global production (Janzen, 2011), thereby freeing them up for human consumption.

6.2.2. Energy efficiency

Using the otherwise untapped energy stored in landscape waste to 'fuel' the lawnscape management system, GLM also results in a more efficient and sustainable use of energy. Unlike CLM which depends on mechanical labour and non-renewable fossil fuels, GLM makes use of animal labour and renewable trophic energy. This is particularly advantageous given the finite nature of fossil fuel reserves, the rising financial costs of extraction, and the diminishing energy return on energy investment in the carbon energy sector (Janzen, 2011).

6.2.3. Land efficiency

Turning marginal and unproductive lawnscapes into a fruitful part of the local food system, while preserving their aesthetic and recreational values, means GLM also results in a more efficient use of land. Today, livestock grazing and feed production accounts for the largest share of human land use and are a major driver of habitat loss around the world (Janzen, 2011). Moving livestock production onto lawnscapes through GLM will not only increase the productivity of these areas, but will reduce demand for new pasturage and free up existing grazing land for alternative uses such as forestry and biofuel production, activities which in themselves can help reduce GHG emissions and increase carbon sequestration (Garnett, 2009; Herrero et al., 2011). By shifting livestock production to areas unfit for other productive uses, a process Garnett calls the 'ecological leftovers approach' (2009, p. 499), GLM can eliminate the opportunity costs associated with livestock production on more versatile land.

7. Conclusion

This study is the first of its kind to compare GHG emissions from grazing and CLM. As such, it is difficult to liken its findings with previous research, particularly as CLM studies tend to exclude compost emissions, and sheep studies are oriented towards product, rather than service provision. That said, lawnmower emissions used in this study (521 kgCO_2e/ha) are comparable to previous studies (498.8 kgCO_2e/ha for Sahu, 2008; 583.9 kgCO_2e/ha for Selhorst & Lal, 2013) when adjusted to a 26-week mowing regime. The GLM emissions found in this study (1747 kgCO_2e/ha) compare with 2446 kgCO_2e/ha (adjusted from a regime of 6305 sheep-days) found by Bell, Eckard & Cullen's Australian grazing study (2012), though significant methodological differences (breed, forage, supplementary feed, vehicle use) could explain this. Nonetheless, the Bell, Eckard & Cullen figure falls below that of CLM.

By replacing lawnmowers and eliminating lawn clipping waste, this study finds sheep grazing can reduce lawnscape management emissions by 34–37%. Although the calculations in this study are based on a specific lawnscape management regime, the methodology developed here provides a versatile blueprint for future emissions comparisons by organisations interested in reducing the carbon footprint of their lawnscaping activities. While additional research is recommended to verify and strengthen the findings presented here and develop a more holistic appraisal of GLM, this study nonetheless highlights the important contribution grazing landscape management can make towards reducing GHG emissions and improving resource efficiency.

Notes

1. This is the same reason why CO_2 produced by animal respiration is not considered as part of GLM emissions.
2. Shepherd for Fort Saskatchewan's (Canada) public park grazing program.
3. The IPCC figure assumes an average live weight of 65 kg. Since Scottish Blackface ewes average 50 kg, enteric emission in this study could be overestimated.

Disclosure statement

No potential conflict of interest was reported by the author.

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