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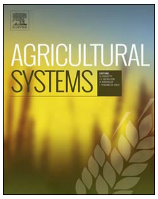

Impacts of soil carbon sequestration on life cycle greenhouse gas emissions in Midwestern USA beef finishing systems

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ABSTRACT

Beef cattle have been identified as the largest livestock-sector contributor to greenhouse gas (GHG) emissions. Using life cycle analysis (LCA), several studies have concluded that grass-finished beef systems have greater GHG intensities than feedlot-finished (FL) beef systems. These studies evaluated only one grazing management system – continuous grazing – and assumed steady-state soil carbon (C), to model the grass-finishing environmental impact. However, by managing for more optimal forage growth and recovery, adaptive multi-paddock (AMP) grazing can improve animal and forage productivity, potentially sequestering more soil organic carbon (SOC) than continuous grazing. To examine impacts of AMP grazing and related SOC sequestration on net GHG emissions, a comparative LCA was performed of two different beef finishing systems in the Upper Midwest, USA: AMP grazing and FL. We used on-farm data collected from the Michigan State University Lake City AgBioResearch Center for AMP grazing. Impact scope included GHG emissions from enteric methane, feed production and mineral supplement manufacture, manure, and on-farm energy use and transportation, as well as the potential C sink arising from SOC sequestration. Across-farm SOC data showed a 4-year C sequestration rate of 3.59 Mg C ha^{-1} yr^{-1} in AMP grazed pastures. After including SOC in the GHG footprint estimates, finishing emissions from the AMP system were reduced from 9.62 to −6.65 kg CO_2-e kg carcass weight $(CW)^{-1}$, whereas FL emissions increased slightly from 6.09 to 6.12 kg CO_2-e kg CW^{-1} due to soil erosion. This indicates that AMP grazing has the potential to offset GHG emissions through soil C sequestration, and therefore the finishing phase could be a net C sink. However, FL production required only half as much land as AMP grazing. While the SOC sequestration rates measured here were relatively high, lower rates would still reduce the AMP emissions relative to the FL emissions. This research suggests that AMP grazing can contribute to climate change mitigation through SOC sequestration and challenges existing conclusions that only feedlot-intensification reduces the overall beef GHG footprint through greater productivity.

1. Introduction

Beef production can be an environmentally deleterious process, leading to high GHG emissions and land degradation, along with feed-food competition. Depending on the accounting approach and scope of emissions included, estimates by various sources (IPCC, FAO, EPA and others) place the contribution of livestock as a whole to global anthropogenic GHG emissions at 7–18%. The United States (U.S.) is the leading beef producer (19% of world production) and among top beef consumers globally (an average of 25 kg per person per year in 2017) (OECD, 2016). In addition, beef consumption is growing globally as the nutrition transition towards greater meat consumption continues in many countries (OECD, 2016). Therefore, producing beef with less GHG emissions (reducing GHG intensity) is of interest both globally and domestically. Life cycle assessment (LCA), the most common approach to GHG emissions accounting, has been used to estimate environmental impacts of beef production.

In previous beef LCA literature, grass-fed (over the entire life cycle) or grass-finished (referring exclusively to the finishing stage) systems are often modeled using simplified grazing parameters typically

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representative of continuous grazing, a simplistic management strategy in which cattle graze the same pasture continuously through an entire grazing season (Crosson et al., 2011; de Vries et al., 2015). This grazing management approach, while still the most common, can negatively impact plant regrowth and recovery, as well as plant communities, and has low productivity (Oates et al., 2011). Grazing management techniques vary greatly, however, ranging from continuous to light rotational to intensively managed. Accordingly, the land, ecosystem, and GHG emission impacts resulting from beef production are highly dependent on the type of grazing management system utilized (Brilli et al., 2017; Rowntree et al., 2016). Additionally, because grass-fed beef production has been increasing in response to United States consumer demand in recent years (Stone Barn Center, 2017), it would be useful to explore the environmental impacts of alternative grass-finishing systems. Some literature has identified beneficial ecosystem services resulting from the adoption of a carefully managed system known as adaptive multi-paddock (AMP) grazing. This approach applies an adaptive strategy that incorporates short grazing intervals with relatively high animal stocking densities, which are designed to allow plant recovery, promoting optimal plant communities and protecting soils (Conant et al., 2003; Teague and Barnes, 2017). These principles were conceptualized by Voisin (1959) as "rational grazing" and have also been embraced within grazing systems such as "holistic planned grazing" (Savory and Butterfield 1998) and "management-intensive grazing" (Gerrish, 2004). Potential AMP grazing benefits include reductions in overgrazing and soil erosion, improved forage utilization and animal productivity, and increased soil carbon (C) sequestration, which might reduce net GHG emissions (Teague et al., 2016).

Soil C sequestration is a critical ecosystem service of grasslands, which can be maximized using best management practices for livestock grazing (Griscom et al., 2017; Liebig et al., 2010; McSherry and Ritchie, 2013; Wang et al., 2015). However, there remains substantial uncertainty about soil C change over time in managed grasslands (Desjardins et al., 2012; Olson et al., 2017; Paustian et al., 2016), with possible limitations to soil C storage related to C and N cycling, including soil N limitations (van Groenigen et al., 2017). Additionally, protecting long-term soil C storage is contingent upon preventing land-use change (Petersen et al., 2013). For these reasons, beef LCAs often assume soil C equilibrium. Given critical relationships between agricultural management and the terrestrial C pool (Olson et al., 2017), as well as the extensiveness of grazing lands (~336 million ha of land in the United States; (Chambers et al., 2016)) and their importance to livelihoods (Asner et al., 2004; Briske et al., 2015; Desjardins et al., 2012), grassland C sinks might represent a significant GHG mitigation strategy that should be included in beef production models. The few studies that considered low rates of soil C sequestration in GHG accounting for beef production indicated potential emissions decreases of 24–535% (Beauchemin et al., 2010; Lupo et al., 2013; Nguyen et al., 2010; Pelletier et al., 2010). Although many used modeled C sequestration from beef simulation studies (Alemu et al., 2017; Beauchemin et al., 2011; Nguyen et al., 2010, 2012), such estimates might not represent actual, on-farm changes in SOC (Petersen et al., 2013; Teague et al., 2011). This need for on-farm SOC data was discussed by Griscom et al. (2017), who identified AMP grazing as a potentially important climate change mitigation strategy, but were unable to include it in their analysis due to lack of robust data.

Previous LCAs have compared feedlot to grass-finishing strategies. Worth noting is that both feedlot- and grass-finishing systems follow similar management practices in the two previous phases of production (cow-calf and backgrounding). A majority of GHG emissions are attributed to the cow-calf sector (Beauchemin et al., 2010). However, most of the differences in beef production environmental impact arise from the finishing strategy employed. An estimated 97% of cattle are feedlot-finished in the U.S., while the remaining 3% are broadly "grass-finished," irrespective of management (Stone Barns Center, 2017). Many studies indicate that feedlot finishing systems have lower cradle-to-gate GHG emissions per kg of carcass weight because grass-fed systems have greater enteric methane (CH_4) emissions (due to microbial ruminal fermentation), attributed to the more fibrous diet and longer finishing times, and lower overall carcass weights (Capper, 2012; Desjardins et al., 2012; Lupo et al., 2013; Pelletier et al., 2010; Stackhouse-Lawson et al., 2012; Swain et al., 2018). However, as noted above, many of these studies did not consider the potential for soil C sequestration in well-managed grasslands, and emissions from feedlot finishing might be underestimated due to a lacking representation of soil changes during feed production, such as soil erosion (Janzen, 2011). From 1982 to 2012, 6.07 million hectares of "prime farmland" in the U.S. were lost due to soil erosion, and currently 4.2 Mg ha^{-1} yr^{-1} are still lost from cropland (USDA, 2015; 2012). Because soil organic matter (SOM) consists of 40–75% C, erosion constitutes a significant loss of soil fertility and water-holding capacity and can contribute to GHG emissions. Furthermore, livestock consume about one-third of all grain produced globally and in the U.S. (FAO, 2012; Schader et al., 2015). For these reasons, soil erosion on land used to produce feed crops is an important indicator of sustainability and should be incorporated into beef LCA accounting, but has generally been excluded. Additionally, emissions from grass-fed systems vary greatly due to differences in regional and on-farm practices. For example, different assumptions about fertilization rates on pasture have resulted in a 5-fold difference in N_2O emissions (Lupo et al., 2013; Pelletier et al., 2010). Studies have identified these gaps and have called for more robust research and inclusion of soil C in future LCA models (Lupo et al., 2013; Pelletier et al., 2010).

Considering the variability in grazing strategies and research gaps in soil C dynamics, the goal of the present study was to estimate the system GHG impacts associated with feedlot (FL) finishing and compare them with finishing using an alternative grazing technique, AMP grazing, including soil C accounting. Additionally, we aimed to answer the call for more robust data of the impacts of AMP grazing on soil C sequestration, as it may contribute to a natural climate solution (Griscom et al., 2017). To do this, an ISO-compliant partial LCA was conducted for the finishing phase of cattle production in the Upper Midwest, U.S., and combined with soil C sequestration results from 4 years of on-farm data collection in the AMP grazing scenario.

2. Materials and methods

All data were combined using a deterministic environmental impact model created in MS Excel. Emissions and land use occupation were calculated for the two comparative beef production finishing systems: FL and AMP grazing.

2.1. System boundaries

Because most management differences and much of the variability among beef production systems are concentrated within the finishing phase, system boundaries were limited to this phase only, thus excluding cow-calf and backgrounding stages. Two different finishing strategies in the Upper Midwest, FL ($>$ 97% of all production) and AMP grazing, were modeled using a combination of on-farm data and scientific literature information. All major GHGs (CH_4, carbon dioxide (CO_2), and nitrous oxide (N_2O)), including those from enteric ruminal fermentation, manure storage and handling, feed production, and on-farm energy use, were included. Tertiary emissions, including those from manufacture of machines, equipment, and infrastructure were excluded, based on their assumed minor contributions (Lupo et al., 2013). Gasses were converted to CO_2 equivalents (CO_2-e) using their 100-year global warming potentials ($CO_2 = 1$, $CH_4 = 34$, $N_2O = 298$) (IPCC, 2014). For continuity and comparison with previous beef LCAs, the functional unit was 1 kg of carcass weight (CW).