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Improving carbon footprinting of agricultural systems: Boundaries, tiers, and organic farming

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ABSTRACT

Purpose: The purpose of this commentary is to call for consistent and improved methodology for agricultural carbon footprint (CF) studies.
Methods: The methods of published agricultural CF studies were compared to identify areas of inconsistency. Organic agriculture has been proposed as an approach to reduce net agricultural greenhouse gas (GHG) emissions and sequester carbon. Therefore we used organic agriculture as a focal system to explore the impact on CF estimates of using inconsistent boundaries, soil emission accounting, and emission factor (EF) tiers.
Results and discussion: Studies of agricultural CF use inconsistent boundaries and most use EFs based on national averages or regional models. As a result the local and farm-to-farm variability of EFs are obscured and the comparability of CFs from different studies is dubious. We propose three principles for agricultural CF calculation: use of consistent broad agricultural system CF boundaries, incorporation of soil emissions and sequestration, and development and use of fine-scale EFs for agricultural inputs. The potential use of organic practices in GHG mitigation efforts, along with the annual inspection process for certified organic farms, justify the future use of organic farms as a longitudinal national or international study population using the proposed principles.
Conclusions: Using different boundaries, or generalized vs. site-specific EFs, can give not only different levels of precision but also fundamentally different answers. Policy based on averaged data or incomplete estimates may be misdirected. To support effective policy and individual decision-making that reduce GHG emissions and/or sequester more carbon, accurate and consistent assessments of the GHG emissions of agricultural practices and systems at a finer temporal and spatial scale are needed.

1. Introduction

Agriculture contributes to global greenhouse gas (GHG) emissions. The direct GHG contributions of agriculture are estimated to account for 10 to 15% of total anthropogenic GHG emissions and 48% of global non-CO_2 anthropogenic GHG emissions (Fig. 1) (Vermeulen et al., 2012; Tubiello et al., 2015). However, estimates of current contributions vary, and many alternative practices could reduce agricultural GHGs or increase C sequestration (Lal, 2004a; Hutchinson et al., 2007). To support effective policy and individual decision-making that reduce GHG emissions and/or sequester more C, accurate and consistent assessments of the GHG emission impacts of agricultural practices and systems are needed.

A carbon footprint (CF) estimates the total balance of emissions and sinks of GHGs from a product or system across its life cycle (Rotz et al., 2010). A CF thoroughly accounts for all inputs and processes within a defined system boundary. The system boundary is an imaginary line drawn around the activities and materials that will be used for calculating CF. As such, the system boundary helps to define the relationship between the scope of the LCA study and the final environmental impacts (International Organization for Standardization, 2006). Outcome of CF studies have potential to supply information that supports effective decision-making to mitigate GHG and climate change, but currently there is poor consistency in the methods of CF calculation for agricultural systems. Consistency is particularly lacking in the choice of functional units, definition of system boundaries, and specificity of emission factors (EFs).

To improve and normalize agricultural system CFs, net soil emissions must be consistently included and considered within the system boundaries. Croplands hold an estimated 362 Pg C, 13% of global terrestrial C (Carvalhais et al., 2014) and nearly 50% as much C as resides in Earth's atmosphere (Fig. 1). Cropland is the most actively managed

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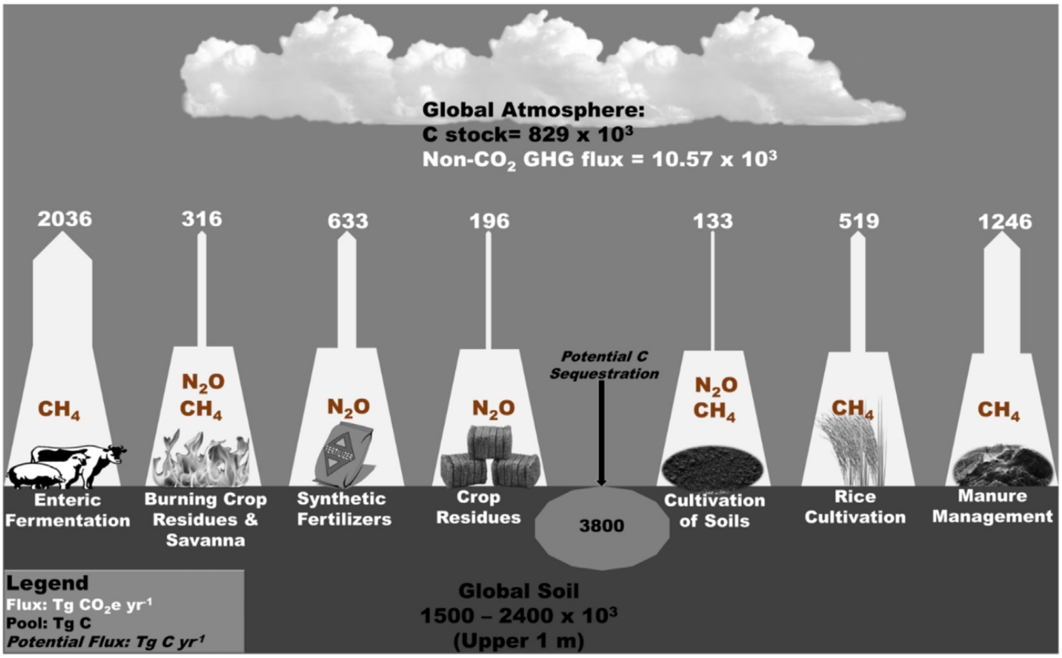

Fig. 1. Agricultural contributions to global non-CO_2 GHG emissions (Tg CO_2e yr^{-1}) estimated for the year 2011 (FAOSTAT, 2011), compared with global soil and atmospheric carbon pools (Ciais et al., 2014) and global potential C sequestration (Lal et al., 2015).

land use, representing an opportunity for active management of its significant C pool. Carbon sequestration in soil may have potential to offset 5 to 15% of the global fossil-fuel emissions per year (Smith et al., 2008; Lugato et al., 2014). One of the goals of Soil Quality Indicators in Life Cycle Assessment Consensus Group (SQILCACG) that met in Dublin in October 2016 is to develop LCA methodology on how to incorporate soil quality into impact pathways and impact assessment models. The SQILCACG group recognizes the importance of incorporating soil dynamics into LCA methodology. However, many studies on CF of agricultural systems still fail to incorporate soil emissions and C sequestration. Including factors affecting C sequestration in GHG emission estimation protocol will not only improve the overall CF accuracy but also further clarify the importance of soil organic carbon (SOC) sequestration as a GHG emission mitigation tool (Smith, 2004; Wiesmeier et al., 2014).

A three tiered approach was provided by the Intergovernmental Panel on Climate Change (IPCC) to estimate GHG emissions (Houghton et al., 1997; Eggleston et al., 2006). Tier 1 uses IPCC national or international default values, tier 2 builds a more specific EF using country-level or more specific data, and tier 3 uses local data from monitoring, experiments, or validated calculation methods (Eggleston et al., 2006). Progress has been made beyond the tier 1 EFs first developed by the IPCC. The country or regional-specific tier 2 EFs for agricultural systems that have been developed over the last several years have increased our understanding of the variability of GHG emission estimates from different sources. Currently, most agricultural CFs use EFs based on national average data or regional models (tier 1 or 2). As a result the ecoregional, local, and farm-to-farm variability of EFs and CFs are obscured. Using generalized vs. site-specific EFs can give not only different levels of precision but also fundamentally different answers (Karimi-Zindashty et al., 2012; Kouazounde et al., 2015; Skiba et al., 2016). Sound policy requires robust scientific reporting of GHG exchange at a finer temporal and spatial scale to identify the most effective management and policies. In this paper, we argue for the development and use of more regional or finer scale tier 3 EFs.

Organic farming systems may be particularly important in agricultural GHG mitigation efforts. Some have proposed government support or justified individual support of organic agriculture as an approach to reduce net agricultural GHG (Niggli et al., 2009; Scialabba and Müller-Lindenlauf, 2010). Yet, inconsistent boundaries, soil emission accounting, and EF tiers make this decision and its basis questionable. Organic agriculture generally uses less energy and stores more C per hectare than conventional agriculture (Tuomisto et al., 2012; Larsen et al., 2014; Reganold and Wachter, 2016). However, energy use and CF on a production unit basis do not always favor organic (Meier et al., 2015; Reganold and Wachter, 2016). Moreover, a wholesale conversion of global food production to organic methods is unlikely. It is necessary to identify the particular factors and practices that lead organic or any system, farm, or product to be more global warming potential (GWP) efficient so that these factors can be adopted as widely as is feasible in all farming systems.

Given the diversity of soils, inputs, transportation, and farming systems across the US and the world, individual EFs and CFs vary from national or regional averages and vary from the findings of individual studies. Policy based on averaged data or large scale estimates may be misdirected. More detailed studies, more accurate input EFs, more complete assessment of food production systems, and more user-friendly tools are needed to accurately identify hotspots, hot moments, and meaningful interventions. Using organic farming as a focal system, here we propose three principles for agricultural CF calculation: use of consistent broad agricultural system CF boundaries, incorporation of soil emissions and sequestration, and development and use of fine temporal and spatial scale EFs.

2. Weaknesses in agricultural carbon footprinting, and their solutions

2.1. *Inconsistent boundaries*

Life cycle assessment (LCA) is systematic set of procedures used to assess environmental impacts associated with all the stages of a product, system, process or service, through production, usage, and disposal (ISO, 2006). As a technique, LCA is used to account for all major resource uses and emissions in the life cycle of a product or system. The LCA methodologies are designed to give a complete picture of inputs and outputs with respect to generation of air pollutants, energy