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Low-carbon agriculture in South America to mitigate global climate change and advance food security

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A B S T R A C T

The worldwide historical carbon (C) losses due to Land Use and Land-Use Change between 1870 and 2014 are estimated at 148 Pg C (1 Pg = 1 billion ton). South America is chosen for this study because its soils contain 10.3% (160 Pg C to 1-m depth) of the soil organic carbon stock of the world soils, it is home to 5.7% (0.419 billion people) of the world population, and accounts for 8.6% of the world food (491 million tons) and 21.0% of meat production (355 million tons of cattle and buffalo). The annual C emissions from fossil fuel combustion and cement production in South America represent only 2.5% (0.25 Pg C) of the total global emissions (9.8 Pg C). However, South America contributes 31.3% (0.34 Pg C) of global annual greenhouse gas emissions (1.1 Pg C) through Land Use and Land Use Change. The potential of South America as a terrestrial C sink for mitigating climate change with adoption of Low-Carbon Agriculture (LCA) strategies based on scenario analysis method is 8.24 Pg C between 2016 and 2050. The annual C offset for 2016 to 2020, 2021 to 2035, and 2036 to 2050 is estimated at 0.08, 0.25, and 0.28 Pg C, respectively, equivalent to offsetting 7.5, 22.2 and 25.2% of the global annual greenhouse gas emissions by Land Use and Land Use Change for each period. Emission offset for LCA activities is estimated at 31.0% by restoration of degraded pasturelands, 25.6% by integrated crop-livestock-forestry-systems, 24.3% by no-till cropping systems, 12.8% by planted commercial forest and forestation, 4.2% by biological N fixation and 2.0% by recycling the industrial organic wastes. The ecosystem carbon payback time for historical C losses from South America through LCA strategies may be 56 to 188 years, and the adoption of LCA can also increase food and meat production by 615 Mton or 17.6 Mton year^{-1} and 56 Mton or 1.6 Mton year^{-1}, respectively, between 2016 and 2050.

1. Introduction

The global C budget has been drastically altered by anthropogenic activities leading to perturbations in the atmospheric composition especially since the onset of the industrial era (Lal 2004; Lal, 2014; Houghton 2014; Le Quéré et al., 2014 and 2015). The components comprising the annual global C budget include five main sources and sinks (Lal 2004; Houghton 2014; Le Quéré et al., 2014 and 2015: i) CO_2 emissions from fossil fuel combustion and cement production that represents 9.8 ± 0.5 Pg C year^{-1}; ii) CO_2 emissions from Land Use (LU) and Land Use Change (LUC) contributing 1.1 ± 0.5 Pg C year^{-1}; iii) atmospheric uptake by 3.9 ± 0.2 Pg C year^{-1}; iv) uptake by land-based sinks, with a mitigation capacity of 4.1 ± 0.9 Pg C year^{-1}, and v) absorption by oceanic sink of 2.9 ± 0.5 Pg C year^{-1} (Houghton, 2014; Le Quéré et al., 2015). Global estimates of historical C losses by LU and LUC range from 45 to 114 Pg C (mean = 79.5 Pg C) for the pre-1870 period, and from 108 to 188 Pg C (mean = 148 Pg C) from 1870 to 2014 (Lal, 2004). Estimates of the depletion of C stock from world soils are at 78 Pg C by cultivation (Lal, 2004) representing 5.0% of the total SOC stored currently in the world soils (to 1-m depth). However, the historical greenhouse gases (GHG) emissions with strong impacts on atmospheric composition include deforestation and burning of native vegetation (67 Pg C) representing 10.8% of the C stock (Lal, 2004; Le Quéré et al., 2014 and 2015) in the terrestrial vegetation (620 Pg C). The onset of land degradation in South America, triggered by the conversion of native

Abbreviations: SOC, soil organic carbon; LU, Land Use; LUC, Land Use change; GHG, Greenhouse gas; LCA, Low Carbon-Agriculture; Pg, billion ton; RDPLi, restoring degraded pasture and livestock intensification; ICLFS, integrated crop-livestock-forest-system; NTcs, no-till cropping system; PCFF, planted commercial forest and forestation; BNF, biological N fixation; IAW, industrial animal waste.

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vegetation to pastureland, has been aggravated by overgrazing and abandoning of the degraded pastures. The historical C losses comprised of: a) the vegetation C emitted into the atmosphere by burning of the native vegetation (conversion to agricultural land) that was estimated at 7.3 Pg C and by oxidation of SOC by ploughing equivalent to 8.1 Pg C (Gloor et al., 2012), while a part of the vegetation-C released is recycled and returned to the global C cycle through land sink and oceanic sink (Houghton, 2014; Le Quéré et al., 2014 and 2015); and b) the fossil C emitted into the atmosphere by combustion of oil, coal and natural gas that creates a hiatus between the global C cycling and geologic C reservoir. South America is a low emitter of GHG from fossil fuel combustion contributing rather small historic emissions of 0.25 Pg C $year^{-1}$ (Gloor et al., 2012). However, the emissions by LU and LUC, especially by deforestation mainly from Amazon and Cerrado biomes contributes 0.34 Pg C $year^{-1}$ (Gloor et al., 2012), and had high impacts on increasing atmospheric concentrations of CO_2 (Gebara and Thuault, 2010; Gouvello et al., 2010; Soares-Filho et al., 2012; Magalhães et al., 2014; Groppo et al., 2015). Brazil has implemented several key domestic and international initiatives to reduce GHG emissions and adopted policies to reduce emissions from deforestation in the Amazon forest by reducing the rate of deforestation by 60% between 2004 and 2014 that represented ~20% less emission by global LUC (Gebara and Thuault, 2010; Gouvello et al., 2010; Groppo et al., 2015).

The potential of agricultural best management practices towards offsetting GHG emissions is estimated at 0.3 to 1.17 Pg C $year^{-1}$ (Lam et al., 2013; Neufeldt et al., 2013; Neufeldt et al., 2015) and represents 2.7 to 10.4% of the global GHG emissions (Lal, 2004; Houghton, 2014; Le Quéré et al., 2014 and 2015). Among these agricultural practices, the C sink capacity of no-till (NT) and associated cropping systems to offset emissions and mitigate climate change has generated intense debate (Powlson et al., 2014; Sommer and Bossio, 2014; Corbeels et al., 2016; Powlson et al., 2016; VandenBygaart, 2016). The debatable issues include the effectiveness of NT to mitigate emissions (Neufeldt et al., 2013; Powlson et al., 2014; Sommer and Bossio, 2014), and the feasibility of adopting agricultural best management practices and upscaling to regional scale (Sá et al., 2013; Corbeels et al., 2016; Powlson et al., 2016). The contribution of NT management to mitigate climate change by C sequestration is perceived to be low presumably because: i) the capacity for soil C sink is finite (Sommer and Bossio, 2014; Adenle et al., 2015; Corbeels et al., 2016; Powlson et al., 2016;), ii) diverse crop sequences or combinations with worldwide adoption of NT promote variable effects of NT on crop yields at global scale (Pittelkow et al., 2014); iii) difficulty of obtaining credible estimates of SOC on landscape scale and requiring a complex framework encompassing a wide range of climate, soils (texture, mineralogy), crops and cropping systems which exacerbate uncertainties in assessing C sequestration (Sá, et al., 2013; Sommer and Bossio, 2014; Adenle et al., 2015; Lam et al., 2013); iv) high risks of re-emission of SOC sequestered because even a single tillage event in a long-term NT soil may negate previous gains in SOC stock (Sá et al., 2014); v) a high variation and uncertainties of the C sequestration rates in fields under NT involving three conservation agriculture principles (FAO, 2014; Kassam et al., 2015) already practiced on <15% of the global cropland; and vi) low amount of the input of biomass-C return because of extreme weather events (e.g., long dry period or excessive rainfall).

Soil C sequestration rates under NT in Brazil selected were based on the three principles that encompass conservation agriculture (e.g., minimum soil disturbance - restricted to the sowing line, permanent soil cover by crop residues or live mulches and crop rotation and intercropping) reported by FAO (2014). Rates of C sequestration for tropical regions range from 0.83 to 1.61 and 1.37 to 2.05 Mg C ha^{-1} $year^{-1}$ for 0–40 cm and 0–100 cm depths for (Sá et al., 2006; Blanchart et al., 2007; Sá et al., 2015; Corbeels et al., 2016; Miranda et al., 2016). These rates for subtropical regions range from 0.91 to 1.61 and 0.52 to 1.95 Mg C ha^{-1} $year^{-1}$ for 0–40 and 0–100 cm layers, respectively (Diekow et al., 2005; Bayer et al., 2006; Sá et al., 2014). In Argentina, rates of soil C sequestration range from 0.40 to 1.55 Mg C ha^{-1} $year^{-1}$ (Díaz-Zorita et al., 2002; Alvarez, 2005; Hernanz, et al., 2009; Alvarez et al., 2014). The present study is based on the hypothesis of overlapping and synergistic effects among LCA activities which could accentuate environmental quality, improve agronomic productivity, and minimize global climate change. The strategy is to develop an approach that encompasses protection and improved management of natural resources through adoption of agricultural best management practices for improving production efficiency. It is this approach that is termed as "Low-Carbon Agriculture (LCA) to mitigate GHG emissions (Gouvello et al., 2010; Soares-Filho et al., 2012; Gebara and Thuault, 2010; Magalhães et al., 2014). Thus, LCA is based on three principles: i) low carbon dioxide (CO_2) emissions from LU and LUC in response to Agricultural best management practices; ii) high CO_2 mitigation through agricultural production systems based on agricultural best management practices; and iii) high C sequestration potential with the adoption of integrated crop-livestock-forestry-systems. The LCA strategy was launched by the Brazilian government as a national program in 2010 to promote specific agricultural activities based on agricultural best management practices which involved six major themes (Gouvello et al., 2010; Soares-Filho et al., 2012; Magalhães et al., 2014): i) restoration of degraded pastureland and promoting livestock intensification based on carrying capacity (RDPLi), ii) expansion of the area under NT and the associated cropping systems with high and diverse biomass-C inputs (NTcs), iii) adoption of integrated crop-livestock-forestry-systems (ICLFS), iv) promotion of biological N fixation (BNF), v) establishment of plantations of commercial forests and forestation (PCFF), and vi) application and recycling of industrial and animal wastes (IAW). Maintaining productivity gains at high levels necessitates adoption of agricultural systems with efficient management of the natural resources (Gouvello et al., 2010; Soares-Filho et al., 2012; Kang, 2013; Magalhães et al., 2014). Further, enhanced use efficiency of external inputs (e.g., seeds, fertilizers, agro-chemicals, machinery and equipment) that can contribute to enhance food security. The concept of food security was established by the United Nation's Universal Declaration of Human Rights in 1948. Article 25, states that: everyone has the right to a standard of living adequate for the health and well-being of himself and of his family, including food (U. Nations, 2014, http://www.un.org/es/documents/udhr/). The situation of hunger in Latin America still affects over 34 million people, which requires greater efforts to achieve hunger eradication during the current generation situation (FAO, 2015). Positive productive performance coupled with a diversity of policies that guarantee access for the most vulnerable, have helped to strengthen food and nutrition security and enabled the region to become a major global food supplier. Thus, an important discussion raises the following question: what is the potential of LCA strategies to mitigate climate change and advance food security in South America? This article is aimed at addressing this question.

2. Material and methods

In this study we used a method based on *scenario analysis* that means a process of analyzing possible future events by considering alternative possible outcomes, sometimes called "alternative worlds" (Duinker and Greig, 2007). Quantitative trend extrapolation simply projecting past data into the future based on the assumption that certain phenomena are likely to persist. This means enable variation and uncertainty to be quantified, mainly by using distributions instead of fixed values in risk assessment.

2.1. Agricultural best management practices and low-carbon agriculture rationale

Tilman et al. (2002) defined sustainable agriculture as agricultural best management practices that meet current and future societal needs for food and fiber, for ecosystem services, and for healthy lives,