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Greenhouse gas emissions and energy efficiencies for soybeans and maize cultivated in different agronomic zones: A case study of Argentina

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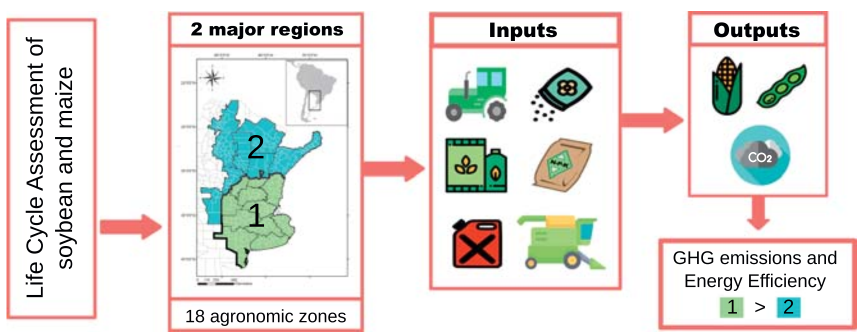
HIGHLIGHTS

- We obtained the carbon and energy footprints of soybean and maize in Argentina.
- Pampean and extra-Pampean regions comprising 1.53 million km^2 were analyzed.
- 18 agronomic zones included in two major regions were considered.
- Highest footprints of GHGs and energy found in extra-Pampean region for both crops.
- The mean annual precipitation explains regional differences in efficiencies.

GRAPHICAL ABSTRACT



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ABSTRACT

Of all human activities, agriculture has one of the highest environmental impacts, particularly related to Greenhouse Gas (GHG) emissions, energy use and land use change. Soybean and maize are two of the most commercialized agricultural commodities worldwide. Argentina contributes significantly to this trade, being the third major producer of soybeans, the first exporter of soymeal and soybean oil, and the third exporter of maize. Despite the economic importance of these crops and the products derived, there are very few studies regarding GHG emissions, energy use and efficiencies associated to Argentinean soybean and maize production. Therefore, the aim of this work is to determine the carbon and energy footprint, as well as the carbon and energy efficiencies, of soybeans and maize produced in Argentina, by analyzing 18 agronomic zones covering an agricultural area of 1.53 million km^2. Our results show that, for both crops, the GHG and energy efficiencies at the Pampean region were significantly higher than those at the extra-Pampean region. The national average for production of soybeans in Argentina results in 6.06 ton/ton CO_2-eq emitted to the atmosphere, while 0.887 ton of soybean were produced per GJ of energy used; and for maize 5.01 ton/ton CO_2-eq emitted to the atmosphere and 0.740 ton of maize were produced per each GJ of energy used. We found that the large differences on yields, GHGs and energy efficiencies between agronomic regions for soybean and maize crop production are mainly driven by climate, particularly mean annual precipitation. This study contributes for the first time to understand the carbon and energy footprint of soybean and maize production throughout several agronomic zones in Argentina. The significant differences found in the productive efficiencies questions on the environmental viability of expanding the agricultural frontier to less suitable lands for crop production.

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1. Introduction

Worldwide, agriculture emits 24% of total anthropogenic Greenhouse Gases (GHG), use an important fraction of the energy and occupy 38% of the Earth's ice free land (Pelletier et al., 2011; Tubiello et al., 2015; FAOSTATS, 2017). Due to population growth, dietary changes and an increased demand for biofuels, agriculture production shall be increased in the next decades, in particular the production of grains (Kastner et al., 2012). This will cause even larger environmental impacts, with associated increases in GHG emissions, energy use and land use change (Godfray and Garnett, 2014). On the other hand, to achieve a global temperature rise lower than 2 °C above preindustrial levels, the scientific consensus calls for a sharp decreasing of GHG (IPCC, 2007). The agricultural sector has a high potential to mitigate climate change, not only due to reductions in fossil fuels but also on emissions of non-CO_2 gases, mainly N_2O and CH_4 emitted in soil cultivation, manufacturing of fertilizers and animal husbandry (Wollenberg et al., 2016).

Maize is the grain with the largest production worldwide, with 960 million tons per year, and soybean is the fourth in quantity with 313 million tons per year (USDA, 2017). Both grains have multiple uses in global markets: directly in food consumption, as additives and supplements, animal feed and primary source for biofuels (Foley et al., 2011; FAO, 2017). The cultivated area for maize has been increased around 66 million hectares (56%) between 1971 and 2014; while the area for soybeans was expanded in an impressive way: from 30 million hectares to 117 million hectares in the same period of time (FAOSTAT, 2017). These expansions of cultivated area had a large impact in South American countries where a large portion of the increase occurs (Gasparri and Waroux, 2015). In Argentina, the total area for maize cultivation has been quite constant. However, as in the rest of the world, yields have experienced sharp increases, which almost tripled the production in a period of 40 years (Edgerton, 2009). On the contrary, soybean cultivation area in Argentina raised enormously from 36,000 ha in 1971 to 19 million in 2014, and at present with nearly 100% genetically modified varieties cultivated using no-till farming and in monoculture practices in several cases. The so-called “soybean package” has been extensively adopted for its effectiveness (Trigo et al., 2009). The sharp increase in soybean cultivation based on large demand of inputs and technology has been one of the main drivers for the expansion of the agricultural frontier in Argentina and South America during the last decades (Zak et al., 2008; De Sy et al., 2015; Fehlenberg et al., 2017).

In 2016, the cultivation area for grains in Argentina was 39 million hectares, of which 52% was dedicated to soybean and 17% to maize, leading to a production of 58.7 and 39.7 million tons respectively (IAIS, 2017). Worldwide, Argentina is the third major producer of soybeans but the first exporter of soymeal and soy oil, accounting for 30.3 and 5.7 million tons exported respectively (USDA, 2017). Besides the production of maize in Argentina represents only 4% of the total globally, the country is the third major exporter (USDA, 2017).

The cultivation of both grains is highly dependent on fertilizers, fuels, machinery and pesticides, which contributes to GHG emissions and energy resource use, two relevant environmental-impact indicators related to agricultural practices. A way to assess their contribution to different production systems consists in estimating the carbon and energy footprint of agricultural products by quantifying the GHG emissions and energy inputs required to produce a given amount of food (Pelletier et al., 2011). Thus, GHGs and energy footprints are defined here as the amount of GHGs emitted or energy used per unit of weight of grain obtained. In the same line, other useful indicators are carbon and energy efficiencies, which are defined as the amount of food produced per unit of GHGs emitted and energy used (Clark and Tilman, 2017). The efficiencies, therefore, account for the production obtained per unit of burden released or resource depleted.

Even though the leading participation of Argentina in the production of grain and their by-product markets, only few studies have attempt to assess the use of energy and GHG emissions of the country's maize and soybeans productions (Dalgaard et al., 2008; Panichelli et al., 2009; Castanheira and Freire, 2013). However, these studies were based on national averages obtained from public databases without including regional variations, which in Argentina are very important due to territorial extension and large ecological variability. On the other hand, as we will discuss in the present work, exploring regional variations lead to understand the convenience or not to expand the agricultural frontier into regions with no favorable conditions for crop production.

Therefore, the aim of the present study is to investigate the carbon and energy footprint of soybean and maize, as well as the carbon and energy efficiencies, by analyzing the production of both crops through different agronomic zones in Argentina, which represents >98% of the soybean and maize production of the country. Variability in efficiencies across different zones due to climate conditions may be relevant not only to assess environmental impacts but also to study the policy implications and potentials for improvements.

2. Materials and methods

2.1. System boundaries

The present study is limited to the production of soybean and maize delivered at farm gate. The carbon and energy footprints were obtained per ton of grain. All stages in the cultivation process, as preparation of the soil, fertilization, sowing, biological soil emissions, harvest and emissions of residues left on the field have been included. The energy and GHG emissions of all agricultural inputs were obtained and included in the impacts. Farm equipment production and human labor were not included in the system boundary due to their small contribution to the overall impact. In Argentina the most common procedure is contracting a service to make the farming labor, which diminish equipment idling and hence the influence of equipment burdens on per hectare based. According to the Argentine Federation of Agricultural Machinery Contractors, rural contractors' participation is 60% for sow, 75% for pesticide applications and 90% of harvest, this last one with the most complex and costly machinery. Therefore, in this case the GHG and energy allocation procedure have to be made taking into account that the equipment has very low idling time. Using data of Mikkola and Ahokas (2010) we found that the GHG emissions and energy embodied in the manufacture, transport from plant to farm and repair, and service and maintenance of farming machinery, is <0.5% of the overall results, accounting for 196 MJ/ha/año (see Table 5 of Appendix A for more details). Infrastructure (e.g., road, rail, etc.) is also excluded in the analysis due to lack of reliable data. Rainfed agriculture is the prevalent practice in crop production in Argentina, thus irrigation considered in this study. Viglizzo et al. (2011) reported that irrigated land in Argentina represents <0.5% of the country surface, mostly located outside our study area and dedicated to wine and olive production.

2.2. Study area

The study extended over approximately 1.53 million km^2 (55% of Argentina's continental area) and it comprises 258 administrative districts divided into 18 agronomic zones, covering all the Argentinian Chaco-Pampean plain (Fig. 1). This area comprises 89% of human population, 98% of bovine cattle heads and over 90% of annual and perennial crops of the country. Dominant biomes in the area are grasslands; tropical, subtropical and temperate forests and shrub lands; with many areas being replaced by croplands (Viglizzo et al., 2011). Agricultural exports from this area include soybean, sunflower, maize, wheat and beef. The agronomic zones were obtained from the Department of Agricultural Estimates of the Buenos Aires Grain Exchange (BAGE, 2017). This geographical zoning is based on homogeneous agronomic criteria, including type of soil, climate and rain patterns.