Journal of Cleaner Production 139 (2016) 799–809

Contents lists available at ScienceDirect

Journal of Cleaner Production

journal homepage: www.elsevier.com/locate/jclepro

Life cycle greenhouse gas emissions from rice production systems in Brazil: A comparison between minimal tillage and organic farming

Flávia Aparecida Nunes [a], Marcus Seferin [b], Vinícius Gonçalves Maciel [b], Simone Hickmann Flôres [a], Marco Antônio Záchia Ayub [a, *]

[a] *Biotechnology & Biochemical Engineering Laboratory (BiotecLab), Institute of Food Science & Technology, Federal University of Rio Grande do Sul, Av. Bento Gonçalves, 9500, P.O. Box 15090, 91501-970, Porto Alegre, RS, Brazil*

[b] *Post-Graduation Program in Materials Engineering and Technology, School of Chemistry, Pontifical Catholic University of Rio Grande do Sul, Av. Ipiranga, 6681, Porto Alegre, RS, 90619-900, Brazil*

A R T I C L E   I N F O

Article history:
Received 8 April 2015
Received in revised form
8 August 2016
Accepted 22 August 2016
Available online 24 August 2016

Keywords:
Life cycle assessment
GHG emissions
Rice cultivation
Minimal tillage system
Organic farming

A B S T R A C T

Knowledge on the environmental impact caused by rice cultivation, the most consumed cereal in the world, is essential to assess agricultural impact on total global anthropogenic emissions of greenhouse gases. Using Life Cycle Assessment (LCA), we compared the Global Warming Potential (GWP) of white and brown rice from two different cultivation systems, minimal tillage and organic, under the practices and climate conditions prevailing in the south of Brazil, the most important rice-producer region in Latin America. The "Cradle to Gate" approach was used, including the stages of cultivation, grain drying, and processing, considering the functional unit of 1 kg of protein produced. The results were characterized using the IPCC 2013 method. The highest value of GWP 100 was observed for the organic white rice, equivalent to 35.53 kg $CO_{2\text{-eq}}$/kg of protein, followed by the organic brown rice, equivalent to 26.50 kg $CO_{2\text{-eq}}$/kg of protein, whereas the lowest GWP 100, equivalent to 15.80 kg $CO_{2\text{-eq}}$/kg of protein, was observed for the minimal white rice. The minimal tillage brown rice, released 20.91 kg $CO_{2\text{-eq}}$/kg of protein. Results clearly show that the cultivation stage is the hotspot for environmental impacts, caused by field emissions, which represented 91% in the organic farming and 61% in the minimal tillage system. The use of mineral fertilizers, in the case of the minimal tillage system, represented 34% of the emissions. This research might help in the elaboration of rice production inventories, as well as in trying to provide reliable information to stakeholders in order to choose sustainable products and processes.

1. Introduction

Rice (*Oryza sativa*), the second most cultivated cereal worldwide, is a very important staple food of more than three billion people in the world, being one of the most relevant foods for human nutrition, especially in Asia and South America (SOSBAI, 2014). Globally, rice accounts for 21% per capita human energy intake, but it is also an important protein source, present in the rice kernels in amounts varying from 4.3 to 18.2% (mass fraction of grain) depending on genotypic characteristics, solar radiation, temperature, and nitrogen fertilization (Walter et al., 2008).

The nutritional quality of a protein is related to its content in essential amino acids able to supply metabolic requirements of humans, as well as to the bioavailability of these amino acids. Although the nutritional quality of vegetable proteins may be deficient in a specific essential amino acid, this limitation can be overcome by nutritional combination with another protein source rich in this amino acid, thus supplying a complete and balanced level of high quality protein in the diet (Damodaran et al., 2010). Rice is rich in methionine, which makes this cereal one of the basic foods of human nutrition. In Brazil, this cereal has a per capita consumption of 108 g per day, providing a minimal of 10% of dietary protein (Kennedy et al., 2002).

According to Smith et al. (2007), the agricultural sector is responsible for about 10–12% of the global anthropogenic emissions of greenhouse gases (GHG). In the case of rice production special attention is recommended because there are strong

Abbreviations: LCA, Life Cycle Assessment; GHG, greenhouse gases; LCIA, Life Cycle Impact Assessment; GWP, Global Warming Potential; MTB, Minimal Tillage Brown Rice; MTW, Minimal Tillage White Rice; ORB, Organic Brown Rice; ORW, Organic White Rice; IPCC, Intergovernmental Panel on Climate Change.

* Corresponding author.
E-mail address: mazayub@ufrgs.br (M.A.Z. Ayub).

http://dx.doi.org/10.1016/j.jclepro.2016.08.106
0959-6526/

differences both in productivity and in the emissions of the important GHG methane (CH_4) and nitrous oxide (N_2O), depending on the cultivation system: irrigated or flooded cultures, or uplands cultivation, the first system characterized by high yields of production, but much higher GHG emissions caused by the anaerobic conditions of the flooded areas (Brodt et al., 2014). Linquist et al. (2012) reported that from the total global warming potential (GWP) of rice fields, CH_4 emissions contribute 92%, followed by N_2O emissions. As rice production is expected to grow in the next years because of population growth and demand, we can expect higher GHG emissions caused by this agricultural activity (Cai et al., 2007).

In the case of Brazil, the 9th biggest world rice producer (USDA, 2015), most of the cultivated area follows the upland cultivation system. However, in the south of Brazil, in particular in Rio Grande do Sul State, which is the biggest South American producer of this cereal, rice is almost exclusively cultivated in flooded areas. It is estimated that the total CH_4 emissions in the Rio Grande do Sul State represents 18% of the total emissions of this GHG in the region (MCT, 2006).

The most widespread rice cultivation in this region of the country is the minimal tillage system characterized by early mobilization (fall or spring) and lower soil mobility, with few operations in the sowing period (SOSBAI, 2014). The seeds are planted in dry soil, followed by irrigation process of the area. In this system, mineral fertilizers are inserted to improve nutritional conditions of the cultivar (Petrini and Vernetti, 2007).

Another typical cultivation system of the region in study is the pre-germinated and organic, to which we describe as organic system in this work. In this system, seedling is carried out using pre-germinated seeds, which are released to the wet soil, rich in organic composts derived from a mixture of ashes from rice hulls burning, organic waste from the rice processing, and pig manure (Petrini and Vernetti, 2007; SOSBAI, 2014). Because water is inserted in this system in the sowing period of the cultivation, a longer period of flooded area is characteristic of the system.

An agricultural system capable of providing good yields of production and, at the same time, minimal environmental impact, would be the ideal production system model. For instance, the minimal tillage system has been widely adopted in order to reduce the impact generated by practices applied to conventional rice farming production because, under this system, there is less soil mobilization during the sowing operation (SOSBAI, 2014).

In pair with new agriculture practices, the use of the life cycle assessment (LCA) methodology has contributed to reduce environmental impacts by providing thorough analysis of the potential environmental impacts of products, processes, or services. Using the compilation and evaluation of mass flows and energy involved in any productive process, decisions on practices and uses, both qualitatively and quantitatively, can be made (Guinée et al., 2001; ISO 14040, 2006).

Although the literature on the GHG emissions produced by rice cultivation is comprehensive (as reviewed by Blengini and Busto, 2009), the LCA of rice production practices and processing are scarce (Blengini and Busto, 2009; Brodt et al., 2014; Hokazono and Hayashi, 2012; Thanawong et al., 2014). Moreover, in Brazil the application of LCA methodology in the agribusiness field is very recent, thus it would be interesting for the economy increasing the use of LCA to assess the potential environmental impacts of all national agricultural production (Ruviaro et al., 2012).

In this context, the aims of this research were to estimate the Global Warming Potential (GWP) related to the production and processing of white and brown obtained by two different methods of cultivation: the minimal tillage and the organic systems, using the life cycle assessment methodology.

2. Materials and methods

We followed the ISO 14040 (2006) and ISO 14044 (2006) for conducting the Life Cycle Assessment based on the impact category global warming potential (GWP) for the systems in study.

2.1. Goal and scope definition

This study aimed to compare the global warming potential of white and brown rice obtained by minimal tillage and organic production systems in order to provide data that could contribute to decision-making for more environmentally friendly agricultural practices. The case under study demonstrates an approach defined as cradle-to-gate, considering production from soil preparation to the packed rice at the factory gate, excluding the distribution and consumption stages. The flowchart depicted in Fig. 1 demonstrates the steps included in both cropping systems (minimal and organic), including the post-harvest phases with their differences.

2.2. Functional unit

Some studies in LCA have considered 1 kg of protein as the functional unit of the system because protein is considered to most important and representative nutrient in foods (Berlin, 2002; Daneshi et al., 2014; De Vries and de Boer, 2010; Nijdam et al., 2012; Schau et al., 2008). The choice of a common nutrient in foods to be compared is a factor more reliable than the mass quantification and provides a good opportunity to be used as a base for the functional unit in food-related LCA studies (Schau et al., 2008). By using protein as a functional unit, we have broader results in the analysis. For instance, De Vries and de Boer (2010), using protein as a functional unit, demonstrated that the production of 1 kg of beef meat has greater environmental impacts than pork and chicken meat, in this order.

Based on these considerations, in this study, the functional unit of the system was considered 1 kg of protein of the final product because each product has a different protein content. In Table 1 is presented the necessary amount of rice to obtain 1 kg protein.

2.3. Data sources – irrigated rice production in Rio Grande do Sul State

Rio Grande do Sul State stands out as the largest national rice producer, accounting for over 61% of total production in Brazil. Basically, there are different types of farming systems used in culture of the irrigated rice in the southern region, which differ in form and tillage time, methods of sowing and initial management of water (SOSBAI, 2014). From this, the major systems used are the minimal tillage, conventional system, direct planting, pre-germinated system, among others.

2.3.1. Conventional system

In this system the preparation of the area is done by using equipment according to the soil type, desired depth of preparation, occurring intense activities of revolving the soil to obtain adequate preparation, followed by surface planning of the area and weed control still early in its development. After such activities it is carried out the planting in which sowing still occurs on dry soil. Concomitantly, there is the application of nutrients (mineral fertilizers) in order to enhance the efficiency of farming, emphasizing the use of urea and formulated products containing nitrogen (N), phosphorus (P_2O_5), and potassium (K_2O), namely NPK (SOSBAI, 2014).

The irrigation starting time occurs in stages when the culture already presents three to five leaves at the base. The suppression of