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Evaluation of two production methods of Chilean wheat by life cycle assessment (LCA)

Evaluación de dos estilos productivos de trigo chileno mediante metodología de análisis de ciclo de vida (ACV)

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ABSTRACT

Agricultural production is an activity that generates environmental impacts, primarily associated with the use of machinery and chemical inputs. For this reason it is expected that cultural practices and technological levels will influence significantly the environmental impacts of different production systems. In this study we evaluated conventional and organic methods using life cycle assessment (LCA). The results identified soil management as the stage of conventional production that generates the greatest environmental impact; the most affected impact categories were acidification, with 15.28 kg SO_2 equivalent per ton of grain produced, and eutrophication, with 4.83 kg PO_4 eq/ton of grain. The category most affected by organic production was soil management, mainly due to the Diesel fuel used in agricultural machinery. In this production method the category of abiotic resource depletion had the greatest impact, with 0.89 kg Sb eq/ton of grain. The use of compost as a strategy fixed important amounts of biogenic carbon, generating environmental benefits in the impact category of climate change –4.39 kg CO_2 eq/ton of grain.

Key words: conventional production, organic production, environmental impact.

RESUMEN

La producción agrícola es considerada una actividad generadora de impactos ambientales, los que se asocian principalmente al uso de maquinaria e insumos agroquímicos. Por este motivo, se prevé que las prácticas culturales y el nivel de tecnificación influyen significativamente sobre los impactos ambientales de los distintos sistemas productivos. En este trabajo se evaluaron los estilos convencional y orgánico mediante la metodología de análisis de ciclo de vida (ACV). Los resultados identificaron el manejo de suelo como la etapa de la producción convencional que genera mayor impacto ambiental, siendo las categorías de impacto acidificación con 15,28 kg SO_2 *equivalente por tonelada de grano producido y eutrofización con 4,83 kg* PO_4 *eq/ton de grano las mas afectadas. Para el estilo productivo orgánico las cargas de mayor importancia se registraron en el manejo de suelo, debido principalmente al diésel utilizado en la maquinaria agrícola. En este estilo productivo la categoría de agotamiento de recursos abióticos presentó el mayor impacto, con 0,89 kg Sb eq/ton de grano, siendo el uso de compost una estrategia debido a que éste fija cantidades importantes de carbono biogénico generándose beneficios ambientales en la categoría de impacto de cambio climático con –4,39 kg* CO_2 *eq/ton de grano.*

Palabras claves: *producción convencional, producción orgánica, impacto ambiental.*

Introduction

Traditional agricultural production methods have profound effects on the environment. They are the main source of the contamination of water, air and soil, reducing biodiversity and agricultural genetic diversity (FAO, 2007). Wheat production in Chile is dominated by the model originated by the green revolution called conventional production. This method produces high yields, with an ideal quality for baking bread. To achieve this, improved seed varieties which are compatible with the available technology must be used, in order to exploit the full potential of a wheat variety (Mellado, 2007).

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However, this system requires the farmer to use highly mechanized technological procedures for pure cultures, with elevated requirements of fertilizer and pesticides (Montalba, 2009).

Currently, farmers, consumers, government institutions and researchers are interested in a more sustainable agriculture which incorporates technologies that are cleaner and friendlier to human and environmental health. This type of agriculture appears as an alternative which intends to develop highly efficient production formulas that take advantage of the natural and cultural potentialities of an area, without destroying the soil, water, air, organisms or the surrounding area (Céspedes, 2005). Comparing different agricultural methods allows the identification of their consequences in terms of the pressures they exert on the environment (Schmitzberger *et al.,* 2005), since each is related to the way the producer operates, the markets, natural resources and specific technologies (Gastó *et al*., 2002).

One way to evaluate production methods in environmental terms is by using the methodology of Life Cycle Assessment (LCA), This method has been used in studies of vegetables (Antón, 2004), fruit trees (Pizzigallo *et al.,* 2008), rice (Blengini and Busto 2009), wheat (Meisterling *et al.,* 2009), grasslands (Haas *et al.,* 2001), milk (Hospido *et al.,* 2003), soil use (Peters *et al.,* 2003), as well as local factors of agricultural production (Milá, 2003), which shows its usefulness in analyses of the potential environmental impact of agricultural production during a life cycle.

The objective of this study is to evaluate and compare in environmental terms two production methods for wheat, conventional and organic, using the methodology of LCA.

Materials and Methods

The study was performed in the 2008-2009 season in the Campo Experimental Maquehue that belongs to the Universidad de La Frontera, located at 38°50'38.33" S and 72°41'57.65" W at an altitude of 80 m in the intermediate depression of the central valley, in the Comuna de Padre Las Casas, Sector Maquehue-Chile. It is located in the agroecological area of La Araucanía called central valley, characterized by a cold temperate climate with 115 days without freezes in the summer period; freezes begin to occur in March. The sum of day-degrees is 900 ºC (base 5 ºC); the annual precipitation is 1350 mm; the dry season lasts 3.5 months and the humid season begins in April (Rouanet *et al.,* 1988). The soil is light textured of the Freire series, an Andisol derived from recent volcanic ash, with slopes of 0-2% (INIA, 1985).

Two production systems were evaluated in this study, (i) conventional production and (ii) organic production, whose details are given in Table 1.

Table 1. Determinants of the agro-ecosystem for the conventional and organic production of wheat evaluated in the study.

Determinants of the Agro-Ecosystem		Conventional System	Organic System
Species and varieties managed		Trigo var. Dollinco	Trigo Ecotype Linaza[a]
Sowing		Fine grain seeder	Fertilizer spreader
Soil management	Preparation	Stubble burning Plowing Harrowing Seedbedding	Plowing Harrowing
	Fertilization	Tractor with fertilizer spreader	Tractor towing carriage for compost application
	Conservation	n.a.[b]	Elaboration of compost using stubble of the crop
Sanitary management	Diseases	Fungicide spraying	n.a.
	Weeds	Spraying of chemical fallow, total herbicide and Graminicide	n.a.
	Pests	n.a.	n.a.
Harvest		Harvester Tractor + towing carriage	Harvester Tractor + towing carriage

[a] Contreras, 2006 y 2007; [b] n.a. = Not applicable.

Objective and scope of the life cycle analysis (LCA)

The objective of the study was to evaluate the environmental effect of two wheat production systems in the Región de La Araucanía using the LCA methodology, identifying the critical points in the production life cycle. The productive study considered the processes utilized in the fields, excluding post-harvest management, that is, a LCA from the cradle to the gate of the field. We also included the processes of extraction of raw material and the production of inputs.

Functional unit (UF) and the system boundary

The function of the system consists in producing a quantity of wheat grains harvested in one season, thus the functional unit selected was 1 ton of wheat. The scope of this study will be from "the cradle to the gate of the field" (Figure 1), which means that the system only considered management within the farm. We included foreground systems, which are the direct agricultural entrances that are a function of the management associated with production, these managements being agronomical production practices which play a role in the system, and background processes, which are indirect agricultural inputs that are a function of management associated with production, such as the processes of extraction and production both of inputs and machines which fulfill their function outside of the foreground system; because these are the same for both productive systems they are considered in the study.

Data quality and positive environmental impacts

The data used to calculate potential emissions were obtained in the field, and included from preparation of the soil to harvest. The information was provided by the administrator of the farm, and was combined with information published by Gonzáles *et al.* (2000). The data include the extraction and production of inputs and fuel, which were obtained from the Ecoinvent data base (Hischier *et al.,* 2009) using the software SimaPro 7.3. The LCA is a balance of inputs and outputs, because of which the use of compost, that allows the capture of carbon in the soil (EPA, 2010), is considered an environmental benefit or positive impact.

Inventory analysis and destination of field emissions

The data were obtained from information recorded in the field, literature, data bases, specialists and administrators. The inventory of agricultural inputs per functional unit and yield with conventional and organic management is shown in Table 2. The calculation of emissions evaluated particularly nitrogenous fertilizers such as urea (Brentrup *et al.,* 2000 e IPCC, 2006), phosporous and potassium fertilers and pesticides, by means of the Ecoinvent

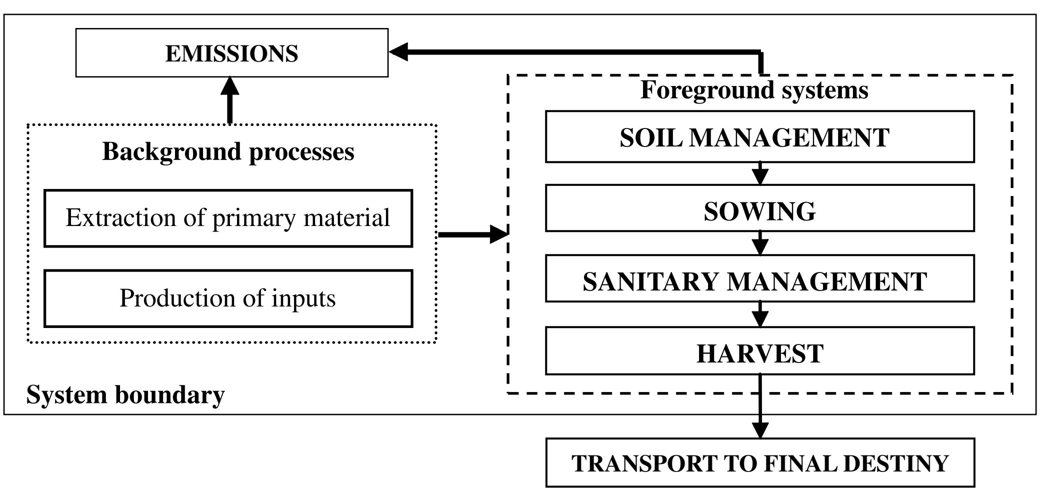

Figure 1. Limits of the wheat production system under study.

Table 2. Inventory of agricultural inputs (by functional unit) and yield of conventional and organic crops of wheat.

Agricultural input	Unit	Conventional wheat	Organic wheat
Seeds			
Seeds for sowing	kg	35.3	44.0
Fertilizers			
Urea	kg	45.3	n.a.[1]
Phosphorous	kg P_2O_5	35.6	n.a.
Potassium	kg K_2O	13.5	n.a.
Compost	Kg	n.a.	2,829.5
Pesticides			
Chemical fallow	kg i.a.[2]	3.5	n.a.
Funguicide	kg i.a.	13.6	n.a.
Graminicide	kg i.a.	0.1	n.a.
Total herbicide	kg i.a.	0.2	n.a.
Diesel consumption			
Chemical fallow	kg	1.9	n.a.
Plowing	kg	13.6	n.a.
Harrowing	kg	4.7	13.3
Seedbedding	kg	3.5	5.0
Sowing	kg	3.8	3.7
Herbicide application	kg	7.0	n.a.
Fertilizer application	kg	7.6	10.0
Harvest	kg	2.8	4.0
Total Diesel consumption	kg	46.4	36.0
Yield	kg/ha	4,528	1,988

[1] n.a. = Not applicable; [2] kg i.a.= Kilogram of active ingredient.

data base. The emissions due to the use of fuels and stubble burning were estimated using the directories of the IPCC (2006). The emissions due to the use of compost were obtained from published articles of the EPA (2010) and IPCC (2006).

Evaluation of impact

The purpose of this phase is to evaluate the significance of the potential impacts using the results of the inventory, associating them with specific categories of environmental impact and with the indicators of these categories (ISO 14044, 2006). The study included the obligatory stages of selection, classification and characterization of impacts, and only the normalization of the optional stages.

Methodology of impact evaluation of the life cycle

The methodology employed was the CML 2000 (Institute of Environmental Sciences of the University of Leiden, Holanda), which defines an environmental profile by quantifying the environmental effect of various categories of the product, process or service analyzed (Muñoz, 2008). The methodological guide of the CML 2000 (Guinée *et al.,* 2002) provides a list of impact categories classified as obligatory, additional and others. A unit of reference is established for each of the categories, expressing the impact as the equivalent quantity of each of the components as a function of the characterization factors. The data obtained were analyzed using the software SimaPro 7.3, which allows LCA to be performed using its own inventory data and bibliographic information.

Results and Discussion

Evaluation of the impact of conventional versus organic wheat production

According to Roy *et al.* (2009), the critical life stage in food production is agricultural production. This is shown in the studies cited by De Gennaro

Table 3. Environmental impact values resulting from the category characterization step using the CML 2000 methodology.

Impact category	Unit	Conventional	Organic
Depletion of abiotic resources	kg Sb eq	3.01	0.89
Acidification	kg SO_2 eq	15.28	1.01
Eutrophication	kg PO_4 eq	4.83	0.22
Global warming	kg CO_2 eq	792.76	–4.39

et al., (2011), which include examples such as the production of bread (Braschkat *et al.,* 2003), pasta (Bevilacqua *et al.,* 2007), cheese (Berlin, 2002) and many others. It is also important to consider the local factors in the analysis of agricultural products (Milà, 2003), taking into account the conditions of climate and soil of the production area. Table 3 shows the values of the categories of environmental impact for the wheat production systems analyzed. Conventional production produced greater environmental impact in all the categories evaluated, which identifies organic production as the more environmentally friendly option, even when the data were normalized with world values to appreciate the relative importance of each impact category (Figure 2). Environmental impacts were generated by the items associated with the management utilized; the system of conventional production had a greater potential to impact the environment (Haas *et al.,* 2001; Milà, 2003; Pizzigallo *et al.,* 2008; Blengini and Busto, 2009; Meisterling *et al.,* 2009; Nemecek *et al.,* 2011).

Milà (2003) indicated that organic production is not necessarily more ecological, since although it reduces one impact by not using pesticides, it produces more environmental damage due to the greater use of machinery. Blengini and Bustos (2009) reported that although organic production reduced the environmental impact within its production, the grain yields were low, reducing the environmental benefits per kilogram of final product. In contrast, Hokazono and Hayashy (2012) showed that if the conventional-organic transition is evaluated, in the selected impact categories organic production produced more environmental impact compared to conventional production, due mainly to the instability of production in the initial years.

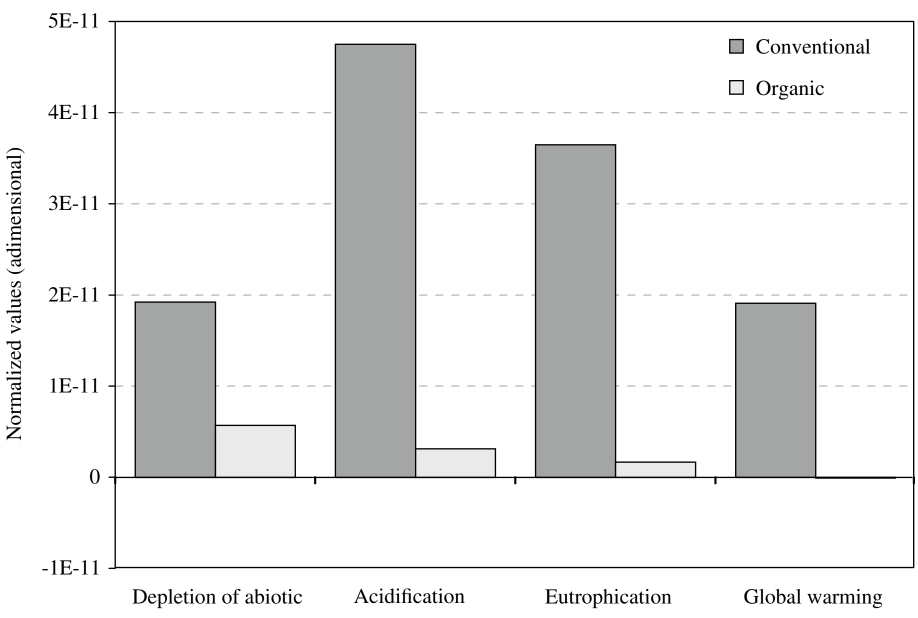

Figure 2. Normalized results of conventional and organic production of wheat using the CML 2000 methodology.

Evaluation of the impact of conventional production

This production system uses a high level of extra-farm inputs, which are potential sources of environmental impact since they are associated principally with extraction, production and use. Figure 3 shows that the conventional production method had environmental impact in all the impact categories; soil management was the factor most responsible, since it involves greater use of inputs and machinery. The normalization of the data revealed the importance of these results; eutrophication and acidification were the categories with greatest impact. Figure 4 details the stages and substances which produced the greatest contribution to environmental impact on acidification; the main contributors were the use of urea, with 12.2 kg SO_2 eq/ton of grain and the emissions of ammonia, with 12.5 kg SO_2 eq/ton of grain. This is explained by the losses associated with the application of urea to the soil, 15% of the total urea applied was lost by lixiviation. The total impact associated with acidification reached 15.3 kg SO_2 eq/ton of grain. This is produced by the use of synthetic nitrogenous fertilizers and varies according to the dose applied (Brentrup *et al.,* 2004b) and the type of fertilizer employed (Charles *et al.,* 2006). Although there are no previous studies of LCA for wheat in Chile, Iriarte *et al.* (2010) studied the production of sunflowers and raps as energy crops for Chile, finding a high contribution due to the use of nitrogenous fertilizer; the greatest impacts were found in the acidification and eutrophication indicators, following the management pattern based on the use of inorganic fertilizers.

Fertilization in conventional production is based on urea, whose use may produce important emissions due to the volatilization of NH_3 during and after application, as well as emissions of SO_2 and NO_x (Brentrup *et al.,* 2000). This is corroborated with our results, in which the NH_3 emissions attributed to the acidification potential contributed the greater part of the emissions of SO_2. As the dosage of inorganic fertilizer increases, so does the acidification potential, producing greater environmental impact (Brentrup *et al.,* 2004b). The use of nitrogen fertilizer in conventional production is also the main cause of eutrophication; the greatest emissions are the lixiviates of NO_3, and NO_x and NH_3, which eventually are deposited in surface water (Brentrup *et al.,* 2004b). Figure 5 illustrates the stages and substances which contributed most to the eutrophication category of environmental impacts. The use of urea and the emissions of ammonia

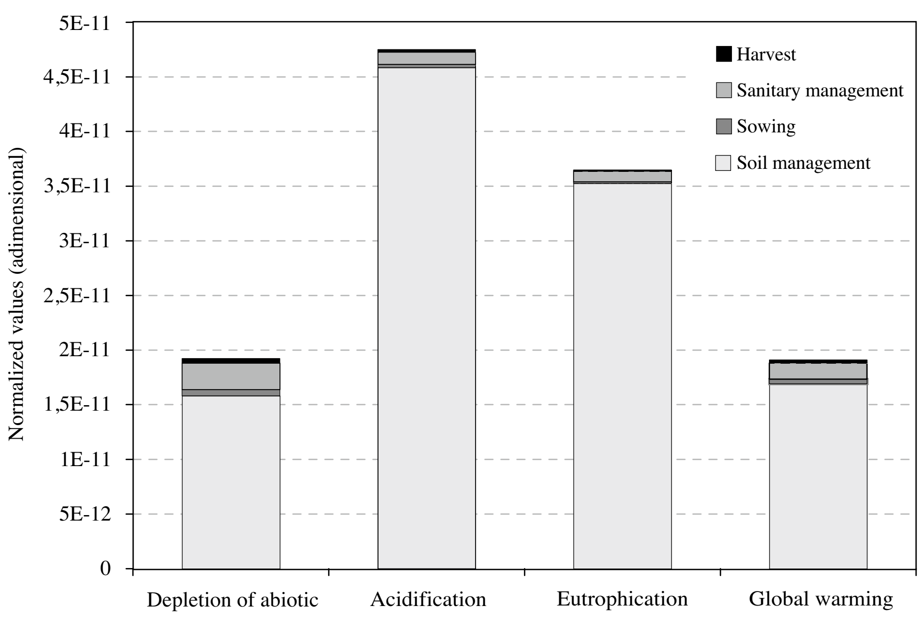

Figure 3. Normalized results of the conventional production of wheat and its contribution to environmental impact categories.

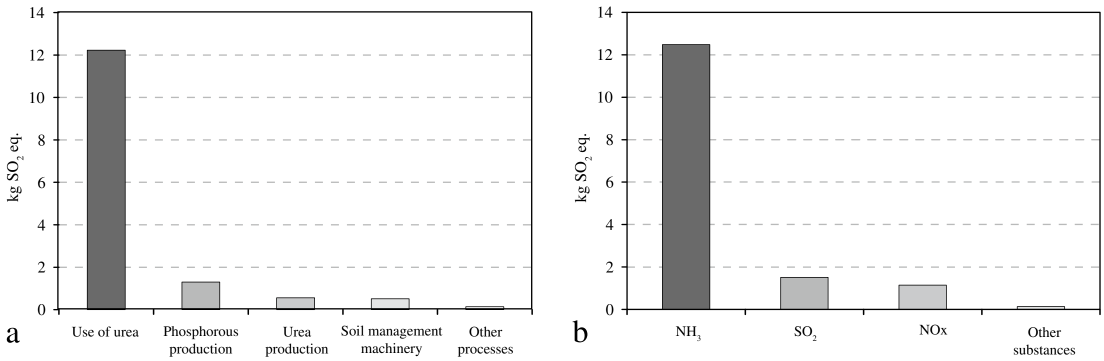

Figure 4. Contribution of environmental impacts produced by conventional production on the acidification impact category, for process step (a) and substances (b).

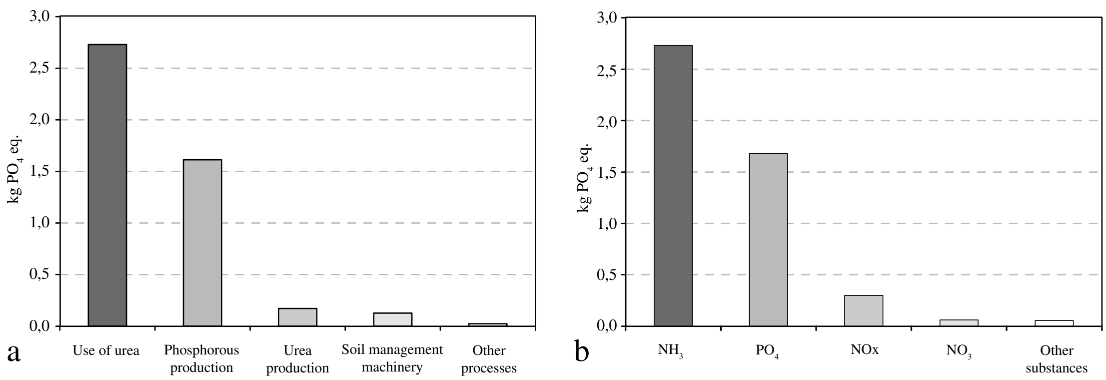

Figura 5. Contribution of environmental impacts produced by conventional production on impact category eutrophication, by process step (a) and substances (b).

associated with its application, which produced 2.7 kg PO_4 eq/ton of grain, were the main factors responsible for the effect on this category. The total impact associated with eutrophication reached 4.8 kg PO_4 eq/ton of grain. The use of phosphorous in agricultural production contributes to the eutrophication of fresh water due to its stimulation of the growth of noxious algae such as *Cyanobacterias* and *Pfiesteria,* which with high phosphorous levels, produced by superficial runoff loss or subterranean flow of applications in excess of the needs of the crops, decrease the oxygen in the water and eventually increase the growth of these anaerobic species (Sharpley *et al.,* 2001).

Evaluation of the impact of organic production

The results for organic production (Figure 6) show that the greatest environmental impacts were produced in the soil management process; the category of depletion of abiotic resources had the greatest impact, mainly due to the consumption of diesel fuel during the agricultural processes, which reached 0.89 kg Sb eq/ton of grain. Figure 7 shows the stages and substances responsible for the environmental impacts in the category of global warming. The machines used in soil management had the greatest impact, with 106 kg CO_2 eq/ton of grain, associated mainly with soil preparation and fertilization; the other main gasses emitted were N_2O, with 265.8 kg CO_2 eq/ton of grain, and CH_4 with 264.1 kg CO_2 eq/ton of grain. As compost undergoes the process of stabilization of the organic material it generates biogenic emissions of CO_2, which were not included. The use of compost contributed –660.3 kg CO_2 eq/ton of grain to the category of global warming due to the carbon fixed. After subtracting the emissions produced by the other processes involved, the final CO_2 was –168 kg CO_2 eq/ton of grain.

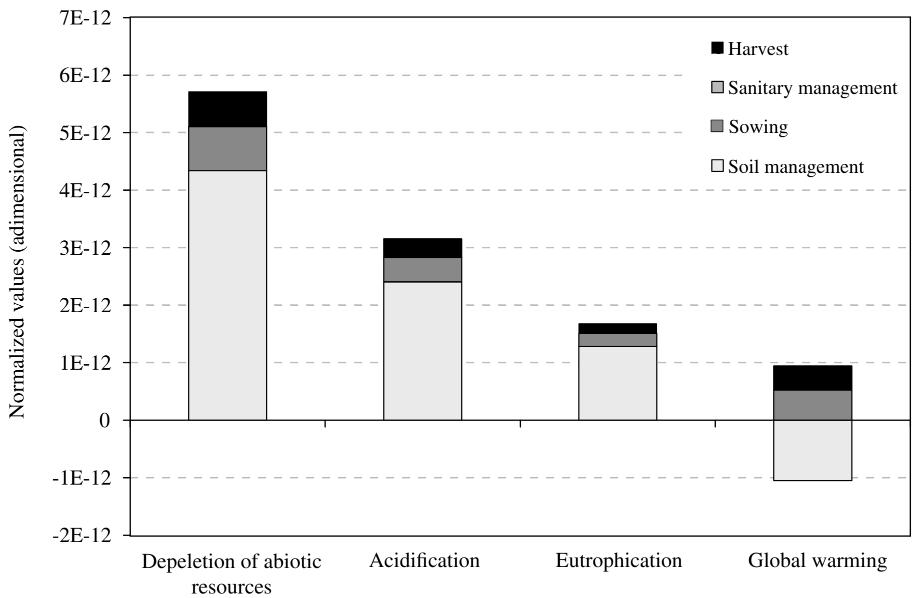

Figure 6. Normalized results of organic production of wheat and their contribution to the impact categories.

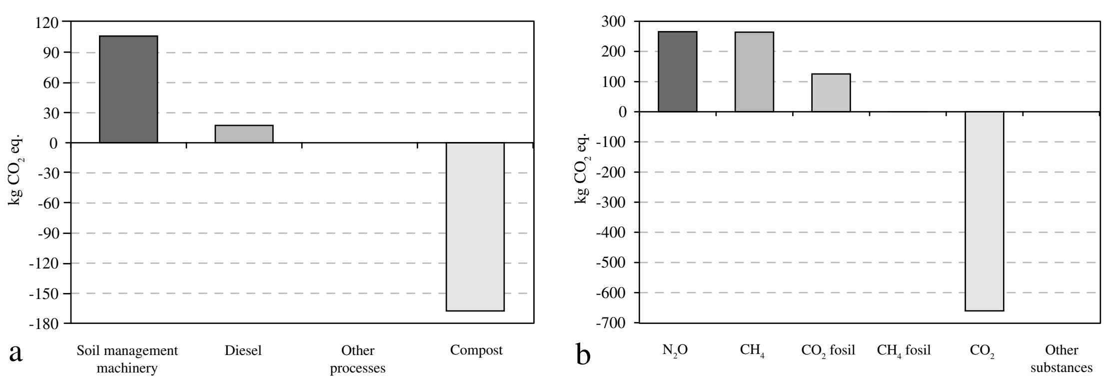

Figure 7. Contributions of environmental impacts produced by organic production on the impact category global warming, by process step (a) and substances (b).

The fertilizers used in organic production have low environmental impact, and in some cases such as compost they have positive environmental impact. Compost production involves an aerobic process in which CO_2, water and a fraction of the humic acids interact to obtain stabilized organic matter from plant remains (Bogner *et al.,* 2007). Stabilized organic matter does not produce CO_2 emission, since its emissions are of biogenic origin (produced naturally), because of which they are not considered in the final balance (IPCC, 2006; EPA, 2010). Also, EPA (2010) indicated that applying compost contributes to the environment, since the CO_2 which could potentially be emitted to the atmosphere is being fixed in the stable organic matter. The results of organic wheat production coincided with the above, and consider compost as a fundamental part of soil management. Although most research on this soil additive have concentrated on improving production and final quality, more attention should be paid to the contribution of the elaboration processes to greenhouse effect gasses (Lou and Nair, 2009).

Conclusions

The potential environmental impacts of the studied productive systems were clearly differentiated as a function of the type of management; conventional production produced greater impacts in the categories of acidification, depletion of abiotic resources, climatic change and eutrophication.

Soil management was the stage which generated the greatest environmental impacts, in both production systems.

Urea was the input which produced the greatest impact in conventional production; the categories of acidification and eutrophication were the most affected by its application.

The principal environmental impacts of organic production were associated with the use of machinery, which affected mainly the categories of depletion of abiotic resources and climate change. In spite of this, the use of compost allowed a decrease in the final impact on climate change, since compost fixes carbon in the soil, producing a positive environmental impact.

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