Life Cycle Assessment of soybean-sunflower production system in the Brazilian Cerrado

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Abstract

Sunflower is an important crop in Parecis region of the Brazilian Cerrado. In 2014, the region produced 232.700 tons of sunflower grains, 45% ofthe national production. Sunflower production comes mostly from a system that has soybean as the main crop. The association of soybean and sunflower can reduce environmental impacts due to shared use of resources. This study performed a “cradle to gate” Life Cycle Assessment (LCA) of the soybean-sunflower production system used in Parecis region and compared its environmental profile to that of the monoculture of these two crops. We evaluated the impacts related to the use of soil (land use change emissions and liming) for each crop according to three allocation criteria: time of soil occupation, yield and gross margin. Although performance on “Climate Change” and some other impact categories had varied according to the allocation criteria used, the soybean-sunflower rotation crop system presented lower environmental impacts on every category when compared to soybean and sunflower monocultures with the same yield. Important impact reductionswere observed on “Climate change” (43%), “Terrestrial acidification” (26%) and “Particulate matter formation” (20%) categories.

Keywords: Environmental Impact Assessment, Environmental Modeling, Savanna, Rotation Crop Systems, Allocation Criteria.

Introduction

The adoption of new production technologies made it possible for Brazil to stand out as a major food world supplier, but the search for sustainability is one of many new challenges, as the global market asks for products with reduced environmental impact (Claudino and Talamini 2013). Life Cycle Assessment (LCA) is a great tool to assess agricultural product environmental performance.

Due to its adaptability (Rizzardi and Milgiorança 1993), sunflower crop yield in Brazilian Cerrado has been encouraging. The Parecis region is the "home" of sunflower in Brazil and is accounted for 61 % and 45% of regional and national production, respectively, in the 2013/2014 harvest (AMM 2014).

Soybean also grow in Parecis region, as monoculture or with sunflower in succession (soybean is a summer crop and it is not possible to grow two soybean crops in the same year). Soybean is the crop that has the greatest economic importance to Brazil: its planted area increased by 49% over the past three decades due to its cultivation in the Brazilian Cerrado, thanks to the development of agricultural technology adequate to this biome (MAPA 2014). Sunflower cultivation in succession to soybean can reduce environmental impacts because of the more efficient land use and sharing of agricultural inputs, machinery and infrastructure. With a LCA study, we can determine this impact reduction, but we must also identify the correct way to allocate the impacts of soybean-sunflower production system between its two products, as this can influence the recommendations of a LCA study.It is noteworthy that we have not found any other LCA study that had evaluated soybean-sunflower crop systems in the scientific literature.

Methods

This study generated inventories of soybean and sunflower production in monoculture and in succession based on the representative typical systems of Parecis region. The most relevant items of the scope of this study are:

a) Reference Unit: 1 ton of grain for each system, with ayield of 3120 kg of soybeans and 1774 kg of sunflower per hectare for monoculture and rotation crop system.

b) Data Sources: Soybean-sunflower system data obtained by interviewing five producers of the Parecis region. Information obtained from these interviews, consulting experts and technical literature allowed us to define the typical soybean-sunflower rotation crop system and monoculture of these two crops. We calculated emissions from the rotation crop system and monocultures following Nemecek and Schnetzer (2011) recommendations, except for heavy metal emissions, that we estimated as proposed by Canals (2003). Data from production of agricultural inputs came from Ecoinvent v2.2. We excluded transport of agricultural inputs from the analysis. Table 1 show main inputs and outputs from LCI.

Products	**Unit**	**Soybean**	**Sunflower**
Product	kg	3.12E+03	1.77E+03
Resources			
Occupation, arable, non-irrigated	ha/year	3.15E-01	3.29E-01
Materials/fuels			
Maizeseed	kg	4.00E+01	3.50E+00
Lime	kg	2.45E+02	2.55E+02
Urea, as N	kg	--	4.42E+01
Single superphosphate, as P2O5	kg	7.20E+01	--
Triple superphosphate, as P2O5	kg	--	1.84E+01
Potassiumchloride, as K2O	kg	7.80E+01	2.40E+01
Herbicides	kg	4.04E+00	2.87E+00
Insecticides	kg	5.80E-01	3.02E-01
Fungicides	kg	3.56E-01	1.54E-01
Emissionstoair			
Ammonia	kg	--	1.44E+01
Dinitrogenmonoxide	kg	2.64E+00	1.87E+00
Nitrogen oxides	kg	5.55E-01	3.92E-01
Carbondioxide, fossil	kg	--	6.93E+01
Carbondioxide, landtransformation	kg	3.99E+03	4.16E+03
Emissionstowater			
Nitrate	kg	1.91E+01	2.89E+01
Cadmium	kg	2.08E-06	2.09E-07
Copper	kg	--	3.88E-07
Zinc	kg	1.73E-07	1.81E-06
Lead	kg	2.02E-07	4.01E-08
Nickel	kg	8.17E-07	1.96E-07
Chromium	kg	1.07E-05	1.32E-06
Emissionstosoil			
Cadmium	kg	2.08E-02	2.09E-03
Copper	kg	--	3.88E-03
Zinc	kg	1.73E-03	1.81E-02
Lead	kg	2.02E-03	4.01E-04
Nickel	kg	8.17E-03	1.96E-03
Chromium	kg	1.07E-01	1.32E-02
Herbicides	kg	4.04E+00	2.87E+00
Insecticides	kg	5.80E-01	3.02E-01
Fungicides	kg	3.56E-01	1.54E-01

Table 1 - Environmental profile of soybean and sunflower crop system and monocultures for 1 ton of crop (allocation criteria: occupation).

c) Allocation Procedure: We allocated the impacts from land use change and limestone use in acidity correction according to the time of occupation of the same area by each crop per year (120 days for soybean and 115 days for the sunflower, per year). We also tried two other allocation criteria, in other to evaluate their influence on the evaluation: yield (3120 kg ha-1 for soybean and 1774 kg ha-1 for sunflower) and gross margin per crop. For the gross margin criterion, impacts from land use change and limestone use were completely allocated to soybean,because the gross margin from sunflower is very small when compared to the gross margin from soybean for the same area. Other impacts from inputs and emissions were attributed to the product accountable for the input consumption or emission, in all three allocation criteria, as in Nemecek et al. (2001).

d) Method: LUC from 1990 to 2009 for soybean and sunflower cultivation were calculated from historical series of CONAB (2015), FAOSTAT (2012) and Macedo et al. (2012). Emissions from LUC were calculated according to EC (2010).We chose the Recipe Midpoint (H) v1.07 / World H as the life cycle environmental impact assessment method. We disregarded impact categories not relevant to the study (marine eutrophication,marine ecotoxicity, ionizing radiation, urban land occupation). SimaPro, version 8.0.4.26, was the software tool used.

Results and Discussion

Table 2 shows soybean and sunflower environmental profile in rotation crop system and monoculture by the occupation allocation criterion.

Impact Category	Unit	Soybean mono	Soybean crop	Sunflower mono	Sunflower crop
Climate change	kg CO2 eq	3.09E+03	1.76E+03	5.39E+03	2.99E+03
Ozone depletion	kg CFC-11 eq	3.11E-05	3.09E-05	7.67E-05	7.07E-05
Terrestrial acidification	kg SO2 eq	2.04E+00	2.04E+00	3.13E+01	2.21E+01
Freshwater eutrophication	kg P eq	1.27E-01	1.27E-01	9.53E-02	8.87E-02
Human toxicity	kg 1,4-DB eq	7.38E+02	7.38E+02	2.18E+02	2.08E+02
Photochemical oxidant formation	kg NMVOC	2.12E+00	2.11E+00	2.67E+00	2.53E+00
Particulate matter formation	kg PM10 eq	8.49E-01	8.47E-01	4.77E+00	3.52E+00
Terrestrial ecotoxicity	kg 1,4-DB eq	1.23E+00	1.23E+00	1.29E-01	1.17E-01
Freshwater ecotoxicity	kg 1,4-DB eq	3.70E+00	3.70E+00	2.46E+00	2.32E+00
Agricultural land occupation	m2a	6.26E+01	6.26E+01	2.08E+01	2.03E+01
Natural land transformation	m2	5.54E-02	5.51E-02	9.76E-02	8.46E-02
Water depletion	m3	3.23E+00	3.23E+00	2.12E+00	2.03E+00
Metal depletion	kg Fe eq	1.51E+01	1.51E+01	1.78E+01	1.63E+01
Fossil depletion	kg oil eq	2.48E-01	2.48E-01	1.81E-01	1.71E-01

Table 2 - Environmental profile of soybean and sunflower crop system and monocultures for 1 ton of crop (allocation criteria: occupation).

We can see that soybean has lower impact than sunflower in half of the impact categories. Emissions of carbon dioxide resulting from Land Use Change (LUC) and nitrous oxide emissions generated by nitrogen fertilizers were the main cause for "Climate change" impacts. For "Photochemical oxidant formation", "Terrestrial acidification" and "Particulate matter formation" categories, the main contaminants were ammonia and nitrogen oxides, also related to nitrogen fertilization. In all these categories soybean has better performance than sunflower, for its ability to fix atmospheric nitrogen, eliminating the contribution of synthetic fertilizers.

For "Human Toxicity" and "Terrestrial and Aquatic Ecotoxicity" categories, soybeans had worse performance because of impacts caused by emission of heavy metals entering the production system by limestone, fertilizers, seeds, and pesticides. Soybean needs more seeds (which contain a large amount of heavy metals) and uses a greater number of pesticides (26 for soybean, 15 for sunflower) and in a greater quantity. In addition, all three allocation criteria assign to soybean the major share of environmental load of liming on the production system.

Sunflower produced in a rotation crop system has reduced environmental impact in all categories when compared to that produced as monoculture, because sunflower benefits from being preceded by soybean, especially for nitrogen fixation, which contributes about 20 kg of this element per hectare, reducing the synthetic nitrogen fertilizer application and emissions. Soybean impact had reduced only for the "Climate Change" category, due to allocation to sunflower of a share of land use impacts (Table 3).

	Soybean in crop system			**Sunflower in crop system**		
	occupation	**yield**	**gross margin**	**occupation**	**yield**	**gross margin**
Climate change	57%	69%	100%	56%	43%	12%
Ozone depletion	100%	100%	100%	92%	92%	92%
Terrestrial acidification	100%	100%	100%	71%	71%	71%
Freshwater eutrophication	100%	100%	100%	93%	93%	93%
Human toxicity	100%	100%	100%	95%	95%	95%
Photochemical oxidant formation	100%	100%	100%	95%	95%	94%
Particulate matter formation	100%	100%	100%	74%	74%	74%
Terrestrial ecotoxicity	100%	100%	100%	90%	89%	85%
Freshwater ecotoxicity	100%	100%	100%	94%	94%	94%
Agricultural land occupation	100%	100%	100%	98%	98%	98%
Natural land transformation	99%	100%	100%	87%	86%	86%
Water depletion	100%	100%	100%	96%	96%	95%
Metal depletion	100%	100%	100%	91%	91%	91%
Fossil depletion	100%	100%	100%	95%	95%	94%

Table 3 - Impact on each category allocated to soybean and sunflower in a rotation crop system, calculated using each the three allocation criteria and normalized as a percentage of the impact these crops have in monocultures of the same yield. Important results are commented on the text.

Our results agree with those obtained by Hayer et al. (2010), who also noted that the inclusion of legumes could reduce the Global Warming Potential for the reasons herein.

Impactsfrom shared land use change and limestone supply were allocated to soybean and sunflower by “occupation”, i.e., in proportion to the time that each crop covered the soil in the rotation crop system. We also tried other two allocation criteria in order to evaluate their possible effect on a decision between rotation crop system and monoculture for each crop. For soybean, changing the allocation criteria affected noticeably only the "Climate change" impact category. As a percentage of the soybean monoculture impact on this category, the soybean-sunflower system scored 57%, 69% and 100% respectively for occupation, yield and gross margin allocation criteria. For this impact category, adopting the gross margin allocation criteria means to assign 100% of the environmental burden to soybean, what is equivalent to assume it as a monoculture.

For sunflower, the impact category "Climate change" was more affected when the allocation criterion was changed: 56%, 43% and 12% of the sunflower monoculture impact on this category, respectively, for occupation, yield and gross margin. The large reduction of impacts in this category for gross margin allocation criterion is due to the allocation to soybean of the full impact related to land use change and use of limestone, as mentioned on the previous paragraph. Another category with some variation for sunflower is "Terrestrial ecotoxicity" (90%, 89% and 85%). This category is influenced by heavy metal contamination of agricultural inputs (limestone, fertilizers and seeds), and for the gross margin allocation criterion, the environmental load contaminants from limestone are attributed exclusively to soybean. Changing the allocation criteria has not affected any other category for more than 1%, for soybeans or sunflower.

For all categories,impacts from rotation crop system were lower than impacts from soybean and sunflower monocultures combined. The categories with greatest impact reduction were "Climate Change", "Terrestrial Acidification" and "Particulate Matter Formation", for which the impact of rotation crop system amounted respectively to 56%, 74% and 80% of the sum of impacts from soybean and sunflower monocultures with the same area and yield.

Nemecek et al. (2008), comparing typical cereal-cereal rotation and cereal-legume rotation alternative systems with the allocation criterion "unit of cultivated area" (ha year-1) observed reduction in “Global Warming Potential”, “Acidification”, and “Eco and Human Toxicity” impacts. Additionally, they noticed impacts in non-renewable energy resources and ozone formation. The cereal-legume system resulted in lower impacts in all of these categories due to reduced application of nitrogen fertilizer, the expansion of the possibilities of using reduced tillage techniques and the lower incidence of disease problems (due to the diversification of crops). Nemecek et al. (2008) also evaluated other two allocation criteria: financial (gross margin) and energy (GJ of harvested biomass). The environmental performance of the cereal-legume system was always higher regardless of the allocation criterion adopted, although the comparative advantages of this system compared to cereal-cereal system have varied depending on the allocation criteria. Another study from the same authors also concludes that nitrogen management by reducing the supply of synthetic fertilizers and the introduction of legumes is a key factor in reducing environmental impacts from rotation crop systems on categories “Global Warming Potential” and “Acidification Potential” among others (Nemecek et al. 2015).

Conclusions

Sunflower-soybean rotation crop system reduced environmental impacts in all categories when compared to the combination of monocultures, because of a number of synergies made possible by sharing land use and other resources. These results can be generalized to any production system in which the reciprocal influences always lead to the reduction of environmental impacts. Different performances in some categories (notably "Climate Change") were obtained by changing allocation criteria for land use impacts, but the environmental impacts of therotation crop system were lower to the corresponding monoculture impact in all categories, no matter the allocation criterion adopted.

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