Life cycle assessment of Brazilian cashew

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ABSTRACT

Cashew (*Anacardium occidentale*) is a native Brazilian perennial tree that is also present on 30 other tropical countries and produces three worldwide-commercialized food products: cashew nuts, apple, and gum. This study assesses the life cycle environmental impacts of Brazilian dwarf cashew considering the management and crop functions. From the joint analysis of both functional units, we conclude that the best option to improve the environmental performance of Brazilian cashew production is to adopt the reference system with modifications regarding fertilization and land use change. From this case study, we highlight the benefits of considering both functional units and all production stages in the study of perennial crops.

Keywords: cashew nut, cashew apple, cashew gum, dwarf cashew, *Anacardium occidentale*

1. Introduction

Cashew orchards are of great importance for the social economy of many developing regions of the world (Azam-Ali and Judge 2004, Hall et al 2007), since this plant grows in harsh semi-arid climatic and soil conditions and generate income to many small farmers. Cashew producers may benefit from the commercialization of cashew nuts (CN), cashew apple (CA) and gum (CG) from the cashew tree in the international market. The renewal of orchards after 20 years of production also generates wood (CW) that is usually used by potteries as a renewable fuel.

World demand for cashew nuts has increased at a rate of about 4% annually from 2007 to 2011 (FAO 2013, INC 2013). This demand was mostly (79%) attended in 2011 by small farmers located in Vietnam, Nigeria, India, Ivory Coast and Brazil. In 2011, the United States, the United Kingdom, Germany and The Netherlands imported 76% of the cashew nut produced in tropical developing regions.

Cashew agriculture research in Brazil and in other countries has focused in developing high productive cashew clones and production systems. As this goal has been achieved in Brazil, research starts to focus on the evaluation of the environmental sustainability of cashew production systems. The knowledge about the environmental hotspots in cashew production may shed light on the identification of improvement options that will contribute to the environmental sustainability of producing regions. Besides, consumers and companies all over the world utilize cashew nuts in nature or as ingredient in diverse food (e.g. snacks, sauces, protein concentrates), making the cashew nut life cycle assessment of interest for many production chains.

This study assesses the life cycle environmental impacts of Brazilian dwarf cashew (Anacardium *occidentale*). We consider two agriculture functions: land management (agriculture system level) and production (product level). The study considering the land management function evaluates the environmental impacts of two production systems and the study focused on production, the impacts caused by cashew products (CN, CA, CG and CW).

2. Methods

We followed ISO 14040 directives to perform a life cycle assessment (LCA) for quantifying the environmental impacts of Brazilian dwarf cashew systems and products (CN, CA, CG and CW).

2.1. Scope and functional unit

The scope of this study is cradle to cashew farm exit-gate, considering the production of inputs (diesel, fertilizers and pesticides), transport of inputs to the cashew farm, and cultivation of dwarf cashew trees. Two functional units are used: one ha with 208 trees for the study of the cropping system; and one kg for the analysis of cashew products (CN, CA, CG and CW). The inventory data for the study of cropping systems covers the production of dwarf cashew cultivated during 20 years. Cultivation is organized by production stage: nursery, establishment (includes land preparation and planting during the first year), low production (4 years) and full production (years 6 to 20).

2.2. Inventory data

Two production systems for dwarf cashew are considered: the reference system (REF-farm) developed along 20 years of research, and the low input system (LI-farm) as practiced by a sample of farms.

Input data for the reference system come from reports of experiments and interviews with researchers on the subject of dwarf cashew production systems. Experiments started in 1980 at the Embrapa Tropical Agroindustry Experimental farm, located at Pacajus, Ceará State, Brazil. Their results are summarized by Crisóstomo et al (2007), Cardoso et al (2013), Crisóstomo (2013), Cavalcanti Junior (2013), Mesquita and Sobrinho (2013), Miranda (2013), Serrano and Oliveira (2013), and Vidal Neto et al (2013).

Input data for the low input system is derived from interviews applied to a sample of ten cashew farmers and two rural extension managers in 2013, located in six municipalities of the Ceará State, Brazil. The Ceará State holds 57% of the cashew production area (IBGE, 2013). The interviewed farmers and extensionists provided the average amount of input and production obtained for CN and CA during production stages, considering the last three years.

Inventory data for the cradle to gate production and transport of inputs used on cashew orchards (manure, mineral fertilizers, diesel, pesticides and plastics) were obtained from the *ecoinvent* 3.0 database (Weidema et al 2013).

2.3. Description of dwarf cashew production

Dwarf cashew production in the REF and LI farms encompass the following stages:

Nursery: Cashew seedlings are produced by grafting in nursery farms. The nursery involves three steps that take 120 to 150 days. First, dwarf seeds are sown on compost substrates that are deposited in small polypropylene tubes (diameter of 6 cm and height of 20). After 60 days of sowing, the germinated plants are grafted on rootstocks of the scion obtained from dwarf clone gardens. The grafted plants stay during 30 to 40 days in a greenhouse. After this time, seedlings are acclimatized in open fields for 30 to 50 days when they are apt to be planted in cashew orchards. Irrigation of the seedlings occurs every day of the production cycle and foliar fertilization, four times per cycle. We considered that 60,000 seedlings of grafted cashew are produced per year in 5.6 ha, with 60% of seeds producing viable seedlings; 20x6x4m grille of high density polyethylene are used to cover the shaded greenhouse (50%), lasting for 5 years; and that the polypropylene tubes last for 10 years.

Establishment (year 1): Land conversion, plowing and harrowing are performed before seedlings transplantation to orchards. The transplantation occurs in the raining season (January to April). Grafted cashew seedlings are planted into pits of 40x40x40cm on sandy soils with the pits spaced 8x6m (208 plants.ha^{-1}). Calcareous dolomite is applied at the bottom of the pits that are then filled with a mixture of surface soil, micronutrients, bovine manure and simple superphosphate at the REF-farm or only with soil poultry or bovine manure at LI-farms. Post-planting fertilization at REF-farm is based on nitrogen and potassium fertilization and at LI-farm on nitrogen from manure. Manual pruning is practiced in order to take out stems, which emerge from the rootstock, and flowers, in order to foster plant growth. In this first year, at the REF-farm, localized irrigation at the pits occurs four times per month during the dry season (from May to December).

Low production (year 2 to 6): Dwarf cashew plants grow until the sixth year after planting when they achieve growth stability. During each production year, the tree has a low and an intense vegetative growth: low in the raining season (January to April) and an intense growth in the dry season (May to December). During the intense growth period, the leaves fall, and flowering and fructification occur. Cashew orchards are rain fed from the second year onwards. Fertilization aiming plant growth occurs along the raining season (January to April). REF-farm uses manure and mineral (NPK) fertilizers and LI-farm, only manure. Manual pruning is practiced after harvest (December to January) and aims to reduce branches interlacing. This increases illumination in the canopy, and prevents pest and disease dissemination among branches. The REF-farm applies herbicides or mechanical weeding below the tree canopy to prevent competition among cashew and other plants (weeds). The LI-farms use manual weeding only before harvest. Both the REF-farm and LI-farms mow between lines of cashew trees to facilitate harvesting and promote soil covering with green manure (mulch). Insecticides, fungicides and herbicides are used only at REF-farm and follow the integrated pest and disease management plan. As many as 97 species of insects and 10 types of fungus may attack cashew orchards in Brazil. The calculus of the amount of pesticide used, however, consider only those pests and diseases that have caused most damage to orchards and that have registered pesticides for this culture. The production of CN (fruit) and CA (pseudo fruit) starts on the second year, and the CG, on the sixth year. CG is produced with the monthly application of growth hormone on lateral cuts made at the tree trunk.

Full production (year 7 to 20): The adult dwarf cashew tree may be 4 m high with a canopy diameter of 6 to 8 m and roots that may achieve 12 m (Crisóstimo et al 2007). CN (kernel and shell) average weigh ranges from 7 to 12 g, and CA, from 80 to 160g. During the full production period, fertilization aiming the CN production of 1,200 $kg.ha^{-1}.year^{-1}$, CA of 2,160 $kg.ha^{-1}.year^{-1}$ and CG of 90 $kg.ha^{-1}.year^{-1}$ is applied at the REF-farm. LI-farm relies only on composted manure and may produce 600 $kg.ha^{-1}.year^{-1}$ of CN and 1,080 $kg.ha^{-1}.year^{-1}$ of CA. Annual mowing, weeding and pruning are performed as in the low production years. At the end of the 20th year, new cashew trees replace old ones and the CW is commercialized at the local market.

2.4. Calculation of emissions

The calculus of greenhouse gas emissions (CO_2, CH_4 and N_2O) from agriculture fields for both production systems follows IPCC (2006). The following airborne emissions are estimated according to the methods described by Nemecek and Schnetzer (2012): ammonia (NH_3) and nitrogen oxides (NO_x) to air; nitrate (NO_3) and phosphorous compounds as phosphate (PO_4) and phosphorous (P) to water; pesticides and heavy metals (Cadmium (Cd), copper (Cu), zinc (Zn), lead (Pb), nickel (Ni) and chrome (Cr)) to soil. All pesticides applied for crop production were assumed to end up as emissions to, and remain as pollutants in the soil. The further fate of the substances is taken into account in the impact methods for human toxicity. We assumed that no leaching of soluble phosphate (PO_4) to ground water occurred because of the high aluminum and iron oxides content usually found in the type of soils where cashew orchards are located (Crisóstomo et al 2007) in Brazil. These oxides adsorb phosphate molecules in soil particles impeding leachate.

The humidity, carbon and nitrogen content of dwarf cashew tree are measured according to Silva et al (2009) from samples of roots, trunk, leaves and steams of a ten years old Clone BRS 226 tree. Samples were collected at Embrapa Pacajus Experimental Station, Ceará, Brazil.

2.5. Allocation procedure

No allocation is needed for the functional unit of one ha with 208 trees. Allocation is necessary, however, for the functional unit of one kg cashew nut products due to the multiple cashew products harvested from a dwarf cashew tree (CN, CA, CG and CW). We applied allocation according to mass and economic criteria to illustrate sensitivity of results for the allocation principle used. Allocation considers the production weight of cashew products over 20 years. The replacement of the cashew orchard allows the commercialization of CW at the end of the 20^{th} year. CG may start to be extracted from dwarf cashew by commercial farms in the sixth year of plant growth. CG market value is assumed the same as the acacia gum that is a similar product and has long been commercialized in the world market. The allocation factors for each farm system and product is presented in Table 1.

Table 1. Allocation factors

		REF-farm			LI-farm		
Product	**Price (US$/kg)**	**Production in 20 years (kg/ha)**	**Economic allocation**	**Mass allocation**	**Production in 20 years (kg/ha)**	**Economic allocation**	**Mass allocation**
CN	0.8	17,330.00	44%	15%	6,432.50	51%	8%
CA	0.4	31,194.00	39%	27%	11,578.50	46%	14%
CG	4.0	1,260.00	16%	1%			
CW	0.004	67,392.00	1%	58%	67,392.00	3%	79%
Total		117,176.00	100%	100%	85,403.00	100%	100%

2.6. Impact assessment

We applied the Recipe model (Goedkoop et al 2009) focusing on the midpoint environmental impact categories natural land transformation, climate change, acidification, eutrophication and human toxicity. The reasoning behind this selection is that these categories are important to the study of fruit products, according to Michalopoulos and Christodoulopoulou 2012). Furthermore, the emissions calculated for cashew production in this study may directly cause these impacts.

The reference situation for land transformation is the change from Caatinga (Brazilian savannah) forest to dwarf cashew orchards.

The method Monte Carlo for uncertainty analysis is applied to the study results. We assume log normal distributions for probability functions and run the model for 1,000 cycles. The Pedigree matrix in SimaPro is used to determine the deviations of each variable (Goedkoop et al., 2008).

3. Results

3.1. Inventory of inputs from primary data per ha

The full and low production stages require most of the inputs per hectare of cashew cultivated in both production systems, i.e. REF-farm and LI-farms (Table 2). In these stages, macronutrients and pesticides are more intensively applied than in the earlier stages. Nursery requires in general the smallest amounts of inputs, although the establishment year requires most of the water and all the micronutrients (boron, copper, manganese, molybdenum, zinc and iron).

Table 2. Primary data of dwarf cashew REF and LI farms, per ha, in each production stage

			REF-farm				LI-farm			
Inventory	**Unit**	**Nursery**	**Establish-ment (year 1)**	**Low production (years 2 to 6)**	**Full produc-tion (years 7 to 20)**	**Total value for 20 years**	**Establishment (year 1)**	**Low production (years 2 to 6)**	**Full production (years 7 to 20)**	**Total value for 20 years**
Seedlings	number	208	208			208	208			208
Cashew nut	t			2.93	14.40	17.33		0.73	5.70	6,43
Cashew ap-ple	t			5.27	25.92	31.19		1.32	10.26	11,58
Cashew gum	t			0.09	1.17	1.26				-
Cashew wood	t				67.39	67.39			67.39	9,36
Inputs										
Area transf.	ha	0.03				1.00				1,00
Lime	t		2.01	2.50	6.49	11.00	0.04	0.21	0.05	0.30
Gypsum	kg		500.00			500.00				
Seeds	kg	1.80								
Boron	g		374.40			374.40				
Copper	g		166.40			166.40				
Manganese	g		416.00			416.00				
Molybdenum	g		20.80			20.80				
Zinc	g		1,872.00			1,872.00				
Iron	g		624.00			624.00				
Urea	kg	0.003	21.27	406.55	3,091.64	3,519.45				
potassium chloride	kg	0.003	10.76	208.00	717.24	936.00				
Single super-phosphate	kg	0.003	161.78	1,109.33	2,311.11	3,582.22				
Organic compost	kg		2,080.00	14,560.00	54,080.00	70,720.00	2,496.00	12,480.00	32,448.00	47,424.00
Deltamethrin	kg	0.003	0.01	1.30	6.49	7.80				
Copper oxyc.	kg	0.02	0.40	34.28	171.43	206.11				
Glyphosate	kg			3.68	21.23	24.90				
Ethephon	kg			3.59	46.73	50.32				
Diesel	l		345.25	461.25	1,199.25	2,005.75	80.00	400.00	1,040.00	1,520.00
Water	l	4,659.20	94,900.00			94,900.00	94,900.00			94,900.00
Plastic	g	213.40								

The majority of dwarf cashew orchards are located on deep, well-drained, sandy loam soil of low natural fertility, usually Quartzarenic Neosols (Quartz Sands), Latosols and Argisols (Podzolics) (Crisóstomo et al 2007). Fertilization is required in these soils to promote plant growth and improve yield. Potassium and phosphorous are essential during growth (low production) stage for root development. Nitrogen increases the flowering period and the yields of CN, CA and CG (Crisóstomo 2013, Lima 2014). The LI-farms apply per ha less fertilizer than the REF-farm in all production stages.

Pesticides are required to control the population of pests and diseases when infestation levels are above the rates determined by the integrated management plan (Cardoso et al 2013, Mesquista et al 2013). These pests and diseases attack seedlings and cashew trees during inflorescence, reducing nut and apple yields. Only the REF-farm controls infestations of pests and diseases. In this farm, deltamethrin (insecticide) is used to control infestations of drills (*Anthistarcha binocularis Meyrick*) and thrips (*Selenothrips rubrocinctus Giard*), and copper oxychlorate (fungicide), to combat Anthracnose (*Colletotrichum gloeosporioides (Penz) Pez. & Sacc)*. Glyphosate (herbicide) is applied to control weeds, especially *Senna obtusifolia, Alternanthera sp., Panicum maximum, Cenchrus echinatus, Eleusine indica, Setaria geniculate, Ipomoea sp., Sida cordifolia, and Solanum sp.*

The low fertilization and no control of pests and diseases in LI-farms result in CN and CA yields that per ha are 63% lower than in REF-farm. CG is a new product from cashew orchards and is not yet produced by most of the commercial farms in Brazil. Nonetheless, Lima (2014) reports that cashew orchards with reduced fertilization rates (150 g.plant^{-1} of N, 300 g.plant^{-1} of P_2O_5 and 90 g.plant^{-1} of K_2O) produce 7% less CG yield per ha than orchards subjected to fertilization as adopted in the REF-farm.

Lime and gypsum are applied to cashew orchard soils, both in the REF and LI-system, because of their high acidity and aluminum saturation percentage (above 40%) (Crisóstomo 2013). Gypsum is incorporated in deep soil layers to reduce aluminum saturation before seedling transplantation at the REF-farm, while lime is applied on all production stages to correct soil pH in both farm systems.

The best climate conditions for dwarf cashew production occur when temperature ranges from 22 to 32^{o}C along the year, relative humidity, from 70% to 85%, and annual precipitation, from 800 to 1,500 mm, distributed over 5 to 7 months per year (Serrano and Oliveira, 2013). The presence of this climate condition allows cashew cultivation in semi-arid regions without irrigation, such as the Brazilian Northeast. Nonetheless, during nursery and the first establishment year, continuous water supply through irrigation is necessary and used by REF and LI-farms. Irrigation is necessary because of the small size of the rooting system that is not able yet to extract water from deep soil layers.

3.2. Impacts per ha of dwarf cashew considering the land management function

The production system adopted by LI-farms cause significant less environmental impacts per ha than the system used by the REF-farm, for all but the land use impact category (Table 3). This result is expected since the LI-farms use less input and generate less emission than the REF-farm. However, both systems may require land transformation for the same area.

The main sources of environmental impacts at the REF-farm and LI-farm are:

Land use and climate change: Carbon stock losses during land transformation and nitrous oxide emissions from nitrogen fertilizers used in cashew orchards emit most of the greenhouse gases causing climate change.

Human toxicity: Fertilizers are contaminated by heavy metals and these are released to soil (e.g. Cd when single superphosphate is applied to agriculture soil). Pesticides applied in cashew orchards are also released to soil. These emissions may degrade human health. This occurs in the REF-farm that uses mineral fertilizers and pesticides. In LI-farms, upstream processes related to the poultry manure production chain emit most of toxic substances.

Terrestrial acidification: The use of mineral nitrogen fertilizers at the REF-farm emits most of the NH_3 and NO_x that cause terrestrial acidification. For the LI-farms, NH_3 emitted in the production of composted poultry manure is the main cause of acidification.

Marine and freshwater eutrophication: The production and use of mineral and organic fertilizers on both REF and LI farms emit most of the nitrogen and phosphorous compounds with potential to cause marine and freshwater eutrophication.

Table 3. Environmental impacts per ha in REF and LI farms, for 20 years

Impact category	**REF-farm**	**Li-farm**	**Uncertainty (LI-farm >= REF-farm), Confidence interval of 95%**
Climate change (kg CO_2 eq.ha^{-1})	176,556.95	117,300.62	1%
Human toxicity (kg 1,4-DB eq.ha^{-1})	36,890.62	768.44	0%
Terrestrial acidification (kg SO_2 eq.ha^{-1})	1,426.53	43.40	0%
Freshwater eutrophication (kg P eq.ha^{-1})	20.22	2.72	0%
Marine eutrophication (kg N eq.ha^{-1})	258.68	142.15	0%
Natural land transformation (m^2.ha^{-1})	19,984.02	19,972.88	51%

3.3. Impacts per kg of cashew products considering the crop production function

Mass as well as economic allocation is used to calculate the environmental impact per kg cashew product (see section 2.5 and Table 1 for mass and economic values). The type of allocation criteria affects the magnitude of cashew products impacts (Table 3). CG is the most sensible product to the choice of allocation criteria due to its relative high economic value. The impact values for CG may increase at least fifteen times when moving from mass to economic allocation.

Table 4. Impacts per kg of CN, CA, CG and CW, considering economic and mass allocation

Cashew Product	**System**	**Allocation procedure**	**Climate change (kg CO2 eq.kg^{-1})**	**Terrestrial acidification (kg SO2 eq.kg^{-1})**	**Freshwater eutrophication (kg P eq.kg^{-1})**	**Marine eutrophication (kg N eq.kg^{-1})**	**Human toxicity (kg 1,4-DB eq.kg^{-1})**	**Land transf. (m2.kg^{-1})**
CN	REF-farm	Economic	4.46	0.04	0.0005	0.01	0.93	0.51
		Mass	1.51	0.01	0.0002	0.002	0.315	0.17
	LI-farm	Economic	9.34	0.003	0.0002	0.01	0.06	1.59
		Mass	1.37	0.001	0.00003	0.002	0.009	0.23
CA	REF-farm	Economic	2.23	0.02	0.0003	0.003	0.47	0.25
		Mass	1.51	0.01	0.0002	0.002	0.31	0.17
	LI-farm	Economic	4.67	0.002	0.0001	0.006	0.03	0.80
		Mass	1.37	0.001	0.00003	0.002	0.009	0.23
CG	REF-farm	Economic	22.31	0.18	0.0026	0.033	4.66	2.53
		Mass	1.51	0.01	0.0002	0.002	0.31	0.17
	LI-farm	Economic						
		Mass						
CW	REF-farm	Economic	0.02	0.0002	0.000003	0.00003	0.005	0.003
		Mass	1.51	0.01	0.0002	0.002	0.31	0.17
	LI-farm	Economic	0.05	0.00002	0.000001	0.0001	0.0003	0.01
		Mass	1.37	0.0005	0.00003	0.002	0.009	0.23

Economic allocation assigns higher impacts for CN, CA and CG in both farm systems since these products have higher market values. Since CG is not yet widely commercialized by LI-farms, no impacts are assigned to this product for this system.

Moreover, mass allocation highlights the participation of CW in impact values, in both farm systems. The lower CN and CA yields obtained in LI-farms explain the higher allocation value assigned for CW.

The combined analysis of allocation criteria and production systems shows that the environmental performance of products cultivated in different production systems change according to the allocation criteria adopted.

If the choice is for economic allocation, CN, CA and CW cause less impact on land use, marine eutrophication and climate change when produced in the REF-farm. If mass allocation is used, these products cause similar impacts for these impact categories. The high yields obtained in the REF-farm are not enough to reduce the impacts of cashew products on the other impact categories (freshwater eutrophication, human toxicity and acidification) to values lower to the ones obtained in the LI-farm.

4. Discussion

In this study, cashew production was evaluated at the per ha (land management) and per kg product (production) levels. The land management study compared two production systems: one resulting from consistent field research (REF-farm system) and the other based on common practice at small and medium sized farms (LI-farm). The comparison of these systems showed that LI-farms perform better in terms of environmental impacts per ha.

However, these farms maintained the same low fertilization rates in all production stages, and hardly controlled pests and diseases, leading to low emissions and impacts but also low yields. These low yields of CA and CN and no production of CG may result in higher impact per kg of product for LI-farms than for ref-farms, according to the allocation procedure chosen. The low yields from the LI-farms also mean low incomes for the small farmers, reducing their capacity to invest in better management practices. The interviews with the LI-farmers also highlighted the reduced access to technical assistance and little knowledge of updated cashew production systems. Considering these aspects, the argument for refraining from the LI-farm system becomes stronger. A better option may be to keep the high yields of the REF-farm system and try to reduce its environmental impacts per ha.

Three main activities considerably affect the environmental performance of the REF-farm system: land use transformation, mineral fertilization and pesticide applications. The best choice for reducing impacts on land use, and as a consequence on climate change and biodiversity, is to establish dwarf cashew orchards in already deforested areas currently set aside or used to produce annual crops. Conversion of Caatinga (Savana) vegetation to dwarf cashew orchards results in losses of carbon stocked on biomass and soil and also cause biodiversity loss in the already much disturbed Caatinga biome. Regarding fertilization options, organic instead of mineral fertilization is preferred from the perspective of impacts per ha. The use of mineral fertilizers in the REF-farm is responsible for the major impacts on human toxicity, acidification and eutrophication. The amount of pesticides can be decreased with the use of intercrop systems that increase biodiversity in cashew orchards (Xavier et al 2013).

The intercrop of cashew trees with leguminous and grass species may decrease the need for mineral fertilization and reduce the level of pest and diseases in orchards. Some small cashew farmers in the Brazilian Northeast already adopt this practice to increase their sources of income, cultivating cashew in association with beans and corn during the raining season, but medium and large farms hardly adopt this practice. Previous research showed that the cultivation of *Canavalia ensiformes* (type of bean) between lines of dwarf cashew trees during the raining season leveled CN yield to 1,179 $kg.ha^{-1}$ already in the fourth low production year (Oliveira et al 2000). This yield is 108.7% higher than the one obtained in the experimental parcel with no consociation. The association of legumes with cashew also reduces weed development and the need for the use of herbicides, besides increasing soil carbon stock, organic matter and nutrient content (Xavier et al 2013). However, further research is still necessary for determining the amount of mineral fertilizers that can be substituted by green fertilization with leguminous species adapted for the semi-arid environmental conditions.

The impact per kg product level was evaluated by means of a sensitivity analysis with both economic and mass criteria to allocate impacts over the multiple product outputs of the cashew orchards. Although both allocation procedures can be adopted to calculate the impacts of cashew products, results considerably change with the choice made. Economic allocation increases the impacts of CN, CA and CG and decreases the impact of CW in all categories. It also leads to the conclusion that products from the REF-farm may cause lower impacts than when cultivated in LI-farms, according to the analyzed impact category. On the other hand, mass allocation does not differentiate products from both production systems, for half of the analyzed impacts categories.

CG is presently starting to be extracted from dwarf cashew by commercial farms and the assumptions made in this study for the evaluation as CG using mass allocation represents a near future situation for Brazilian cashew farms. Nonetheless, CG real price is not settled yet in the local or international markets. The value used for CG was assumed the same as the acacia gum, although this situation is not yet at stake now since CG is starting to be commercialized. The acceptance of this new product by the food industry is not yet clear and it may take years for CG to become a real substitute product for the acacia gum. Nevertheless, CG is expected to be commercialized in few years, and the study results are therewith representing a future situation.

The prices for CN and CA are volatile ranging from $ 0.4 to 0.8 per kg of CN and from $ 0.2 to 0.4 per kg of CA, respectively, in the last five years. We therefore recommend the use of mass allocation for the evaluation of cashew products. This is also in accordance with ISO 14040 that recommends allocation on physical relationships over allocation based on other relationships.

5. Conclusion

Cashew production in small and medium farms in Brazil use a low input system with reduced environmental impacts per ha. These farms, however, also have low yields and profits. Many years of experimental research developed a reference production system with increased yields of nuts and apples as well as gums extracted from the trees trunk. This reference system relies on fertilization with specific rates for each production stage, and on the integrated management of pests and diseases. The higher yields per ha result in the reference system having similar or lower impacts per kg of product than the low input systems, for half of the impact categories.

The impacts caused by Brazilian cashew orchards and products change according to the choice of functional unit (i.e. per ha or per kg product) and allocation procedure adopted (i.e. mass or economic allocation). When the land management function is applied (one ha of cultivated orchard), the low input production system is preferable, but if the production function is chosen the results per kg of product produced in each system are not conclusive.

From the joint analysis of both functional units, we conclude that the best option to improve the environmental performance of Brazilian cashew production is to adopt the REF-farm system with modifications. That is, this system provides higher yields and income for the cashew farmers and may cause less impact if orchards are installed in agricultural or degraded areas and intercrop practices are adopted.

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7. References

Azam-Ali SH, Judge EC (2004) Small-scale cashew nut processing. FAO, Rome

Cardoso JE, Viana FMP, Freire FCO, Martins MVV (2013) Doenças do cajueiro [Diseases in cashew orchards] In: Araújo JPP [ed] O agronegócio Caju: práticas e inovações [Cashew agribusiness: practices and innovations]. Embrapa, Brasília, pp. 218-238

Cavalcanti Junior AT (2013) O que plantar [What to plant]. In: Araújo JPP [ed] O agronegócio Caju: práticas e inovações [Cashew agribusiness: practices and innovations]. Embrapa, Brasília, pp. 61-75

Crisóstomo LA, Pimentel CRM, Miranda FR, Oliveira VH (2007) Cashew – Dwarf Variety. In: Johnston AE (ed) Fertilizing for high yield and quality: Tropical fruits of Brazil. International Potash Institute, Switzerland, pp. 50-69

Crisóstomo LA (2013) Clima, solo, nutrição mineral e adubação para cajueiro anão precoce [Climate, soil and mineral nutrition and fertilization for dwarf cashew]. In: Araújo JPP [ed] O agronegócio Caju: práticas e inovações [Cashew agribusiness: practices and innovations]. Embrapa, Brasília, pp. 43-59

FAO (Food and Agricultural Organization) (2013) FAOSTAT Production and Trade, Cashew nut – 1994-2011. http://faostat.fao.org/site/342/default.aspx

Goedkoop M, Heijungs R, Huijbregts M, Schryver A, Struijs J, Van Zelm R (2009) Recipe 2008: Report I - Characterisation. RIVM, The Netherlands, pp. 1-126

Hall M, Patel P, Sarmiento G, Smith N, Sostowski A, Waxman S (2007) Benchmarking the Global Cashew Industry. Development Alternatives Incorporated (DAI), Washington, pp 1-74

IBGE (Instituto Brasileiro de Geografia e Estatística) [Brazilian Institute for Geography and Statistics] (2013) Levantamento sistemático da produção agrícola 2013 [Brazilian sistematic research of agriculture production]. http://www.sidra.ibge.gov.br

INC (International Nut and Dried Fruit Foundation) (2013) Global Statistical Review 2007-2012. https://www.nutfruit.org/en/

International Panel on Climate Change (IPCC), 2006. Guidelines for National Greenhouse Gas Inventories. IPCC, Geneva

Lima REM (2014) Produção simultânea de goma, pseudofrutos e frutos de cajueiro anão precoce sob diferentes níveis de irrigação e adubação [Dwarf cashew simultaneous production of cashew nuts, apple and gum using different irrigation and fertilization levels]. Master thesis, Agronomic Engineering Department of the Ceará federal University, pp. 1-100

Mesquita ALM, Sobrinho RB (2013) Pragas do cajueiro [Pests in cashew orchards] In: Araújo JPP [ed] O agronegócio Caju: práticas e inovações [Cashew agribusiness: practices and innovations]. Embrapa, Brasília, pp. 195-214

Michalopoulos G, Christodoulopoulou L (2012) Product Category Rules: Fruits and Nuts. UN CPC 013. The International EPD®System, pp. 1-18

Miranda FR (2013) Irrigação do cajueiro [Cashew irrigation]. In: Araújo JPP [ed] O agronegócio Caju: práticas e inovações [Cashew agribusiness: practices and innovations]. Embrapa, Brasília, pp. 168-174

Nemecek T, Schnetzer J (2012) Methods of assessment of direct field emissions for LCIs of agricultural production systems. Data v3.0. Agroscope, Zurich

Nemecek T, Kagi T (2007) Life cycle inventories of agriculture production systems. Data v2.0. ecoinvent report No. 15

Oliveira FNS, Lima AAC, Aquino ARL, Costa JBA (2000) Adubação verde com leguminosas em pomares de cajueiro anão precoce [Green fertilization with legumes in dwarf cashew orchards]. Boletim de Pesquisa no. 31. Embrapa Tropical Agroindustry, Brazil, 19p

Serrano LAL, Oliveira VH (2013) Aspectos botânicos, fenologia e manejo da cultura do cajueiro [Botanic aspects, phenology and management practices to cultivate cashew]. In: Araújo JPP [ed] O agronegócio Caju: práticas e inovações [Cashew agribusiness: practices and innovations]. Embrapa, Brasília, pp 1-111

Silva FC, Abreu MF, Pérez D, Vieira PA, Abreu CA, Raij B, Gianello C, Coelho AM, Quaggio JA, Tedesco MJ, Silva CA, Cantarella H, Barreto WO (2009). Manual de análises químicas de solos, plantas e fertilizantes [Manual for the chemical analysis of soils, plants and fertilizers]. Brasília: Embrapa Informática Agropecuária, pp. 107-189

Vidal Neto FC, Barros LM, Cavalcanti JJV, Melo DS (2013) Melhoramento genético e cultivares de cajueiro [Genetic breeding and cashew cultivars]. In: Araújo JPP [ed] O agronegócio Caju: práticas e inovações [Cashew agribusiness: practices and innovations]. Embrapa, Brasília, pp. 481-508

Xavier FAS, Maia SMF, Ribeiro KA, Mendonça ES, Oliveira TS (2013) Effect of cover plants on soil C and N dynamics in different soil management systems in dwarf cashew culture. Agriculture, Ecosystems and Environment 165: 173-183

Weidema B P, Bauer C, Hischier R, Mutel C, Nemecek T, Reinhard J, Vadenbo C O, Wernet G. (2013). Overview and methodology. Data quality guideline for the ecoinvent database version 3. Ecoinvent Report 1(v3). St. Gallen: The ecoinvent Centre

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