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Assessment of the environmental impact of three types of fertilizers on the cultivation of coffee at the Las Delicias indigenous reservation (Cauca) starting from the life cycle assessment

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Evaluación del impacto ambiental de tres tipos de fertilizantes en el cultivo de café del resguardo indígena Las Delicias (Cauca) a partir del análisis de ciclo de vida

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ABSTRACT: This paper aims to assess and to compare the environmental performance of three different types of fertilizers in the production of coffee using the methodology of Life Cycle Assessment (LCA) in the Las Delicias indigenous reservation (located in the northern area of the State of Cauca) in order to standardize the process. In this sense, some coffee producers used chemical fertilizers; others used poultry manure, and most coffee producers, used compost. They also applied artisanal techniques while conserving their ancestral traditions and cultures in the coffee production chain. Using the LCA, we found that of three types of fertilizers (chemical fertilizer, poultry manure, and compost), the use of compost shows the minimum environmental impact on the category of climate change and acidification, meanwhile the use of chemical fertilizers is better in the category of terrestrial ecotoxicity and land use. Finally, the use of poultry manure obtained a better performance in the categories of human toxicity and eutrophication. Therefore, the best decision adjusted according to the results would be to fertilize with compost, due to its lesser impact on soil acidification.

RESUMEN: Este trabajo busca evaluar y comparar el desempeño ambiental de tres tipos de fertilizantes en la producción de café a partir de la aplicación de la metodología de análisis de ciclo de vida en el resguardo indígena Las Delicias (ubicado en el Norte del Departamento del Cauca) a fin de estandarizar los procesos. En este sentido algunos caficultores emplean fertilizantes químicos, otros usan gallinaza y la mayoría emplea compost, trabajan con técnicas artesanales, y conservan sus tradiciones ancestrales y culturales en los procesos productivos. Del ACV se encontró que de los tres tipos de fertilizantes (fertilizantes químicos, gallinaza, y compost), el uso del compost presenta menores impactos en la categoría de cambio climático y la acidificación, mientras que el uso de fertilizante químico es mejor en la categoría de toxicidad terrestre y el uso de la tierra. Finalmente el uso de gallinaza obtuvo mejores desempeños en la categoría de toxicidad humana y eutrofización, por tal motivo la decisión que mejor se ajustaría de acuerdo a los resultados es la de fertilizar con compost ya que presenta menores impactos en acidificación del suelo.

1. Introduction

The Las Delicias indigenous reservation is located between the municipalities of Buenos Aires and Santander de Quilichao, Northern area of the State of Cauca (Colombia). It has a productive structure of conservation that seeks an economic balance in harmony with the environment. However, the main agricultural activity consists of the production of coffee, as a driver of the community´s economy and is performed as a subsistence method and its performance is lower than 50% in relation to technified operations. Thus, the development of this pilot intends to provide the Life Cycle Assessment tool as a source of differentiation in relation to product quality for the members of the reservation, respecting their culture and worldview as a NASA community. For such a purpose, a comparison of the proportion of the environmental impact generated

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by different production modes (chemical fertilizer, poultry manure, and compost) will be carried out through the use of LCA; in order to identify the production process stages that require greater attention in order to achieve an organic and a high-quality coffee production.

2. Life Cycle Assessment

The Life Cycle Assessment (LCA) is a methodological tool based on a holistic approach designed to assess, to control, and to mitigate the impacts on the environment by studying the different stages involved in the production of the goods and services processes from procurement of raw materials to final disposition thereof.

The LCA came into being in the early 60s and had a boom in the scientific community due to the growing concern of the scarcity of natural resources and environmental pollution, which was reflected on historical events with the publication of "Silent Spring" written by Racher Carlson in 1962. This publication showed evidence of the harmful effects of pesticide use on the environment, the oil crisis in the early 70s, and the publication of the" limits to growth" by the Club of Rome in 1972 [1].

Then, due to the importance of the life cycle assessment in the scientific community, The United Nations Environment Programme (UNEP) and the Society for Environmental Toxicology and Chemistry (SETAC) launched in 2002 an International Life Cycle Partnership, known as the Life Cycle Initiative (LCI) in response to the claim by Governments around the world for a Life Cycle economy expressed in the first global ministerial environment forum in Malmo, Sweden in 2000. It aims to promote life cycle thinking globally and facilitate the exchange of knowledge of over 2,000 experts worldwide and four regional networks from different continents as ALCAs- Australian Life Cycle Society, ISLCA- Indian Society for LCA, JLCA-LCA Society of Japan and KSLCA- Korean Society for LCA [1].

As a result of the above events, the scientific community had the need to standardize the procedures to make an LCA; for this reason, the family of standards ISO 14040-14044 arises, these standards regulate the subject matters related to the development of life-cycle assessment, such as the life cycle inventory, the assessment of environmental impacts, and their interpretation.

In this sense, the ISO 14040 standard in 1997 with its updated version as of 2006, standardized the procedures for making an LCA [2]. Likewise, the Colombian Institute of Technical Standards and Certification (ICONTEC) by the NTC 5459 established the definition of the concepts necessary for the implementation of an LCA [3] such as the definition and the scope of the Life Cycle Assessment, this ISO (14040) considers aspects such as system limits and procedures for assigning weights impacts. See Figure 1.

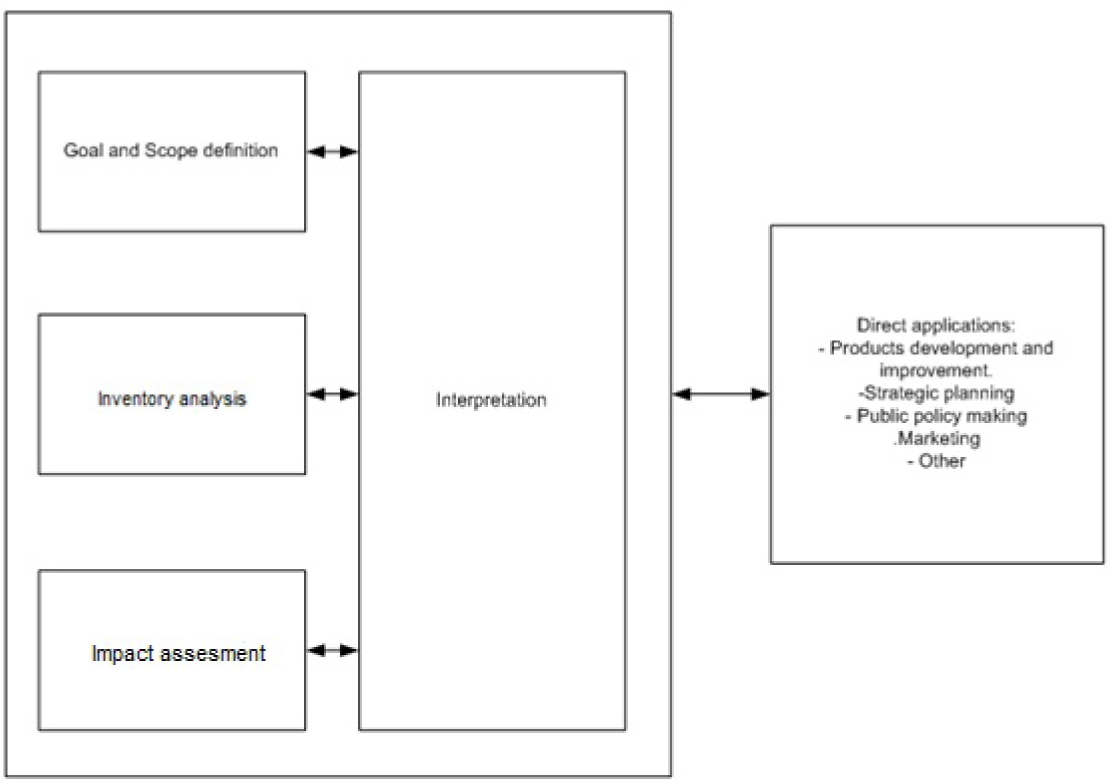

Figure 1 Phases of an LCA. Source: [2]

In a few words, the Life Cycle Assessment attempts to model the flow of materials and energy during a production, process of goods and services, in order to determine the environmental impacts generated according to the methodology and category of impacts selected to provide a basis for assessing and comparing different processes, and to propose fewer damaging alternatives to the environment [4, 5].

Coffee currently has a pilot project run by the company Tchibo where they measure the carbon footprint in a conventional coffee chain (from cradle until the cradle grave, including the transport from Tanzania to Germany). A cup of coffee is connected to a carbon footprint of 59.12 g CO2e which is equivalent to 7 grams of coffee powder with 0.125 liters of water consumed where 54.89% of the carbon footprint comes from the cultivation and processing on the farm [6]. In addition, together with ICONTEC, CENICAFÉ managed to establish a methodological framework led by Colombian Technical Standard (NTC 5947) referenced in the PAS 2050 standard to calculate the carbon footprint of *Café de Colombia*. Moreover, CENICAFÉ used a computational tool called the CREFT Model, allowing them to calculate the fixings of the coffee growing in pilot tests performed for each batch, evaluated according to agro-ecological conditions in Nariño considering that each region has its own parameters that need to be modeled. Furthermore, conducting a study where they analyze the carbon footprint in the coffee productive chain with different certification standards in Costa Rica, they found that coffee farms generated between 0.5 and 1.1 kg CO2 / kg of green coffee bean produced [7], in the same way Noponen *et al*. [8] find that in the stage of cultivation, the emissions of CO2 are between 2.55 and 3.120 kg CO2-eq/kg green coffee for the conventional coffee and 1.41 and 1.9 kg CO2-eq/kg green coffee for the organic.

Additionally, so far there is no evidence of LCA measurements and calculations in the production process of coffee in the Las Delicias indigenous reservation and its surroundings. Hence, this methodology seeks to make a social appropriation of knowledge by the community with regards to quality management through LCA, in addition to other benefits, such as the recognition of origin coffee of the Las Delicias indigenous reservation.

With all this being said, the study focuses on the flow of materials and energy generated, as well as the use of LCA as input for the development of a quality management model for the stage of cultivation and harvest of origin coffee at the Las Delicias indigenous reservation due to the importance of coffee production in the economy of this community. Indeed, according to the census data as of 2013, this indigenous reservation is made up of 2,722 people; this figure corresponds to about 126 families, 60 of them live on the growth of coffee and intercropping.

3. Study case: production of origin coffee at the Las Delicias indigenous reservation, northern area of the state of Cauca

3.1. Indigenous reservation and coffee producers

The Las Delicias indigenous reservation has an environmental, economic structure that develops productive forms of conservation, exchange and economics seeking balance and harmony with the territory. The community at the reservation has its own form of government and authority, which is the council, made up of a director who is popularly elected. The ACIN is a joint government organization in the area and both the Councils and the Association are recognized by the State as public entities of special character, with autonomy to govern their territories, to do justice, to legislate, and to manage their resources and the resources given by the Nation, according to their customs and uses (NASAACIN-Asociación de Cabildos del Norte del Cauca).

The main economic activities of the indigenous reservation are agriculture and small-scale mining. Agricultural activity in this area is basically for internal consumption, with yields of about 50% less compared to the technologically-advanced plantations.

3.2. Location

The reservation and NASA indigenous community of the Las Delicias is located in the municipalities of Buenos Aires and Santander de Quilichao, which is located in the northwest region in the state of Cauca, between 806,000 and 846,000 North coordinates and 1´028.000 and 1 ´058 000, with an area of 406,7 km^2. 03º01'08" latitude north and 76º38'37" longitude west. The villages where the coffee producers are located, and are part of the study are Buenos Aires, Las Delicias, New Granada, Jasmine, Esmeralda, San Gregorio and Santander de Quilichao, village Miraflores and Alto San Francisco. It has borders on the north of the Police Inspectorate of Mazamorrero, and the village of Santa Catalina, on the east with Santander de Quilichao

3.3. Agro-Environmental Characteristics, living conditions, farming practices and coffee processing

Thanks to the environmental conditions by the different climate zones (from 1400 m.a.s.l to 1800 m.a.s.l.) that this reservation has, different products can be grown (cassava, coffee, and fruit) as well as plants used for food, medicine, and the construction in the region. These conditions make the reservation an agro diverse territory which requires strengthening food security and sovereignty for the community. Several of the producers, parents, and grandparents claim that they have used agro-ecological practices, but in recent decades, they have been using smaller amounts of chemical fertilizers for production, between 50 and 90 grams of fertilizer are used per tree compared to conventional crops of coffee that require 120 grams of fertilizer per tree [9].

Coffee cultivation and processing practices are characterized by procedures rooted in the region since the early 1970s, which have been based on empirical production, in which the producers are not familiar with the measurement of the amounts of fertilizers and the use of water for the washing of coffee, or any other kind of raw material. Similarly, coffee producers do not keep a systematized process of the impacts of each of the materials and resources used as for the production, processing, and transportation of coffee. With the use of LCA methodology, it is proposed that coffee producers take ownership of the process and consider the environmental impacts of production with better practices.

Out the 60 farming families in the council, 50% expressed interest in improving the control cultivation process and collectively, build a high quality coffee management system. Some also expressed their desire to recover traditional varieties that have been lost in the area as those called Caturra, Arabic, Bourbon, among some others.

As for the coffee washing process, most performed manual pulping, washing is done in sacks, and drying takes place directly in the sun. However, several of these producers have not implemented the drying canopies and the use of tanks for the washing after the fermentation of the coffee has been made.

The use of high vegetation cover in the cultivation has several purposes for these producers, one of them is to reduce temperature and to improve the relative humidity, improving soil conditions in times of drought, since they do not have an irrigation system besides help to increase the contents of organic matter, litter production and branches. The coffee harvest is done in two seasons, April and May being the main crop and small collections of coffee crop knowns as "traviesa" which is carried out in the months of November and December.

4. Life Cycle Assessment of origin coffee production from the Las Delicias indigenous reservation

4.1. Definitions

Goal

The objective of the Life Cycle Assessment in the production of origin coffee from the Las Delicias indigenous reservation of northern Cauca, is to elaborate an inventory of materials and energy flow for the stage of cultivation, harvest and transport to the cooperative CENICAFE; and to develop the Life Cycle Assessment of the production of 1 kg. of mixed coffee produced in (6) different batches of the reservation with 3 different types of crops (Traditional with chemical fertilizers, organic with compost, and organic with poultry manure), as well as the different characteristics of height, type of coffee, and type of batch (see Table 1). We only focus the study on the stages described above because these are the only stages in the life cycle of the coffee where producers have the ability to influence the environmental impacts and quality of coffee; this information will be used for developing a quality management model for the stage of cultivation and harvest of origin coffee.

Table 1 Batch of indigenous reservation evaluated under the LCA

ID	Height (meters)	Temperature. °C	Relative Humidity	Type of coffee	Crop	Benefit	Wash	Drying
1	1.623	25.0	70.1	Castillo, Colombia, Caturro	Chemical Fertilizer	Dynamo	Tank	Direct
2	1.773	24.0	65.2	Castillo, Caturro	Chemical Fertilizer	Manual	Burlap sack	Direct
3	1.705	29.5	54.4	Castillo, Caturro	Poultry manure	Manual	Burlap sack	Marquee
4	1.426	29.6	57.4	Colombia	Poultry manure	Manual	Burlap sack	Marquee
5	1.803	22.5	68.5	Colombia, Caturro	Compost	Manual	Burlap sack	Marquee
6	1.750	25.1	62.9	Supreme	Compost	Manual	Tank	Marquee

Scope

The scope of this study is delimited from the raw materials (not taking into account their transportation, from the point of production to the reservation) to the drying process and final transportation to Santander de Quilichao, where it is sold at CAFINORTE (Cooperative of coffee producers of Northern Cauca). The cropping time was considered with 2 crops between March-April and November-December of 2014 (see Figure 2).

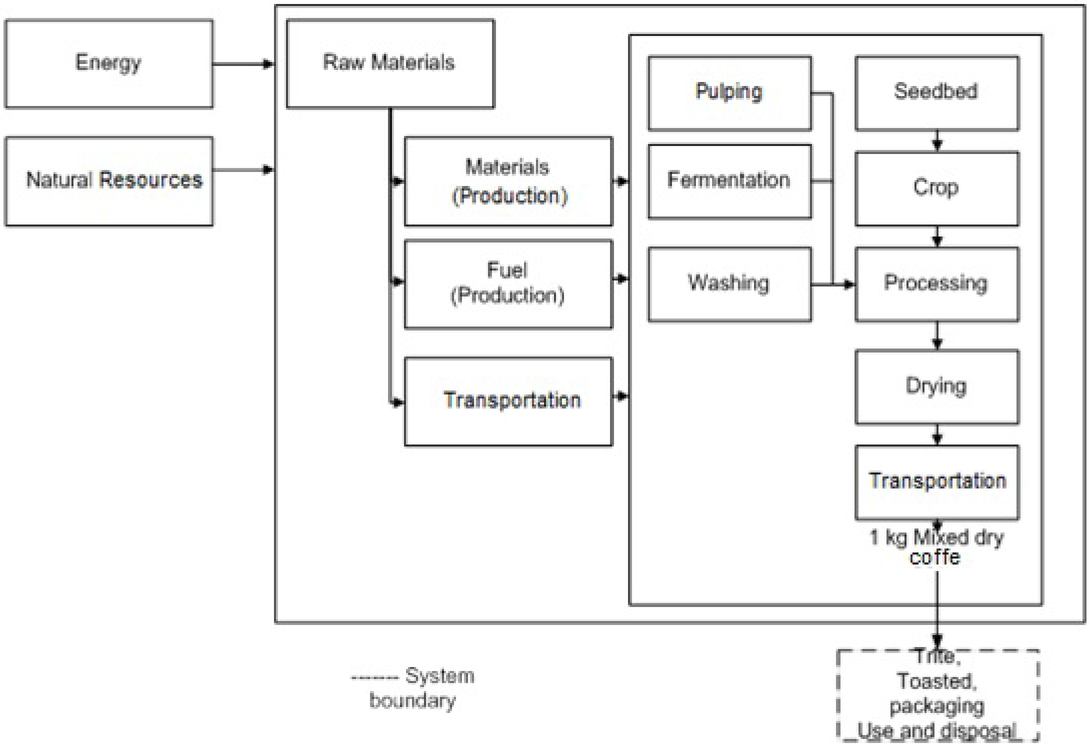

Figure 2 System boundaries and phases of the Life Cycle Assessment of the production of 1 kg. mix of dry coffee origin

Temporary boundary

According to Mourad [10], agricultural products have short harvest time and an average productivity of two years. For example, the coffee at the Las Delicias indigenous reservation has a harvest period between the months of March - April and November - December consisting of periodic yields of a year of abundant harvest followed by a lower one, the minimum period of analysis is recommended for two years of cultivation since there is a large variation in power consumption, fertilizers, and pesticides, applied during periods of cultivation. It is also recommended to consider within the period of the study the crop rotation, as this helps to reduce fertilizer requirements of soils, as well as control of pests and diseases. This paper only includes the data of one year of grown coffee between January and December 2014.

4.2. Methodology

Data collection

The study of the life cycle assessment of the production of origin coffee, in order to implement a quality management model in the Las Delicias indigenous reservation or northern Cauca, began with the socialization of the study with the authorities and the producers of coffee of the indigenous reservation. After the meeting, 30 of the 60 families producers of coffee expressed interest in improving the control cultivation process, with these families and inventory of preliminary data was elaborated for knowing what variety of coffee they grow. Other variables may be taken into account such as the altitude and the temperature, the type of fertilizers and pesticides they used and what kind of benefit, wash and drying they used.

With this preliminary information, we started through previous agreement with the reservation and voluntary subscription to the Project of 20 indigenous families who are farmers and coffee producers. The coffee crops are located on an appropriated altitude. They are between 1400 and 1800 m.a.s.l. The temperature is also suitable between 24 and 30 °C and it is one benefit for coffee. Doing the agreement with these families, we started making a survey and personal interviews. We visited their crops, and we made a detailed inventory of the quantity of trees of coffee and their varieties. In like manner, we inventoried other associated crops of coffee. Similarly, the age of the trees of coffee also was taken into account, besides each property was delimited with a GPS to make a map of the crops of the study, we also wanted to know the type of production techniques they use, whether organic or inorganic, and the type of fertilizers and pesticides used by them, if applicable.

An important aspect of the characterization emphasized on determining how the coffee processing was performed; that is, how each producer carried out the process of fermentation, washing, and drying of coffee. As well as the conditions of the crops, the quantities of the coffee produced and the capability of the families to start a standardized process of measure in all the stages of the coffee under the study. Finally, due to the quality of the data, the time and the capabilities of the farmers to establish and inventory of data, we selected 6 different batches of the reservation with different types of characteristics, such as: production in heights between 1,426 and 1,803 meters; Caturro, Castillo, and Colombia coffee varieties; and which have an installed processing system. An important aspect was the impossibility of measuring the flows and the quantities of materials used to produce 1 kg of coffee of each variety. The study focuses on measuring and comparing the impact associated to the use of tree types of fertilizers in the production of 1 kg of coffee. Fertilizers have an impact on some critical moments of production for the coffee quality depending on the stage of the cultivation in which they are. This way is convenient to count on a quality management model of fertilization.

Materials and energy of the Life Cycle Assessment

- *Changes in land use*: According to the history of the council, land use in this area has not changed its agricultural potential in more than 50 years; therefore, the land use factor is not taken into account when determining CO2 emissions. In this sense, all batches studied have agricultural potential greater than 10 years.
- *Electricity*: The use of electricity to produce coffee is minimal, given the fact that the producers selected for this study sun dry their coffee and use mechanical tools in the other processes, such as pulping. The coffee producers use low power engines in their pulping machines; those engines have the capacity of pulping 300 Kg. of coffee per hour. The electricity used in this study is the electricity mix of Colombia which is made up of 63% hydroelectric and 37% thermoelectric.
- *Transportation*: The carriage of dry coffee is performed from the indigenous reservation to the CAFINORTE headquarters in Santander de Quilichao, where the coffee is sold by farmers. This carriage is made in a particular kind of buses, which are called "Chiva" or "Escalera buses", in this region, and its corresponding distance is 18 kms.
- *Water*: From the information supplied by the farmers, it was determined that the seedlings and the crops are not watered depending on the rains for such a purpose.

Table 2 Life Cycle Inventory of 1kg of mixed coffee production through 3 different types of fertilizers

Settings	Units	Conventional fertilizer	Compost fertilizer	Poultry manure fertilizer
Inputs				
Enegy				
Total	kWh	1.24E-03		
Electricity public network	kWh	1.24E-03		
Materials				
Total	Kg.	1.62E-02	1.62E-02	1.62E-02
Plastic bags	Kg.	5.00E-03	5.00E-03	5.00E-03
Burlap sacks	Kg.	1.12E-02	1.12E-02	1.12E-02
Other resources				
Water during cultivation	Lt/m^2	2.13E-03	2.13E-03	2.13E-03
Fertilizers				
Total	Kg.	4.77 E-02		
N	Kg.	2.25 E-02		
P	Kg.	3.60 E-03		
K	Kg.	2.16 E-02		
Organic fertilizer				
Total			1.50E+00	1.50E+00
Compost	Kg.			1.50E+00
Poultry manure	Kg.		1.50E+00	
Land use				
Land use	M^2	1,92E-04	1,96E-04	1,44E-04
Output				
Pulped Cherry (organic waste)	Kg.	4.00E-01	4.00E-01	4.00E-01
Honey water	Lt.	1.80E+00	1.80E+00	1.80E+00
Mucilage	Kg.	1.80E-01	1.80E-01	1.80E-01
Evaporated water	M^3	3.00E-01	3.00E-01	3.00E-01

In this sense, according to IDEAM [11], it rains 199 days a year in the state, with an average annual precipitation rate of 1.23 m.a.s.l. This information corresponds to the station located in the city of Cali to 1.81 m.a.s.l, and 55.2 km. away from Santander de Quilichao. As for the processing stage, water use is done when the coffee is washed in tanks, and some others wash it in sacks.

- *Fertilizers*: Fertilization is performed mainly with organic products by some producers and some others do it with chemical fertilizers during the cropping stage. According to this, when the fertilization is made with chemical products, they use NPK 25.4.24-type fertilizer; and when it is done organically, they use compost made of organic waste from farms or industrial poultry manure bought in Santander de Quilichao.
- *Secondary materials*: Most used materials in the production of coffee are plastic bags where the seedlings grow and the biodegradable burlap sacks and the dry parchment coffee is stored for transportation, which are made of burlap, a biodegradable compound (see Table 2).

Life cycle inventory

In Table 2 is showed the inventory of material flow for the life-cycle assessment of coffee production.

Impact Categories and software used

The impact categories selected for this study were: Acidification and eutrophication potential, human toxicity, land use and terrestrial ecotoxicity of the CML 2001 methodology, and climate change potential in 100 of the IPCC 2007 methodology. These categories and the data collected were used in the software Umberto NXT LCA.

5. Results

The process step which mostly contributes to the environmental impacts of the system is the stage of growth, indeed, the use of chemical fertilizers, compost, or poultry manure contributes between 47.3% and 99.73% of environmental burdens in each one of the categories selected for the study. In this sense, in the category of climate change the crop with chemical fertilizer produces the 88.69% of the total environmental loads in contrast to the crop with poultry manure that produces 79.8% and the crop with compost that produces 48.9% of the environmental loads, as shown in Figure 3. For conventional production with chemical fertilizers, an amount to 4.14E-01 kg CO2 eq is released into the atmosphere. An acceptable figure compared with studies conducted in [7] where figures range from 5.03E-01 and 1.1 kg. CO2 eq / kg. for the same crop.

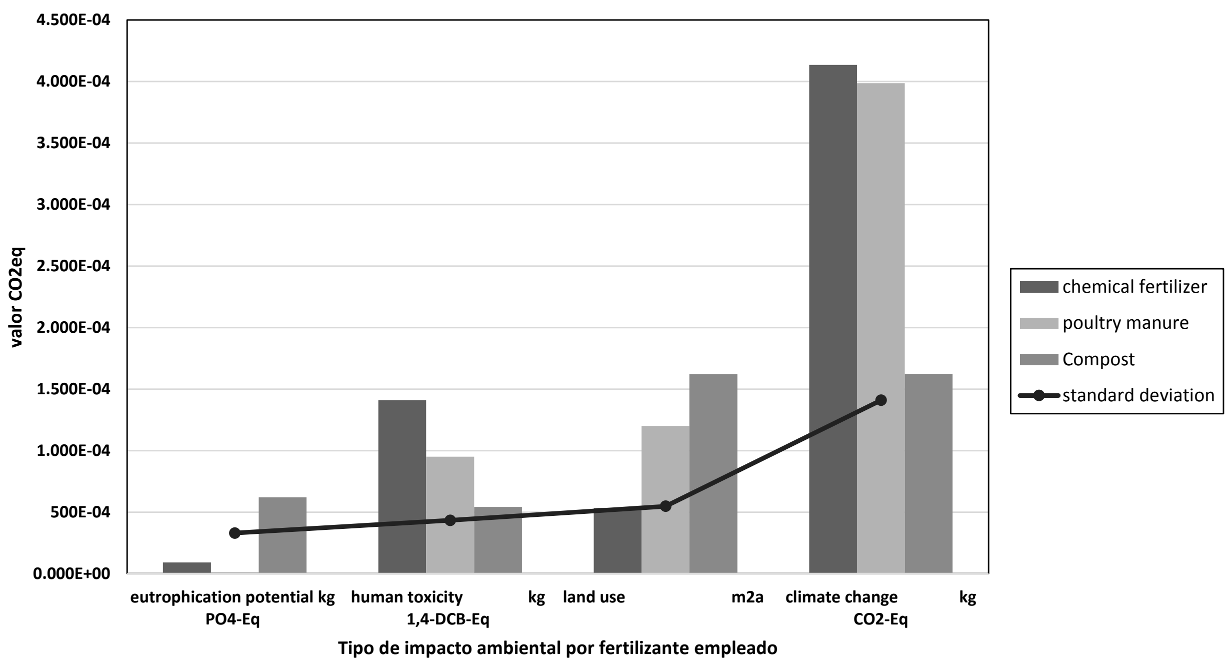

Figure 3 Environmental Impacts LCA has on different types of fertilizer to 1 kg. of parchment coffee mixed

In other categories of impact on the traditional crop from chemical fertilizer, we found an amount of 2.14 E-03 kg SO2-eq / kg. of coffee, for the potential acidification, an amount of 9.10 E-03 kg PO4-Eq of coffee for potential eutrophication; 1.41 E-01, 1.4-DCB-Eq / kg. of coffee for human toxicity and 1.77 E-03 kg 1.4-DCB-Eq / kg. of coffee for terrestrial ecotoxicity. On the other hand, as for the organic crop with poultry manure, we found an amount of 3.51E-03kg SO2-eq / kg. of coffee for potential acidification; 1.34E-03 kg PO4-eq / kg. of coffee for potential eutrophication; 9.50E-02,1,4-DCB-Eq / kg. of coffee for human toxicity and 2.22E-03 kg 1.4-DCB-Eq / kg. of coffee for terrestrial ecotoxicity. Finally, as for organic crop with compost, the results were as follows: 1.07E-03 kg SO2-Eq / kg. of coffee for potential acidification, 6,20E-02 kg PO4-Eq / kg. of coffee for eutrophication potential; 5.3E-02 , 1.4-DCB-Eq / kg. of coffee for human toxicity and 1.13E-02 kg, 1.4-DCB-Eq / kg. of coffee for terrestrial ecotoxicity.

The use of compost has less negative impact on the status of climate change and acidification, while the use of chemical fertilizer is best in the category of terrestrial ecotoxicity and land use. Finally, the use of poultry manure obtained better performance in the category of human toxicity and eutrophication, for that reason, the decision that best adjusted according to the results, is to fertilize with compost because it has less negative impact on acidification.

6. Conclusions and recommendations

The coffee production at the Las Delicias indigenous reservation proved to have better environmental performance through the use of compost in the growing stage, because the poultry manure used by farmers, is obtained by an industrial process in Santander de Quilichao while the organic compost is produced by each of the producers. However, to obtain a more accurate result, it is necessary to know the historical series behavior of the different variables studied, in this sense the time period of the study is limited and it will be taken into account in future researches about environmental performance.

For the three types of fertilizers, the stage of transportation was the least one, which had an impact on the Life Cycle Assessment. Indeed, transportation is 18 km to the point of sale of green coffee or parchment, which is significantly negligible in terms of environmental burdens.

The use of electrical energy for the pulping of coffee cherries significantly contributes to the impacts on each of the categories, especially in the category of climate change. In this sense, when compared to other farms the use of energy can be replaced by a mechanical pulping machine, which is the most used by the producers of the indigenous reservation.

LCA found that of the three types of fertilizers for the crop (with compost, poultry manure and chemical fertilizers), the crop that has the best performance is that done with compost. Finally, this work contributes to a proposal to improve the quality and environmental performance of the coffee production process.

The use of the LCA tool is useful for a quality management model that incorporates the environmental component in the production process and allows producers to recognize the impacts associated with the production of their coffee. We selected these stages because the producers have the possibility to influence the environmental impacts and quality of coffee. As we described in the objective this information may be used for developing a quality management model for the stages of cultivation and harvest of "Café de origen". So far, this approach of LCA as a tool for quality management has not been used in coffee production processes in indigenous communities.

Although the results are preliminary, the data obtained with the diagnosis, show that these results are consistent when compared with similar studies conducted to know the carbon footprint of coffee production in different locations. These results serve as a reference for studies that want to apply the LCA methodology, respecting the culture and worldview of communities.

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