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Applying life cycle management of colombian cocoa production

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Abstract

The present research aims to evaluate the usefulness of the application of Life Cycle Management in the agricultural sector focusing on the environmental and socio-economic aspects of decision making in the Colombian cocoa production. Such appraisal is based on the application of two methodological tools: Life Cycle Assessment, which considers environmental impacts throughout the life cycle of the cocoa production system, and Taguchi Loss Function, which measures the economic impact of a process' deviation from production targets. Results show that appropriate improvements in farming practices and supply consumption can enhance decision-making in the agricultural cocoa sector towards sustainability. In terms of agribusiness purposes, such qualitative shift allows not only meeting consumer demands for environmentally friendly products, but also increasing the productivity and competitiveness of cocoa production, all of which has helped Life Cycle Management gain global acceptance. Since farmers have an important role in improving social and economic indicators at the national level, more attention should be paid to the upgrading of their cropping practices. Finally, one fundamental aspect of national cocoa production is the institutional and governmental support available for farmers in face of socio-economic or technological needs.

Keywords: cocoa production; Colombia; life cycle management; sustainability; taguchi loss function.

1 Introduction

The objectives of concepts intended to asses and implement sustainability in agriculture are to consolidate the complex and diverse principles of this theoretical paradigm and to transform them into recommendations for agricultural practices (Von Wirén-Lehr, 2001). Regarding agro-food industrial activities, research around the world has introduced different tools for measuring the impact of production processes on the framework provided by product life cycle analysis. These research initiatives have proposed improvements in all production stages in order to boost environmental performance as a whole. Such improvements not only seek to meet consumer demands for environmentally friendly products, but also to increase productivity and competitiveness of green product markets (Mattsson et al., 2000; Huijbregts et al., 2001; Heller & Keoleian, 2003; Black et al., 2011; Carof et al., 2013).

Cocoa (*Theobroma cacao* L) is a very popular fruit due to the fact that all kinds of chocolates and confectionaries are made from its beans (Efraim et al., 2010). It is a tropical crop originated from Central and South America grown under humidity conditions that produces from 0.5 to 2 kg of dried and fermented cocoa beans per tree annually (Medeiros & Lannes, 2010).

Currently, Colombia is the fifth producer worldwide and the third one in Latin America. According to the Cocoa Development Ten Year Plan 2012-2021, in Colombia, there are 660,000 hectares available for growing this crop. Requiring an investment of $2.5 billion (Colombian peso) in the next ten years, these lands production is projected to reach 246,000 tons by the year 2021. Following studies by the Ministry of Agriculture, the sector currently employs 70,000 workers and is projected to recruit 40,000 more by 2014, 130,000 at the end of the plan (2021), and 100,000 in the medium term (Federación Nacional de Cacaoteros, 2012).

Nevertheless, in Colombia there is need for research on the productivity of this crop, whose production system has not been modernized. According to FAOSTAT, in 2011, the cocoa cultivation area in Colombia was 99,205 hectares, with a productivity of 446 kg·ha, which is certainly a small figure when compared to that of the first producer worldwide (Ivory Coast: 700 kg·ha) (Food and Agriculture Organization of the United Nations, 2011). This low productivity, which results from the old hybrid materials grown in most Colombian plantations, has consequently determined the low international competitiveness featuring this product in Colombia. Contrasts are also outstanding at the national level. In 2010, the department of "Norte de Santander (N. de S)" reached an average yield of 477 $kg \cdot ha^{-1}$, while the department of Santander reached 564 $kg \cdot ha^{-1}$ in the same year. Furthermore, these are both low figures when compared to the national production objective: 1,500 $kg \cdot ha^{-1}$ (Colombia, 2010).

Looking forward to improve sustainability indicators, the agro-food industry is in need of methodologies that are capable of incorporating information on environmental impacts and life cycle costs (Bélanger et al., 2012). Life Cycle Management (LCM) provides an adequate framework for analyzing and managing the sustainability of goods and services. This approach has been used by global businesses to improve the environmental, social, and economic performance of their offerings in order to ensure

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a more sustainable value chain (United Nations Environment Programme, 2011).

Therefore, the present research aims to evaluate the use of LCM in the agricultural sector focusing on the environmental and socio-economic aspects of decision making in the Colombian cocoa production. Such appraisal is based on the application of two methodological tools: Life Cycle Assessment (LCA) and Taguchi Loss Function (TLF).

LCA is a methodology that follows ISO 14040/44 standards and seeks to provide an assessment of the environmental performance of a product or service throughout its life cycle, from cradle to grave: extraction of raw material, production or processing, use, and subsequent disposal (International standardization Organization, 2006).

Among the recent LCA agricultural studies (Mouron et al., 2006; Zufia & Arana, 2008; Pardo & Zufia, 2012; Roer et al., 2012; Ruviaro et al., 2012), only one study evaluated the application of LCA in the cocoa production in Ghana, in which the entire system was required to produce and process 1 kg of cocoa (Ntiamoah & Afrane, 2008). On the other hand, TLF quantifies the variability of a given process. It has been used to analyze the interaction between the economics of production and process quality in the manufacturing industry (Castillo-Villar et al., 2012). TLF is an effective tool for justifying and evaluating the effects of quality improvements such as tolerance tightening strategies, whose effects on quality have been assessed from an economic standpoint (Berk & Berk, 2000; Bernardo et al., 2001; Ozdemir & Maghsoodloo, 2004; Liao & Kao, 2010). Nevertheless, those studies have not yet been applied to the agro-food industry and limited research on TLF has been published.

In this context, the main objective of the current paper was to develop a proper and comprehensive perspective of cocoa production sustainability by means of Life Cycle Management analysis applied to a case study in Colombia. Therefore, current research was used to draw up LCM-based guidelines integrating social, economic, and environmental indicators of sustainability within the cocoa industry. This study is intended to be a useful LCM reference for diverse stakeholders such as farmers, engineers, and environmentalists as well as government and LCA advisors.

2 Methodology

Life Cycle Assessment (LCA) was used to evaluate the environmental impact of the cocoa production system and Taguchi Loss Function (TLF) was applied to measure the economic impact, which is actually a way of estimating benefits. The social implications of the analysis are described next and conclusions are drawn.

2.1 Environmental aspects of LCA

LCA comprises four steps: goal and scope definition, inventory analysis, impact assessment, and interpretation.

Goals and scope definition

This step addresses the definition of the system under assessment, the limits of the study (*i.e.*, the processes to be analyzed), and the functional unit.

Therefore, the system comprises the cocoa production process from nursery sowing and includes site preparation and final planting to fertilization, phytosanitary management (including insecticides, herbicides and fungicides), and energy consumption (fuel and transport). The functional unit is based on "1 ha of land planted with cocoa with a projected 25 year life span".

Inventory analysis

The data used in the present study correspond to 2012, when cocoa planting area was about 116,777 hectares. Research has been conducted on the departments with the largest production records at the national level, namely Santander, with 40.7%; *N. de S*, with 8.3% and Antioquia with 5.3%. Social, economic, and environmental data were obtained from 30 farms representing the current state of cocoa farming in each zone and department, which actually corresponds to conventional cropping and currently reaches yearly averages of 400 to 800 $kg{\cdot}ha^{-1}$. Thus, large farm size or high production records were not the guiding criteria employed to select the productive units.

Table 1 shows the collected inventory data that correspond to energy and supply inputs and outputs of the system in question. They were classified into two categories: a) a questionnaire has been used in order to obtain primary data directly from the farmers regarding supply (fertilizers, nursery bags, pesticides, etc.) and energy (fuels) consumption records, whose values were adjusted to the functional unit and b) secondary data were taken from the ecoinvent database (Ecoinvent, 2004).

Environmental impact assessment

The CML 2 baseline 2000 method (Centre for Environmental Studies, 2001) was used to evaluate the environmental profile of the cocoa production system in question (Leiden University, 2001). Along these lines, Global Warming Potential (GWP, measured in Kg of CO_2 equiv.), calculated over the next 100 years, was taken into account due to the importance of this global phenomenon that affects local conditions (United Nations, 2005).

Interpretation

During this stage, the inventory data collected from the farms were transformed into interpretable environmental impact values adjusted to functional unit (1 ha per year). This allowed evaluating the environmental impact of the production system's supply inputs and outputs. The results of this research were presented in Ecopoints and were developed using a LCA Software called LCA-Manager 1.3 developed by SIMPPLE, Spain.

Table 1. Inputs and outputs per hectare per year of cocoa production for the 30 farms.

Farmer	yield ($kg{\cdot}ha^{-1}$)	Cal (kg)	Plastic bags (kg)	Gasoil (kg)	Fertilizer (kg)	Herbicide (kg)	Insecticide (kg)
y1	3.00E+02	0.00E+00	1.16E+00	0.00E+00	0	Glyphosate = 5.10E+00	0
y2	2.00E+02	0.00E+00	1.16E+00	1.46E+01	0	0	0
y3	2.00E+02	0.00E+00	1.27E+00	1.76E+01	N-P-K: 15-15-15 = 2.50E+02	Paraquat = 3.75E+00	0
y4	3.00E+02	0.00E+00	1.16E+00	0.00E+00	0	Glyphosate = 1.17E+00	0
y5	4.67E+02	3.30E+02	5.80E-01	9.55E+00	0	Glyphosate = 1.20E+01	0
y6	1.33E+02	0.00E+00	1.16E+00	0.00E+00	N-P-K: 15-15-15 = 1.00E+02	Glyphosate = 5.10E+00	0
y7	6.70E+01	5.50E+02	0.00E+00	0.00E+00	N-P-K: 18-18-18 = 1.00E+02	0	0
y8	2.33E+02	5.00E+02	1.27E+00	1.85E+00	N-P-K: 15-15-15 = 1.50E+02	Paraquat= 0.93E+00	0
y9	2.00E+02	0.00E+00	1.27E+00	0.00E+00	N-P-K: 15-15-15 = 1.50E+02	0	0
y10	7.00E+02	1.50E+02	0.00E+00	0.00E+00	N-P-K: 15-15-15 = 1.50E+02	0	Chlorpyrifos = 1.23E+00
y11	3.66E+02	0.00E+00	1.16E+00	0.00E+00	Urea and DAP = 2.00E+02	0	7
y12	4.80E+02	2.20E+02	0.00E+00	0.00E+00	urea = 5.00E+01	0	0
y13	2.50E+02	5.50E+02	1.27E+00	0.00E+00	Urea. TSP and KCl = 1.00E+02	0	0
y14	2.50E+02	0.00E+00	1.27E+00	0.00E+00	Organic = 1.10E+03	0	0
y15	2.25E+02	5.00E+01	1.16E+00	0.00E+00	N-P-K: 10-30-10 = 5.00E+01	0	0
Y16	5.00E+02	0.00E+00	9.57E-01	0.00E+00	Organic = 5.00E+02; plus N-P-K: 15-15-15 = 1.00E+02	0	Chlorpyrifos = 0.25E+00
Y17	6.00E+02	0.00E+00	7.25E-01	0.00E+00	N-P-K: 15-15-15 = 1.00E+02 plus Organic = 1.20E+03	Glyphosate = 1.27E+01	0
Y18	3.33E+02	6.66E+02	1.16E+00	0.00E+00	Organic = 1.20E+03	Glyphosate = 6.35E+00	0
Y19	3.33E+02	0.00E+00	1.16E+00	0.00E+00	N-P-K: 20-15-20 (1.50E+02)	0	Chlorpyrifos = 1.27E+00
Y20	5.00E+02	0.00E+00	1.27E+00	0.00E+00	Organic = 1.00E+03	0	Chlorpyrifos = 1.23E+00
Y21	2.00E+02	3.00E+02	1.16E+00	0.00E+00	Organic = 2.00E+02	Glyphosate = 1.25E+00	0
Y22	6.00E+02	5.50E+02	1.27E+00	0.00E+00	Urea. DAP and KCl = 1.00E+02	0	Chlorpyrifos = 1.00E+00
Y23	5.71E+02	3.00E+02	7.25E+02	7.98E+00	N-P-K: 15-15-15 = 1.00E+02	Glyphosate = 5.10E+00	0
Y24	3.60E+02	3.13E+02	7.25E-01	1.46E+01	Organic = 1.50E+03	0	0
Y25	3.75E+02	0.00E+00	8.10E-01	9.93E+00	Organic = 1.25E+03	0	0
Y26	1.00E+03	1.00E+02	0.00E+00	0.00E+00	Organic = 3.00E+02	0	0
Y27	1.00E+03	2.00E+02	1.16E+00	5.10E+00	Urea. DAP and KCl =3.00E+02	0	0
Y28	5.00E+02	7.50E+02	1.04E+00	0.00E+00	Organic = 2.00E+03	Glyphosate = 1.42E+01	0
Y29	2.50E+02	0.00E+00	1.16E+00	0.00E+00	N-P-K: 15-15-15 = 2.00E+02	1	0
Y30	2.40E+02	1.10E+02	1.27E+00	0.00E+00	Urea. DAP and KCl = 1.50E+02	0	0

2.2 TLF economic assessment of the cocoa production system

Taguchi's Loss Function (TLF) was used as the nominal-is-best characteristics when y is at the target. The function depends on the magnitude of variation, which is allowed in both directions from the target value, and is formulated in Equation 1:

$$\mathbf{L(y) = k\,(y - T)^{2}} \tag{1}$$

Where T is the nominal value of the productivity target specification; y is real field productivity; L is the loss associated to a particular difference between y and T; and k is the quality loss coefficient, whose value depends on the cost at any specified limits and on the width of such specification, *e.g.*, $T \pm \Delta$, where Δ is the customer's tolerance to deviation of y from the target (Phadke, 1989).

Thus, L(y) estimates the cost of failing to meet a given quality standard of the product, resulting in deviation from its target value. The loss can be incurred by the customer as scrap costs; by the producer as inappropriate farming practices; or by society in general, as environmental costs.

Accordingly, Taguchi's Loss Function allowed an economic analysis of the farms in terms of income not perceived by the producers due to inadequate farming management, which prevents them from reaching the objective value (T). One scenario was defined through variations in T, the departmental (T_1) productivity goals. The four leading criteria used for direct cost calculation were labor, inputs, equipment and tools, and other costs (Table 2). Moreover, the specification criteria used for calculating the marginal revenues of banana, timber, and cocoa clone productivity per hectare and time period (years) are shown in Table 3.

Table 2. Leading criteria for direct cost calculation.

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7-25	TOTAL
Labor	3.06E+06	2.00E+06	1.69E+06	2.16E+06	2.54E+06	2.82E+06	4.08E+07	5.51E+07
Inputs	3.19E+06	8.09E+02	1.03E+06	1.01E+06	1.43E+06	1.43E+06	2.02E+07	2.91E+07
Equipment and tools	3.00E+02	9.40E+01	8.70E+01	1.01E+06	1.62E+02	2.37E+02	2.73E+06	4.62E+06
Other costs	3.92E+02	2.53E+02	2.69E+02	3.36E+02	3.70E+02	3.96E+02	5.60E+06	7.62E+06
TOTAL	6.94E+06	3.15E+06	3.08E+06	4.52E+06	4.50E+06	4.88E+06	6.94E+07	**9.64E+07**

Table 3. Leading criteria employed to calculate marginal revenues for banana, timber and cocoa clones are in CP (Colombian pesos).

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7-25	TOTAL
Cocoa beans (kg)			2.02E+06	3.01E+06	3.61E+06	4.52E+06	8.58E+07	9.90E+07
Horn platain (cluster)		6.40E+06	3.20E+06	1.60E+06				1.12E+07
PCC Cedar Wood pink (m^3)							2.19E+07	2.19E+07
TOTAL	0.00E+00	6.40E+06	5.22E+06	4.61E+06	3.61E+06	4.52E+06	1.08E+08	**1.32E+08**

CP = Colombian pesos.

2.3 Social aspects

Colombian cocoa farming is a subsistence family activity featured by scarce land property (16 ha in average) that generates 8.5 employments per ha (Mantilla et al., 1996). This aspect was assessed using field surveys, which allowed measuring a series of social indicators such as labor, electric power, basic sanitation, sewer availability, and access to water and communications.

3 Results and discussions

3.1 Environmental results using LCA

The results of the current research showed that appropriate improvements in farming practices and supply consumption are likely to enhance decision making in the cocoa growing sector towards sustainability.

Figure 1 summarizes each of the studied farmers' environmental profile. The GWP of cocoa production was found to attain positive and negative values. The former correspond to net CO_2 emissions, while negative values represent CO_2 credit. The highest environmental impact resulted from the use of fertilizers, which account for approximately 90-96% of the total life cycle's emissions. The highest emission percentage among the studied farms corresponds to a 250 kg·ha^{-1} dose of a 15-15-15 fertilizer, which far exceeds the records of the other farms employing synthetic fertilizers. Yet, the decision to apply these amendments depends on plantation quality and management, shade intensity, and soil depth and drainage. In some regions, high soil fertility makes it unnecessary to use fertilizers during the first five years of production.

When comparing the use of synthetic and organic fertilization, it can be observed that the latter results in negative GWP values, which implies environmental benefits because the avoided impact that would result from the use of synthetic fertilizer is higher than that of the cropping activity itself. Therefore, there is no doubt that the use of organic fertilizer significantly contributes to reducing environmental impacts such as CO_2 emissions. Yet, some authors have stated that this situation is not really desirable since it does not only prevent obtaining higher yields and profits, but it also affects disease resistance (Suárez & Hernández, 2010).

Particular attention was also paid to inputs aimed at phytosanitary management, whose selection has a strong influence on their environmental burden. Thus, the total emissions of the 30 farms studied was 9.32E+02 kgCO_2-Eq, in which herbicides make up 76%, insecticides 22%, and fungicides 1%. Therefore, even when the contribution of phytosanitary inputs themselves is low compared with those of the whole cocoa production process, choosing them carefully and in appropriate doses can lead to important CO_2 emission reductions in this step.

3.2 Economic results

Table 4 shows the economic performance of the studied farms during the cocoa production lifespan. Negative values of *L(y)* indicate occasional losses determined by deviations from (T_1), which is the target value of the departmental productivity goals.

The corresponding departmental T values were only overcome by 10 (out of the 30 studied) farms, which are thus shown to have reached higher revenues than those of the other 20, whose values ranged from –5.68E+06 to –4.76E+07. Only two farms reached T values above 800 kg, thus coming close to achieving the national objective. In contrast, farm **y6**, with an L(*y*) score of –4.76E+07, is the one that loses most of the profit, as its productivity is the least likely to reach objective value of T. This is mostly due to the plantation renewal technique, which consists of grafting on old stocks (colloquially known in Spanish as "*injerto en leño viejo*").

A common factor determining low productivity in all studied farms resulted from the intense precipitations that affected the country during the 2010/2011 cocoa production year. This, coupled to constant temperatures between 25 and 27 °C, favored the development of pathogen fungi, among which *Moniliophthora roreri* determined approximately 40% productivity losses in the studied farms.

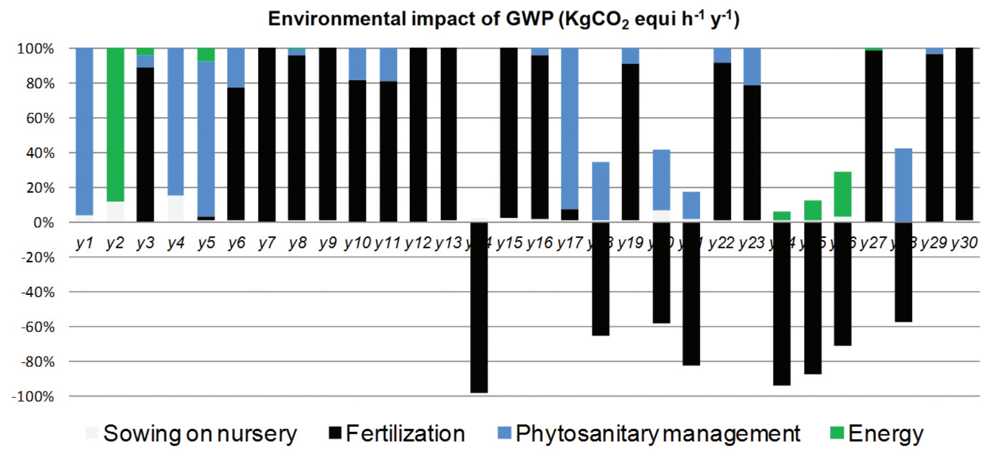

Figure 1. Environmental impact of the studied farms - a GWP analysis.

Table 4. Environmental and economic performance of the 30 studied farms according to Taguchi's Loss Function (TLF); cut off criteria yield >300.

Farmer	T1 (Departmental)	K	L (per ha per 25 years)	kg CO_2 Eq (per ha per year)
Y1	4.77E+02	2.76E+02	−8.63E+06	5.61E+01
Y4	4.77E+02	2.76E+02	−8.63E+06	1.46E+01
Y5	5.64E+02	1.92E+02	−1.82E+06	1.43E+02
Y7	4.77E+02	2.76E+02	−4.63E+07	4.17E+02
Y10	4.77E+02	2.76E+02	1.37E+07	1.14E+02
Y11	5.28E+02	2.76E+02	−9.92E+05	6.07E+02
Y12	4.77E+02	2.76E+02	2.48E+03	1.67E+02
Y16	5.64E+02	1.92E+02	7.85E+05	1.38E+02
Y17	5.64E+02	1.92E+02	2.48E+05	1.46E+02
Y18	4.77E+02	2.76E+02	−5.71E+06	−6.06E+01
Y19	4.77E+02	2.76E+02	−5.71E+06	3.08E+02
Y20	4.77E+02	2.76E+02	1.46E+05	−6.27E+00
Y22	4.77E+02	2.76E+02	4.17E+06	2.02E+02
Y23	5.64E+02	1.92E+02	9.39E+03	2.45E+02
Y24	5.64E+02	1.92E+02	−7.99E+06	−1.47E+02
Y25	5.64E+02	1.92E+02	−6.84E+06	−1.13E+02
Y28	5.64E+02	1.92E+02	7.85E+05	−5.41E+01

3.3 Social results

It was observed that the cocoa farming families have electrical power and potable water utilities; the latter is usually provided by small local aqueducts. In addition, they are provided with adequate primary and secondary roads, whose functions are restricted due to the condition of tertiary roads and local walking paths.

Children and youngsters contribute to the agronomical labor and attend rural schools. Similarly, women combine housework with occasional farming. It is worth noting that depending on farm size and land administration tenancy system (direct or delegated), it is possible to find more than one family in the same production unit. The typical house of these cocoa farming families is built with low quality materials such as clay brick or wood planks walls; Zinc roofs, and cement or soil floors. Moreover, houses are often used for sun drying of the cocoa beans.

The cultural and entrepreneurial orientation and heterogeneity found among the surveyed farmers showed how some of them take better advantage of the available opportunities to obtain higher prices per kg of cocoa beans. One of such opportunities is the "green product" labels, which, by promoting good agronomic management practices, as well as fauna, flora, soil, and water resource conservation, contributes to achieving higher export prices and providing community and environmental benefits.

The government plays an important role in the socio-economic improvement of cocoa growers. For example, in

Santander, a $0.22 U.S. dollar subsidy per kg of cocoa bean sold is granted by the department government. In addition, a $0.67 U.S. dollar subsidy is granted at the national level. Thus, the cocoa growers of Santander feel confident with the support they receive for producing at good quality levels. This explains quite well the fact that the department of Santander is the largest cocoa producer in the country.

4 Conclusions

There is no doubt that the use of Life Cycle Management as an assessment tool for the agricultural sector is very important for evaluation of environmental loads, thereby improving sustainability indicators. Climate as well as technological, cultural, and socio-economical differences clearly characterize the agro industrial management process in any context and in any region. This leads to important differences in the LCA results, and it means that any extrapolation of existing European LCA data for the case of a developing country would imply serious errors. However, its function is always the same: production and consumption of foods for its habitants. Therefore, the potential of this methodology both for the evaluation of the environmental performance of cocoa production and for other agricultural purposes cannot be ignored.

Cropping practices and supply consumption vary from one farm to another. In some of them, both factors are minimum or inexistent, while in others they are considered high if compared to those of other farms analyzed in the same department. However, the application of Taguchi's loss function allows concluding that the adoption of poor agronomic practices or lack in adoption of those practices certainly takes a toll on productivity (T value) and quality, both resulting from poor plant nutrition.

Finally, a fundamental aspect of national cocoa production is the institutional and governmental support available. For example, in Santander, cocoa is one of the main pillars of the economy, whose production generates rural development in the region. This makes cocoa farming strong and centered on the sustainable management of the crop and the adequate development of harvest and post-harvest labors. Additionally, some of the surveyed growers see their farms not only as a source of family income, but also as an agribusiness. This can be observed by the fact that synthetic agrochemicals are seen by these farmers as the last fertilizing option, which reflects cultural change towards a sustainable and environmentally friendly agribusiness.

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