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Sustainability of Sugarcane Farms in the Milagro Canton, Ecuador

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Abstract*—The objective of the research was to evaluate the sustainability of sugarcane cultivation in the Milagro Canton of the Guayas Province in Ecuador, addressing the economic, ecological, and social dimensions, according to the Multicriteria Analysis methodology. A survey was applied to a representative probabilistic sample of 277 sugarcane growers from a target population of 422 agricultural production units dedicated to sugarcane in the Milagro Canton. In the economic dimension, the economic indicator (EconI) was 1.64 (below the referential value of 2 proposed as sustainable by the methodology) due to limitations in the diversification of production, number of marketing channels, dependence on external inputs and access to credit, despite presenting an acceptable planted area, productivity, and profitability. In the ecological dimension, the conservation of soil life and avoiding its degradation was deficient, the management of limited biodiversity, the nutrition of the crop mainly with chemical fertilizers and degradation factors, the irrigation system and burning practices are susceptible to improvement (Environmentally Sustainable Index [ESI] of 1.25). In the social dimension, the Social Indicator (SI) of 3.1 was due to values of Satisfaction of basic needs, acceptability of the production system, social integration, and acceptable ecological awareness. The results indicate that sugarcane cultivation in the Milagro Canton is not sustainable because the General Sustainability Index (GSI) was 1.99, less than 2, and not all the indicators exceeded said value.

***Keywords*— Sustainability; environmental sustainability; economic sustainability; social sustainability; sugar cane; Cantón Milagro.**

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I. INTRODUCTION

Sugarcane is an important crop in Ecuador and one of the most important in Guayas, the most important sugar province in the country (INEC [National Institute of Statistics and Censuses] [1]. Being a crop of great economic influence at the world level. However, their management practices represent a challenge to achieve more sustainable and environmentally friendly agricultural production. Prasara-A and Gheewala [2] affirm development that meets the needs of the present without compromising the ability of future generations to meet their own needs. In this sense, Vieira et al. [3] point out that sugarcane cultivation must be profitable, the management system must make optimal use of resources, as well as th

e use of other natural resources, such as water, which will significantly influence the environmental impact, minimizing such impact while production must be socially acceptable. The sustainability of sugarcane cultivation is not optimal in the province of Guayas due to environmental contamination. Also, Andrade et al. [4], the burning of sugarcane during the harvest stage persists for a long time in the atmosphere with particles in suspension and affects neighboring farmers who have different crops, as well as the populations surrounding the large sugarcane plantations, creating a problem social and environmental. The implementation of new, cleaner technological systems would produce massive layoffs of people hired to cut crops at harvest time, also causing a great social problem. In recent years, new planting systems have been implemented that have allowed an increase in the number of plants per hectare, which brought with it an increase in water consumption, an increase in pests and diseases, and a subsequent excessive use of pesticides for its control. Soil deterioration is being caused, among other factors, by the gravity irrigation system, which requires large sheets of water per ha and per 10-month campaign, of more than 13,000 m3/ha [5]. Drip irrigation systems with fertigation are widely used worldwide and increase productivity by more than 50 t/ha, reduce the cost of irrigation water by 30 to 45% and the amount of fertilizers by 25 to 30%. The objective of this study was to carry out a sustainability analysis of the sugarcane producing farms in the Milagro Canton, Guayas province, Ecuador.

II. Materials and Methods

A. Geographic Location

The research was carried out in the Milagro canton, located in the southern center of the Ecuadorian coastal region, on an extensive plain crossed by the Milagro river, at an average altitude of 11 meters above sea level and with a humid tropical climate of 25 ºC and precipitation of 1361mm. In the Milagro canton, sugarcane currently occupies about 50% of the cultivated area.

B. Methodology

The sustainability analysis of sugarcane production systems was conducted through the application of a survey. García-García et al. [6] establishes as a starting point a finite population sampling giving an estimated target population of 422 sugarcane-producing units declared for the Milagro canton with a team of 2 people from May to September 2022. The random sample size was determined by the sampling formula used [7].

$$n = \frac{\frac{4PQ}{d^2}}{\frac{\frac{4PQ}{d^2}-1}{N}+1} \qquad (1)$$

Where:

n = Sample size
N = Target population
P = Proportion of the population that meets a condition (0.5)
Q = (1-P), the proportion of the population that does not meet the condition (0.5)
d = % error (0.10)

The sustainability analysis was carried out according to the Multi-criterial Analysis methodology of Sarandón et al. [8]. The analysis was used by other researchers, such as Painii-Montero et al. [9], that evaluate the economic, environmental and social dimensions, with certain modifications required for the specific case of the present study in sugarcane. The data was treated using a scale from zero to four for the indicators, one being the lowest value and four the highest. Lewandowska-Czarnecka et al. [10] also establishes the following social, environmental and economic indicators. This allowed us to compare the farms and carry out the analysis of the sustainability dimensions. Therefore, some previous studies [11]–[14] considered as a starting point for the analysis of different sustainability indicators and sub-indicators as shown in Table 1.

TABLE I
INDICATORS AND SUB-INDICATORS TO MEASURE SUSTAINABILITY IN SUGARCANE AGROECOSYSTEMS IN THE MILAGRO CANTON, GUAYAS PROVINCE, ECUADOR.

ECONOMIC DIMENSION (ED)	SOCIAL DIMENSION (SD)	ECOLOGICAL DIMENSION (ED)
A. Food self-sufficiency	A. Satisfaction of basic needs	A. Conservation of soil life
A1. Diversification of production	A1. Housing	A1. Vegetation cover management
A2. Self-consumption production area	A2. Access to education	A2. Crop rotation
B. Net monthly income	A3. Access to health and health coverage	A3. Crop diversification
B1. Net monthly income per family group	A4. Services	B. Land degradation
C. Economic risk	B. Acceptability of the production system	B1. Vegetal cover
C1. Diversification for sale	B1. Producer satisfaction	C. Biodiversity management
C2. Number of channels for commercialization	C. Social Integration	C1. Temporary biodiversity
C3. Dependence on external inputs	C1. Relationships with other members of the community	C2. Special biodiversity
C4. Area dedicated to cultivation	D. Knowledge and ecological awareness	D. Crop nutrition
C5. Productivity (t/ha)	D1. Knowledge and ecological awareness	D1. Fertilization methods
C6. Access to credit		D2. Fertilizer application
		E. Degradation factors
		E1. Irrigation type
		E2. Tillage practices
		E3. Crop burning

The sub-indicators of the economic dimension were evaluated based on scales from 0 to 4 with the different levels of each variable to assess sustainability and contribute to the calculation of the Economic Indicator (EconI), with the same weighting for each case. According to the Multicriteria Analysis methodology, the scales must be adapted to the reality of each crop and each study area. The scales of the sub-indicators of the economic dimension can be seen in Table 2. On the other hand, to calculate the Economic Index (EconI) the following formula was applied:

$$EconI = \frac{\frac{A1+A2}{2}+B1\,\frac{C1+C2+C3+C4+C5+C6}{6}}{3} \qquad (2)$$

Yu et al. [15] also establish levels to evaluate economic sustainability. For this reason, in the present work, a scale has been coupled to evaluate different aspects of sugar cane. In the ecological dimension, the different levels of each variable were also evaluated using scales from 0 to 4 to assess sustainability and contribute to the calculation of the Enviromental sustainablel Index (ESI), with the same weighting for each case. The scales of the sub-indicators of the ecological dimension can be seen in Table 3.

TABLE II

SUB-INDICATORS AND SCALES TO ASSESS ECONOMIC SUSTAINABILITY OF SUGARCANE IN THE MILAGRO CANTON, ECUADOR

Valuation	a. Food self-sufficiency		b. Net monthly income	C. economic risk					
	A1. Diversification of Production	A2. Self-consumption production area (ha)	B1. Net monthly income per family group ($)	C1. Diversification for sale	C2. Number of marketing channels	C3. Dependence on external inputs	C4. Area devoted to cultivation (ha)	C5. Productivity (t/ha)	C6. Access to credit (sources)
4	> 9 products	≥ 1	≥ 500	≥ 5 products	≥ 5 channels	0 to 20%	≥ 50	≥ 100	≥ 4
3	from 7 to 9	0.8-0.9	400-500	4 products	4 channels	20 to 40%	31-40	91-100	3
2	from 3 to 5	0.5-0.7	300-400	3 products	3 channels	40 to 60%	21-30	81-90	2
1	from 2 to 3	0.2-0.4	200-300	2 products	2 channels	60 to 80%	11-20	71-80	1
0	< 2 products	≤ 0.1	≤ 200	≤ 1 product	≤ 1 channel	80 to 100%	≤ 10	≤ 70	No access

TABLE III

SUB-INDICATORS AND SCALES TO EVALUATE ECOLOGICAL SUSTAINABILITY OF SUGARCANE IN THE MILAGRO CANTON, ECUADOR

Valuation	a. Conservation of soil life			B. Soil degradation	C. Biodiversity management		d. Crop nutrition		E. Degradation factors		
	A1. Management of vegetation cover	A2. Crop rotation	A3. Crop diversification	B1. Plant cover (%)	C1. Temporal biodiversity	C2. Spatial biodiversity	D1. Fertilization methods	D2. Fertilizer application	E1. Type of irrigation	E2. Tillage practices	E3. crop burning
4	100 %	Rotate crops every year/Let the lot rest for a year/incorporate legumes or green manures	Fully diversified establishment, with crop associations and natural vegetation	100 %	Rotate every year. Let the paddock rest for a year or incorporate legumes or green fertilizers	Fully diversified establishment, with associations between them and with natural vegetation	Follow technical methods and soil analysis	Use 100% organic inputs	Drip	100% Mechanization	Harvest with burning, and burning after the harvest
3	75 to 99%	Rotates every year. Does not let the soil rest	High diversification of crops, with an average association between them	75 to 99%	Rotates every year. Does not let the soil rest	High diversification of crops with medium association between them	Follows technical recommendations	Uses 25% chemical fertilizers with 75% organic inputs	Sprinkling	75% mechanization with 25% manual	Harvest with burning, but no burning after the harvest
2	50 to 75%	Rotates every 2 or 3 years	Medium diversification, with a very low level of association between them	50 to 74%	Rotates every 2 or 3 years	Medium diversification, with a very low level of association between them	According to the soil analysis	Employs 50 % chemical fertilizers with 50% organic inputs	Pivot	50% mechanization with 50% manual	Green harvest, but burning after the harvest
1	25 - 50 %	Carry out rotations eventually	Little crop diversification, without associations	25 to 49%	Carry out rotations eventually	Little crop diversification, without associations	By budget	Use 75% chemical fertilizers with 25% organic inputs	Furrows	25% mechanization with 75% manual	Harvest in green, and does not burn after the harvest
0	< 25 %	Does not perform rotations.	Monoculture	0 to 24%	Does not carry out rotations	. Monoculture	Traditional methods	Uses 100% chemical fertilizers	No irrigation	100 % Manual	Harvest green, but does not burn after the harvest

For its part, the Enviromental Sustainable Index (ESI) was calculated from the sub-indicators presented above using the following formula:

$$ESI = \frac{\frac{A1+A2+A3}{3}+B1+\frac{C1+C2}{2}+\frac{D1+D2}{2}+\frac{E1+E2+E3}{3}}{5} \quad (3)$$

TABLE IV

SUB-INDICATORS AND SCALES TO ASSESS SOCIAL SUSTAINABILITY OF SUGARCANE IN THE MILAGRO CANTON, ECUADOR

Valuation	**Satisfaction of basic needs**				**Acceptability of the production system**	**Social integration**	**Knowledge and ecological awareness**
	A1. Housing	A1. Access to education	A3. Access to health and health coverage	A4. services	B1. Producer satisfaction with his production system	C1. Relationship with other members of the community	D1. Knowledge and ecological awareness for conservation
4	Of finished material. Very good.	Access to higher education and/or training courses	Health center with permanent doctors and adequate infrastructure	Complete installation of water, electricity and nearby telephone	He is very happy with what he does. He would not do another activity, even if it brings him more income	Very high	He conceives ecology from a broad vision, beyond his farm and knows its fundamentals
3	Of material finished. Good	Access to secondary school	Health center with temporary staff moderately equipped	Installation of water and electricity	He is happy, but he was doing much better before	High	He has knowledge of ecology from his daily practice. Their knowledge is reduced to the farm with the non-use of agrochemicals plus conservation practices

2	Regular. Unfinished or deteriorated.	Access to primary and secondary school with restrictions	Poorly equipped health center and temporary staff	Installation of electricity and well water	He is not completely satisfied. He stays because it's the only thing he knows how to do	Media	He only has a biased view of ecology. You have the feeling that some practices may be harming the environment
1	Bad. Unfinished, deteriorated, dirt floor	Access to primary school	Poorly equipped health center without suitable personnel	Without electricity and water from a nearby well	Not satisfied with this way of life. He longs to live in the city and take care of another activity.	Low	He does not present ecological knowledge or perceive the consequences that some practices may cause. But it uses low-input practices.
0	Very bad	No access to education	No health center	No electricity and no nearby water source	He is disillusioned with the life he leads, he would not do it anymore. He is waiting for an opportunity to leave the production.	Null	Without any kind of ecological awareness. He carries out an aggressive practice towards the environment because of this ignorance. .

Sawaengsak and Gheewala[16] calculates the Social Index (SI) from the sub-indicators, the following formula was used:

$$SI = \frac{\frac{A1+A2+A3+A4}{4}+B1+C1+D1}{4} \quad (4)$$

Finally, for the calculation of the General Sustainability Index (GSI) the following formula was used:

$$GSI = \frac{IK+IE+IS}{3} \quad (5)$$

III. Results and Discussion

Volkov et al. [17] revealed that in the economic dimension, the sub-indicators A1 and A2 of food self-sufficiency found were less than 1, indicating a great deficiency of diversification of production with less than two products and self-consumption area of less than 0.4 ha for self-consumption. The average for sub-indicator B was 3.84, which represents a value close to 500 US dollars of monthly income, above the referential sustainability value of 2. On the other hand, the sub-indicators of section C of economic risk indicate a scarce diversification for the sale of a single product (C1), a single marketing channel (C2), a relatively high dependence on external inputs, of the order of 40 to 70% (C3), an average sugarcane area close to the 50 hectares (C4), an average productivity between 80 and 100 tons of cane/ha in a 12-month cycle, (C5) and one or two sources of credit (C6).

On the economic profitability of sugarcane in Ecuador, Iñiguez–Iñiguez et al. [18] found that the returns on investment in sugarcane cultivation in the Malacatos Parish in the Province of Loja are relatively low, but there is profit. The strengths and weaknesses of the economic dimension and its respective Economic Indicator (EconI) and sub-indicators can be seen visually in Figure 1. It graphically visualizes the weakness of the Milagro sugarcane agroecosystems in the Self-Sufficiency sub-indicator. Food (A), the strength in the sub-indicator of Net Monthly Income (B), and the values for the variables of the Economic risk sub-indicator (C), with special strength in the sub-indicator C4 of Average sugarcane area.

Dieleman [19] found that in the ecological dimension, for indicator A of Conservation of soil life, the values were low with less than 25% soil cover (A1), acceptably continuous rotations (A2), and little crop diversification, without associations (A3). In the soil degradation indicator (B), the percentage range of soil cover was from 0 to 24%. In biodiversity management (C), temporal biodiversity (C1) was acceptable with rotations every two or three years or more, but spatial biodiversity (C2) was deficient with the presence of monoculture plots without associations or plots with little diversification. of crops. Regarding crop nutrition (D), the fertilization method (D1) was acceptable according to soil analysis, and the application of fertilizers (D2) was not very sustainable with 75% chemical fertilizers and 25% organic fertilizers. On the other hand, in Degradation factors (E), the type of irrigation (E1) majority by gravity with furrows, the tillage practices (E2) 50% mechanized and 50% manual and the burning of the crop (E3), carry out harvest with burning, and most burn again after the harvest.

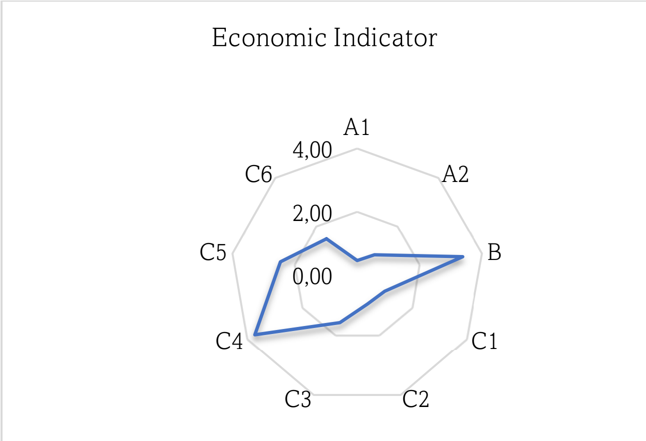

Fig. 1 Sub-indicators of the Economic Indicator (EconI)

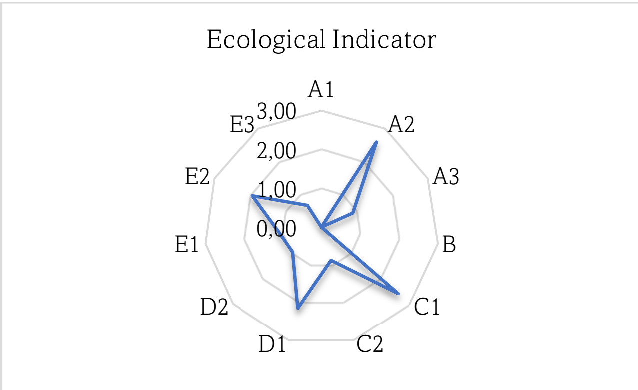

Fig. 2 Sub-indicators of the Ecological Indicator (EcolI)

In the environmental aspect, Silalertruksa and Gheewala [20] affirm that the monoculture of sugarcane and the use of burning for the harvest causes environmental degradation. For their part, Lewandowska-Czarnecka et al. [10] pointed out that the cultivation of sugarcane in the Province of Cañar in Ecuador generated environmental impacts affecting the soil due to the application of pesticides, fertilizers, and residues captured in watercourses and sewage systems [21], as well as the loss of soil microorganisms caused by the burning of sugarcane at harvest. Air pollution also occurs due to smoke emissions produced by the burning of the crop at harvest and the transformation process of the sugar industry. Crop residues and industrial processes also contaminate the water. The strengths and weaknesses of the ecological dimension and its respective Environmental Sistainable Index (ESI) and sub-indicators, can be seen visually in Figure 2. This graphically reflects strength in sub-indicator A2 of continuous rotations, C1 of temporary biodiversity [22], D1 of the method of fertilization, and E2 from mechanized tillage practices, presenting weaknesses in the others mentioned above. Semin et al. [23] and Desniorita et al. [24] In the social dimension, in the aspect of Satisfaction of basic needs (A), Housing (A1) was good and finished, in Access to education (A2) mainly at the secondary level, in Access to health and health coverage (A3) it was poorly equipped health centers with temporary staff, and Services (A4) had electricity and well water in the majority and drinking water in some cases. Concerning the Acceptability of the Production System (B), the farmers stated that they were happy with their sugarcane crop but that they were doing better before. On the other hand, in Social Integration (C), the relationship with other members of the community was high to very high. Finally, regarding knowledge and ecological awareness (D), the sugarcane growers have a notion of ecology and the possible impact on the environment due to their agricultural practices, and in some cases they apply ecology on their plots in their daily practice, reducing the use of agrochemicals and doing conservation practices, but without a broader vision beyond their farm and without delving into the scientific foundations of agroecology. In the social aspect, Galdos et al. [25] point out that sugarcane is an endogenous resource that constitutes a factor of local development and is a source of employment and livelihood for numerous families in the Jipijapa Canton in Ecuador, in addition to being a crop of great importance in the country and part of one of the most important agro-productive chains. The strengths and weaknesses of the sociocultural dimension and its respective Social Indicator (SI) and sub-indicators can be seen visually in Figure 3, which graphically reflects the strength of the social dimension in practically all the sub-indicators.

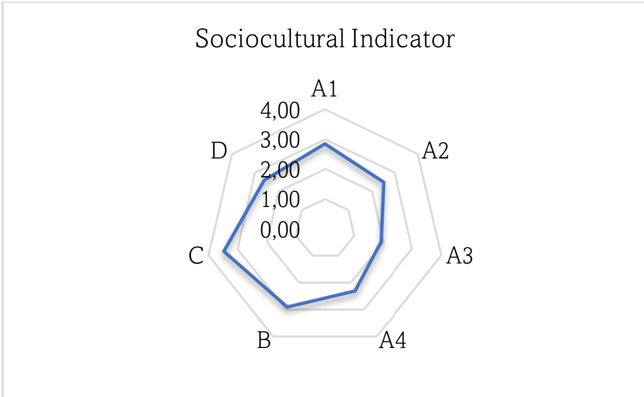

Fig. 3 Sub-indicators of the sociocultural dimension

Lampreia-Dos Santos and Ahmad [26] revealed the results of all the economic, ecological and social dimensions sub-indicators, as shown in Table 5.

TABLE V
RESULTS OF SUB-INDICATORS OF ECONOMIC, ECOLOGICAL AND SOCIAL DIMENSIONS

Economic Indicator (EconI)	A1	A2	B	C1	C2	C3	C4	C5	C6		
	0.47	0.84	3.38	1.01	0.95	1.59	3.73	2.46	1.51		
Ecological Indicator (EcolI)	A1	A2	A3	B	C1	C2	D1	D2	E1	E2	E3
	0.00	2.60	0.89	0.00	2.60	0.89	2.16	0.97	1.08	1.94	0.66
Social Index (SI)	A1	A2	A3	A4	B	C	D				
	2.86	2.51	1.95	2.32	2.90	3.47	2.60				

To calculate the General Sustainability Index (GSI) of sugarcane cultivation in the Milagro Canton, the values of the Economic Index (EconI), the Enviroemtal Sostainable Index (ESI) and the Social Index (SI) were averaged, obtaining a value of 1.99, as can be seen in Table 6.

TABLE VI
. GENERAL SUSTAINABILITY INDEX OF SUGARCANE IN THE MILAGRO CANTON

EconI	**EcolI**	**IS**	**GSI**
Economic Indicator	Ecological Indicator	Indicator Social	General Sustainability Index
1.64	1.25	3.1	**1.99**

The General Sustainability Index (GSI) result is 1.99 [27], which is less than the reference value of 2. According to the methodology of Sarandón et al. [8] a crop is sustainable when the General Sustainability Index is greater than 2 and at the same time each of the three indicators (economic, ecological and social) are also greater than 2. In the present study, only the Sociocultural Indicator was greater than 2 with a value of 3.1, and the economic and ecological indicators were less than 2 with values of 1.64 and 1.25, respectively. The strengths and weaknesses in sugarcane cultivation's economic, ecological and social dimensions in the Milagro Canton can be seen graphically in Figure 4, which reflects an important strength only in the cultural dimension.

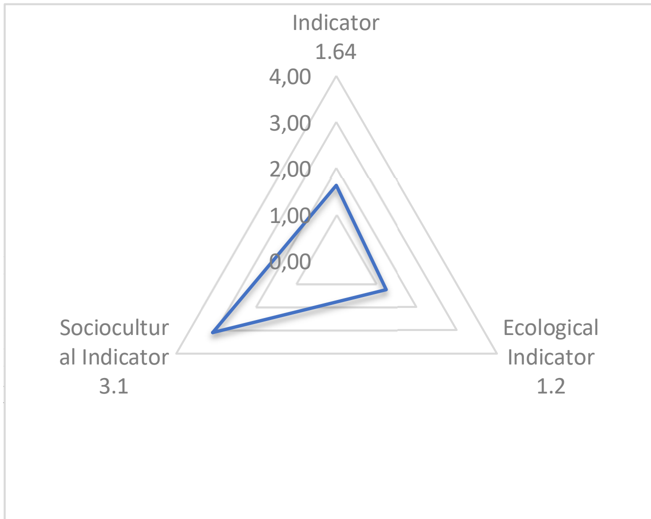

Fig. 4 Economic, Sociocultural and Ecological Indicators of sugar cane in the Milagro Canton.

America, the Caribbean, Asia and Africa, were not sustainable in the environmental dimension due to their high dependence on agrochemicals and the lack of knowledge of the aptitude of the soil for its use, this conditioned by economic aspects. In the cultivation of sugarcane in Ecuador, Gonzabay et al. [30] reported intermediate to high sustainability for the Indices of Economic Responsibility (ERe), Environmental Responsibility (ER) and Social Responsibility (SR), for the company Sociedad Agrícola e Industrial San Carlos S.A., a leading company in the sugarcane sector in the Ecuador, but using the GRI (Global Reporting Initiative) methodology.

A principal component analysis was also established as a starting point for correlations between the variables under study [31]. The variables related to pests, diseases, irrigation, crop rotation, and fertilization have a relatively close relationship, as can be seen graphically in Figure 5.

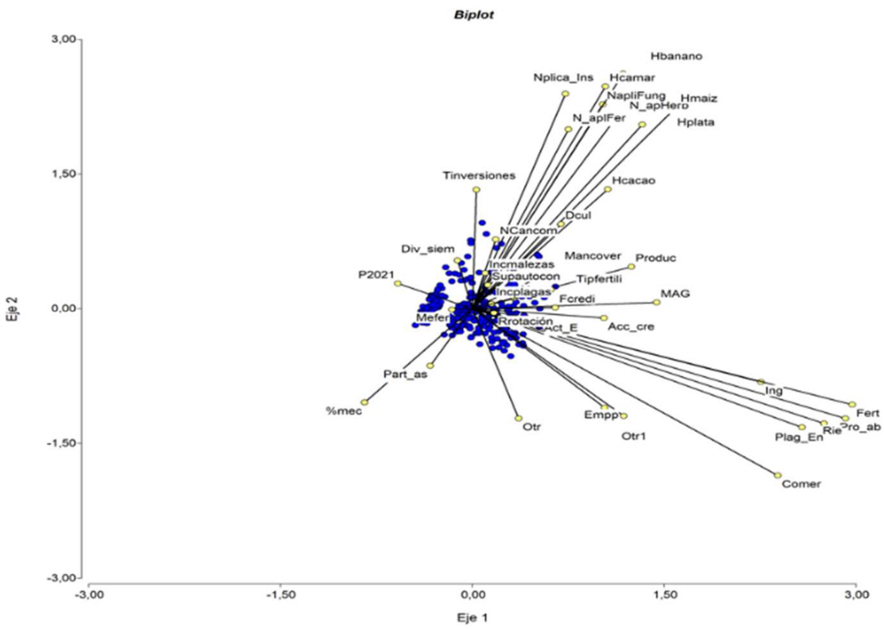

Fig. 5 Principal Component Analysis

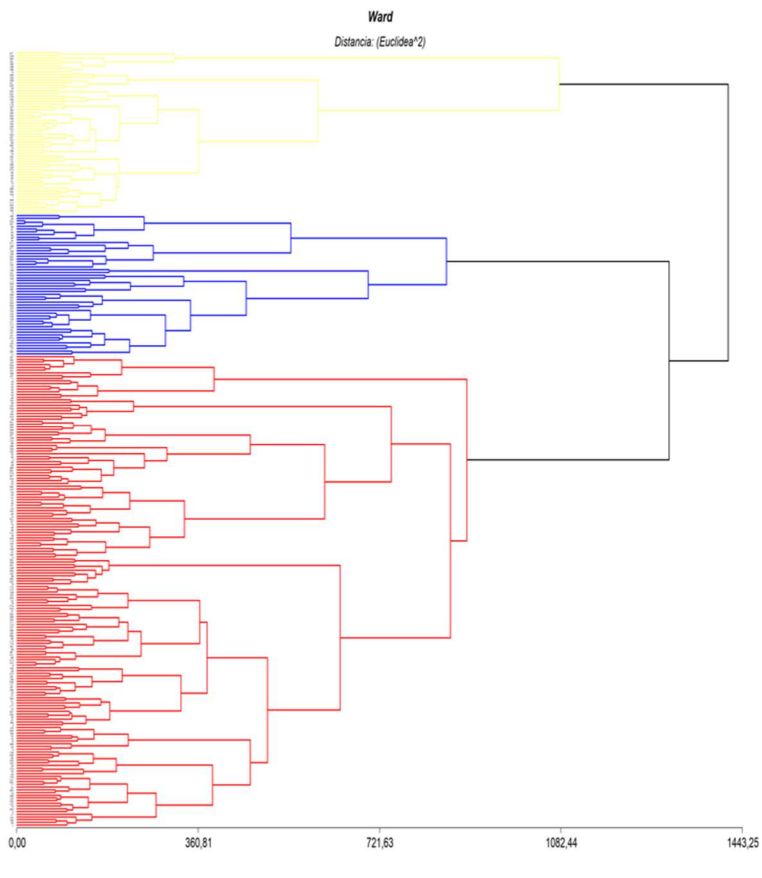

Fig. 6 Cluster Analysis

According to the variables studied, the surveyed farmers were sufficiently heterogeneous to be grouped by Cluster Analysis into three well-defined clusters or groups, as can be seen graphically in Figure 6.

IV. Conclusion

Koij and Saba [32] allow the grouping of the components by characters. The cultivation of sugarcane in the Milagro Canton is not sustainable according to the Multicriteria Analysis methodology, because its General Sustainability Index is less than the reference value of 2, and the economic and ecological indicators do not exceed that value either. Cultivating sugar cane in the Milagro Canton is sustainable in the social dimension but not in the economic and ecological dimensions.

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