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RESEARCH ARTICLE
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Sustainability of agroecological farms in Toacaso, Cotopaxi-Ecuador

Sustentabilidad de fincas agroecológicas en Toacaso, Cotopaxi-Ecuador

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Abstract

The objective of this research was to determine the consequences of the adoption of agroecological production systems in the parish of Toacaso in terms of social, environmental, economic, and general sustainability. Considering the economic, social, cultural, and environmental dimensions, the methodology proposed by Sarandón (2002) was used to determine the indicators. The methodology proposed by Ortiz and Pradel (2009) was adopted in the evaluation of impacts in Integrated Pest Management programs. Surveys with questions related to the social, economic, and environmental consequences were conducted on 44 agroecological farmers and 44 conventional producers in the parish of Toacaso. Additionally, a sample of 44 conventional producers from the parish of Mulaló was identified as "control" treatment, which allowed to perform a comparison with and without the adoption of agroecological practices. The 27.27% of the 44 productive units that implemented the agroecological production system achieved general sustainability, the average general sustainability index was 2.16, where 86.36% achieved environmental sustainability, 47.72% economic sustainability, and 47.73% social sustainability.

Keywords: *sustainability, environmental sustainability, economic sustainability, social sustainability, adoption, agroecology.*

Resumen

El objetivo de esta investigación fue determinar las consecuencias de la adopción en términos de sustentabilidad social, ambiental, económica y general de sistemas de producción agroecológicos de la parroquia de Toacaso. Para determinar los indicadores se utilizó la metodología propuesta por Sarandón (2002), considerando las dimensiones económica, social, cultural y ambiental y se adaptó la metodología propuesta por Ortiz y Pradel (2009) en la evaluación de impactos en programas de Manejo Integrado de Plagas, se realizó encuestas con preguntas alusivas a las consecuencias sociales, económicas y ambientales, dirigida a 44 agricultores agroecológicos y 44 a productores convencionales en la parroquia Toacaso. Adicionalmente, se identificó como tratamiento "control"

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a una muestra de 44 productores convencionales tomados en la parroquia Mulaló, lo que permitió realizar una comparación con y sin adopción de prácticas agroecológicas. De las 44 unidades productivas que implementaron el sistema de producción agroecológica el 27,27% alcanzaron sustentabilidad general, el índice promedio de sustentabilidad general fue de 2,16, 86,36% alcanzo sustentabilidad ambiental, el 47,72% sustentabilidad económica, y el 47,73% tienen sustentabilidad social.

Palabras clave: *sustentabilidad, sustentabilidad ambiental, sustentabilidad económica, sustentabilidad social, adopción, agroecología.*

Introduction

The current challenge of agriculture is to produce enough food for a growing population, which is estimated to reach 9.1 billion people by 2050 (Pérez et al. 2018). According to the projections of the Instituto Nacional de Estadística y Censos [INEC] (2010) Ecuador will reach 23.4 million inhabitants. The challenge is even greater because more nutritious, healthy and innocuous food needs to be produced (Hunter et al. 2017) to ensure the food safety of people; while conventional agriculture has resulted in increased food production, it has also generated environmental problems due to the inappropriate use of agrochemicals. For this reason, sustainable agriculture is proposed to achieve these objectives with minimal environmental impact, according to (Pérez et al. 2018) it is necessary not only to produce more food but also to ensure sufficient resources such as clean water, agricultural land, energy, and labor.

Agroecology is a holistic approach based on the practice of ecological principles that promote the efficient use of energy to produce food with little dependence on external inputs, in diverse and socially equitable agro-systems (Altieri 2018; Gliessman 1998) This form of production is an alternative for family farming, traditionally devalued (Heifer Foundation, 2014) and ignored by public policies that favor commercial agriculture (export, industry, and markets) (Idrovo, 2016).

The consequences of intensive production, with high dependence on external inputs, have been evidenced in the deterioration of the production systems of farmers. Although agrochemicals have supported food production, they have also had negative effects on the environment and human health, it is estimated that every year around 25 million farmers worldwide have involuntary pesticide poisoning (Carvalho, 2017). And that some 1.8 billion farmers worldwide use pesticides to protect their crops, the mechanisms of action of pesticides are not limited to pests, but also have negative effects on biodiversity, ecosystems, and health (Carvalho, 2017). McLaughlin et al. (2014) report case studies on the association between breast cancer and agriculture, and the relationship between pesticide exposure and miscarriage. Zúñiga et al. (2021) report the evidence generated from the study of seven agricultural regions of Chile on the exposure to pesticides in children, the general population, and agricultural workers, with negative effects on cognitive functioning, nervous system, reproductive system, genotoxic and carcinogenic. On the other hand, Meeker & Boas (2011) remark evidence of impaired thyroid function with exposure to pesticides. Similarly, Everett & Matheson (2019) notes the association of herbicide and insecticide use with gestational diabetes in women exposed to agriculture.

Idrovo (2016) reports an increase in the import of fertilizers and pesticides; in Ecuador increased by 69% in the period 2005 to 2015 with an increasing trend to industrialization and agricultural exports indicating also greater investment of production units.

Naranjo (2017) mentions that in Ecuador crops such as corn, potato and tomato are among the crops with the highest use of pesticides, in the same way, the case of vegetables whose seeds are imported. In addition, it is common practice among farmers to apply higher amounts of pesticides when insect resistance to certain compounds increases, usually by increasing the frequency of application or using products with more toxic active ingredients.

Given the high risk of intensive agriculture using external resources, and the existence of experiences of adoption of agro-ecological farming; it is necessary to study the consequences of the adoption of agro-ecological methods in terms of economic and general environmental sustainability. This analysis will allow drawing lessons on how to solve the problem of family agriculture in Ecuador and contribute to mitigating the impacts of conventional agriculture on the environment and the health of producers and consumers.

The objective of this research was to determine the consequences of the adoption of agroecological methods for the cultivation of vegetables in Toacaso in terms of economic, social, and environmental sustainability.

Materials and methods

Methodology

This study was conducted in the Andean region of Ecuador, in Toacaso parish located in the canton Latacunga, Cotopaxi province.

Three stages of adoption of agro-ecological practices were identified in farmers: a consolidated stage that shows the adoption of efficient practices in the management of soil, water, crops, animals, and commercialization, which have between 13 and 22 years of having adopted agroecological practices; the second stage of transition in which farmers who adopted this production system after 13 years and the initial stage to which belong those farmers who have taken more than 20 years to adopt this production system.

The Framework for the Evaluation of Natural Resource Management Systems incorporating Sustainability Indicators (MESMIS) was used to determine the consequences of adoption in terms of, social, economic, and environmental sustainability.

The indicators were determined using the methodology proposed by Sarandón (2002), considering the economic, social, cultural, and environmental dimensions. The methodology proposed by Ortiz and Pradel (2009) was adopted in the evaluation of impacts in Integrated Pest Management (IPM) programs, using surveys with questions that investigate the social, economic, and environmental consequences.

The MESMIS methodology was applied in 7 stages: 1) Characterization of productive systems through surveys on farmers, 2) Identify critical points of production systems of the environmental, economic, social, and technical types that can affect the stability of the productive system, 3) Build indicators, 4) Measure each indicator, 5) Obtain the index of economic, social, environmental sustainability, 6) Analysis of results 7) Comparison of results of agroecological production system with conventional production systems. (Masera et al., 2000)

The questionnaire addressed 44 agroecological producers and 44 conventional producers (non-agroecological) in the parish of Toacaso was used as an instrument.

Additionally, a sample of 44 conventional producers (non-agroecological) taken in the parish of Mulaló, which has similar agroecological conditions to the parish of Toacaso, was identified as a “control” treatment.

The indicators to determine the social, environmental, and economic sustainability index were constructed using the methodology proposed by Sarandón (2002). The data were standardized by converting to a scale from 0 to 4, with 4 being the highest value of sustainability and 0 being the lowest value. Some indicators were estimated by multiplying the value of the scale by a coefficient in function of the importance of each variable regarding sustainability, as observed in the formulas used to obtain the index of social, environmental, and economic sustainability, respectively.

Formula to determine the sociocultural sustainability index:

$$SSI = \frac{2\left[\frac{2A1 + 2A2 + 2A3 + 2A4}{7}\right] + 2B + C + D}{6} \quad [1]$$

Formula to determine the environmental sustainability index:

$$EI = \frac{\frac{A1 + A2 + A3 + A4}{4} + \frac{B1 + B2 + B3}{3} + \frac{2C1 + C2 + 2C3}{5}}{3} \quad [2]$$

Formula to determine the economic sustainability index:

$$KI = \frac{2\left[\frac{A1 + A2}{2}\right] + B + \frac{C1 + C2 + 2C3}{4}}{4} \quad [3]$$

General Sustainability Index

To determine the general sustainability index (Gen SI), economic (KI), environmental (EI) and sociocultural (SCI) indicators were used. A productive system is sustainable if the general sustainability index is greater than two (Gen SI > 2) and if none of the three dimensions has a value less than two (Sarandón, 2002).

The formula for determining the overall sustainability index:

$$Gen\ SI = (KI+EI+SCI)/3 \quad [4]$$

Socio-cultural, environmental and economic sub-indicators, and their evaluation are presented in the following tables.

The sociocultural scale and sub-indicators for satisfying basic needs are shown in Table 1, and the indicator scale for acceptability of the productive system, social integration, and ecological awareness is shown in Table 2. The environmental scale and sub-indicators of soil conservation are shown in Table 3, the indicator scale for risk of erosion is shown in Table 4, and the indicator scale for management of biodiversity is shown in Table 5. The economic indicators food self-suffiency scale and sub-indicators are shown in Table 6, the indicator scale for adequate income for a family is shown in Table 7, and the scale and sub-indicators of economic risk are shown in Table 8.

Results and Discussions

General Sustainability

It was found that only 27.27% of the 44 production systems that adopted agroecological production methods achieved general sustainability, the overall average sustainability index was 2.16.

General sustainability was observed in 6 productive units of the consolidated agroecological production systems corresponding to 46.15%, in 5 productive units of the production systems in the transitional stage representing 35.71%, and in 1 productive unit of the production systems in the initial stage of adoption of agroecology equivalent to 5.88%. All economic, environmental, and social indicators were higher for the consolidated

Table 1. Scale and sub-indicators for meeting basic needs.

Indicator: A. Meeting basic needs				
Sub-indicators:				
Scale	A1. Land tenure and type of housing	A2. Access to Education	A3. Access to Health	A4. Access to Basic Services
4	Own brick or mixed dwelling	Farmers or their children have access to university	Public Hospital	Electricity, water, phone, cell phone, internet
3	Own block housing	Farmers or their children have access to technological studies	Public health center	Electricity, water, cell phone, internet
2	Borrowed brick or mixed housing	Farmers or their children have access to high school	Private Medical coverage	Electricity, water, phone or cell phone
1	Borrowed block house	Farmers or their children have access to primary school	Folk healer	Electricity, water
0	Block Leased House	Farmers and their children have no access to education.	No access	No access

Table 2. Indicator scale: acceptability of the productive system, social integration and ecological awareness.

Scale	Indicators:		
	B. Acceptability of the production system	C. Social Integration	D. Ecological awareness and healthy eating
4	It has more healthy food and improves its nutrition, found no disadvantages.	Very high (4: partnerships, links with non-agricultural enterprises, links with the private sector and NGOs)	Broad Vision: environmental care and health.
3	Sometimes it has more food and would like to grow larger area.	High (link to 3 of 4)	It reduces to No use of agrochemicals.
2	It has more food, but there are no markets and prices are low.	Middle (2 of 4)	It perceives that it consumes healthy products that improve its nutrition.
1	It has more food, but it loses a lot (economic loss), it is not profitable, it produces less.	Low (link 1 of 4)	It has a slight ecological knowledge (some practices)
0	There are no advantages to the production system.	Null	No awareness of food and ecology.

Table 3. Scale and sub-indicators of soil conservation.

Indicator: A. Conservation of soil				
	Sub-indicators:			
Scale	A1. Crop rotation with legumes	A2. Crop diversification	A3. Organic matter in soil	A4. Type of tillage
4	Permanent rotation with legumes	More than 20 species grown in association	More than 6% OM in soil	Zero Tillage
3	Eventual rotation with legumes	6 to 20 species cultivated in association	3 to 6% OM in soil	Manual tillage
2	Rotation with corn and potato	1 to 15 species grown in association	1 to 2.9% OM in soil	Tillage with Yunta
1	Eventual rotation with other crops	from 6 to 10 species grown in association	Less than 1% OM in soil	Mixed Tillage
0	Does not rotate	up to 5 cultivated species	Does not incorporate OM	Mechanical Tillage

Table 4. Indicator scale: Risk of erosion.

Indicator: B. Risk of erosion			
Scale	Sub-indicators:		
	B1. Pending	B2. Irrigation	B3. Use of insecticides and fungicides
4	0 to 5%	Drip	not applicable
3	5 to 15%	spraying	1 application
2	16 to 30%	mixed	2 applications
1	31 to 45%	gravity	3 applications
0	less than 45%	rainfed	4 o more

Table 5. Scale of indicators: Management of Biodiversity.

Indicator: C. Management of Biodiversity			
	Sub-indicators:		
Scale	C1. Crop diversity	C2. Diversity of animals	C3. Undertakes practices of: seed production, use of living barriers, crop rotation, crop association
4	more than 20	9 or more	Performs all four practices
3	16 to 20	6 to 8	Performs three practices
2	11 to 15	3 to 5	Performs two practices
1	6 to 10	1 to 2	Performs a practice
0	5 or less	0	No practice

Table 6. Food self-sufficiency scale and sub-indicators.

Indicator: A. Food self-sufficiency		
	Sub-indicators:	
Scale	A1. Diversification of production	A2. Area dedicated to agro-ecological production
4	more than 20 products	more than 1.5 ha
3	16 to 20 products	1 to 1.5 ha
2	11 to 15 products	0.51 to 0.99 ha
1	6 to 10 products	0.1 to 0.5 ha
0	5 or fewer products	less than 0.1 ha

Table 7. Indicator Scale Adequate Income for Family.

Indicator: B. Adequate income for the family	
	Sub-indicators:
Scale	B
4	Meets the following conditions: a) Does not work in other activities outside of the productive unit, b) Expresses it has more food, c) States that the money he receives for agriculture supports its family d) has access to credit
3	complies with 3 conditions of income for the family
2	complies with 2 conditions of income for the family
1	complies with 1 condition of income for the family
0	It does not meet any sufficient income conditions for the family

where the systems in the consolidated stage had an average Gen SI of 2.49, in the systems in transition stage the Gen SI was 2.12 and, in the systems, in the initial stage of adoption the Gen SI was 1.87. This can be seen in Table 9, Table 10, and Figure 1.

Among the factors that affected sustainability are the diversification of production, the area designated for agro-ecological production, diversification for sale, and the number of commercialization channels that affected the economic index, others like the diversity of associated crops, the type of tillage, and the diversity of cultivated species and animals affected the environmental index, access to education and the acceptability of the production system, social interaction, knowledge, and ecological awareness affected the sociocultural index.

In the conventional productive systems of Toacaso, it is observed that, on average, the social sustainability index was 1.65 and in Mulaló 1.40, the sociocultural factors were determinants for this result: access to education, basic services, acceptability of the productive system, social integration and knowledge and ecological awareness. For the agroecological system was 2.06. This can be seen in Table 11 and Figure 2.

Table 8. Scale and sub-indicators of economic risk.

Indicator: C. Economic Risk			
	Sub-indicators:		
Scale	C1. Diversification for sale	C2. Number of commercialization channels	C3. Dependence on external inputs for production
4	more than 20 non-value-added products, or 16 or more value-added products	5	Does not use fertilizers, fungicides, insecticides or herbicides
3	16-20 non-value-added products, or 11-15 value-added products	4	Uses fertilizers only
2	11 to 15 non-value-added products, or 6 to 10 value-added products	3	Uses pesticides 1 to 2 applications
1	to 10 non-value-added products, or 5 value-added products	2	Uses pesticides 3 or 4 applications
0	5 or less non-value-added products, or less than 5 value-added products	1	Uses pesticides more than 4 applications

stage, followed by the transition stage and finally the initial stage of adoption, a trend that was maintained in the general sustainability index

The environmental sustainability index reached an average value of 1.63 in the conventional systems of Toacaso and 1.36 in

Table 9. Gen Si agroecological production systems in consolidated, initial and transitional stage (KI: economic sustainability index; EI: environmental sustainability index; SCI: sociocultural sustainability index; SI: overall sustainability index)

Stage of Adoption	**KI**	**EI**	**SCI**	**Gen SI**
Consolidated	2.32	2.69	2.45	2.49
Transition	1.90	2.41	2.05	2.12
Initial	1.65	2.26	1.69	1.87
Average	1.96	2.45	2.06	2.16

Table 10. General sustainability of agroecological production systems by adoption stages (KI. Index of economic sustainability, EI. Environmental Sustainability Index, SCI. Sociocultural Sustainability Index, Gen SI. General Sustainability Index).

Stage of adoption	Value	**KI**	**EI**	**SCI**	**Gen SI**	**Sustainability**
Consolidated	> a 2	69.23 %	84.61 %	18.18 %	46.15 %	YES
	< a 2	30.77 %	15.39 %	81.82 %	53.85 %	NO
Transition	> a 2	64.28 %	100 %	22.72 %	35.71 %	YES
	< a 2	35.72 %	0.00 %	77.28 %	64.29 %	NO
Initial	> a 2	17.64 %	76.47 %	6.81 %	5.88 %	YES
	< a 2	82.36 %	23.53 %	93.19 %	94.12 %	NO

Table 11. Gen SI of the agroecological and conventional production systems of Toacaso and Mulaló.

PRODUCTION SYSTEM	**KI**	**EI**	**SCI**	**Gen SI**
AGROECOLOGICAL TOACASO	1.96	2.45	2.06	2.16
CONVENTIONAL TOACASO	1.14	1.63	1.65	1.475
MULALO	1.02	1.36	1.40	1.259

(KI. Index of economic sustainability, EI. Environmental Sustainability Index, SCI. Sociocultural Sustainability Index, Gen SI. General Sustainability Index)

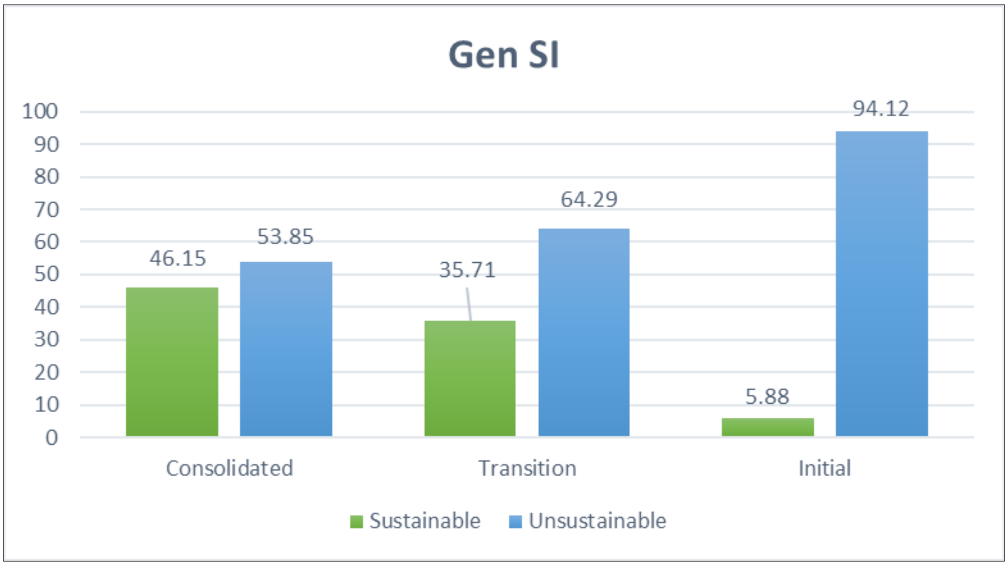

Figure 1. Overall sustainability of agro-ecological production systems by adoption stages

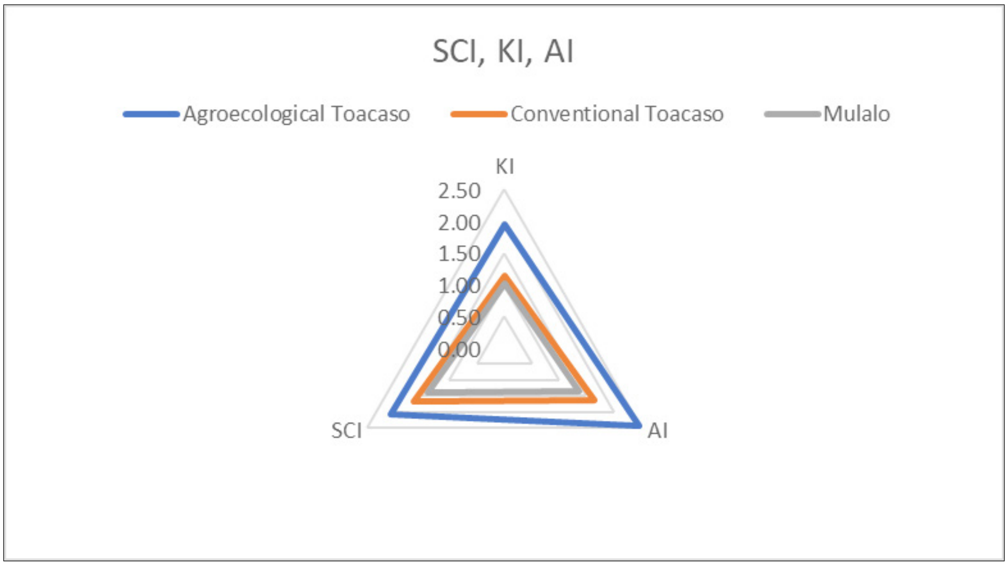

Figure 2. Gen SI of the agroecological and conventional production systems of Toacaso and Mulaló. Scale: 0= lower sustainability value, 4= higher sustainability value

Mulaló, in this case, crop rotation, crop diversity, organic matter in the soil, type of tillage, diversity of cultivated species, and animal diversity were found as determining factors, in the case of Mulaló in addition to those aforementioned; water management and use of practices that favor biodiversity were added. In the agroecological system, the average environmental sustainability index was 2.45 (Table 11 and Figure 2). Studies conducted by Sanjinez (2019) in rice crop report as factors that affected the environmental index the lack of crop rotation, lack of crop diversification, and poor management of biodiversity, Anzules (2019) mentions among other limiting factors of this indicator in the cocoa crop, crop diversity, and biodiversity, Coaquira (2020) states that among the determining factors in environmental sustainability in potato crop were the use of machinery and the irrigation system.

The average value of the economic sustainability index was 1.14 for the conventional system of Toacaso, 1.02 for Mulaló, and 1.96 for the agroecological system of Toacaso. These values were influenced by the diversity of production, the area used for cultivation, sufficient income for the family, diversification for sale, and the number of commercialization channels (Table 11 and Figure 2). Other studies such as Marquez (2015) in coffee cultivation found diversity for sale as a determining factor of the economic index, Aliaga (2019) in chili Supano cultivation found diversification of sales as determining factor, Anzules (2019) in cocoa cultivation found a diversity of production as limiting factor.

Overall sustainability analysis of the production systems found that 46.15% of the farms which adopted agroecological production are sustainable, compared to 9.09% of the conventional farms of Toacaso and no farms of Mulaló, as shown in Table 12 and Figure 3. Similar values were obtained by Anzules (2019) with 48% of sustainable farms assessing the sustainability of cocoa in Santo Domingo de los Tsáchilas, Ecuador, and Marquez (2015) with 4.92% sustainable conventional farms and 39.34% sustainable organic farms in the coffee study in Cusco, Peru.

Conclusions

The largest number of productive units that achieved general sustainability, out of the three surveyed production systems, was presented in those that have implemented agroecological practices, presenting greater sustainability in the farms in the consolidated stage followed by those in transition and initial stage respectively.

Environmental determinants of sustainability

Table 12. Sustainability of agro-ecological and conventional production systems in Toacaso and Mulaló.

PRODUCTION SYSTEM	Value	**KI**	**EI**	**SCI**	**Gen SI**	**Sustainability**
AGROECOLOGICAL TOACAZO	> a 2	69.23	84.61	47.73	46.15	YES
	< a 2	30.77	15.39	52.27	53.85	NO
CONVENTIONAL TOACAZO	> a 2	2.32	18.18	22.73	9.09	YES
	< a 2	97.73	81.82	77.27	90.91	NO
MULALO	> a 2	2.27	0	6.82	0	YES
	< a 2	97.73	100	93.18	100	NO

(KI. Index of economic sustainability, EI. Environmental Sustainability Index, SCI. Sociocultural Sustainability Index, Gen SI. General Sustainability Index)

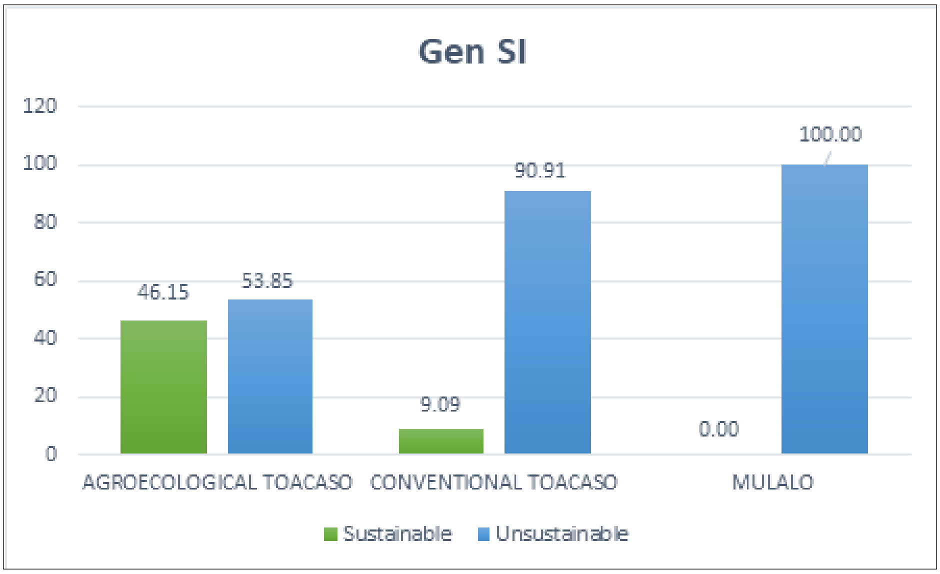

Figure 3. Sustainability of the agroecological and conventional production systems of Toacaso and Mulaló.

were crop rotation, crop diversity, soil organic matter, type of tillage, diversity of cultivated species, and animal diversity, in the case of Mulaló; in addition to the aforementioned, water management and use of practices that favor biodiversity.

The sociocultural factors that influenced sustainability were added: access to education, basic services, acceptability of the productive system, social integration and knowledge, and ecological awareness.

The economic factors that influenced sustainability were the diversity of production, the area allocated for cultivation, sufficient income for the family, diversification for sale, and the number of commercialization channels.

The adoption of agroecological systems has generated positive environmental, sociocultural, and economic consequences, their strengthening and planning will favor sustainable development in the Toacaso parish.

Conflicts of interest

The signing authors of this research work declare that they have no potential conflict of personal or economic interest with other people or organizations that could unduly influence this manuscript.

Author contributions

Elaboration and execution, Development of methodology, Conception and design; Editing of articles and supervision of the study have involved all authors.

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