Research Article

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Sustainability of *Theobroma cacao* L. production systems in the municipality of Algeciras, Huila, Colombia

Summary

This research study evaluated the sustainability of cocoa *(Theobroma cacao* L.*)* production systemsin the municipality of Algeciras, Huila, under two production models, organic and conventional. The research was carried out with farmers from the Algeciras Producers' Association APROCALG. With the information obtained in the interviews, a group of indicators was designed, classified in three dimensions: ecological, economic and social, in order to identify the sustainability of the production systems from an integral vision. The results showed that both production systems have similarities,since the cultural practices carried out by the farmers are the same; however, the difference is determined by the use of synthetic fertilizers and, in some cases, the use of insecticides to control pests and diseases present in the agroforestry system.

Keywords: Agroforestry system, agroecology, sustainability, *Theobroma cacao* L

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Introduction

The production of *Theobroma cacao* L. in Colombia is considered one of the main production opportunities associated with resilience processes in the context of post-conflict development, which has allowed choosing this crop as a sustainable option to substitute illicit crops. Joint efforts to promote the cocoa sector have focused on increasing cocoa production by including cultural management practices in the daily care of their crops. Likewise, the creation of producer associationsand the exploration of new market niches has been achieved through the generation of differentiatedproducts, such as fine and aroma cocoa, which has allowed producers to access more favorable prices and promote value-added incentives in the various products.[1]

In the last decade, the municipality of Algeciras has stood out for its good quality cocoa production, based on a more environmentally and socially sustainable production, due to the collective work that has been developed, especially by the Association of Cocoa Producers ASOPROCALG. However, itwas identified that the producing farms in this area lack organized information that allows them to validate the profitability of their production systems within the framework of organic agriculture for some producers and in other cases conventional agriculture, given that the production models currently lack sustainability indicators according to their production units. In this sense, the present research aimed to generate sustainability indicators to help guide the operation of production systems. Based on the importance of production in the municipality of Algeciras for the cocoa sector in the department, an evaluation of the sustainability of the producing farms was carried out, based on the generation of sustainability indicators of the real state of these production units, since production systems have and are determined by components in addition to production itself, such as social, environmental and economic components, given that agricultural systems are complex systems andwork in an integrated manner.[2]

Materials and methods

The study was conducted in the municipality of Algeciras, department of Huila, Colombia, the study area was chosen because it currently has the largest area under cocoa cultivation compared to othermunicipalities in the department. Algeciras is located 53 km from Neiva, the capital of the department,latitude north 2° 31' 22.588" and longitude west 75°18' 57.427", has an average temperature of 22°C, average annual rainfall of 1,500 mm and an altitude ranging from 800 to 3,000 meters above sea level. Cocoa production in this municipality stands out for having certifications of organic production and good agricultural practices, ranked as the only municipality that has advanced in this process inthe department and the sixth nationally, as well as the first organic certification in the country for cocoa cultivation.

The association of cocoa producers of the municipality of Algeciras APROCALG, is composed of 98members, of which 25 producers have a current organic certificate, with an estimated area of 56.30 hectares cultivated, reporting an estimated production of 50 tons. A sample of 20 production units based on organic and conventional agriculture was taken for the study, in order to obtain differencesbetween the two production approaches. The farms are similar in their size of cultivated area, as wellas in the characteristics of the crop structure.

During the development of the research, a group of sustainability indicators was created, oriented to analyze this variable from three groups of criteria, environmental-ecological, economic and sociocultural, this type of analysis allowed to understand in an integral way the limitations and possibilities for the sustainability of the systems. The results of this participatory approach are expected to favor the feedback process among the community. In the main case of this work, the methodological reference was taken from the authors Cepal, 2011; Bravo-Medina et al., 2017 and INTA, who, from their research applied to productive systems, have defined methodologies to evaluate the sustainability of systems based on the integrality of the sociocultural, economic and environmental components. In order to collect and consolidate the information necessary for the creation of the indicators, a semi-structured interview instrument was applied to 20 producers.

Results and discussion

For the analysis of the ecological dimension, 8 indicators were determined, as explained below; soil cover (IEC1), this indicator was related to soil protection against natural factors such as wind and soil erosion that directly affect the biological component of the soil. The second indicator (IEC2) generated analyzes the presence or absence of shade in the crop, an important factor for the profitability of a system, since the diversity of the systems allows obtaining several sources of production of goods and services for the family. On the other hand, the species used for shade in cocoa plantations are species that provide important ecosystem services for the stability of the ecosystem, such as organic matter supply, temperature reduction, soil conservation, wildlife diversification, strengthening of the biological component of the soil, shade, among other important services. The third ecological indicator (IEC3), emphasizes productive diversity, since healthy ecosystems are characterized by a high diversity of species, since the greater the diversity, the more the systems canbe kept in balance from the regulation capacity generated by the diversification of the structure, in terms of soils, products, services and products for commercialization and for self-consumption. Likewise, the fourth indicator (IEC4), is focused on the relationship in the use of organic or chemicalsynthesis fertilizers, because a system is more sustainable in the long term, if the practices carried out are in favor of soil conservation as an indispensable resource for the proper functioning of the system.

Subsequently, the relationship between pest and disease management (IEC5) was evaluated. It is a reality that the use of chemical methods for pest and disease control through the use of pesticides isa practice that has a negative impact on the environment. In many cases, agrochemicals are not selective and can cause the death of beneficial organisms, for this reason the use of biological or mechanical control methods help to reduce the negative impact of the use of chemical synthesis products in agroecosystems, in addition, when it is decided to apply the same product for a prolonged period of time, it will lose effectiveness and on the other hand will have irreversibly affected the biological component of the ecosystem. Indicator number six, which focuses on the health status of the trees (IEC6), is one of the most important, because the constant control of diseases through cultural practices can reduce their negative effect by 80%, since cocoa crop diseases are mainly related to the use of cultural management practices. However, in the study area this is a problem, since there is not enough laborto carry out these activities, mainly in the production units led by elderly people who do not have an established generational relay.

Likewise, indicator seven is defined as the use of herbicides (IEC7) since these products are responsible for the reduction of the biological diversity of the system, especially of pollinating organisms and natural biological controllers, which is why the use of these products is not viable in the cocoa production system. Finally, indicator 8 focuses on the evaluation of crop pruning practices(IEC8), in the cocoa plant and the system in general, pruning is essential to maintain the health of the agroecosystem, and also favors the production of pods, since this practice is related to the provision of light, and the stability between temperature and relative humidity of the system.

Equation 1

$$((((2*EC1) + EC2) /3) + ((EC3+EC4) /2) + ((EC5+(2*EC6)) /3) + ((((2*EC7) + EC8) /3)) /4$$

Some indicators have greater value since they are mainly related to the balance of theecosystem, mainly the biological component and the soil component.

EC1: Ecological Indicator 1: Soil cover

EC2: Ecological Indicator 2: Shade in crop

EC3: Ecological Indicator 3: Productive Diversity

EC4: Ecological Indicator 4: Ratio of chemical and organic fertilizers in the soilEC5: Ecological Indicator 5: Disease and pest management

EC5: Ecological Indicator 6: Crop Health Status

EC7: Ecological Indicator 7: Herbicide Use

EC8: Ecological Indicator 8: Crop pruning practices

Economic dimension (EDI)

For the analysis of the economic component, 7 indicators were taken into account. Indicator number1 (IE1) is directly related to the productive diversification generated by the system, as well as the availability of various sources of direct or indirect income to reduce dependence on a single source of livelihood. Indicator number two is food production for self-consumption (E2), since self-productionof food is not only a contribution to food security and sovereignty, but also helps to cover part of the expenses incurred by the family nucleus for food. Therefore, a system is mostly sustainable when it produces food that complements the family diet.

Indicator number three evaluates the percentage of products destined for sale (IE3), the percentage of products that are destined since it generates economic resources that allow the acquisition of othergoods and services of basic necessity, and even those foods that are not produced on the farm, since the diversity of products that the nucleus destines for sale favors the possibility of achieving economic sustainability.

The fourth indicator is obtaining income from off-farm work (IE4) for the case of the study area, not all family production systems currently have the capacity to generate products that can be marketed locally, so some families have off-farm jobs. On the other hand, access to training (IE5) is focused on, since it is one of the most important aspects for the constant updating of knowledge focused on crop management, and the IE6 is also defined, which is the evaluation of the method of payment for the sales of farm products, since this determines the frequency with which income is received. Finally, the IE7 of the economic dimension is focused on analyzing the tenure and type of housing on the farm, since it is an indicator of economic analysis in rural and urban environments.

Equation 2

$$((((2\times E1) + E2 + E3) \div 4) + (((E4+E5) \div 2) + (((2\times E6) + E7) \div 3$$

The above formula includes seven formulated economic indicators, E1: Diversification of production;E2: Self-consumption; E3: Annual cocoa production; E4: Access to other income; E5: Access to training; E6: Type of payment for sales; E7: Tenure and type of housing.

Sociocultural dimension (ISC)

The first indicator is land ownership (ISC1), this variable enables the incorporation of improvements to the productive system. Likewise, the establishment of productions for relatively long periods of time strengthens the links with society, also collaborating in the commercialization processes of the products. As well as access to education (ISC2), this aspect is of vital importance for the development of the productive systems, this increases the quality of life of the family members, and at the same time, incorporates tools for access to information that offer good opportunities to the family unit, which allow improving the quality of life of the people. An important aspect, especially nowadays, is the participation of women in decision making (ISC3), since women influence the development of the farm, in many productive systems it is important to favor the economic development of the family, due to the integrality in decision making. On the other hand, access to primary services (electricity, gas, water, telephony) (ISC4) is a factor that not only makes it possible to produce, but also to live in better conditions.

Social integration and participation in associations is the CSI indicator5, because it mainly favors those producers who have low production volumes, therefore, it is essential to offer differentiated or associative markets, where there are producers with higher volumes that sustain supply and enable smaller scale producers to sell low volumes of production. In addition, significant contributions are made by government institutions that not only transfer knowledge and technologies to producers, butalso finance production structures and high-cost inputs to maintain the functionality of the system.

Equation 3

(S +S15 + (S +S23 +(2×S4) ÷4))) ÷3

The above equation includes the five indicators formulated for the environmental component, **S1:** Land tenure; **S2:** Education; **S3:** Women's participation; **S4:** Access to basic services; **S5:** Belongs to an associative group.

Analysis of sustainability indicators

From the application of the indicators designed for this research, the ecological results were obtainedfor the group of farmers impacted by the project, in this dimension the indicators with the highest score were; **IEC1.**Soil cover (**1**); **IEC7**. Herbicide use (**3.95**); **IEC5** Pest and disease management (**3.9**); **IEC3** Productive diversity **(3.75)**; **IEC2.** Shade in the crop (**3.35**) (Table 1); these results are associated with the fact that farmers in the municipality of Algeciras have adopted good practices in their crops, such as pruning, shade management, non-application of insecticides and herbicides, aswell as the diversification of species through the implementation of agroforestry arrangements, mostof which in this municipality are composed of fruit trees, timber, musaceae and cocoa as the main crop of economic interest. The adoption of good practices is related to the participation of producers in training sessions where they have learned about good agricultural practices; however, not all producers have organic certification, mainly due to the use of synthetic fertilizers.

The results allow us to affirm that the production systems in the study area are sustainable, because there are several products and ecosystem services that allow the conservation and richness of the ecosystem, which is summarized in higher productivity, and therefore, higher profitability. Regardingthe soil, ecological indicator 1, presents that all the production systems analyzed have plant cover associated with the presence of leaf litter, which favors the constant contribution of organic matter tothe soil, in turn, inhibits the growth of weeds, thus avoiding the use of herbicide products that turn outto be harmful to the soil, since, they can alter the structure and functioning of the soil through direct effects on several components of its microbiota,[3] on the other hand these products affect the health, mainly of those who are in contact at the time of application, results of different research show that the effects on health by commonly used herbicides, in the short term intoxications can occur due to absorption in the organism directly or indirectly and in the long term chronic damage can arise.[4]

Regarding pest and disease management, the high score (3.9) is attributed to the fact that most of the interviewed producers state that their pest control practices are focused on cultural practices andcontrol with biological products; González-Jaramillo et al.[5] found in his research on the use of organic insecticides, that they present higher profitability, given the result of the economic analysis according to the highest benefit/cost ratio found for T3 (Ginger and onion) with $1.76, i.e., for each dollar invested and recovered, $0.76 is earned, it was concluded with this research that the use of this natural insecticide, in doses of 750cc liters/ha, increased the productivity of the cocoa crop.[5] On the other hand, in the research conducted by Pilaloa et al. (2022), it was found from the evaluation of four treatments (T1: *Bacillus sp* + pruning; T2: *Trichoderma spp*+ pruning; T3: Mancozeb; T4: Control with only pruning), that in spite of the differences that were shownfor the variables incidence, number of flowers and healthy cucumbers among the treatments, it is corroborated that the application of any type of biofungicide diminishes the damage caused by the fungus and that pruning alone is the least efficient, evidenced in the yield variable, which did not present statistical differences between treatments 1, 2 and 3. However, the economic analysis showed T1 *Bacillus sp* + pruning as the most profitable with a benefit-cost ratio of 1.29 dollars with an application of 1.5 l ha-1.[6]

Likewise, Viera-Arroyo et al.[7] found in their research on biological control, that one of the most useful organisms for cocoa production systems is *Trichoderma* spp. which is considered the main antagonistic fungus that has been formulated and is widely used in agricultural applications due to itsbiological control mechanism, it is also known for its impact on plant growth, decomposition processesand bioremediation.[8] These benefits favor the agricultural sector to apply environmentally friendly practices.[7]

One of the statements that caused special attention during the research, is that some producers interviewed state that biological products such as *Trichoderma* spp. were not effective for pest control, this may be due to various reasons, such as inadequate storage conditions of the product, expired products or may be related to the bad application of the product, since to increase the effectiveness of this organism it is necessary that it is applied alone, without mixing with other products, even if theyare biological, it is not allowed to mix it at the time of application (Table 1).[7]

Table 2 shows the results obtained with the application of the economic indicators, where the sevenindicators designed are shown, with their specific score; the indicator that obtained the highest value was the one related to the annual production of cocoa; where it is stated that the minimum average annual sale is 300kg, exceeding 900kg per year, another relevant indicator is the one associated with the type of payment that the producers receive when selling their products, obtaining a score of 2.8/3.00, this is because most of them interviewed receive cash payment. On the other hand, indicator 2, related to self-consumption, is mentioned with relevance, where most of the interviewees state that they do not contribute more than 10% of the products offered by the production system, this includes not only cocoa, but also fruit trees, timber and fruit trees, therefore, it is considered a negative point that does not favor the sustainability of the family, Since the importance of considering agrobiodiversity as a determining component of the sustainability of the agrifood system highlights the fundamental role of family farming (Acevedo-Osorio et al., 2020, p2).

It is important that farmers identify the economic potential they have, based on the opportunity to diversify their production, as well as the option of allocating a specific area for the construction of an orchard that favors the availability of fresh and reliable food for the family. Another outstanding indicator is the type of housing, where it is evident that farmers have decent housing for their families on their farms, showing that the work focused on cocoa production and agriculture in general has been profitable, which has allowed the construction and adaptation of housing.

Table 1 Overall results of the ecological indicators for the total number of respondents

Type of Indicator	Producer name and number/indicators	Overall results by indicator
Ecological	IEC1.Soil cover: 0 does not have; 1 if it does have cover	1
Ecological	IEC2. Shade in the crop: 0 has no shade; 1 has one species for shade; 2. 2 species for shade, 3. 3 species for shade, 4. more than four species for shade.	3,35
Ecological	IEC3. Productive diversity: 0. Monoculture; 2. Cultivation with musaceae; 3.	3,75
Ecological	IEC4. Ratio in the use of organic and chemical fertilizers: 0 does not fertilize; 2 applies only chemical; 3 applies organic and chemical, 4. applies organic.	3,4
Ecological	IEC5. Pest and disease management: 0 no control; 1 chemical control; 3. chemical and cultural control; 4. cultural and biological control.	3,9
Ecological	IEC6. Crop health status: 0 no disease control; 1. has more than three diseases; 2. has three diseases; 3. has two diseases; 4. has one disease.	3,15
Ecological	Herbicide use: 0 no weed control; 1. applies herbicide once a year; 2. applies herbicide twice a year; 3. applies more than three times a year; 4. applies herbicide with scythe, hoe or machete.	3,95
Ecological	Crop pruning practices: 0 no pruning; 1. pruning once a year; 2. pruning twice a year; 3. pruning more than three times a year; 4. pruning and fertilizing the crop all at once.	1,65

Source: Own elaboration.

Table 2 General results of the economic indicators for the total number of respondents

Type of indicator	Producer name and number/indicators	Overall results by indicator
Economic	Diversification of production: 0 Does not diversify; 1. Produces one or two products; 2.	2,5
Economic	Self-consumption: 0 does not contribute to self-consumption, 1 contributes between 5% and 10%, 2. contributes between 10% and 20%, 3. contributes between 20% and 50%, 4. contributes more than 50%.	2,1
Economic	Annual production kg of cocoa: 0. did not produce cocoa; 1. sells between 200kg and 300kg; 2. sells between 300kg and 500kg; 3. sells between 500kg and 800kg; 4. sells more than 900kg.	3,45
Economic	IE4. Access to other income: 0 No income. 1. income from the farm is the only income; 2. performs other activities; 3. all household members perform other activities; 4. have pension or subsidy income.	1,95
Economic	IE5. Access to training: 0. Does not receive training; 1. Receives training whenever invited; 2. Receives monthly training; 3.	1,1
Economic	IE6. Type of payment for sales: 0 no sales; 1. on credit; 2. on credit and cash; 3. cash.	2,8
Economic	IE7. Tenure and type of housing: 0 do not have, 1. house in wood, 2. house in bareque, 3. house in cement.	2,45

Source: Own elaboration.

For the five sociocultural indicators defined, the results are shown in Table 3, where the highest scoreis given for ISC1. Land tenure (3.35), this result is associated to the fact that most of the intervieweeshave a deed or legal document of their land, which has allowed them to access credits, as well as the participation in projects offered by different local and national institutions, which have favored the strengthening of crops, as well as the direct and indirect benefits of belonging to a farmers' association. It is also evident that not all the farmers interviewed have completed their basic academictraining, as well as the low participation of women in the work related to the cultivation of cocoa. Figure 2 shows the distribution of the indicators associated with the farmers interviewed, in this graphtwo groups of producers are divided, under organic crop management and conventional management, the biggest difference between the two groups is mainly given in the indicators IEC4 (Ratio in the use of organic and chemical fertilizers); IEC5 (Pest and disease management); ISC3 (Participation of women). Therefore, the difference in the other indicators is minimal, highlighting those mentioned above that are directly related to the use of chemical synthesis products comparedto the use of biological alternatives that are more environmentally friendly.

Table 3 General results of the sociocultural indicators for the total number of respondents

Type of indicator	Producer name and number/Indicators	Overall results by indicator
Sociocultural	ISC1. Land tenure: 0. loan; 1. tenant; 2. purchase or sale or owner with document; 3. owner with reform title; 4. owner with deed.	3,35
Sociocultural	ISC2. Education: 0 no education; 1. Incomplete primary education; 2.	2,4
Sociocultural	ISC3. Women's participation: 0 women do not participate; 1. They support the farm work; 2. 3. Women receive income for their work. 4. Women invest resources in the farm.	2,9
Sociocultural	ISC4. Access to basic services: 0 does not have access to any service; 1. Access to energy service. Access to energy and water services. 3. Access to water, energy and telephone service. 4. 4. Access to water, energy, internet, television, and telephone services.	2,7
Sociocultural	ISC5. Belongs to an associative group: 0 does not belong to any associative group, 1. belongs to an association. 2 belongs to two associations. 3 belongs to the association and actively participates in it. 4. Belongs to the association and participates in events organized by the community action board.	1,85

Source: Own elaboration.

However, practices based on agroecology, tropical agriculture and organic agriculture favor the recovery of soils and the biological biodiversity associated with these systems, thus improving the microbiological status of the soil and its quality, which is summarized in the availability of nutrients forthe crop, thus favoring the increase in production and is reflected in economic income by quantity andquality of product; *Priego*-Castillo et al.[9] conducted a similar study, where the analysis of the results was approached under the categories of attributes and dimensions of sustainability.

The results of the comparison indicate a higher sustainability for the organic case with 67.75%, while in the conventional case it was 47.32%, for the organic case it was closer to the desirable values dueto its values in the attributes of adaptability, equity and self-management. In the analysis by dimension of sustainability, the organic case obtained higher sustainability results, especially in the environmental dimension, as can be seen in Figure 2. Thus, the authors draw an important conclusionfocused on the fact that both systems can improve their level of sustainability if an integral agroecological management is carried out that contemplates the updating of knowledge and skills through professional assistance, participation in local markets and promotes the autonomy of the productive units (Figure 1).[9]

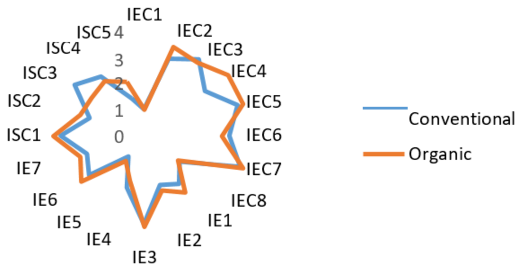

Figure 1 Relationship between sustainability indicators of organic and conventional production systems.

In terms of sustainability, the most favorable result is obtained for production systems under organic management (Figure 2), since the cultural tasks carried out correctly and constantly favor the controlof pests and diseases that affect production, and the use of biological controllers that have replaced the application of insecticides has facilitated the growth of organisms that perform functions such as pollination in the crop, as well as the improvement of the soil microbiota, which is directly affected bythe application of herbicides and insecticides. In addition, Figure 2 shows high scores for the indicators related to the use of chemical and organic fertilizers, use of insecticides, use of herbicidesand shade in the crop, which obtain scores between 4.8 and 5.0 because these are practices that producers have frequently implemented in their crops, which promotes the adequate use of resources, especially the soil resource, which is in a constant process of nutrient cycling from the source of leaf litter. At the same time, the limited use of herbicides facilitates the process of soil recovery from the work done by the associated macro and microorganisms.

Figure 2 In terms of sustainability, the most favorable result is obtained for production systems under organic management.

Classification of system typologies

On the other hand, Table 4 presents the results associated with the identification of typologies of productive systems present in the study area, where two typologies have been identified based on the structure of the agroforestry arrangement: cocoa, musaceae, fruit trees, timber and cocoa, musaceae, fruit trees. These results are positive, since there are several ecosystem services associated with agroforestry arrangements, including carbon sequestration, organic matter supply, bird watching, soil moisture conservation, erosion protection, microclimates and soil conservation.[10]

Table 4 Typologies of farms identified in the municipality of Algeciras

System	Distribution composition structure of the production systems	Organic fertilization system	Conventional system
S1	Cocoa, musaceae, fruit trees, timber trees		X
S2	Cocoa, musaceae, fruit trees, timber trees		X
S3	Cocoa, musaceae, fruit trees		X
S4	Cocoa, musaceae, fruit trees, timber trees	X	
S5	Cocoa, musaceae, fruit trees, timber trees		X
S6	Cocoa, musaceae, fruit trees, timber trees		X
S7	Cocoa, musaceae, fruit trees, timber trees		X
S8	Cocoa, musaceae, fruit trees, timber trees	X	
S9	Cocoa, musaceae, fruit trees	X	
S10	Cocoa, musaceae, fruit trees, timber trees	X	
S11	Cocoa, musaceae, fruit trees, timber trees		X
S12	Cocoa, musaceae, fruit trees, timber trees	X	
S13	Cocoa, musaceae, fruit trees, timber trees	X	
S14	Cocoa, musaceae, fruit trees, timber trees		X
S15	Cocoa, musaceae, fruit trees, timber trees	X	
S16	Cocoa, musaceae, fruit trees, timber trees	X	
S17	Cocoa, musaceae, fruit trees		X
S18	Cocoa, musaceae, fruit trees, timber trees	X	
S19	Cocoa, musaceae, fruit trees		X
S20	Cocoa, musaceae, fruit trees, timber trees	X	

Likewise, the diversity in terms of production of other products besides cocoa stands out, as a resultof the transformation that has taken place from cocoa monoculture to sustainable production systems, reducing dependence on a single product.[11] This is evidenced by a good profitability of the production system, and in turn, its conservation over time, associated with the provision of ecosystem services is directly related to land use and agroecological strategies implemented on each farm (Pañuela-Cala, 2022).

Conclusion

This study validates the importance of analyzing the sustainability of production units from an integral perspective, which allows us to demonstrate the relationship that can be imparted by factors that are believed to be external to the production system, but which, in turn, have a direct and indirect influenceon the stability of farming families.

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Conflicts of interest

The authors declare that there is no conflict of interest.

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