Assessment of the sustainability of the small-scale food production system in Guachetá, Colombia.

– opportunities for agroecological interventions

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Swedish University of Agricultural Sciences, SLU
Department of Biosystems and Technology
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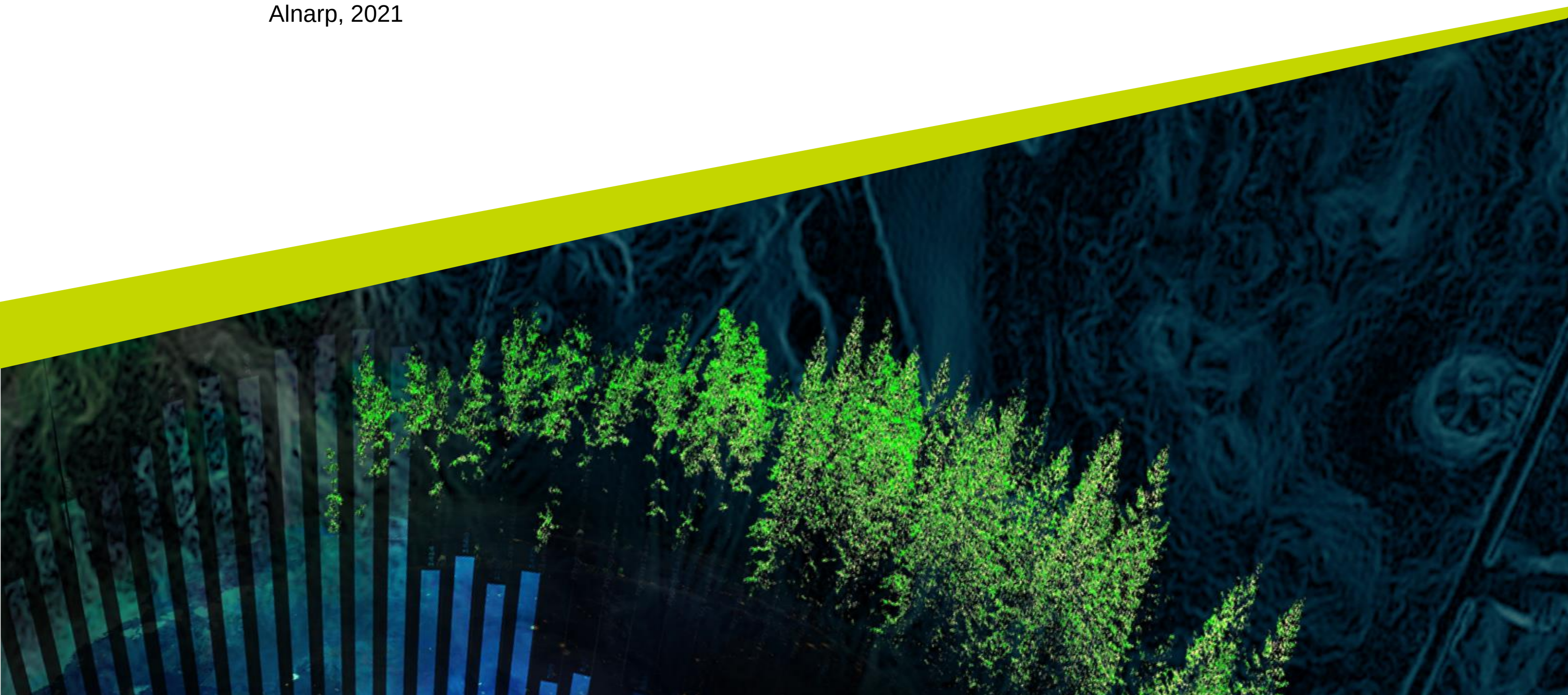

Assessment of the sustainability of the small-scale food production system in Guachetá, Colombia – opportunities for agroecological interventions

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Abstract

Small-scale farming systems in the Colombian Andes are vulnerable to threats that affect not only the food production and self-sufficiency of local communities, but that can affect the well-being of farmers and the environment. A holistic perspective of agriculture leads to understanding of the complexity of agroecosystems including its elements, processes, dynamics, interactions, synergies and trade-offs. This thesis examines the main characteristics, contexts and enabling environment for small-scale farming systems in Guachetá, Colombia, in order to identify and analyse the main agricultural problems in the municipality and possible solutions for them. Using the Tool for Agroecology Performance Evaluation (TAPE), the 10 elements of agroecology were evaluated on 7 farms along with the assessment of the performance of the systems using core performance criteria based on 5 key dimensions of sustainability. Furthermore, the analysis of qualitative data obtained from interviews with farmers and other actors, such as associations' representatives and academics in the fields of soils and agricultural science, facilitated the understanding of their perspectives in relation to the challenges that peasant farmers face. The results of this study show that the prevalence of dry climatic conditions and the variation on the typical rain patterns pose a major challenge for the current production system. In addition, the enabling environment, in regards to responsible governance and circular and solidarity economy, constitutes one of the major limitations. Currently, there are negligible possibilities for participation on the governance of the land and there is limited access to markets that offer fair conditions and proximity between consumers and producers. Also, the current agricultural practices reflect dependency on agrochemical inputs that, according to the analysis of the elements of agroecology, leads to low efficiency of the systems, limited agricultural biodiversity and low synergies within the agroecosystems. It is concluded that implementation of agroecological principles and practices that resemble natural ecological processes and that are characterized by joint action can aid in overcoming these issues leading to the improvement of the sustainability of food systems in Guachetá.

Keywords: agroecology, agroecological assessment, TAPE, small-scale agriculture, climate change, participation, Colombia.

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Foreword

Two years ago, I came to Sweden as an environmental biologist looking for a slight change of direction in my career. Having some studies in agrological surveys, I had a background predominantly in natural sciences and I was very curious about agroecology to gain a deeper knowledge of it as a science for sustainable agriculture. Nevertheless, I found many things that I was not expecting. I found discussions in the classroom. I found diversity of backgrounds, opinions and perspectives. I found that agroecology as a scientific discipline was only a part of the story, a part of a bigger picture. By learning the importance of participation, communication, and interactions I gained a renewed interest in social disciplines. Previously, I knew that research in the fields of natural sciences should have some positive impact on society, but through my process in the Master I could experience how social dynamics are deeply intertwined with scientific research and the need for application of different practices and technologies in the agricultural sector. Several of the topics addressed in the different courses renewed my interest in the sustainable development of the agricultural sector in my own country. Often, lectures made me wonder "how can this knowledge could be applied in my country?" or "how can all these things be relevant and contribute to the improvement of the state of agriculture?". Partially, this is what inspired me to do this work, where I felt reconnected with a part of my own culture and discovered the possibilities for the application of the knowledge accumulated during these two years. What's going to happen now? How is this going to make an impact? Well, that's part of the journey; there are many things yet to be discovered.

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Abbreviations

CAET	Characterization of agroecological transition
DEM	Digital Elevation Model
DNP	National Planning Department
FAO	Food and Agriculture Organization of the United Nations
IDEAM	Institute of Hydrology, Meteorology and Environmental Studies
IGAC	Geographic Institute Agustín Codazzi
SDGs	Sustainable Development Goals
SAFA	Sustainability Assessment of Food and Agriculture Systems
TAPE	Tool for Agroecology Performance Evaluation

1. Introduction

Improving sustainability for agriculture and food production systems is a complex challenge that needs to be tackled (Barrios et al., 2020). In order to encompass the economic, social and environmental dimensions of sustainable development, the United Nations adopted the 2030 Agenda with 17 Sustainable Development Goals (SDGs) in an attempt to extend the work done with the Millennium Development Goals and expand beyond what was not considered nor achieved before (UN, 2015). Although there is a strong interrelation between the 17 Goals (Barrios et al., 2020) and it's been stated that they are integrated and indivisible (UN, 2015) in the field of agricultural production, some of them take more relevance, namely, zero hunger (SDG 2), responsible consumption and production (SDG 12), and climate action (SDG 13). Nonetheless, the current conventional or industrial model of food production has not proven capable of achieving these goals. Agricultural systems that are resource-intensive and highly dependent on external inputs have been able to supply large volumes of food to the global market, yet peoples' needs in different regions of the world have not been met and a number of unintended consequences have stemmed from these agricultural systems (Altieri & Nicholls, 2005; FAO, 2018). Several environmental problems have arisen from this way of production, including the degradation of land and soil, pollution and contribution to climate change, the deterioration of terrestrial ecosystems through habitat loss and fragmentation, and a series of derived social and economic issues, such as decreasing profit margins for farmers, social inequality and emigration from rural areas (Gliessman, 2015).

Ubaté Valley, located in Guachetá in the central part of Colombia, is a good example of how peasant agricultural systems are affected by both climate change and industrialisation of agriculture (Carrillo, 2017; Franco-Vidal et al., 2015; La Villa, 2020). It has been reported in several studies that there is a trend of increasing emigration from the rural areas and abandonment of agricultural activities in the region, while there is a decreasing production and profitability in agriculture (Canal Trece, 2019; Leon 2018; Vargas, 2015). However, there is lack of knowledge on the reasons or causal relationships behind these trends, and identifying solutions and opportunities can help increase our understanding for sustainable development of agriculture in this region. This study aims to identify and analyse the challenges and opportunities for agroecological development in Guachetá, a municipality in Ubaté Valley, by performing a sustainability assessment of small food production systems using a multi-criteria sustainable assessment tool (Tool for agroecology performance evaluation) developed by FAO in 2019 and by interviewing key stakeholders in the study region.

1.1. The case of Guachetá.

In the central region of Colombia lies a geographical area called the Ubaté Valley which is recognized across the country for its peasant agricultural production and especially for the development of the dairy sector. For this reason, the Ubaté Province has been given the name of the "milking capital of Colombia" (Vargas, 2015; La Villa, 2020). Located in a zone of the Eastern Andes Mountains known as the Altiplano Cundiboyacense (a high plateau between the departments of Cundinamarca and Boyacá), this province is an administrative division within the department of Cundinamarca in Colombia and is constituted by 10 municipalities. Guachetá is one of the municipalities lying within the Ubaté Province and occupies an area of 17 900 ha (Figure 1). In a broad sense, these municipalities show a high degree of specialization in livestock raising (Carrillo, 2017).

Since the 19th century, livestock raising for dairy production has been a prevalent cause for the transformation of the landscape of the valley, contributing to the logging of the native low montane dry forest and the expansion of improved grasslands (Franco-Vidal et al., 2015). Since the livestock-dairy industry is recognized as one of the main drivers of the economy of the province, the management objectives for the basin and the development plan of Cundinamarca prioritize its maintenance and strengthening by different means, while increasing the degree of specialization of the agricultural sector (Franco-Vidal et al., 2015; Gobernación de Cundinamarca, 2016).

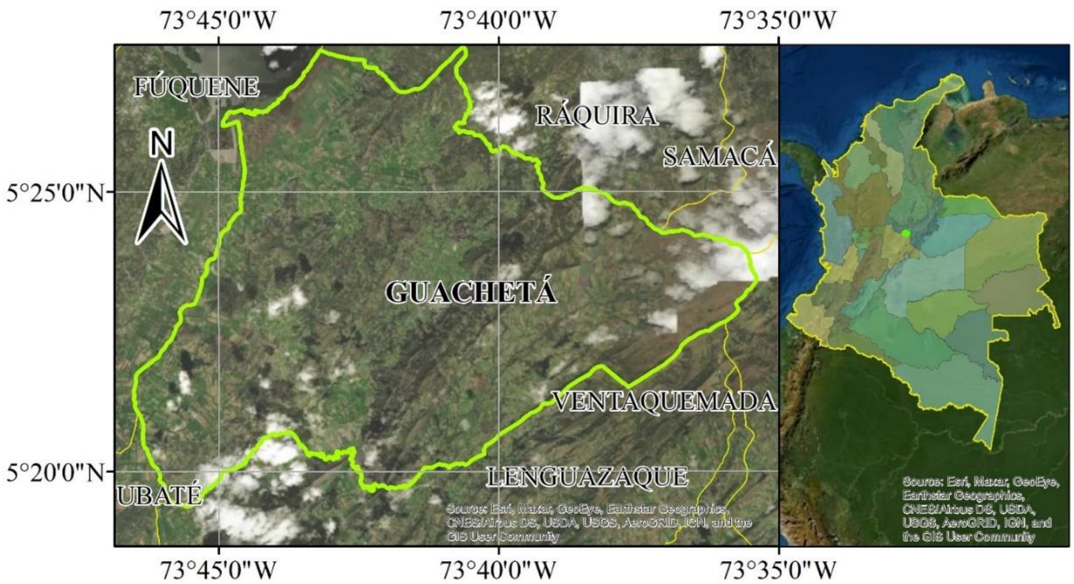


Figure 1. Geographic location of Guachetá within Colombia.

Besides the characteristic milk production of the zone, another important agricultural activity is potato (*Solanum tuberosum*) cultivation. Other important crops include onion, tomatoes, and strawberry (TerriData, 2020). The municipality has also been immersed in the coal mining boom in the last decades, thus it has become another relevant economic activity (León, 2018).

Although the dairy sector is considered a key factor for the economic development of the region, there is evidence of some problems that affect it, including the high production costs for small-holders and the effects of climate on the activity (Carrillo, 2017). In fact, over the years the region has faced a series of crises regarding its food production. The increased precipitation that led to floods during 2011 and 2012 caused a reduction in the milk production by up to 50%, with a loss in the bovine population of 38% (La Villa, 2020). Also, the drop in the prices of milk resulting in lower profitability has generated crises among milk producers since 2013. Due to narrow profit margins and competition from imported dairy products, several small producers have been unable to maintain their production which has led them to sell their land and cattle (Vargas, 2015). This constitutes a major cause for the migration of the rural population to the cities and the abandonment of the countryside and the agricultural activities, mainly motivated to search for better job opportunities and better living conditions (Canal Trece, 2019).

Moreover, the dairy sector is not the only one that has been affected during the last years. During 2020, the drop of potato prices in the international market affected several peasant households all over the Altiplano Cundiboyacense. In this situation, many of these farmers were forced to bring their produce to the closest highways trying to sell it to the travelers instead of using the regular distribution channels because the profit margins became negligible (Rodriguez & Garcia, 2020). Moreover, some agriculturalists registered substantial losses, forcing them to sell other of their own goods (e.g. machinery, land, livestock) in order to cover the debts acquired with banks. Under this scenario, many of them have stated that they did not want their children to engage in agriculture in the future (Semana, 2020), considering that other activities like mining are a more secure source of income (Leon, 2018). The promotion of the specialization of agriculture in the region for decades has led to a widespread livestock farming and potato cultivation, which has also resulted in an oversimplification of the landscape dominated by grasslands and less diversity of agricultural products.

A system that depends on few products might be more vulnerable to external threats and less resilient both in ecologic and economic terms (Gliessman, 2015). This has become evident with the issues that peasant agriculture has faced over time which come along with a declining interest among the rural population for the perpetuation of agriculture, hindering the development of the locality's self-sufficiency and food security. This way of food production has also had some environmental impacts, including a threat to the local biodiversity and inefficient use of resources (Franco-Vidal et al., 2015). Although temporal solutions have been implemented to overcome some of the difficulties that agriculture in the Ubaté Valley faces (e.g. construction of levees to control floods) (La Villa, 2020), the described situations are symptoms that the current food production system in the region is facing a series of difficulties that might be systemic problems. To address these issues effectively, a correct diagnosis of the current situation and the major constraints for the development of sustainable agriculture is required. Thus, there is a need for an accurate and sufficient understanding of the system that covers all the sustainability dimensions, and that allows for the identification of the weaknesses of the production system, which can aid in identifying feasible solutions.

1.2. Understanding agroecology

Agroecology has emerged as an alternative approach to conventional agriculture, that aims to achieve sustainable agricultural production (FAO, 2018). Throughout the years, different translations, meanings, and understanding of this term among and within different cultures have generated confusion about this concept (Wezel et al., 2009). Its roots in the scientific literature date back to the late 1920s and although it is recognized as a complex discipline, there are three main ways to understand this term: as a science, as a practice, and as a social movement (FAO, 2018; Gliessman, 2015; Wezel et al., 2009). Probably the first use of this concept, referred to the application of ecology to agriculture or the combination of ecology and agronomy, leading to the birth of the concept of 'agroecosystems' in the 1970s. Further on, during the 1980s it started to be understood as both a set of practices and as a movement (Wezel et al., 2009). Thus, through time different elements have been adding up to its definition, such as a holistic perspective, systems-thinking, protection of natural resources, food security and sovereignty, equity, indigenous/traditional knowledge, and diversity (Altieri & Nicholls, 2005; Gliessman, 2015; Wezel et al., 2009).

As a scientific discipline, agroecology has moved from focusing only on individual farms or agroecosystems to study the whole food production system, which encompasses its ecological, social, cultural, political, and economic dimensions (FAO, 2014a; Wezel et al., 2009). A design and management of agricultural systems based on the application of ecological concepts and principles is what constitutes agroecology from a scientific and practical point of view (Altieri & Nicholls, 2005). Moreover, the practice of agroecology gives value to the local, empirical, traditional knowledge of farmers that is consistent with those ecological principles (Gliessman, 2015). This idea is also strongly related to the understanding of agroecology as a social movement, which promotes the configuring of land as family farm territories while defending these spaces from industrial agribusinesses (Rosset & Martínez-Torres, 2012). In this sense, agroecology stands for peoples' rights to define their own ways to produce food through ecologically sustainable methods that guarantee healthy, fair and culturally appropriate production in local context, or what is called food sovereignty (Altieri, 2013).

Therefore, the goal of agroecology is to accomplish the sustainability of food production systems through the optimization of the processes that occur within them (flows of energy and matter, biological interactions, synergies, etc.), which implies to consider the interactions between and within natural environment and humans, and all the social aspects derived from these interactions (FAO, 2018). In this sense, concepts like ecological intensification which stands for harnessing ecosystem services through the management of service providing organisms, aid in accomplishing a sustainable agricultural intensification (Tittonel, 2014; Bommarco, 2013). Thus, the application of a set of ecological and social principles within the agroecological theoretical framework offers the opportunity to meeting the food needs in a global scale, while meeting other social and environmental goals (Barrios et al., 2020). The agroecological principles consider the complexity of dynamics and components of food systems and provide a guide towards obtaining a more sustainable production (Altieri & Nicholls, 2005). These principles include the improvement of recycling of nutrients and biomass where an increased dependence on natural processes can be achieved (reducing the dependence on external inputs); the diversification of the systems in time and space, using (often traditional) breeds and varieties adapted to local conditions; making appropriate matches between production and the natural productive potential and limitations of the land; the enhancement of beneficial biological interactions which derive in the promotion of ecological processes and services; the conservation of natural resources (soil, water, energy, biological resources); minimizing losses and improving resource use efficiency; minimizing external inputs, specially synthetically manufactured ones; and the use of renewable sources of energy (Altieri & Nicholls, 2005; Gliessman, 2015).

Furthermore, Gliessman (2015) has described three distinct levels of conversion to sustainable agroecosystems at the farm scale and two more that go beyond this scale. On a first level, the efficiency of the practices should be improved to reduce the amount of inputs; a second level contemplates the replacement of conventional or industrial practices and products with more environmentally benign ones (e.g. organic farming); the third level deals with the redesign of the agroecosystem with fundamental changes in its functionality; the fourth level seeks to establish more direct relationships between consumers and producers; and finally, the fifth level is about building a new global food system were the main issues that affect the dominating paradigm of food production are overcome.

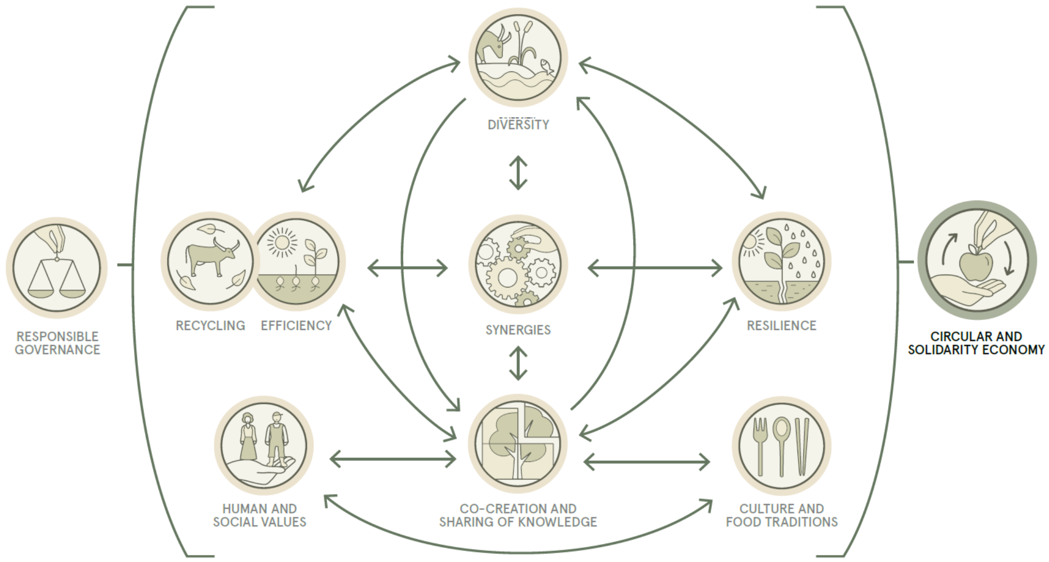


Figure 2. The 10 elements of agroecology.
Source: FAO, 2018.

Since implementing agroecology has shown to be a promising and feasible approach to contribute to sustainable development, the Food and Agriculture Organization of the United Nations (FAO) emanated the 10 elements of agroecology (Figure 2) as a guidance for the transformation of the food and agricultural systems towards a wide spread sustainable agriculture and to achieve Zero Hunger and other interconnected SDGs (FAO, 2018). The 10 elements of agroecology give an analytical framework that supports the decision-making oriented towards the goal of sustainability of food production systems (Barrios et al., 2020). These elements are interlinked and interdependent, but can be clustered into 3 main groups: those that define the common characteristics of the systems, practices and approaches are (1) diversity, (2) synergies, (3) efficiency, (4) resilience, (5) recycling, and (6) co-creation and sharing of knowledge; those related with context features are (7) human and social values and (8) culture and food traditions; and those that determine an enabling environment are (9) responsible governance and (10) circular and solidarity economy (FAO, 2018).

1.3. Small-scale farming systems

Altieri & Nicholls (2005) pointed out that an agroecological approach has the potential to enhance the productivity of smallholder or peasant agricultural systems. This is of major importance because it has been recognized that these systems produce a large share of the total global food supply (more than 80% for some regions), and occupy between 50 to 80 percent of total farmland (FAO, 2014b; FAO, 2017; Graeub et al., 2016). Thus, it is vital to gain understanding of small-scale systems and develop strategies to assess and improve the sustainability of small-scale and peasant agriculture. It's appropriate to mention that the concept of small-scale agriculture often overlaps and is used exchangeable with other terms, such as low-input, low-technology, low-income, smallholder, subsistence or family farms, among others, even though these terms might have slight differences in their meanings (Khalil et al., 2017).

Although in the past it has been reported that smallholder farmers produce around 70-80% of the world's food, more recent estimates show that the total food supply from farms smaller than 2 ha oscillates around 30-34%, which is produced on 24% of gross agricultural land (Ricciardi et al., 2018). This means that even though small farms' production might have been previously overestimated, small farms still are major contributors to the global food production. Moreover, the importance of the food supply that these farming systems offer cannot be regarded only to the amounts produced alone but other variables should also be considered, including wastage, crop allocation, diversity and nutrient production. In fact, species richness and diversity is greater in small farms, since larger farms show a higher level of specialization in certain crop groups (Ricciardi et al., 2018).

Although small-scale farming systems are generally conceived as those that occupy an area smaller than 2 hectares (Ricciardi et al., 2018), the definition of a small-scale production and producers varies according to the context of application, including the role of small-scale production on rural economy and the purpose of analysis (Khalil et al., 2017). The different approaches to define small-scale producers make use of distinct criteria, and although internationally agreed definitions are stated, they are not intended to enforce a replacement of the local or national understanding of this concept (Khalil et al., 2017). An international definition presented by the High-Level Panel of Experts on Food Security and Nutrition stated that a small-scale agricultural system is:

> … an agricultural holding run by a family using mostly (or only) their own labour and deriving from that work a large but variable share of its income, in kind or in cash. The family relies on its agricultural activities for at least part of the food consumed – be it through self-provision, non-monetary exchanges or market exchanges. The family members also engage in activities other than farming, locally or through migration. The holding relies on family labour with limited reliance on temporary hired labour, but may be engaged in labour exchanges within the neighbourhood or a wider kinship framework. (CFS HLPE, 2013)

The definitions of smallholders can either be based on single or multiple criteria, which often include the endowment factors of production (land area, labor and technology), the type of management (involvement of the family), the connection with the market, and the economic size. For example, on the basis of their relation to the markets, farming systems can be categorized as subsistence and near subsistence smallholders, small farms that generate surplus production for a market, and large farms. The economic size might refer to the gross income, being a small-farm e.g. one that has revenues below 250.000 USD per year. In regards to the endowment factors, a limit of 2 hectares is the most common measure for small-scale farms, nonetheless not all countries share this criterion. In Latin America and the Caribbean, out of 18 countries that use the size criterion, 15 use a different threshold than 2 ha, of which 13 use greater thresholds (Khalil et al., 2017).

The type of management criterion is strongly related to the definition of family farming, which is often characterized by farming operations run by the family or household members with a limited amount of hired labor where the responsibility of the management relies on the head of the household (Garner & de la O Campos, 2014). Family farms play a critical role in global food security as they constitute more than 98% of all farms in the world and family farmers are seen as key actors in the goal of achieving food and nutritional security and ending global poverty (Graeub et al., 2016). Most commonly, the term “family farm” is used referring to certain farming systems in the developing world, especially in Latin America (Garner & de la O Campos, 2014) where the vast majority of farmers are peasants who use traditional and subsistence methods in small plots of land for food production (Altieri & Nicholls, 2005). Indeed, there have also been recognized overlapping similarities between the concept of family farming and that of peasant agriculture (Garner & de la O Campos, 2014).

As mentioned before, Altieri & Nicholls (2005) stated that the productivity of traditional peasant farming systems could be enhanced by the promotion of agroecological principles. Despite their limited endowment and low use of external inputs, these are productive systems that can be biologically restructured to optimize the agroecosystem processes and to improve efficiency. While agroecology recognizes the value and importance of traditional agricultural practices developed over generations and that provide insights into sustainability, it also makes use of the knowledge obtained by scientific research. Thus, the authors state that an agroecological approach can lead to agricultural intensification of farming systems in Latin American, by relying on local knowledge and the incorporation of scientific understanding on the agroecosystem’s interactions and processes.

1.4. Assessment of food production systems

The study of food production systems aims at gaining a comprehensive understanding of its components, interactions, processes and emergent properties (Gamble et al., 1996). It has been recognized that the understanding of food systems requires a holistic approach that considers the different constituent elements of them, including the food supply chains (production, storage, distribution, processing, markets), the food environment (surrounding, opportunities and conditions), and the consumer behavior (HLPE, 2017). One proposed approach to enhance the comprehension of the dynamics of these systems has been the identification of its drivers, that are understood as processes that affect or influence food systems over long periods, such as the population growth, the concerns for food safety, the degradation of natural resources and trade expansion (Béné et al., 2019).

Likewise, agroecology provides a framework for the assessment of the complexity of agroecosystems (Altieri & Nicholls, 2005). When dealing with the question of sustainability evaluation for agriculture and estimating the impact of selected strategies on the performance of agroecosystems, different approaches have been proposed to arrive at a common framework that gives a complete description and assessment of the systems (Altieri & Nicholls, 2005). Thus, the challenge for researchers has been to identify common parameters or indicators that describe the level of "sustainability" of agroecosystems, considering the ecological foundations of systems productivity, the economic aspects and the cultural context in which the systems are immersed (Gliessman, 2015).

For example, between 2009 and 2013 FAO developed the Sustainability Assessment of Food and Agriculture Systems (SAFA) guidelines as an attempt to give an international reference to assess the synergies and trade-offs between the dimensions of sustainability along the food supply chain. Having in mind the needs for a common language for sustainability and a holistic approach that enables the understanding of the complexity of agricultural production, SAFA considers four dimensions of sustainability for the assessment of food systems: environmental integrity, economic resilience, social well-being, and good governance. Then 21 themes derived from these dimensions and, from them, 58 subthemes and 116 indicators were defined. Thus, the standardized metrics of the indicators guide the assessment of sustainability by identifying issues, risks or gaps that hinder the achievement of sustainability goals (FAO, 2014b).

More recently, due to the growing interest in agroecology and the heterogeneous methods and data for evaluating the performance and impacts of agroecology, the need for common, global and harmonized evidence in regards to performance of agroecology has arisen. Given that FAO is the custodian agency for 21 SDG indicators, is experienced in developing methodologies, tools, and frameworks to measure the sustainability performance of food system, and has been given the responsibility of assisting communities in the transition towards more sustainable agriculture, in 2019 the Tool for Agroecology Performance Evaluation (TAPE) was proposed as a global analytical framework to assess the multi-dimensional performance of agroecology and to support the transition towards more agroecological foods systems. Aiming to support decision-making processes based on evidence, TAPE provides a guidance on how to assess food systems within an agroecological theoretical framework. This tool allows to obtain data that leads to an adequate description of food production systems from an agroecological perspective given the need for comprehensive performance measurements for food systems (FAO, 2019).

TAPE consist of three diagnostic steps (steps 0, 1 and 2) and an analysis and participatory interpretation of results (step 3). Based on primary and secondary information, step 0 involves a general description of systems and contexts, including the characterization of agroecological zones, production systems and enabling environment. Step 1 is the characterization of agroecological transition (CAET) which is based on the scoring of the 10 elements of agroecology for a given system, which allows to identify its strengths and weaknesses. The elements are used as core criteria and few semi-quantitative indices are defined to characterize each of the elements. The 37 indices that take the form of descriptive scales belonging to the 10 elements of agroecology are presented in Table 1. The whole CAET can be performed by using direct surveys with relevant stakeholders like producers, member of the households or leaders of the community. High scores across all the elements indicate that the system is well-engaged in the agroecological transition (FAO, 2019).

Step 2 involves the assessment of core performance criteria on 5 key dimensions considered pertinent to sustainability of food systems, namely, Environment & climate change, Health & Nutrition, Society & Culture, Economy, and Governance. For this, a short list of 10 core criteria was established as a multidimensional framework addressing these dimensions: (1) secure land tenure, (2) productivity, (3) income, (4) added value, (5) exposure to pesticides, (7) dietary diversity, (8) youth employment, (9) agricultural biodiversity, and (10) soil health. The quantitative and qualitative criteria are based on indicators that are also collected by using surveys. Each criterion is also linked with SDGs' indicators and is intended to contribute to estimate the performance of agroecology (FAO, 2019).

Finally, Step 3 includes the joint analysis of step 0, 1 and 2 to highlight the strengths and weaknesses of the system as well as a participatory interpretation of result. Thus, an identification of the trade-offs and synergies between elements of agroecology and sustainability dimensions can be carried out with the participation of the community. Hence, this step allows to do a review on the CAET results, the performance criteria results, and how those results can be related and explained given a context and enabling environment (Step 0). This step involving relevant actors allows to discuss the different way on how the data is analyzed as well as to identify ways to improve the performance of the system (FAO, 2019).

Table 1. 37 semi-quantitative indices of the 10 elements of agroecology (FAO, 2019).

Diversity	Crops
	Animals
	Trees
	Diversity of activities, products and services
Synergies	Crop-livestock-aquaculture integration
	Soil-plants system management
	Integration with trees
	Connectivity between elements of the agroecosystem and the landscape
Efficiency	Use of external inputs
	Management of soil fertility
	Management of pests & diseases
	Productivity and household's needs
Recycling	Recycling of biomass and nutrients
	Water saving
	Management of seeds and breeds
	Renewable energy use and production
Resilience	Stability of income/production and capacity to recover from perturbations
	Mechanisms to reduce vulnerability
	Indebtness
	Diversity of activities, products and services
Culture & Food Tradition	Appropriate diet and nutrient awareness
	Local or traditional identity and awareness
	Use of local varieties/breeds and traditional knowledge for food preparation
Co-creation & Sharing of knowledge	Platforms for the horizontal creation and transfer of knowledge and good practices
	Access to agroecological knowledge and interest of producers in agroecology
	Participation of producers in networks and grassroot organizations
Human & Social Values	Women's empowerment
	Labour
	Youth empowerment and emigration
	Animal welfare
Circular & Solidarity Economy	Products and services marketed locally
	Networks of producers, relationship with consumers and presence of intermediaries
	Local food system
Responsible Governance	Producer's empowerment
	Producer's organizations and associations
	Participation of producers in governance of land and natural resources

1.5. Qualitative assessment of social perspectives

Another research approach that aids in understanding the complexity of social phenomena in the agricultural context is the qualitative hypothesis-generating research that recognizes the existence of unclear issues and the lack of knowledge on a topic to formulate specific questions. Using the grounded theory method for agrarian diagnostic studies, the qualitative research aims at the development of hypotheses by applying theoretical coding to qualitative interview data (Auerbach & Silverstien, 2003). For this purpose, interviews are the main source of information because they facilitate obtaining insights on people's perspectives about a phenomenon of interest (Yin, 2018). Considering the principle of ‘questioning rather than measuring’ (Auerbach & Silverstien, 2003), the generation of hypotheses using theoretical coding is a process where the insights of different participants are collected and analyzed in order to identify repeating ideas that can be categorized into themes and theoretical constructs. Therefore, it requires collecting qualitative data through interviews that pursue a specific line of inquiry, while having the tone of a fluid conversation. These are known as unstructured, semi-structured, in-depth, or intensive interviews (Yin, 2018). Hence, the selected participants for interviews are those who can share their lived experiences because they are closely related to the phenomenon under study. Also, as an alternative to random sampling common in quantitative studies, the grounded theory considers the theoretical sampling as more realistically possible. Instead of requiring randomness to determine the research participants, theoretical sampling implies selecting participants that are related or have information related to the research concerns because it values the direct life experience (Auerbach & Silverstien, 2003).

In summary, this research approach recognizes the subjectivity of the experiences, values and perspectives as part of human interactions and social issues derived from them. The knowledge that can be obtained from the shared information allows the formulation of postulates or hypothesis as conclusions for the understanding of a specific topic or research concern (Auerbach & Silverstien, 2003). Thus, such approach can be a powerful tool to evidence the real struggles that faces a community on the context of agricultural studies.

2. Objectives

This study aims to identify the main constraints and opportunities for the perpetuation, development and improvement of small-scale agriculture in Guachetá, Colombia, from an agroecological perspective. Thus, the specific objectives of this project are to:

- Describe the major contexts and characteristics of the small-scale food production system in Guachetá considering the different dimensions of sustainability
- Perform a multi-criteria sustainability assessment of farms using the Tool for Agroecology Performance Evaluation (TAPE)
- Identify the underlying reasons that limit or constrain the development of sustainable agriculture in the municipality
- Recognize potential improvements for agricultural development and propose feasible interventions

3. Methods

In order to describe and gain a holistic understanding on the food production system in Guachetá, the Tool for Agroecology Performance Evaluation (TAPE) was applied in 7 farms since this methodology aims at assessing the agroecological multi-dimensional performance of systems implementing the three diagnostic steps of the methodology. The first step (Step 0) was completed by accessing and analyzing mainly official data about the locality. Information for the other two steps was obtained by interviewing and applying surveys to farmers. Due to the constraints of the study, it was not possible to perform a full TAPE assessment for the systems analyzed, but the steps of the methodology were implemented to a large extent. Because of the COVID-19 travel restrictions, all interactions were done remotely via online/telephone. Therefore, it was not possible to evaluate core performance criteria such as soil health, productivity, added value and women's empowerment since those criteria require or are improved by having interactions in person.

The contact with farmers and other participants allowed not only to perform the surveys required to obtain the data for the TAPE analysis but it was also possible to develop an unstructured interview to obtain insights and explanations reflecting the different stakeholders' perspectives in regards understanding the agricultural situation.

3.1. Description of contexts and characteristics

Step 0 of TAPE focused on the characterization of biophysical environment including the soils, landforms, land cover, natural vegetation and climate. Most of this information was obtained from official sources, such as the documents generated by the Geographic Institute Agustín Codazzi (IGAC, in Spanish *Instituto Geográfico Agustín Codazzi*) and the Institute of Hydrology, Meteorology and Environmental Studies (IDEAM, in Spanish *Instituto de Hidrología, Meteorología y Estudios Ambientales*). To contrast this information, a digital elevation model (DEM) of the zone was obtained from ASF DAAC (2011) and was processed and analyzed with ArcGIS Desktop 10.8. This software was used to generate other maps, such as rainfall distribution, geomorphology, land cover, land use capability and land use conflicts, which support the description of the main characteristics of the study area.

The description of the climatic conditions for the municipality was based on the public available hydrometeorological data from IDEAM (IDEAM, 2021). The available data from 11 meteorological stations within and surrounding the municipality were used for the study and the variables analyzed included daily values of total precipitation, maximum and minimum temperature, sunlight, humidity and wind. The time frame selected for this purpose was between 1991-01-01 and 2020-12-31, although for some of the stations the information was fragmented because there were periods when there were no available records. For one of the stations, the information since 1962 was available and considered for comparison. Thus the main inferences and conclusions where based primarily on the stations that provided the most complete information. The information about the hydrometeorological stations and the variables considered is presented in more detail in Appendix 1. The daily meteorological data were processed to establish monthly and annual results that describe the climate of the zone. The annual rainfall estimates at each of the meteorological stations were interpolated using the software ArcGIS Desktop 10.8 to generate a raster surface using a natural neighbor technique to generate a map that describes the spatial distribution of precipitation in the municipality. Also, the potential evapotranspiration (ETo) was calculated using the software CROPWAT 8.0 with the FAO adapted Penman-Monteith approach, requiring as climatic input data the temperature, daily sunshine, relative humidity and windspeed. Then, for the climatic classification of the region, the results of this analysis were compared with the National reference criteria from IGAC (2014a).

There is limited accessible information about other aspects of the biophysical environment, such as geomorphology and vegetation for the specific location. The published cartographic studies to the date are general (scale 1:100 000) and make very general descriptions of the whole department, but are not specific to the municipalities. Thus, the official digital cartographic data was directly processed directly clipping it to the zone in order to see the variability of the landscape as something that influences the agroecological conditions. The available information included the Digital Soil Map of the Department of Cundinamarca (IGAC, 2001a), the land use capability map of Cundinamarca (IGAC, 2001b), the Colombia's national land use conflict map (IGAC, 2013) and the land cover map for Colombia (IDEAM, 2014), which is based on the Corine Land Cover methodology. The land use capability in Colombia is an adaptation of the methodology developed by the U.S. Department of Agriculture. The methodology analyzes the permanent limitations for use of the land which represent a risk of degradation. According to this, eight agrological classes that indicate a maximum potential of use for the land are defined. The land belonging to classes I to IV is the one that can be used in agriculture, from an intensive way (class I) to strongly restricted with increasing conservation practices (class IV); classes V to VII correspond to land that can be used, in a more restricted way, in agricultural, livestock, agroforestry and/or forestry activities; lands that should be used only in preservation, conservation and ecotourism correspond to class VIII and have no capacity to productive activities (IGAC, 2014b). The definition of the use conflict of the territory relies on a conceptual model that considers the environmental offer of lands in terms of their main physical, biotic and environmental characteristics, and the existing coverage of land and predominant uses assigned to them in the process of occupation of the territory (demand). The comparison between the environmental offer and demand results in the definition of concordance between the current use and the recommended potential use, or discrepancy due to under or overutilization of the land (IGAC, 2012).

Additionally, several socioeconomic variables were described based on the information available in the public databases from the National Planning Department (DNP, in Spanish *Departamento Nacional de Planeación*), including a general description of the rural population. This description comprises the number of households belonging to a range of productive units (farms) sizes, which breaks are based on information provided by National agricultural census, as well as the total areas belonging to different farm sizes.

3.2. Sampling and participants

The participants involved in this study included several stakeholders, including 10 farmers or producers, 2 representatives of farmer's associations, a representative of a local official entity that gives technical assistance for agriculture, and 3 academic experts within the fields of agriculture, soils and agroecology. The farmers included in this study were asked how they identify themselves, if they identified as peasant farmers, if agriculture was their main means for the livelihoods of the household, how much of their production was for commercial purposes or for self-consumption at the household, the principal product of their activity, and who runs the farming operations. For the purposes of this study small-scale farmers were defined as those who identified themselves as peasants or small producers, whose farming operation was run totally or mostly by members of the household and whose total area of the farm was under 3 hectares (matching the national classification of size for productive agricultural units). The information about each participant can be found in Table 2 in the Results section.

The selection of participants was done as a convenience sample by recruiting those who were possible to access via distance. Using a snowball technique, the initial participants were asked to suggest other relevant respondents. Thus, the research sample grew from the first participants that included a representative of farmers' associations and two farmers. The initial contact with the first participants was done during the first week of February 2021 and individual interviews and surveys were performed until mid-March. All the interactions with the participants were carried out remotely via phone calls, online videocalls, e-mails and texting.

3.3. Interviews and surveys

The interaction with all of the participants began with the explanation of the aims of the study and the importance of their participation to collect the data. Then they were asked if they were willing to participate in the interview and if they had any inquiries before starting. The interviews and surveys were conducted in Spanish. A total of 16 semi structured interviews were performed with the participants and the questions were selected according to the group or category in which they were classified: farmers, representatives or experts (see Table 2). Thus, prior to the application of the interviews, customized questions were defined for each group in order to understand the perceptions of different stakeholders regarding main challenges that faces agriculture in the municipality (Appendix 2). These answers were registered as transcripts that were analyzed further on. In addition to the open questions, several statements about the agricultural production in the locality were presented to the respondents and they specified their level of agreement to these statements in a Likert Scale (completely agree, agree, neither agree nor disagree, disagree, or completely disagree). These statements were formulated to get the participants' opinions in the topics of traditional knowledge, perceived support, importance of diversity and natural environment, use of agrochemicals, climate, training, and interest of youth in agriculture. Also, the farmers were presented with eight common problems for agricultural production (climatic events, high costs of inputs, low prices of products, water supply, lack of knowledge, pests and diseases, low production, low soil fertility) and were ask to select the 3 that were most relevant for them and to rank them according to the level of importance. The participants were also allowed to comment on these statements and problems and their comments were also registered.

In the case of the farmers, after the interview was done they were asked if they wanted to continue with the survey at the farm or household level for the TAPE analysis which would require more specific information about their production and the whole system. Seven farmers were willing to collaborate with the survey. The survey included the structured questionnaires developed by FAO (2019) for the characterization of agroecological transitions (CAET – Step 1) and core criteria of performance (Step 2). All the interviews and surveys ended asking the participants if they had additional comments or questions.

3.4. Analysis of data gathered from surveys and interviews

For the CAET according to the 10 elements of agroecology, 37 semi-quantitative indices were scored based on a selected answer from 5 possible predefined options for each of the questions that match each index. Thus, each index was scored ranging from 0 to 4 according to the description of the characteristics of the system assessed. The scores of all the indices belonging to a particular element were summed and the totals were standardized on a percentual scale to obtain the general scores for each element, allowing to show the strengths and weaknesses of the systems in relation to the agroecological theoretical framework. Then, the general scores for the elements obtained at each farm were averaged allowing to get an overall score of the small-scale farming system. These results were represented using radar-type diagrams for each of the systems assessed.

For the step 2 of TAPE, only six out of the ten core criteria were evaluated due the impossibility of a closer interaction with the participants and other limiting conditions of the study. Hence, the core criteria considered for this study were Secure land tenure, Income, Exposure to pesticides, Dietary diversity, Youth empowerment, and Agricultural diversity. The data from Step 2 was analyzed using a "traffic light" approach where three sustainability levels were considered: desirable (green), acceptable (yellow) and unsustainable (red). The way in that the scoring system is applied also depends on the core criterion evaluated. For Secure land tenure the questionnaire included aspects of legal documentation, the perception on secure access to land and the rights to dispose of their properties. Therefore, the scores depended on whether the farmers gave a positive or negative answer for three different questions (see Appendix 4). According to the methodology, a desirable state would be achieved when there was a legal recognition of access to land for the farmer through formal documents and their names on it, if they had a perception of secure access to land, and the existence of rights to sell, bequeath, and inherit. On the contrary, an unsustainable state is that where there is no documentation, insecure access to land and/or no rights over the land. The acceptable level, considers different scenarios when some of these conditions are met.

Because the data for calculation of Income can be considered as sensitive information and can be scarce, the approach for the calculation of this criterion was based on the perceptions of the farmers on their income. Thus, they were asked if their income had been increasing, decreasing or was stable, and how it was compared to the average in the region. A desirable level is reached when there is a perceived increasing trend in income and if it is higher than the average of the region; it is acceptable if the income is stable and at least similar to the average of the region; and red if the income is decreasing or is lower than the average of the region.

For Exposure to pesticides, the questionnaire considers the type of pesticides used, the relative amounts of organic and synthetic pesticides, the mitigation techniques for application and other ecological practices for pest management. Hence, a desirable level could be achieved if the quantity of organic pesticides used is higher than the synthetic pesticides, highly and moderately toxic pesticides (class I and II) are not used, and at least 4 different mitigation techniques are used when applying the pesticides. It can also be achieved if there is no use of synthetic pesticides at all and there are integrated techniques for pest management besides organic pesticides. For an acceptable state, there must not be used highly toxic pesticides (class I), at least 4 different mitigation techniques are used when applying the pesticides and there is use of organic pesticides and other integrated techniques to some extent. An unsustainable exposure to pesticides is that where the previous conditions are not met.

The scoring for Dietary diversity is based on the count of 10 groups of food consumed within the previous 24 hours (grains, white roots and tubers, and plantains; pulses; nuts and seeds; dairy; meat; eggs; dark green leafy vegetables; vitamin A-rich fruits and vegetables; other vegetables; other fruits). Then if the participants have consumed at least 7 of these dietary groups, that would be considered a desirable dietary diversity; if they consumed at least 5, that would be an acceptable level; and less than 5 is considered unsustainable.

The Youth employment was based on the proportions of youth (15 – 24 years old) working in agricultural activities, in education, working outside, and of those who had emigrated the system. Contrary to the other criteria and elements, it was defined one common score for all the systems based on the information gathered and added from every household. The scores are calculated taking into consideration two different domains which have a weight of 50% over the final score: employment/activity and emigration. For the employment/activity domain, the scores are calculated based on the proportions of youngsters that work in agricultural production, those who are in education or training, those who have no defined activity and those who have left the community due to lack of opportunities. In the case of the emigration, it is calculated based on the proportions of youngsters who are willing to continue the agricultural activity of their parents, those who would emigrate given the chance, and those who had already left. Then the scores of the two domains are computed to obtain an overall score that if is equal or higher to 70% is considered desirable, if is between 50% and 70% is acceptable, and below 50% is unsustainable.

Finally, the agricultural biodiversity was estimated based on the numbers of animal species and breeds, the relative area occupied by different crops and the presence of natural vegetation, trees, and pollinators. The agricultural diversity criterion considers as indices the Gini-Simpson indices for crops and animals as well as the index of natural vegetation, trees and pollinators which is based on the scoring of the indicators of bee keeping, productive area covered by natural or diverse vegetation and the presence of pollinators and beneficial animals, based on some predefined scores base on their presence and abundance. Then, the general score is an average value of these indices and if it is a value equal or higher to 70% it is considered desirable, if is between 50% and 70% is acceptable, and below 50% is unsustainable.

The analysis and results of the participants responses to the different statements on agriculture were presented in a stacked bar chart where the response distribution is shown by subdividing the response for each statement according to each category. Similarly, the ranking of the main problems for agriculture that the participants gave was aggregated and presented in a chart that allows to show the relative importance of the different problems selected.

Finally, the transcripts resulting from the semi-structured interviews were analyzed using the coding method. The theoretical coding procedure was applied first reducing the texts to manageable proportions by selecting what was considered relevant text related to the research question. Then, there were identified repeating ideas among the participants, when similar words, phrases or general ideas were expressed by different participants. Later on, repeating ideas that had something in common were grouped in themes or implicit topics that allow the organization of the ideas. Afterwards, these themes were organized into larger ideas or theoretical constructs that lead to the development of theoretical narrative that explained the major challenges for the small-scale agriculture according to the points of view of the participants.

These results were then analyzed and compared together with the results of the characterization of agroecological transition and the review of the performance criteria having in mind the context and enabling environment described in step 0. Therefore, the description of the processes and dynamics of the system and the identification of weaknesses, strengths, synergies, and trad-offs, lead to recognize those areas were the application of agroecological can help to face the challenges and difficulties that the small-scale agriculture in the locality experiences.

4. Results

Starting with a general description of the system, these results characterize the level of agroecological transition according to the 10 elements of agroecology and describe the performance of the systems assessed. Moreover, the perspectives in regards to agriculture by different relevant actors are presented.

4.1. Description of the main characteristics and contexts of the system

The characteristics and contexts described in this study comprise the natural conditions given in the municipality of Guachetá that have an effect on agriculture. These include the heterogeneity of the landscape, in terms of slopes, landforms and vegetation, as well as the characterization of the climate, which is dominated by a bimodal rainfall regime. This set of characteristics have also allowed to determine the potential for sustainable use of the land by the official authorities. Moreover, these contexts also include a brief description of some socio-economic aspects.

4.1.1. Biophysical environment

Topography and landforms

According to the information processed from the DEM, Guachetá lies approximately between 2540 and 3600 m.a.s.l., meaning a range of 1060 m between its lowest and its highest points. It shows a high variation on the landscape with flat areas that have slopes below 12% mostly found within the western part of the municipality and steep slopes higher than 75% associated with a mountain landscape (Figure 3).

In fact, the landforms present within the boundaries of the municipality are mainly associated either with depositional or structural morphogenetic environments. The first environment resulted mostly in the formation of a plain landscape containing fluvial lacustrine terraces and floodplains (Figure 4). On the other hand, the structural morphogenetic environment is related with the mountain landscape which contains as landforms the hogbacks, homoclinal ridges, and hills. The reverse surface is arranged in the direction of the angle of dip of the rock strata with a value of 30 ° to 70 ° for hogbacks and between 10 ° to 30 ° for ridges. Thus, the information obtained from the DEM (Figure 3) is consistent with the available official cartographic material, where the steepest slopes are associated with the hogbacks and then the homoclinal ridges (Figure 4).

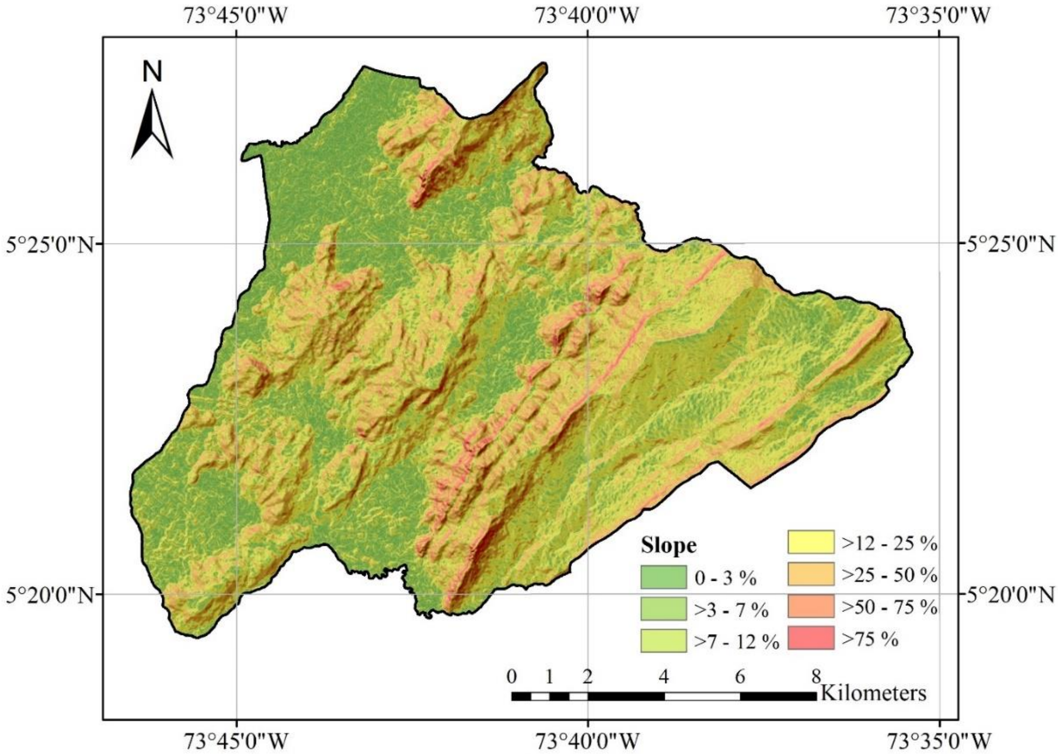


Figure 3. Slope map of Guachetá.
Source: own elaboration based on ASF DAAC, 2011.

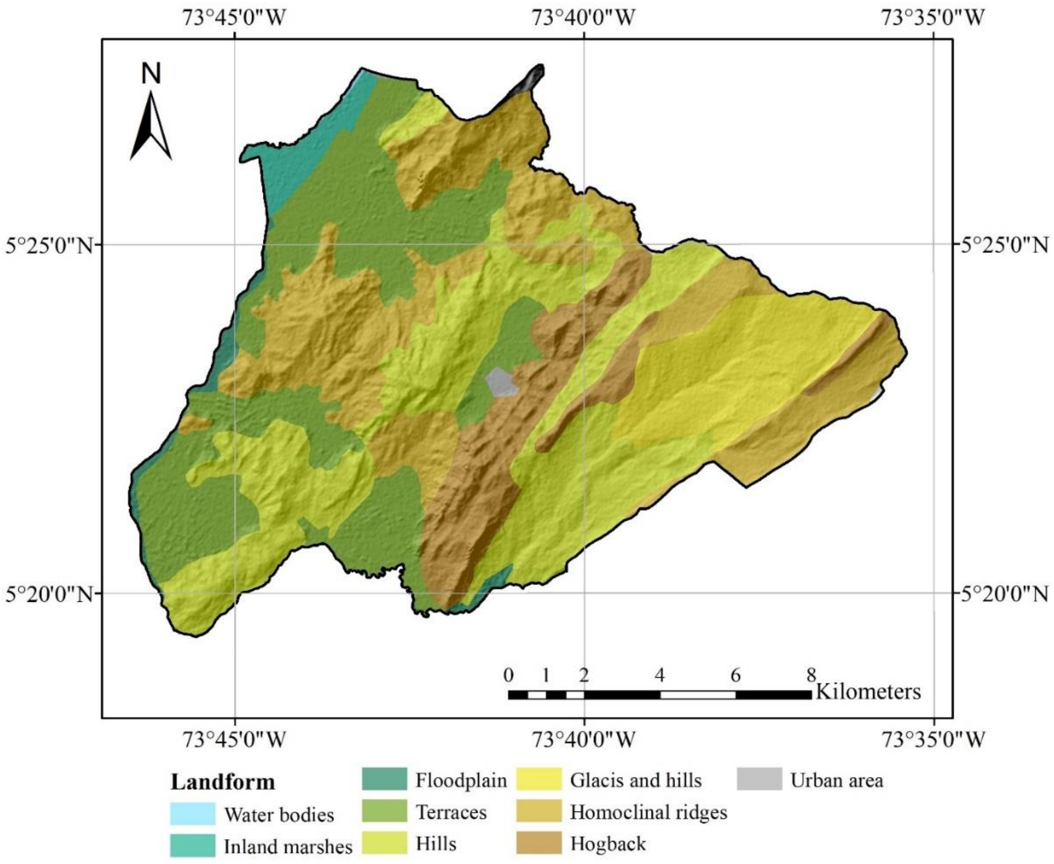


Figure 4. Landforms present in Guachetá.
Source: own elaboration based on IGAC, 2001a

Climate

The information for the description of temperature and relative humidity was taken from the station ISLA DEL SANTUARIO (see Appendix 1), since this was the only station among the 11 stations included in the study that had complete available climatic data over the past 30 years. As is it shown in Figure 5, these three variables show little variation throughout the year in the study area. The range of variation of the average monthly relative humidity is between 74.2 % to 79.5 %, reaching its highest values during April and November whereas the lowest values are present during January and July.

For the maximum temperature the values oscillate around 25 °C while the minimum temperature is often close to 6 °C. It should be noted that the difference between maximum and minimum temperature is highest during January. Thus, during this month (and to a less extent during December and February) it is more likely to have extreme variations of temperature within a day which can lead to frosts that may affect agricultural production.

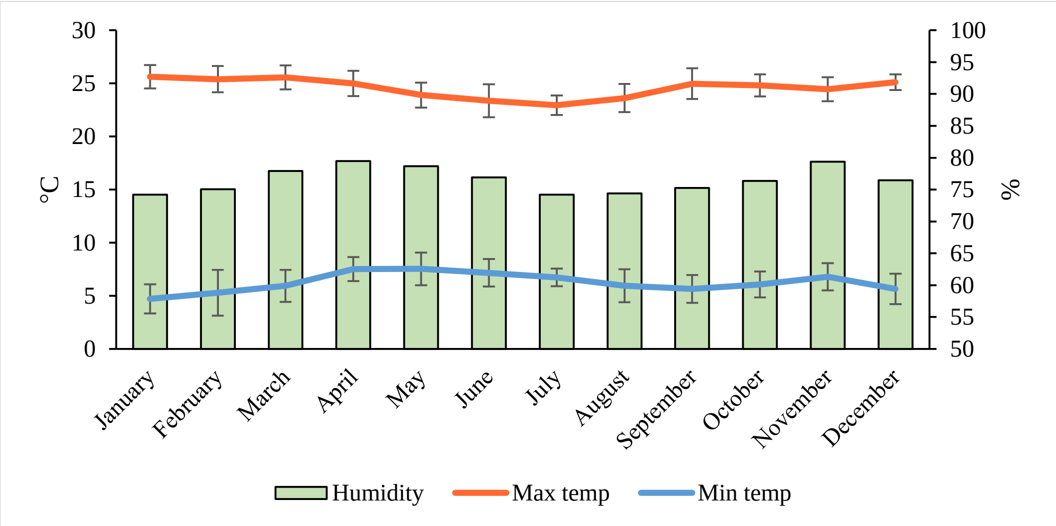
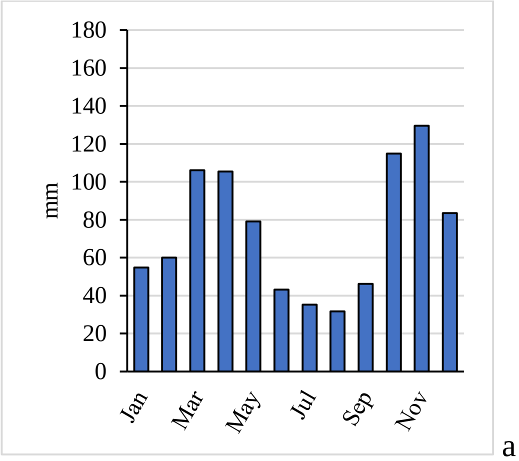


Figure 5. Monthly average values of maximum and minimum temperature, and relative humidity for Guachetá, based on the data from 1991 to 2020. (Error bars show standard deviation throughout the years).

On the other side, the rain patterns in Guachetá show a bimodal regime, where two rainy seasons have been identified with peaks during March-April and November, as it is shown in Figure 6. This figure depicts the monthly rainfall calculated for two meteorological stations showing similar trends. Nevertheless, they differ in the total amounts of monthly and annual rainfall, since the total annual rainfall calculated for GUACHETA station (central zone) is of 890 mm but for ISLA DEL SANTUARIO station (northwest) is 1126 mm.



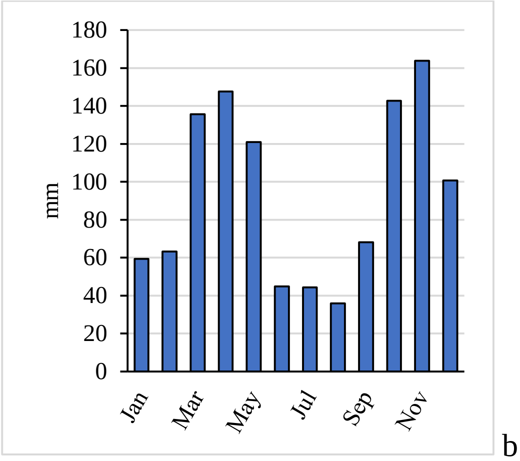


Figure 6. Average monthly precipitation estimated from the data collected between 1991 and 2020 for two meteorological stations:
(a) GUACHETA [24010170] and (b) ISLA DEL SANTUARIO [24015120].

The precipitation shows an uneven distribution of rainfall throughout the territory, with numbers that oscillate between 800 mm and 1126 mm of total annual precipitation, although the values in most of it lay below 1000 mm. As it is shown in Figure 7, the highest values are present in the Norwest zone, whereas, in general sense, the central zone where the GUACHETA meteorological station is located is a more accurate representation of the whole territory.

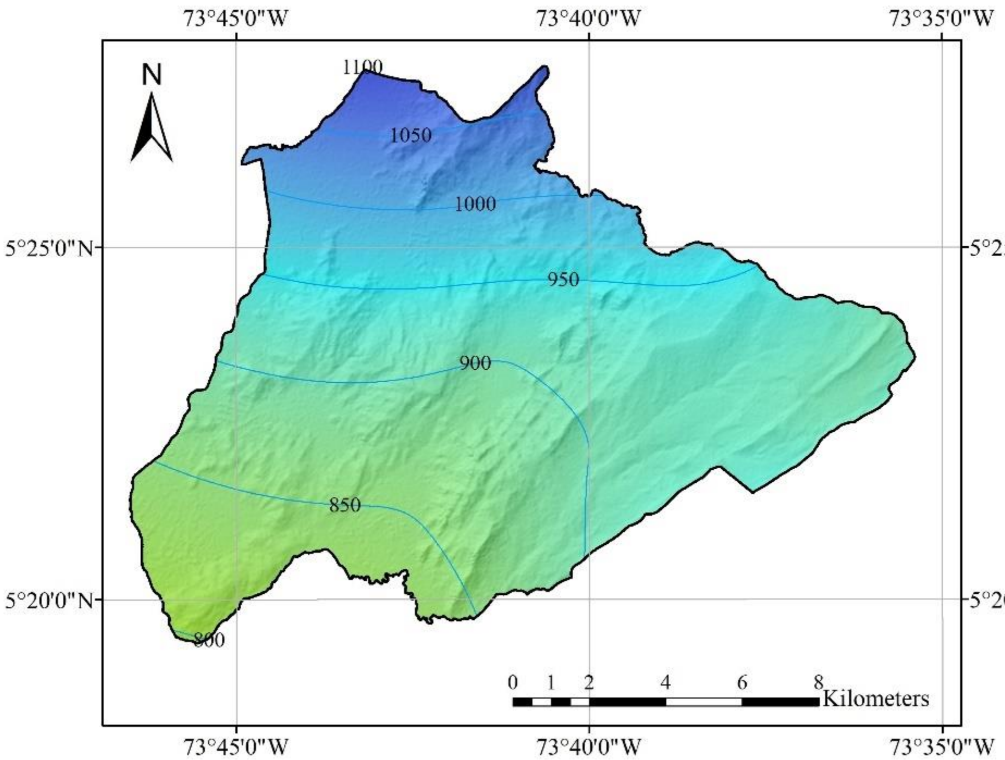


Figure 7.Spatial distribution of annual precipitation (mm) in Guachetá.

An average value of annual potential evapotranspiration was estimated at 1429 mm. Thus, the relation between potential evapotranspiration and precipitation (ETo/P) was established at 1,6 for GUACHETA station and at 1,3 for ISLA DEL SANTUARIO station. According to IGAC (2014a) values of ETo/P ranging from 1 to 2 for locations between 2000 and 3000 m.a.s.l. indicate a dry cold climate. This is consistent with the information obtained from IGAC (2001a) which indicates that most of the land is under a dry cold weather, while a smaller share of the territory above 3000 m.a.sl. is under a wet very cold climate.

Observing the rain patterns over time led to the analysis of the variation in the precipitation values over the years, which is depicted in Figure 8 and Figure 9. Although there are no big observable differences in the values of average precipitation over time, there is an increasing variation in the values of total annual precipitation. Within the last 10 years, the region has experienced the highest and lowest values of total annual precipitation since 1962, during 2011 and 2015 respectively. Moreover, there is a significant variation in the values of total monthly precipitation during recent years. In 2019, the total rainfall during March was notably higher than the average, dropping below the average in April, and going back to a normal trend during May. The rest of the months of 2019 indicate slightly dryer conditions than an average year. A more erratic situation was observed for 2020, when the first rainy season (Mar-May) showed dryer conditions, with a more wet June than usual. Also, the precipitation during October registered a value under the normal range of variation, whereas heavy rainfall was experienced during some days in November which led to a value of monthly rainfall notably higher than the normal values; a similar situation was experience in December to a less extent.

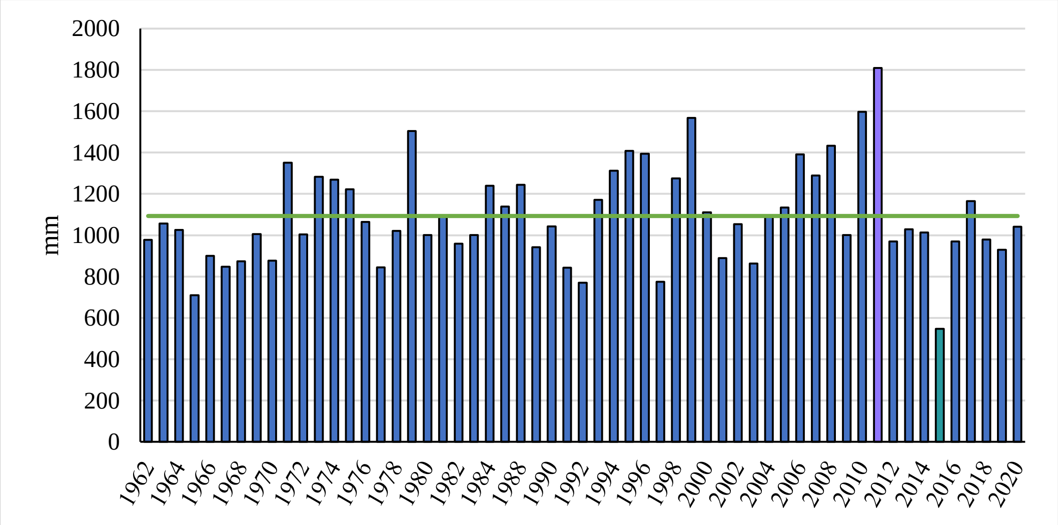


Figure 8. Total annual rainfall (mm) between 1962 and 2020 for the station ISLA DEL SANTUARIO. Highest and lowest values shown in different colors.

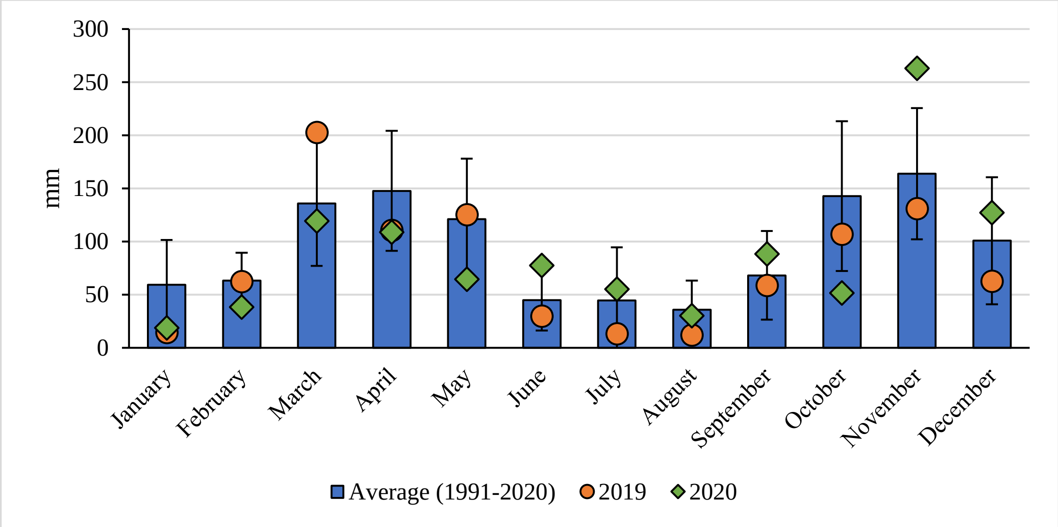


Figure 9. Average monthly precipitation compared with the rainfall registered for 2019 and 2020 for the station ISLA DEL SANTUARIO (error bars represent one standard deviation).

Vegetation and land cover

According to the Holdridge life zone system (IGAC, 2014a), since the dominating climate in most of the area is dry cold with a rainfall between 500 to 1000 mm, an average bio temperature between 12 - 18 °C corresponds to a low montane dry forest. For a smaller part, the natural vegetation is that of a low montane rain forest whereas for the zones located above 3000 m.a.s.l. it is of rain montane forest.

Within the boundaries of the municipality the biggest share of the territory is covered by pastures, that along with the agricultural land sum up to 64% of the total area (Figure 10). The natural vegetation is mostly represented by shrub and/or herbaceous vegetation (27.7%), which are mainly found in the east (Figure 11) where the high altitude and cold weather pose a limitation for agriculture. The remaining area is covered by open spaces with little or no vegetation (4.5%), inland wetlands (1.9%), forest (1.6%) and artificial surfaces (0.4%).

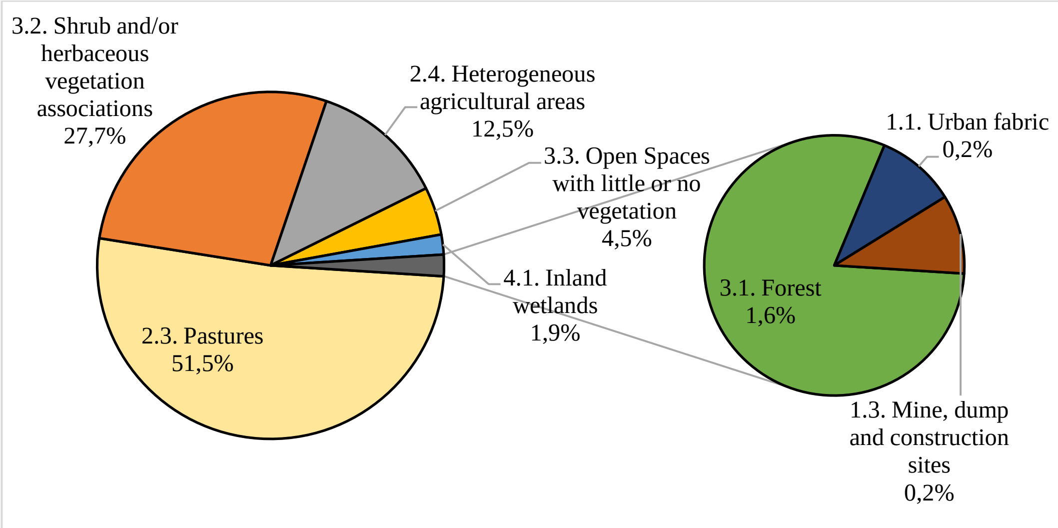


Figure 10. Proportions of different land covers found in Guachetá.
Source: own elaboration based on IDEAM (2014).

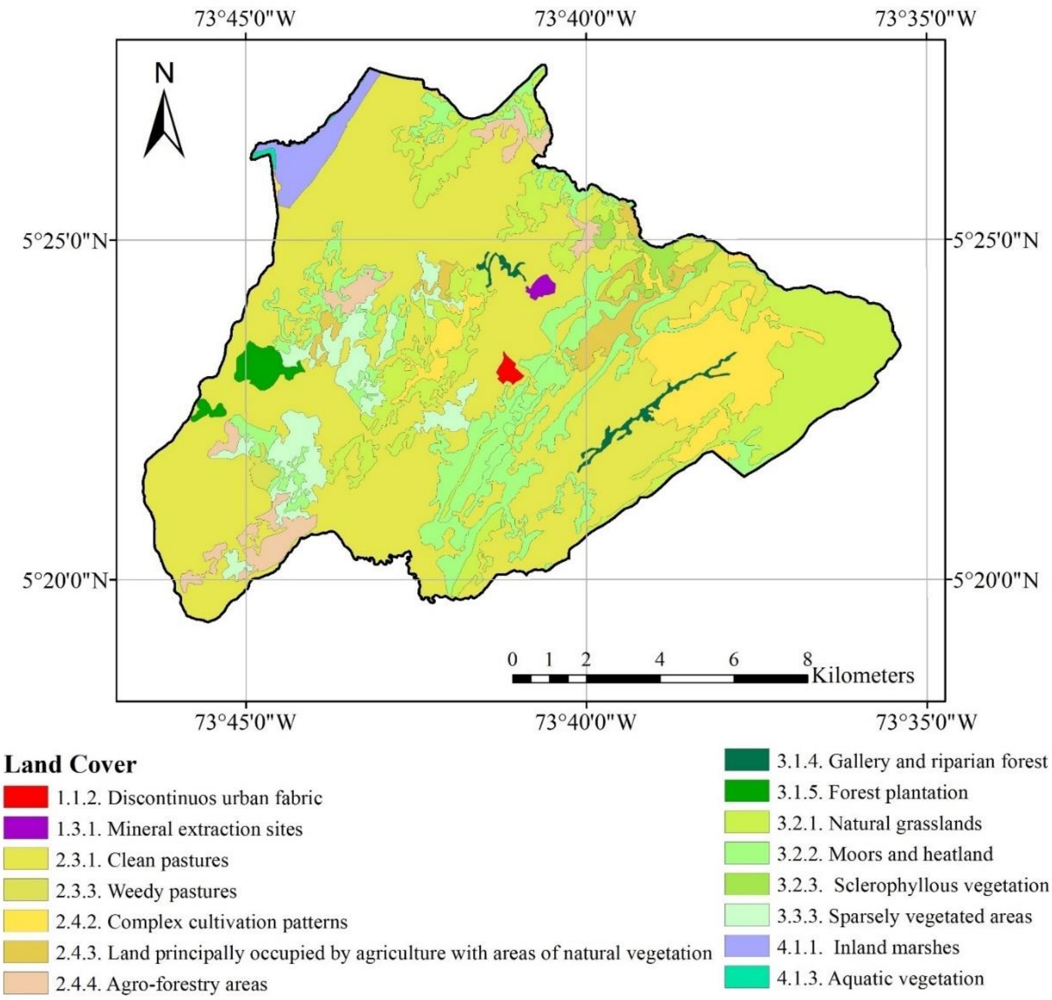


Figure 11. Land cover map of Guachetá.
Source: own elaboration based on IDEAM (2014).

4.1.2. Land use capability and conflicts

Figure 12 depicts the map of Guachetá classified according to its land use capability. Out of the eight possible classes for land use considered in the methodology, only five are identified within this territory. The majority of the land is classified under class VI (41%) mainly due to the limitation of the climate, combined with the steepness of the slopes and the risk of erosion. In fact, most of these lands are found where there are hills, glacis and homoclinal ridges or in areas where the high altitude supposes a very cold climate that imposes a considerable limitation to agricultural production. Thus, the steepness of the slopes along with the low rainfall during one semester are major limitations for a big share of the area, whereas in other parts the very cold climate or the erosive processes are more relevant. According to IGAC (2014b) these lands are only suitable for some semi-perennial or perennial, semi-dense and dense crops, agroforestry, forestry, or extensive livestock raising if overgrazing is avoided and there is an adequate management of pastures. For these purposes the implementation of soil conservation practices is required.

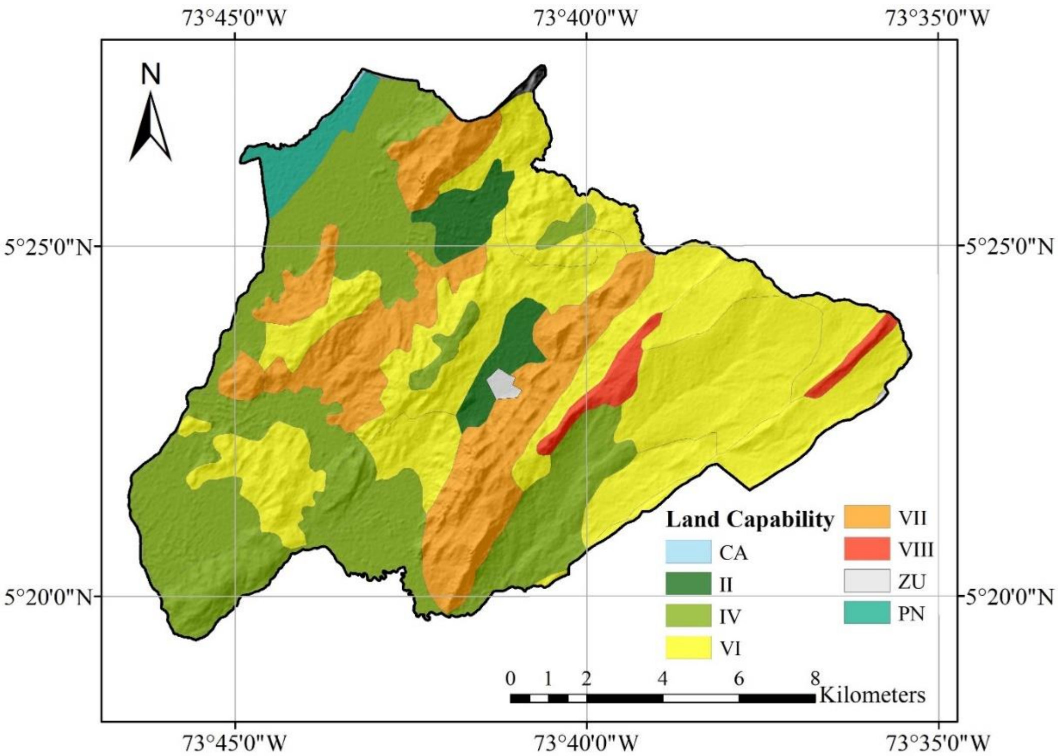


Figure 12. Land use capability in the study area. CA-water body, PN-protected area, ZU-urban. Source: own elaboration based on IGAC (2001b).

In second place, the class IV accounts for the 32% of the territory and is mainly located in the flat zones of the terraces and the flood plain, and in some of the hills where more steep slopes are present. One of the main limitations for land use in these areas is the characteristics of the soil, since they have an imperfect drainage, moderate effective depth and moderate to low soil fertility. Also, some areas are susceptible to occasional flooding, although there is also low rainfall during a semester. For the class IV lands located in the hills, the limitations are more related with steeply sloping slopes, poor rainfall during the two semesters, low fertility and shallow effective soil depth. Therefore, these lands are restricted to specific crops and require careful management and conservation practices. They can be used in livestock with good-yielding pastures and with technical management of paddocks. Agroforestry is a good option in sectors with steeper slopes, eroded areas and susceptible to deterioration. In sub-humid and semi-arid areas such as Guachetá, crop yields are directly related to the distribution of rainfall; thus, high yields can be obtained during years adequate humidity (IGAC, 2014b).

Part of the remaining area (18%) is classified under class VII, which is present only in the hogbacks and the ridges. Thus, the dominating limitations are the steepness of the slopes that are mainly above 50%, the shallow effective soil depth, the erodibility, and the poor rainfall throughput the year. Consequently, the lands are suitable for forestry for conservation purposes and permanent multi-stratum vegetation cover is absolutely necessary given the very high susceptibility of soils to deterioration. Nonetheless, when the topography and the soils offer sufficient effective depth, a sustainable use of productive forest can be done, and even agroforestry systems can be established with soil conservation and water management practices aimed at preventing and controlling erosion processes (IGAC, 2014b).

The "best soils" found in the zone, according to their land use capability, are those of the class II occupying 4% of the municipality area. These soils are only present within the terraces and their only limitations are related with climate since they have risk for frosts and water deficit during part of the year. Therefore, these lands are suitable for agricultural production with transitory, semi-perennial, or perennial crops as well as intensive livestock raising with high-yield pastures. For this case, they require supplemental irrigation and some conservation practices.

Finally, the remaining area corresponds either to the class VIII, protected areas or waterbodies. The class VIII lands are found in the hogbacks where the steepness of the slopes is higher than 75%, with shallow soils and low precipitation throughout the year. Thus, due to their extreme vulnerability (very steep areas) they should only be used for the conservation of nature or its (IGAC, 2014b).

On the other hand, the map showing the land use conflicts is presented in Figure 13. According to this information, 46% of the land is under an adequate use with no conflicts meaning that the environmental offer matches the demand in only that part of the territory. On the other hand, 29% of the total area is underutilized whereas 25% of it is overutilized, meaning that this share of the land has been subjected to the degradation of natural resources, especially the soil.

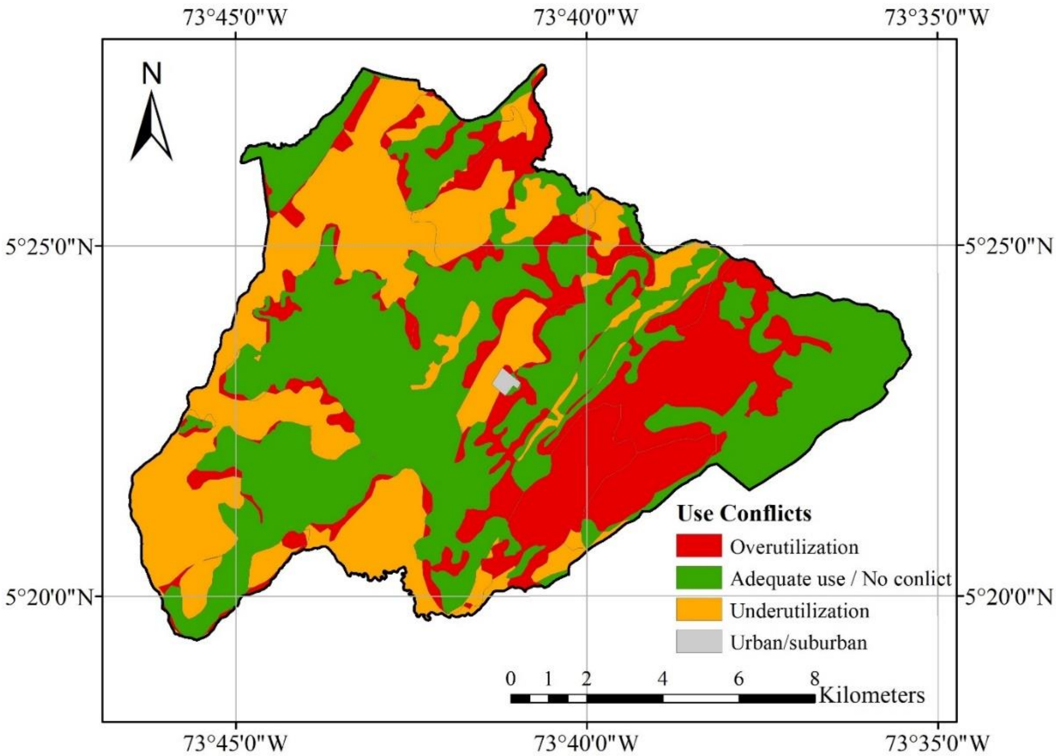


Figure 13. Land use conflicts in the study area.
Source: own elaboration based on IGAC (2014).

Also, the proportion of land under conflict for each agrological or capability class is illustrated in Figure 14. Class II lands have the highest share of underutilized land, since they have the highest productivity potential. A big part of this area is covered by pastures for extensive livestock raising, nonetheless the land characteristics allow to have a more intense agriculture in a sustainable way according to IGAC (2014b) criteria. A similar situation arises for some class IV lands, where crop production would be a more suitable production than only having pastures. Nonetheless, the class IV lands that lie on the hills with more steep slopes experience overutilization due to overgrazing that can leads to erosion. Likewise, the overutilization conflicts present in the class VI, VII and VIII lands are due to the presence of livestock in lands with high erodibility where, instead, there should be less intense activities that promote the conservation of soil and the native vegetation. Moreover, part of the protected areas identified within the territory are overutilized, namely, the protected area surrounding the Fúquene lagoon that has been used for growing pastures.

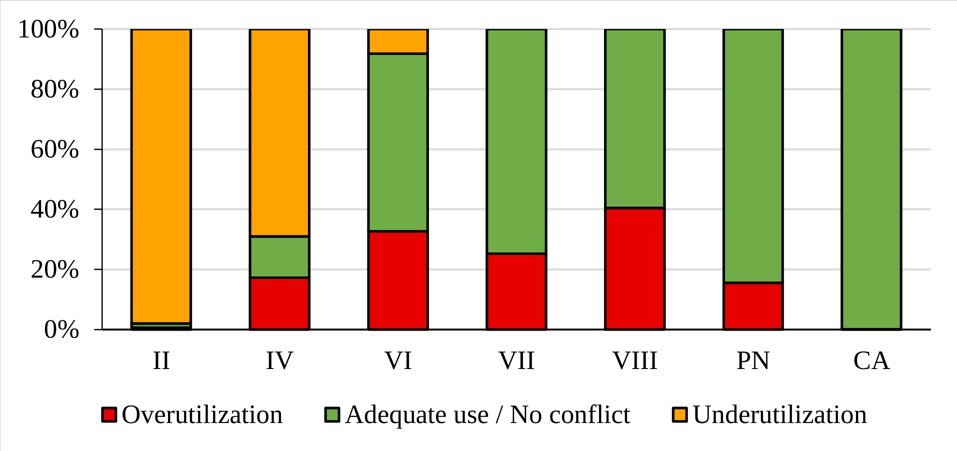


Figure 14. Percentage of area with land use conflict per each agrological class. CA-water body, PN-protected area.

4.1.3. Socio-economic aspects

Out of the 14 241 inhabitants reported in 2020 in the municipality (Terridata, 2020), 7 722 people live in rural areas (54.2%). As it is shown in Figure 15, most of the households in the rural areas are farms or productive units smaller than 1 hectare (49.1%) or between 1 to 3 hectares (27.2%), whereas productive units larger than 10 hectares represent only about 6% of the total households. However, when looking at the total area occupied by the farms within the territory there is a different situation. Most of the land is occupied by productive units larger than 100 hectares (37.6%) and the farms larger than 10 hectares occupy about 64% of the total area. In contrast, only the 15% of total land is occupied by farms smaller than 3 hectares. This means that more than half of the territory belongs to less than 5% of the rural population, whereas more than 75% of the productive units lie within the 15% of the area, showing an uneven access to land.

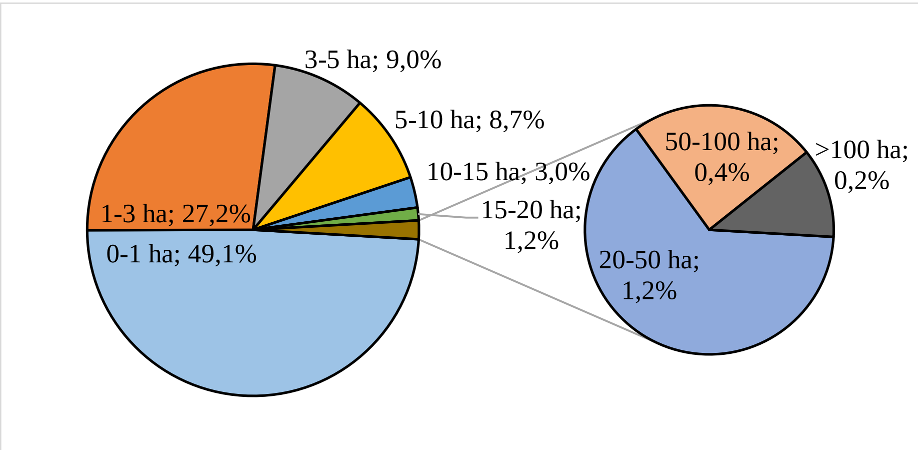


Figure 15. Percentage of number of households classified according to different farm sizes. Source: own elaboration based on TerriData (2020).

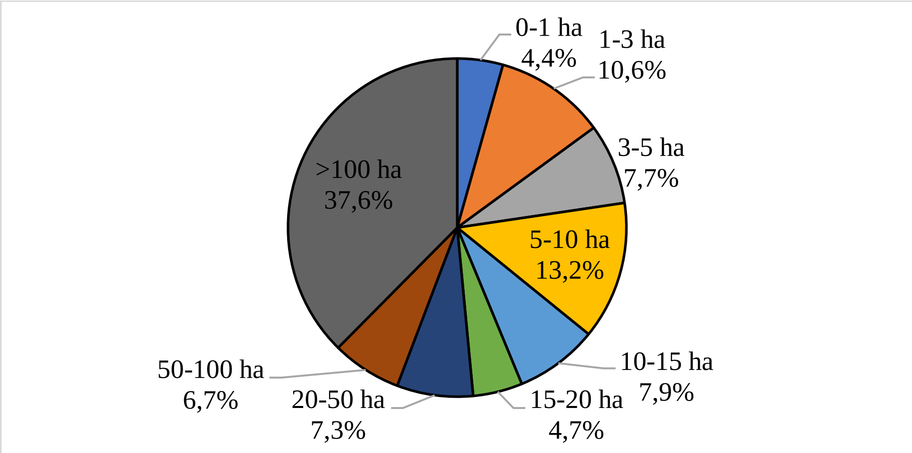


Figure 16. Percentage area of the municipality occupied by different farm sizes. Source: own elaboration based on TerriData (2020).

The production of annual crops in the municipality is dominated by potatoes, which accounts for the 83.6% (4 144 t per year) of total amounts of annual vegetable products (Terridata, 2020). Yet, the total yields have been estimated at 16.19 t/ha, a value that lies below the national mean production of 20.17 t/ha and is also much lower than the 23.3 t/ha reported for Cundinamarca. Similarly, onions are the second most important annual crop with a total production of 699 t per year (14.11%), but the yields of 18.39 t/ha are lower than the mean values reported for Cundinamarca (20.39 t/ha) and Colombia (22.63 t/ha).

4.2. Participants

All of the farmers interviewed indicated that they identified themselves as small-scale farmers, were proud of being peasants, and shared the culture, traditions and identity of the peasant farmers of the Altiplano Cundiboyacense. The information about the size in area of their holding (endowment factor), if agriculture was their main means for the livelihoods of the household, how much of their production was for commercial purposes or for self-consumption at the household, the principal product of their activity, and who runs the farming operations, is presented in Table 2 together with the information about the other participants.

Table 2. Participants.

Group	ID	Description						Participation in study	
		Agriculture is the main means of subsistence	*Identifies as peasant or small producer*	*Production for sale or self-consumption*	*Main product*	*Farming operations run by*	*Area of the holding (ha)*	*TAPE surveys*	*Semi-structured interviews*
Farmers	P1	Yes	Yes	Mostly for sale	Potatoes	Household members with occasional hired/ exchanged labor	<1	X	X
	P2	Yes	Yes	Mostly for sale	Milk	Household members	1-3	X	X
	P3	Yes	Yes	Mostly for sale	Milk	Household members with occasional hired/exchanged labor	1-3	X	X

Group	ID	Description						Participation in study	
		Agriculture is the main means of subsistence	*Identifies as peasant or small producer*	*Production for sale or self-consumption*	*Main product*	*Farming operations run by*	*Area of the holding (ha)*	*TAPE surveys*	*Semi-structured interviews*
	P4	Yes	Yes	Mostly for sale	Potatoes	Household members with occasional hired/exchanged labor	<1	X	X
	P5	No: Wages	Yes	Mostly for self-consumption	Milk	Household members	1-3	X	X
	P6	No: Mining.	Yes	Mostly for sale	Potatoes	Household members	<1	X	X
	P7	Yes.	Yes	Mostly for sale	Potatoes	Household members with occasional hired/exchanged labor	1-3	X	X
	P8	No: Machine operator.	Yes	Equaly for sale and self-consumption	Milk	Household members	<1		X
	P9	Yes	Yes	Mostly for sale	Milk	Household members	1-3		X
	P10	Yes	Yes	Equaly for sale and self-consumption	Milk	Household members	1-3		X
Representatives	R1	Association of potato producers and cold climate agricultural products of Guachetá							X
	R2	Association of milk and bovine producers Valle Verde of Guachetá							X
	R3	Municipal Agricultural Technical Assistance Unit (UMATA)*							X
Experts	E1	Agrologist. PhD Soil Science. Former Deputy director of IGAC. Former dean of Agrology faculty at UJTL. Former Director of Center for Scientific Research and Environmental Studies UJTL.							X
	E2	Agrologist. MSc Soil Science. Former Director of Environmental impact assesment Specialization and Environmental Sciences Master programs.							X
	E3	Agronomist. PhD Agroecology. Director of Department of Biological and Environmental Sciences UJTL.							X

*The Municipal Agricultural Technical Assistance Unit (UMATA) has the responsibility of offering agricultural technical assistance related with animal health, project planning, food security, crops selection, and genetic improvement. The essence of this office is to aid small producers through the promotion of economic development, peasant markets, training, agreements with other entities, support to agricultural associations, bank agreements, environmental education, and collection of agrochemical containers, among other services.

4.3. Characterization of agroecological transition (CAET) of the systems

Based on the scoring of the 37 indices for the 10 elements of agroecology, the characterization of the level of agroecological transition for the 7 assessed agroecosystems was performed. The scores for each element and each system are presented in Table 3 and Figure 17 is a visualization of the results of the CAET for each of the farms, grouped according to their similarity for illustrative purposes. The scores obtained for each individual index of the elements are presented in Appendix .

Table 3. General scores of the 10 elements of agroecology for each of the assessed agroecosystems

ELEMENT	P1	P2	P3	P4	P5	P6	P7	Average
DIVERSITY	50.00%	50.00%	56.25%	18.75%	68.75%	62.50%	56.25%	**51.79%**
SYNERGIES	43.75%	50.00%	31.25%	25.00%	68.75%	50.00%	50.00%	**45.54%**

ELEMENT	P1	P2	P3	P4	P5	P6	P7	Average
EFFICIENCY	31.25%	50.00%	18.75%	25.00%	62.50%	50.00%	18.75%	**36.61%**
RECYCLING	37.50%	43.75%	25.00%	37.50%	50.00%	56.25%	37.50%	**41.07%**
RESILIENCE	43.75%	37.50%	62.50%	37.50%	50.00%	56.25%	43.75%	**47.32%**
CULTURE & FOOD TRADITION	83.33%	83.33%	91.67%	83.33%	75.00%	91.67%	75.00%	**83.33%**
CO-CREATION & SHARING OF KNOWLEDGE	58.33%	33.33%	16.67%	50.00%	8.33%	58.33%	33.33%	**36.90%**
HUMAN & SOCIAL VALUES	68.75%	62.50%	62.50%	62.50%	62.50%	75.00%	56.25%	**64.29%**
CIRCULAR & SOLIDARITY ECONOMY	41.67%	41.67%	25.00%	33.33%	58.33%	66.67%	25.00%	**41.67%**
RESPONSIBLE GOVERNANCE	50.00%	33.33%	16.67%	33.33%	16.67%	50.00%	41.67%	**34.52%**

The element that showed the most similarity in total scores among all the producers was Human & Social Values. The general scores for this element ranged between 56,25% (P7) to 75,00% (P6). Although for the indices of *women's empowerment* and *labour* most of the scores obtained were either 3 or 4, the index of *youth empowerment and emigration* lowered significantly the overall result for the element since in most of the cases the scores were 1 and in one case it was 0 (P7). This is because according to the farmers, most of the young people believe that agriculture is too hard and wish to emigrate and dedicate their lives to other activities. The index for *animal welfare* showed medium to relatively high scores since, in general, farmers intend to avoid that animals suffer from hunger or thirst and in most cases the animals are not prone to diseases, but can experience some stress.

Another element that exhibited a low variability between farms was Culture & Food Tradition. Overall, this was the element that obtained the highest scores, ranging from 75,00% (P5 and P7) to 91,67% (P3 and P6). In general, people have access to an appropriate diet and are aware of good nutritional practices whether they apply them or not (*appropriate diet and nutrition awareness*), there is respect for traditions and local identity (*local or traditional identity and awareness*), and traditional food preparation is in place with the use of local products (*use of local varieties/breeds and traditional knowledge for food preparation*).

Resilience was an element that showed a higher variability in its scores due to more varied answers about *indebtedness* between producers. While for some farmers their debts are about half of their income (P1, P2, P4 and P7), others have no debts because they had never applied to any kind of loans or other financial support (P5 and P6). Also, the *diversity of activities, products and services* is different between the farms, ranging from only two or three productive activities (P2 and P4) to more than three activities and one service (P3). For the index of *stability of income/production and capacity to recover from perturbations*, the responses where very homogeneous and generally low since most of the producers indicated that their profit margins had been decreasing through the years, with variable production and little capacity to recover from perturbations. Likewise, regarding the *mechanisms to reduce vulnerability*, although farmers have theoretical access to loans it is hard to get those in practice. Insurances are not common, and for some of them although the community might be supportive their capacity to help each other is limited. Thus, the general scores for Resilience varied from 37,50% (P2 and P4) to 62,50% obtained for the farmer P3, who was the only one that indicated a stable income, who had the highest diversity of activities, and whose debts were limited.

In terms of Recycling, the producers show some similarities in their practices although the indices also show some differences while the general scores for the element range from 25,00% (P3) to 56,25%. Regarding the *renewable energy use and production*, most of the farmers purchase gas as a form of energy for the household consumption, they are connected to the electric power distribution of the municipality which relies on thermal powered stations (coal-fired) and hydroelectric power, and use to some extent animal traction. Thus, there is not a significant amount of self-produced and renewable energy consumption. Also, the *water saving* index showed in general low values since the farms do not count with more than one technique for water harvesting or saving and, in fact, three of them do not have any equipment or practice of this purpose. On the contrary, the *recycling of biomass and nutrients* scored high for most of the agroecosystems because the majority of the residues generated at the farms are recycled (crop residues as animal feed, manure as fertilizer) and little waste is burnt. The most notable differences among producers were about the *management of breeds and seeds*; there are distinct degrees of dependence on the purchase of genetic resources from the market. For example, P3 depends completely on the market for obtaining new animals and seeds whereas for P6 the majority of genetic resources are self-produced through the reproduction of their breeds and varieties.

Responsible governance was one of the elements that presented the lowest general scores, although they show a higher variability than the previous elements with values between 16,67% (P3 and P5) and 50,00% (P1 and P6). Regarding the *producers' empowerment*, all the participants alleged that their rights were recognized and respected but their bargain power was reduced and their context did not stimulate them to improve their livelihoods or to develop their skills. Their perception on *participation in governance of land and natural resources* was more variable although all of them claimed that there are not fully operational mechanisms that allow producers to participate in the governance. Most of them said that their influence on decisions is either limited or that they were completely excluded. This last group of farmers (P3 and P5) was not directly involved with their community through any organization or association either, thus the *producers' organizations and associations* index scored the lowest value, meaning non-existent cooperation and no communal support. Most of the other farmers showed different degrees of involvement with a farmers' associations, as for some of them the role of the organization was marginal and represented no significant support while for others the association supposed a support for access to markets and other services.

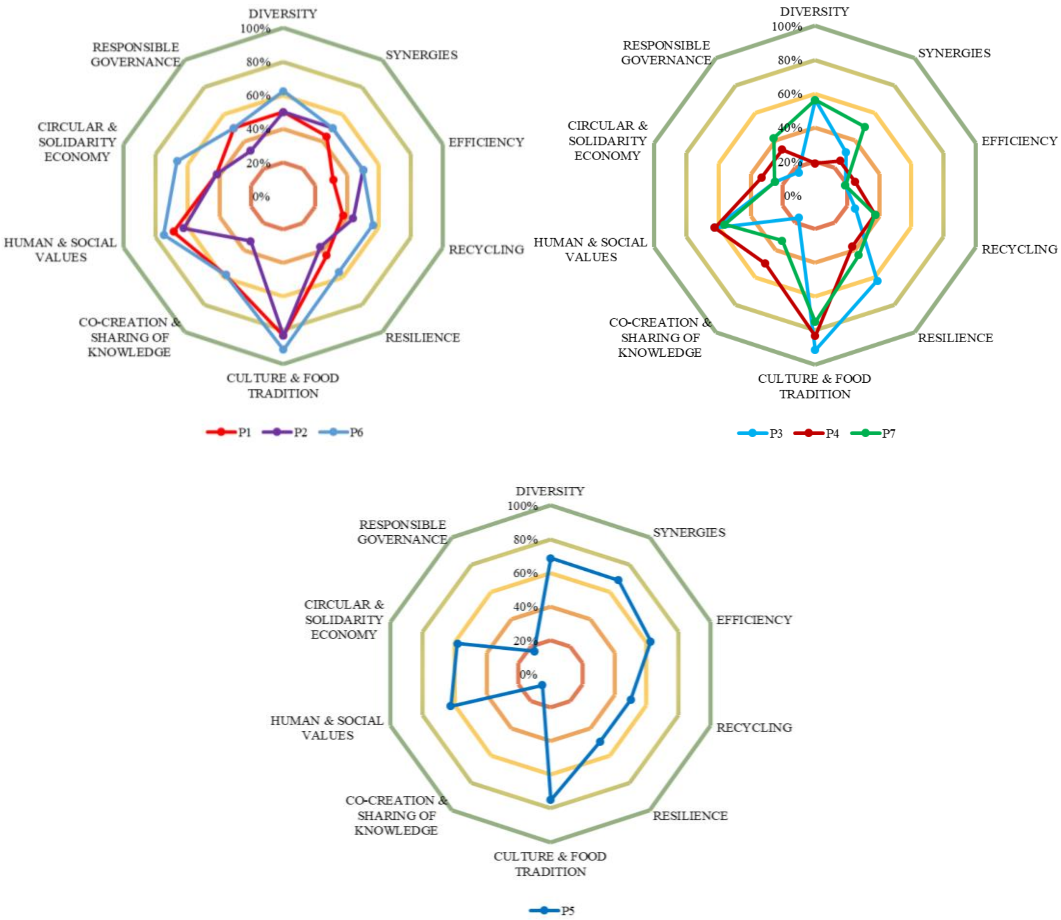


Figure 17. Radar type diagrams of results of the characterization of agroecological transition (CAET).

These differences in farmers' perceptions, relationships, and involvement with a farmers' association were more evident when analyzing the Co-creation and Sharing of Knowledge element, since this was the element that showed the most varied general scores ranging from 8,33% to 58,33%. The associations represented the main *platform for horizontal creation and transfer of knowledge and good practices* along with some limited efforts done by the local official agencies. Those farmers who showed no involvement with an association also claimed that there were no available platforms for producers. On the contrary, other farmers pointed out the existence of platforms for this purpose although it is not used to share knowledge on agroecology specifically. In a similar way, the *participation of producers in networks and grassroot organizations* was very variable, since one producer claimed to be isolated with no relations with their community (P5), while others were well interconnected, participating in events with the inclusion of women. Concerning the *access to agroecological knowledge and interest of producers in agroecology,* although most of them do not know the scientific concept of "agroecology", some of them show agroecological principles in their practices and interest in spreading the knowledge. Nevertheless, some other farmers have little understanding about agroecological principles and do not trust alternative practices to conventional agriculture since it is perceived as less productive.

In the case the element of Diversity, most of the farms scored values between 50,00% and 68,75%, but one scored a very low value of 18,75% (P4). In that case the *crops* diversity of the farm was minimal, since the production was done under a monoculture and the *animals'* diversity was also very low with only one species produced. On the rest of the farms, there were no single crops occupying the majority of the area but there were at least two or three crops with significant cultivated area and in the most diverse cases (P2, P5 and P6) at least four adapted crops were grown using intercropping within a spatially diversified area. Also, the farms accounted for at least two different species of animals and, in the best scenarios, there was a significant amount of them. Nevertheless, the index that showed the lowest scores among all producers was the presence of *trees (and other perennials),* since only in one case there was a significant number of perennials of different species (P7), in two cases there where some trees of more than one species within the farmland (P5 and P6), while in the other cases there were only few trees of one species, or they were absent. The *diversity of activities, products and services* described in the elements Resilience was also considered for the general scoring of Diversity.

Connected to this, the Synergies showed a similar behavior among farmers. The lowest score of 25,00% described this element for P4, while the highest value of 62,50% was obtained for P5. The *crop-livestock integration* was medium for more than half of the farms, since animal manure is often used as fertilizer and they are mostly fed with feed produced within the farm. In the other cases the scores for this index were higher, especially for P5 where there is a complete integration because the animals are fed only with the production of the farm, all the manure is used for fertilization and they produce more than one service. The *soil-plants system management* also differs between farms in term of their practices to protect the soil. In no case the soil is left bare after harvest since it is either used to grow grass for the livestock or prepare for cultivation again. Nevertheless, the use of monocultures by P4 gives the system a low score, while distinct practices that promote the conservation of soil in the other farms gives them higher scores, obtaining the highest values for P2 and P5 because form these farms all the soil is covered, with regular crop rotation and intercropping. *Integration with trees* and *connectivity between elements of the agroecosystem and the landscape* were the indices that had the overall lowest scores. For P3 and P4 there was no integration, meaning that the trees didn’t have a role within the system, and no connectivity, meaning a high uniformity and absence of (semi)natural environments. For the rest of the farms, there was a low to medium integration with trees because the number of trees was reduced or the services and products provided were limited. Also, the connectivity with the landscape was medium to low.

When evaluating the efficiency of the systems there were also noticeable differences between farms, obtaining low values of 18,75% for P3 and P7 while the highest value of 62,50% describe this element for P5. In the less favorable scenarios the *use of external inputs* (energy-fuel, fertilizers, phytosanitary substances, genetic resources, etc.) was high and all of them were purchased from the market, whereas in other cases some inputs were produced in the farm. The *management of pests & diseases* for most of the agroecosystems scored low (especially P3 and P4) since chemical pesticides are used regularly and other types of management like biological substances and organic practices are limited or not used. However, for P6 this management is mainly done using organic practices and for P5 there is no use of chemical pesticides while biological substances (chili pepper) are the norm. Also, the *management of soil fertility* showed a high variability in scores between the systems. The lowest values for P3 and P7 were associated with a regular use and dependency on synthetic fertilizers, while in P1 and P4 manure is also applied to a little extent. For P2 and P6 organic practices are more regularly used and the use of synthetic fertilizers is uncommon, while for P5 no synthetic fertilizers are used. The last index of this element is *productivity and household’s needs* and for these cases there seems to be a negative relationship with the other indices. In other words, the lowest scores were obtained for P5 and P6 while the highest were for P3 and P4. In the case of P5 it was because the production of the farm does not meet their needs for food or other essentials, rather they have to rely on other external activities as main sources of income. Similarly, for P6 the production only covers their needs for food. In the other cases, production covers needs and generates surplus and for two of the farms it allows to have sporadic savings. Then, the ones who rely less on external inputs are also the ones that expressed to have lower revenues.

Finally, Circular & Solidarity Economy showed general scores between 25,00% (P3 and P7) and 66,67 (P6). Regarding the *local food system,* in general inputs are purchased from outside the municipality or the region although some food supply is locally available and there is exchange of goods and services between local producers to some extent. The index *networks of producers, relationship with consumers and presence of intermediaries* showed low scores for the majority of the systems assessed since although there are networks of producers, they do not work properly, there is little to non-existent relationships with final consumers, and the intermediaries have control over the marketing process. In contrasts, P6 has a direct contact with consumers with no intermediaries to sell their products. Thus, regarding the *products and services marketed locally* P6 along with P5 obtained the highest scores since all their products are marketed locally, whereas for the other farms although local markets exist only part of the product are locally marketed.

As summary, Figure 18 shows a generalization of the results obtained from the CAET where the elements' scores of the 7 agroecosystems assessed were averaged allowing to identify the overall strengths and weaknesses of the small-scale agriculture in the municipality. The strongest element of all is Culture & Food tradition and the second one is Human & Social Values, although for this one the scores were low mainly due to the lack of interest or opportunities for the youth within the agricultural sector. Of the remaining elements, Diversity was the only one that had an average score slightly above 50%. For this element the scores are lowered mainly because of the lack of incorporation of perennials and the limited number of products and services offered at the farms.

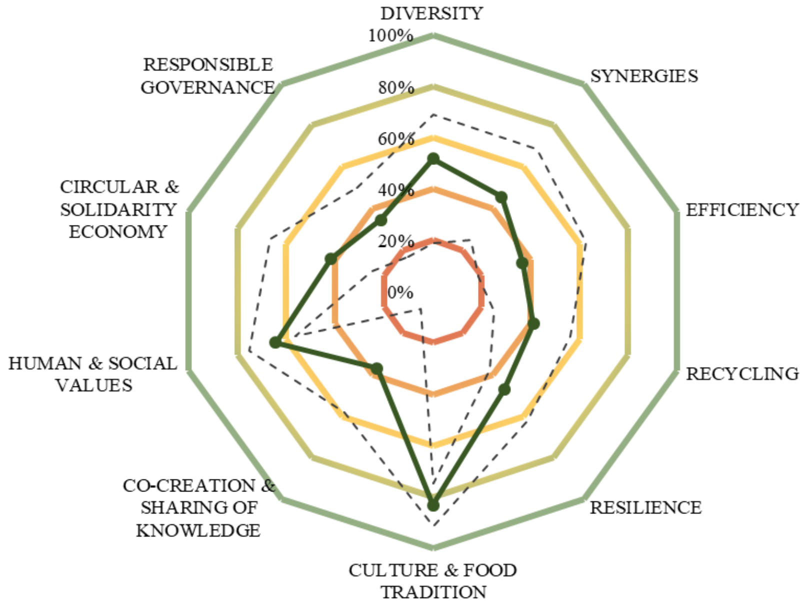


Figure 18. Radar type diagram of average results of the CAET for the small-scale farming system. The dotted lines indicate the range of variation.

Responsible Governance, Co-creation & Sharing of Knowledge, Efficiency, Recycling, and Circular & Solidarity Economy were the elements that showed the lowest average scores. Three of them are connected with social-related issues and the relations of the farmers with the community, being one related with context features (Co-creation & Sharing of Knowledge) and the other two (Responsible Governance and Circular & Solidarity Economy) those that determine an enabling environment (see Figure 2). The Efficiency is affected especially by the dependence on the purchase of external inputs for the control of pests and diseases and the fertilization of the soil. The low scores for Recycling are due mostly to the poor water management and the lack of production and use of renewable sources of energy.

Finally, the Synergies were affected by the lack of integration of trees within the systems and the poor connectivity with the natural landscape, whereas the Resilience of the systems was lowered mainly due to the low stability of the income and productivity of the farms.

4.4. Performance of the systems

As previously mentioned, it was not possible to evaluate four of the core criteria due to the constraints of the study (impossibility to have face-to-face interviews due to travel restrictions). The results for the remaining 6 core criteria are presented in Table 4.

Table 4. Results of core criteria of performance applied to the individual systems.

CORE CRITERIA	P1	P2	P3	P4	P5	P6	P7
SECURE LAND TENURE	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable
PRODUCTIVITY							
INCOME	Acceptable	Unsustainable	Acceptable	Unsustainable	Unsustainable	Unsustainable	Unsustainable
ADDED VALUE							
EXPOSURE TO PESTICIDES	Unsustainable	Unsustainable	Unsustainable	Unsustainable	Desirable	Unsustainable	Unsustainable
DIETARY DIVERSITY	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable	Desirable
WOMEN´S EMPOWERMENT							
YOUTH EMPLOYMENT	Acceptable						
AGRICULTURAL BIODIVERSITY	Acceptable	Acceptable	Acceptable	Unsustainable	Desirable	Acceptable	Acceptable
SOIL HEALTH							

The Secure land tenure which belongs to the Governance dimension suggested a desirable state for all of the agroecosystems assessed. This is because there is there is legal recognition of access to the land, the perception of the farmers is that it is secure and they have the right to sell, bequeath, and inherit. Also, the Dietary diversity is in a desirable state for all the households. This criterion is based on the Minimum Dietary Diversity for Women and in all of the cases the participants indicated that within their households there were consumed least 7 out of the possible 10 different food groups within the previous 24 hours.

The criterion of Youth employment was evaluated as a whole, considering the answers of all the participants to compute a common score, which was “acceptable”. Out of the total youngster population between the ages of 15 and 24 years old, only one was currently working in agricultural production while the majority were having some kind of education and training and one more had left the community due to lack of opportunities. Also, only one person showed interest in continuing with the agricultural activity of their parents, while the others would emigrate given the chance or had already emigrated. Thus, the weighted score for this criterion was of 65% mainly because education or training is considered favorable for the youth despite the fact that in general they are not willing to continue with the agricultural production.

The Agricultural biodiversity showed different scores for the different systems, although in most of the cases this criterion was scored as “acceptable”. In most cases the Gini-Simpson index for crop species and varieties scored higher than 50% and for P2, P3 and P5 the scores were higher than 70%. Similarly, Gini-Simpson index for animal species and breeds was above 50% for 5 of the systems assessed and its maximum values were registered for P1 and P5. The index of natural vegetation, trees and pollinators was lowered in most cases due to the scarce productive area covered by natural vegetation within the agroecosystems. Nevertheless, in all of the cases the farmers reported a significant or abundant presence of beneficial organisms within the agroecosystems. The only cases that reported scores different than “acceptable” for this criterion were P4 and P5. P4 was a system were the crop production was dominated by monocultures and where there was only one animal breed, thus the Gini-Simpson indices were 0. In contrast, P5 had a high diversity of crops and animals, leading to scores in all the indices above 70%.

In terms of exposure to pesticides, only P5 had a desirable state whereas the others were considered as unsustainable for different reasons. In the case of P1, they used highly hazardous pesticides of class I although they applied a few mitigation techniques and had attempted some ecological management of pests. The other farms use moderately toxic pesticides of class II, but they do not use enough mitigation strategies (P2 and P6), there is no use of organic substances or other integrated practices (P3 and P4), or both (P7). Instead, P5 only used cultural control, by choosing resistant varieties, removing manually plants with signs of disease, and implementing intercropping and crop rotations.

Finally, the criterion of Income was evaluated based on the perceptions of the farmers on their income. For most of them this criterion turned out to be unsustainable because their income has declined through the years although they do not think that it differs significantly from the average of the region. Only P1 and P3 indicated that their income was somehow stable.

4.5. General perceptions on agriculture

The results of the participants' perspective on the different statements about agriculture are presented in Figure 19. Most of participants strongly agreed on that climate had become more unpredictable and that in the past more variety of products were cultivated, indicating a general trend towards specialization and reduction of agricultural diversity within individual agroecosystems. However, almost 70% showed some level of disagreement on that it is better to specialize on only one or few products. Some of them mentioned that they preferred to have different products from the farms to mitigate the risk for losses, but others also indicated that the size of the farm also affected how specialized it should be, that is to say, they believe that it is better to specialize for large farms.

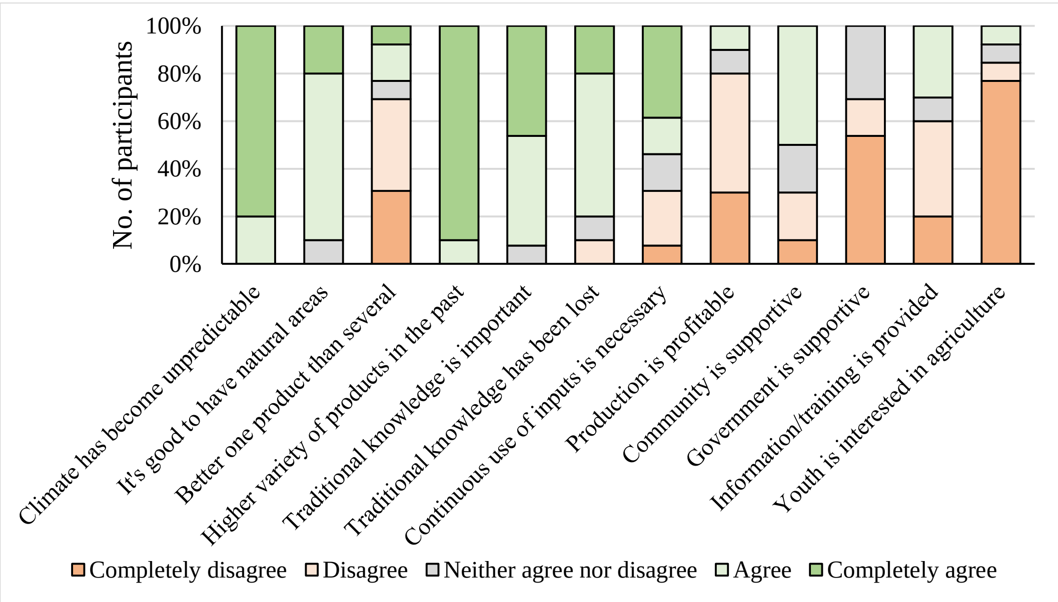


Figure 19. Stacked bar chart representing the level of agreement of the participants about 12 different statements.

Most participants also responded that it is good to have natural uncultivated areas within agricultural land, although only 20% had a strong opinion on this. Similarly, most participants remarked that traditional knowledge is important for agriculture but that much of it is been lost through time. On these regards, participants also commented that they perceive that other sources of knowledge like scientific research are also important, and despite that traditional knowledge is threatened, some of it is still conversed in some small-scale farming operations.

On the contrary, the statement that most of participants had a strong disagreement with was that the youths are interested in dedicating to agriculture. Only one of the participants agreed with these statements, which was P7, where they have one young family member actively involved with running the farm operation. Also, they showed a general disagreement with the statement that indicated the agricultural production was profitable enough to have a stable income, pay debts, have decent living conditions and have some savings. Similarly, almost 70% of respondents stated that they couldn't trust that government would support farmers, and within that group, more than half of total participants had a strong opinion about it. On the other side, more than half of the participants felt that their community was supportive, although up to 30% of them showed some level of disagreement.

Regarding the need for continuous use of inputs, slightly more than half of respondents agreed on that the use of agrochemicals was mandatory in order the maintain a reasonable amount of production. Nevertheless, they often referred to how the production was performed in the past when the fertilization was based on the use of manure and crop residues and the pest control was more oriented to organic practices, but now they feel that if they do not have this continuous input it would become economically unsustainable. Also, in a general sense they feel that the information and training that they are offered is not enough to obtain valuable knowledge that supports agricultural production.

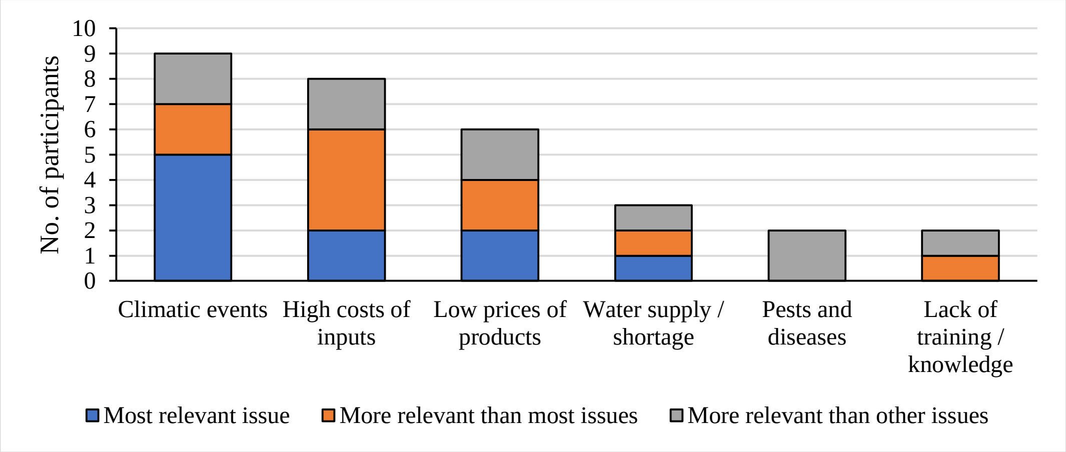


Figure 20. Ranking of most relevant problems for agricultural production.

On the other side, the results on the ranking of the issues that farmers most commonly face is presented in Figure 20. Almost all of the farmers interviewed indicated that the climatic events, such as droughts, frost or floods, were among the most important issues they faced, and half of them said that it was the most relevant problem. Also, the low profitability was reflected in the high cost of inputs and the low prices that they get form their products, which leaves them with very narrow profit margins. Also, the water supply was recognized as a major problem for some of the farmers, while pests and lack of knowledge were considered as less important. Low fertility of the soil and low amounts of production were not mentioned by any of the participants among the most important issues.

4.6. Main challenges identified by different stakeholders

The results of the semi-structured interviews analyzed through theoretical coding are presented below. Two main theoretical constructs were identified from several repeating ideas that were group into 5 main themes.

A. Individual small-scale farms face several productivity and profitability issues

A.1. Climate-related factors affecting productivity

There are biophysical environmental conditions that constitute major constrains to achieve a higher productivity. Some of these are related with the natural agroecological conditions of the zone but there is also evidence of the alteration of the typical conditions, processes and dynamic on a global scale which can be related to anthropogenic activities.

A.1.1. “Verano” is too harsh.

‘Verano’ is the Spanish word for ‘summer’. In the local context it is not used to describe the typical summer season of temperate zones, but it refers to the dry seasons with low rainfall. Most of the participants pinpointed this as one of the major challenges for agriculture due to the lack of access to water since agriculture is predominantly rainfed and continuous irrigation is no possible in most cases. This is because of the lack of equipment for irrigation and because there is an uneven access to water depending on the location of the farms within the landscape, which determines their possibility to implement rainwater harvesting, store rainwater in pits or obtain water from streams. “It would take a magnificent irrigation project. It would need irrigation to make up for the water deficiency”, said one of the experts. Nevertheless, most of them indicated that lack of rainfall and limited access to water during the dry season is one of the main factors affecting productivity of crops. Indeed, one of the experts alleged that the zone of the Ubaté Valley has an exceptional dry climate in comparison to the conditions of the region and that a great project for an irrigation district would be required in order to suffice the water deficiency. A second expert also mentioned that access to water is a fundamental issue and that measures must be taken in order to guarantee the availability of water.

A.1.2. The climate has become too unpredictable.

Also connected with the intensity of the dry periods is the variation on the typical climatic patterns. “The climate is not the same as a few years ago; you can no longer plant potatoes in November” said one of the farmers. A second one also mentioned: “You no longer know when it rains. We have no alternatives due to the lack of rain. Before there was more confidence in the times”. They describe this as one of the main factors affecting their productivity since they feel unable to predict when would be the best time to sow. This is both related with the variation on the typical rain patterns during the year and the expected time for frosts. They said that previously the sowing season was around November, when they could expect some rain. Also, they knew that there would be frosts during January. But, during the last years there are not so clear patterns and there are delays in the rain. Also, the time for frost seems to be spreading to other months, but this is also variable between years. Then, there is an increased risk of losing the harvest and the investment of cultivation due to climatic events.

A.2. Paradigms about agricultural production: shift towards conventional agriculture

One of the key factors that determine the outcomes of agricultural production is the ways in which it is carried out. Since the second half of the last century the traditional farming systems have been enforced to shift to more conventional systems.

A.2.1. External inputs: “Nowadays we always need to spray to control pests.”

Among the biological factors influencing the productivity of farming systems, pest control was the one mentioned in almost all of the interviews. Farmers relate especially to the production of potatoes and the maintenance of pastures for dairy cattle production. There are several different pests and diseases that affect the potatoes, although among the most important and predominant ones according to the farmers is the Guatemalan potato moth (*Tecia solanivora*). For the pastures, the most important pest is a bug (*Collaria columbiensis*) that “withers” the grass.

Therefore, many farmers described their dependency on external inputs, especially pesticides, and how this was not the case in the past. One of the most common repeating ideas was that they acknowledged how their parents and grandparents didn’t require to have this kind of inputs to have some productivity and how alternative practices to manage pests, like the use of “ají” (chili pepper), were in place. Nonetheless, there’s been a shift in the conception of how the production should be carried out. Now farmers feel that a constant use of inputs, to obtain enough produce to make a living, has become mandatory. This is especially critical for the potatoes since different participants mentioned that there are several different chemical substances that they need to apply to prevent the potatoes from being affected by different pests and diseases. “Unfortunately, now inputs are mandatory; today for the potato, it has to be poisoned”, expressed one of the farmers. However, they also said that they have experienced how it becomes more and more difficult to control pests and diseases the more they use pesticides. In their understanding, they believe that the pesticides they use also come with a new “bug” or pest. In words of one of the farmers, “when inputs were used, each one came with its "virus", that in the future will be harmful”. Also, some of them regret the use of these substances because of the pollution that it causes and the unintended effect on health, and that it would be ideal if there was the possibility to shift towards the use of alternative methods to manage pests. The farmers who reported less problems with pests with the use of alternative practices, also indicated that that production was mainly for self-consuming at the household, being it relatively small.

A.2.2. Reduced diversity of products

Connected with the increasing amount of agrochemical inputs that the agricultural production had experienced over the last generations, there is an increasing trend in specialization of farms in single products. This phenomenon was more evident for the participants in relation to the larger farms, but it has also affected the small-scale farming systems. Two of the experts mentioned that they have seen how the diversity of products has decreased towards only having milking cows and that the family orchards have become rarer. “The sheep have disappeared. The home garden is rarely used” One of the farmers said that “nobody sows anymore”. Some farmers pointed out that for larger operations it became easier to manage a reduced number of products, yet they also believed that more diverse systems reduce the risk of losses. There seems to be a mismatch between the way how agricultural production is currently carried out and how they actually think that it should be done. From their explanations, they believe that there it is good to have some diversity within the farmland, but they feel that managing more diverse systems pose a risk to guarantee them their living while more specialized systems seem to be more productive and competitive, thus, more reliable.

A.3. Low, decreasing and unstable profit margins

Making a living from agriculture is a true challenge for many peasants. “The small farmer lives miserably on bottles of milk”, acknowledged one of the participants.

This poses a discouraging and demotivating scenario that leads the farmers and family members to reconsider if they are willing to continue with the agricultural production.

A.3.1. Raising costs of inputs and other expenses.

As most of the farmers expressed their dependency on agrochemical inputs, they also mentioned that the prices of inputs are nowadays too expensive and their prices increase every year. This means that farmers must engage on relatively high investments to guarantee a minimum amount of production. It includes the expenses on fertilizers, salt, concentrates and phytosanitary substances, but also on services like the cooling for the milk or the preparation of land than is done by renting machinery. Since there are duties and taxes for imported agrochemicals, the farmers have to bear all these costs without aids from the government to lower them. For example, in the case of potatoes, the investment can be high because of the different pests and diseases to prevent require large amount of different chemicals. Moreover, these costs have risen disproportionately over the course of the years, as mentioned by most of the participants. One of the farmers mentioned that the prices of concentrates for cattle had increased by 30% during the last couple of years. Likewise, technologies that possibly would improve production and the livelihoods of farmers are not available to the small producers because they turn out to be not affordable for them. Also, year after year the cost of living is much higher.

A.3.2. Decreasing and unstable prices of agricultural products and no bargain power.

"That the price has the value of our work", was the desire expressed by one of the interviewed farmers. They indicated that the prices of agricultural products are very low and that there seems to be a decreasing trend which makes it not profitable in the long run. Different participants identified several factors determining this low and decreasing prices. On one hand, many recognized their disconnection with consumers and the preponderant role of intermediaries in marketing. Thus, the prices of the products are fixed and imposed by intermediaries so farmers must accept those prices because they have no influence on them regardless of the investment they put into their production. "You burn your back, and you have to give it away at the price of nothing", claimed one of the farmers. Thus, in general there is identified an unfair marketing due to and uneven bargain power. "Intermediaries earn three times as much as they pay for the products", said another farmer. Another factor that they identified in lowering the prices was the import of agricultural products without a proper governmental intervention: "… imports from Ecuador, from Canada", "the United States and the Netherlands", have caused the drop-in prices according to different participants. Products like potatoes are very poorly paid and in general the production of crops is not considered as profitable as that of milk. Yet, the situation for milk producers is also critical since the milk prices never go up. “Three years ago, the liter was being sold at 1,300 pesos [0.34 USD] and now it is sold at 1,190 [0.31 USD]”. Moreover, the fear expressed by different farmers is that the prices of products drop anytime now. This whole situation is discouraging for farmers and people feel disappointed to have a productive unit. Demotivation is exacerbated when comparing wages from agriculture with those from mining; a person working in the mines can earn more than twice than a farmer and has better social security conditions.

A.3.3. Debts, credits and taxes.

Although there is access to credit, there are no any subsidies and farmers fear that if they have problems with their productivity they wouldn’t be able to pay back the money. Moreover, the interest rates of the credits that farmers have access to do not represent a big advantage in relation to other types of credit and those credits benefit mostly the large producers. “In theory, the small producer has access to credit, but the peasant who asks for a loan, if for some reason does not get enough [from their production], goes bankrupt and the banks finish them off”. Also, there is a general perception that taxes are very high and that there is a very unfair treatment. “… you have to pay the bank anyway” and “everybody's hung up on taxes” mentioned one of the farmers. Another described that in order to pay their debts they “… had to sell the cattle cheaply” and “… it was time to rent out” their lands since they couldn’t continue to use some of them for production.

B. Lack of support and collaboration between relevant stakeholders

B.1. Pessimism and distrust towards institutions and organizations

Overall, there is a generalized distrust from farmers in Guachetá towards institutions and orders organizations, including associations. This has built up over time and is related with the lack of effective measures that aid the development of agriculture, perceived corruption within organizations and public entities, and lack of representation of the interest of the rural population.

B.1.1. Perceived corruption and disinterest on the part of the government and other organizations leads to insufficient/ineffective support for agriculture

All the participants agreed on that the national and local governments have not shown enough support towards agriculture and small-scale producers. Most farmers mentioned that they have never received any support from the government and that what they have they have earned themselves. “We have been forgotten, sometimes we have to do this ‘with our nails’ (with almost no means)”. Within the group of experts, they mentioned that a farmer “is the most unprotected person in Colombia (…) [The government] doesn’t give them anything”. The general perception is that there is no evidence of interest on the part of the government on the countryside, the food production and the future. “I think that the state has abandoned the rural sector”, said one participant. There is not enough investment, control, collaboration or aids. “We are all concerned that production is sustainable, but the State fails in concrete actions”. Also, there is a general perception that the few aids offered by the government do not reach the agriculturalists. Farmers explain how they must do paperwork to apply for some support, but that it doesn’t work so well and that it can only be done through the associations. Also, there are too many promises during elections that are not kept and the only way to get some support is if you “get along with politicians”, as one of the participants suggested. Moreover, the information is not clear or is fragmented so the people do not know what happens with the money. Nonetheless, the corruption is not only perceived in the government. There is also distrust in the associations and some claim that “their path had deviated”. The projects that association apply to do not always work, and when they do, many people who don’t have the will to cooperate from the beginning appear later to take advantage of the aids.

B.1.2.Lack of leadership, representation and associative culture.

A common feeling among farmers is that they do not consider that their interests are represented and that there are no leaders that understand the implications (and “suffering”) of a peasant lifestyle. “They [governments] do not know what hunger is, they do not know what it is to work the fields. It is very difficult for them to accept that a person planted and lost a potato harvest. They don't know what a peasant is”. At the same time that many acknowledge the lack of peasant leadership within the community, in general there is a lack of will to associate and to participate in communal projects. Participants pointed out the need for cooperation and organizations, while some indicate that there is no community culture or culture of associativity and that getting to common agreements is challenging. “It is difficult to associate, because people are different and some seek to take advantage” Also, in many cases the role of the association is perceived as marginal and is mostly to provide support to producers for access to the markets: “companies are more interested in buying in bulk than from individual producers.”

B.2. Lack of mechanisms for coordination, communication, learning, transfer and exchange of information and knowledge.

The inadequate communication, cooperation and articulation between different relevant stakeholders has led to a scenario where the possibilities for improving the conditions of agriculture in Guachetá are limited.

B.2.1. Decision-makers in positions of power ignore the struggles and reality of agriculture

The aids that farmers can apply (often through associations) are often not monetary but in kind, in form of inputs, for example. Nevertheless, the offered aids do not often meet their actual needs. “Not that they give us the inputs, but that we can decide what to invest in” expressed one of the farmers. This situation reflects the disconnection and lack of understanding from the decision makers in regards to the challenges that small-scale farmers face on their activity. In words of one of the participants: “Most of the projects are formulated by people who do not know the agricultural sector. It is formulated in an office in Bogotá where the needs of the countryside have not been evidenced”. Hence, it highlights the necessity for participation and coordination with agriculturalists in governance and decision-making.

B.2.2. Limited coordination between different official entities and with farmers.

There is not an effective communication between different entities at the governmental level whose purpose is to address the problems of agriculture in the country. Although there might be knowledge in the different official entities, there is not an articulated work that leads to the improvement of the conditions for production or the well-being of small-scale farmers. There are several entities, offices and agencies that deal with different aspects of environment, agriculture and rural development, but there doesn’t seem to be a clear way in which there is cooperation to develop projects that have a desired impact in the long term. Also, there is no continuity in the projects started by different administrations since the positions in the public sector change every 4 years, and the will to continue or start new projects depends on the vision of each administration.

B.2.3. Lack of knowledge, training and education.

All of the participants expressed that there is not enough information and training for farmers, and the trainings that they have undergone cannot be applied due to lack of other means like economical resources. It is recognized a strong need to implement technologies that allow a sustainable development of agriculture. The associations have played a role in the training of farmers, but it is very limited. In the past there were some extension programs in other to train farmer in the use of the natural resources and the production, but all of this has been lost, indicated one of the experts. Despite being so close to the capital, there is no strong knowledge and education among the farmers. One of the farmers acknowledged their lack of information and guidance on the study of the soil and its use. Indeed, as mentioned by one of the experts, the knowledge of the land is too general and there is the need of more detailed information on soils so that proper and more accurate recommendations could be established. This means that currently the land is not being used properly which is a problem directly related with sustainability. There is also a problem of communication with universities that have the potential to do research and created knowledge. One participant said: “There is pressure on universities to publish in English. Literature has to be put into the language of the people. You have to respect the language of the one you intend to educate. The peasants, in addition to Spanish, have dialects. You have to learn to transmit it. The peasants sometimes cannot read. You have to have strong social work on hand”.

5. Discussion

In this study, the surveys for the characterization of agroecological transition and the evaluation of the performance of the systems, along with the semi-structured interviews, made it possible to obtain a general comprehension of the small-scale agricultural production in Guachetá. Agriculture in Colombia has already encountered the constraints and difficulties derived from climate change, which include the unpredictability of the future rain patterns and other related climatic events such as frosts, floods and droughts (Jacobs et al., 2019). The description of the main characteristics and contexts of the systems and, more specifically, the characterization of the biophysical environment along with the perceptions of the farmers allowed to understand one of the biggest challenges for peasant farmers in Guachetá. Because the region is located in a dry cold climate, some agricultural practices had been partially adapted to conditions of water limitation. The past generations of farmers were used to have two main seasons of "Verano" (low rain) and periods of frosts that were more or less predictable, so agriculturalists considered these natural occurring conditions for their production. However, the participant farmers have described an increasing unpredictability of climatic conditions as an adverse situation for their production and their experiences are consistent with the available climatic data.

In fact, Colombian agriculture can be very sensitive to climate change scenarios, which may affect several dynamics and processes of the agricultural landscape (Lozano-Povis et al., 2021; Ortega & Zambrano, 2020; Nuñez et al., 2021). For example, the effects of the alteration of the typical bimodal rain system and the intensity of rainfall have also been registered for Norte de Santander, another department in the Eastern Colombian Andes. In that case, the research conducted with the farmers exposed the impact of climate change on the reduction of agricultural and livestock production, the susceptibility to pests and diseases, and the intensification of water scarcity, among other problems (Nuñez et al., 2021). Likewise, Lozano-Povis et al. (2021) have described how the expected effect of climate change would increase the temperature in the Andes affecting several Latin-American countries, including Colombia. The increase in temperature would produce an increase in the values of potential evapotranspiration and, therefore, to scenarios where water scarcity is prevalent. Consequently, there would be losses in several important crops (e.g. potato, corn and quinoa) along the Andes and the livelihoods of farmers would be seriously affected.

Nonetheless, the adaptation to climate change and the optimization of production under water-limiting scenarios can be achieved if continuous monitoring of the state of agriculture is in place and suitable and appropriate measures, technologies and practices are implemented (Jacobs et al., 2019; Ortega & Zambrano, 2020; Patnaik & Bhowmick, 2018). In Europe, the climate change adaptation strategies recognize the need for the implementation of measures in different instances, from the national and regional levels down to the farm level. Some of the technical measures to redesign the agroecosystems include the promotion of the use of adapted varieties and breeds, reduced tillage, precision farming with efficient irrigation, agroforestry, crop diversification and rotation, modification of crop calendars and organic farming, among others (Jacobs et al., 2019). In contrast, this study has shown how the traditional peasant farming in Guachetá has undergone a process of conventionalization with a gradual reduction on the agricultural biodiversity, an increasing dependency on external inputs, and low integration within the elements of the agroecosystems and with the natural landscape. This has derived in a poor efficiency of agroecosystems, an inadequate use of the natural resources which undermines their ecological and economical basis, and decreasingly narrow profit margins for rural communities. Although in Colombia some general guidelines have been proposed in its National Plan for Adaptation to Climate Change (DNP, 2012) and in the Guide for adaptation to climate change based on ecosystems (M.A.D.S., 2018), there are still no specific measures or clear guidelines that are being implemented. Thus, further efforts are needed while there is room for the implementation of measures the lead to a sustainable agriculture in the context of climate change but this is also conditioned by an enabling environment that will be discussed further on.

Also, the appropriateness of the measures, practices and technologies to be implemented must be considered. This means that they should address an intended purpose according to identified needs and wants of the rural population in a particular local context (Patnaik & Bhowmick, 2018), in this case, the needs for knowledge and practices to withstand limiting climatic conditions, among others. Having this in mind, the implementation of agroecological principles, such as the conservation of natural resources and the enhancement of their use efficiency, can aid in improving the sustainability of peasant agricultural systems in the Colombian context (Altieri & Nicholls, 2005; Gliessman, 2015). For example, a study on the water requirements of burley tobacco in the municipality of Ovejas (Sucre, Colombia) allowed the acquisition of adequate information for crop calendars. Considering the local agroecological environment, a tool was developed to propose optimal planting times as a way of perpetuate and improve the cultivation (Ortega & Zambrano, 2020). Likewise, rainwater harvesting can be an appropriate option since it has been recognized as a suitable approach for agricultural intensification (Piemontese et al., 2020). Instead of losing the potential water supply from the heavy rainfall that is concentrated in few days and that leads to increased runoff and potential erosion, there is potential to harness this water source.

In line with the agroecological principle of making appropriate matches between production and the natural productive potential and limitations of the land (Gliessman, 2015), the heterogeneity of the landscape, reflected in the analysis of the slopes and the description of landforms, is a variable that must be taken into consideration if an overall improvement of the conditions of farmers is to be achieved. For instance, some of the lands that are inadequate for intensive agriculture due to high slopes (classes VI and VII), might actually be suitable for the implementation of rainwater harvesting. Moreover, the analysis of the official general estimations of land use capability and conflicts for the municipality, facilitated the identification of locations where changes need to be implemented for a more sustainable production. For example, a considerable share of the land of classes II and IV are suitable for agricultural use with more intensive practices. A sustainable approach for this is that of the ecological intensification (Tittonel, 2014), which focuses on harnessing ecosystem services that contribute to the agricultural production, by supporting and regulating them. These services include the formation and conservation of soil, nutrient cycling and pollination (Bommarco et al., 2013). On the contrary, an unsustainable use of land by overutilization is present in a fourth part of the territory, that is more suitable for conservation, having productive forests or agroforestry (IGAC, 2014b). Then, if these recommendations for land use are followed, a more diversified agricultural landscape and systems would be promoted within the region in accordance with agroecological principles. In other words, alternative land uses can lead to a less homogenous landscape, reflected in the analysis of land/vegetation cover, and promote a better integration with trees and connectivity between elements of the agroecosystem and the landscape (as indices of the element *synergies*), while facilitating the evaluation of the possibility to implement practices or technologies like rainwater harvesting. However, feasible and effective water harvesting potential estimates lead to the promotion and actual implementation of this practice when they consider both biophysical assessments and the socioeconomic dimension (Piemontese et al., 2020). Consequently, it becomes necessary to identify the socio-ecological conditions in order to achieve and effective coordination between farmers and other relevant stakeholders if such technologies are to be applied.

Therefore, the possible measures or solutions to address the identified issues would require an active participation in the governance of the land, which is the weakest point identified with the CAET. Only an adequate enabling environment can facilitate the implementation of measures, practices and technologies on a scale that leads to overcome the issues that faces the municipality. Part of ensuring an enabling environment is to develop governance mechanisms that are inclusive, transparent and accountable (FAO, 2018). In contrast, the environment described by the farmers in the present study indicates that operational mechanisms that enable an active governance of the land and the natural resources are absent.

Moreover, the overall perception obtained from the participants in the interviews showed that there is a generalized distrust in official support, institutions, associations or other types of organizations and that the communication between relevant stakeholders within the agricultural sector is insufficient to support farmers. Thus, if the aim is a more sustainable agriculture that improves human well-being and life quality, responsible governance mechanisms at different scales, from local to national level, need to be implemented, in accordance with the 10 elements of agroecology described by FAO (2018).

As stated by Gliessman (2015), conversion efforts towards sustainable agricultural systems require the redesign of the systems themselves in a way that their functionality resembles ecological processes. Still, the redesign of the systems cannot be regarded only on farm level but, as Beddoe et al. (2006) stated, if sustainability is the main goal, it is desirable a transition to a socio-ecological regime that focuses on the goal of sustainable life which requires the redesign of worldviews, institutions, and technologies, as components of culture. This evolutionary process on a cultural level takes time and requires partnership and collaboration between relevant actors. In fact, the development of collective commitment based on shared perspectives and the construction of new understanding is essential to address present and future challenges (Brower et al., 2016). Thus, the strengthening of collaborative action in Guachetá would be the basis to tackle some of the challenges that the current food system faces, since complex or systemic problems cannot be overcome by individual parties (Brower et al., 2016). While the results suggest that there is a profound unawareness of the reality and needs of the Colombian peasant population on the part of the decision makers at the governmental level and a lack of articulation between entities and other relevant stakeholders, the application principles of multi-stakeholder partnerships such as effective communication and collaborative leadership (Brower et al., 2016) can aid in overcoming these issues.

A participation and collaboration approach can also serve to promote and improve the co-creation and sharing of knowledge, another element that showed a very low average score in the CAET. In fact, this is a core element within the agroecological theoretical framework since it drives proper decision-making (Barrios et al., 2020). Participatory processes facilitate the co-creation of knowledge that promotes the creation of agricultural innovations that are customized to local contexts. In this regard, the experiential knowledge of producers on agricultural biodiversity, management, markets, and institutions plays a central role (FAO, 2018). Indeed, as rural peoples' knowledge emerges from practical experience in a local context, it can be highly specific and bounded to that context (Scoones & Thompson, 1994). Thus, dialogue and interaction between the knowledge of the agriculturalists and the scientific knowledge produced and held by official institutions and universities can lead to the creation and implementation of agroecological innovations that help in dealing with the challenges of the system, including climate change (Scoones & Thompson, 1994; FAO, 2018). This type of collaboration that involves transdisciplinary engagement as a mutual learning process (Barrios et al., 2020) can speed up the generation of knowledge where it is lacking, for example, in the acquisition of detailed soil information for the municipality. Since the scale of the current available soil data is for general studies (1:100 000), the minimum mappable area is 100 ha meaning that the variation presented within units smaller than this area is not accounted for within the current studies. This means that even if there were a unidirectional transfer of knowledge from the official entities to the farmers, this knowledge is too general and doesn't necessarily represent an advantage in terms of an adequate use of the land. Therefore, participatory processes are required if it is desired to promote sharing and generation of knowledge in concordance to local socioeconomic and biophysical conditions. Moreover, this can indorse a widespread access to agroecological knowledge, leading to a widespread diffusion and application of its principles as a way to achieve a sustainable food system (FAO, 2019).

The other element of the enabling environment, circular and solidarity economy, also showed one of the lowest average scores of the CAET. Again, the lack of networks of producers and the disconnection between producers and consumers are the main contributors to these low scores. More sustainable and equitable markets can only be guaranteed when local markets are prioritized and there is support to local economic development (FAO, 2018). Furthermore, theses aspects should take special relevance within the context of an economic system heavily influenced by international trade. In contrast, according to the participants' experiences, the national government has proven to be unable to stimulate and protect smallholders before the challenges an international free market poses. The unsettling thing about the situation is that this element can also be linked to the low resilience of the systems related to unstable income and an overall low capacity to recover from perturbations and to the unsustainable income for most of the farms assessed in the performance of the systems. The current system leaves the small-scale farmers in a situation of high vulnerability which can also be reflected in the lack of interest of the youth in agriculture, which supposes a major threat to the perpetuation of small-scale farming. The generational turnover issues of the farms have been previously described in many countries worldwide as there is a general decrease in family farm successions, which demands an active support to young farmers for the perpetuation of agriculture (Carbone & Subioli, 2011; Rodriguez-Lizano et al., 2020). Therefore, part of reducing the economic strain on farm households is to facilitate access to local markets and reduce the number of intermediaries in the food supply chain. One example on how this can be done is with the use of technological innovations like apps aimed at supporting the sustainability of agricultural landscapes that can potentially reduce the distance between producers and consumers (Shriram & Mhamane, 2018; Inwood & Dale, 2019). Then again, the best solutions to implement come from co-creation processes that consider local contexts and realities (Barrios et al., 2020).

Also, this is only one side of the economic strain that farmers described. The other part is reflected both in the CAET and in the evaluation of performance of the systems. The majority of producer expressed the increasing dependency on external inputs and, especially, on pesticides. This was reflected in the low efficiency of the systems being one of the elements with lowest average value. Also, the use of pesticides was described as unsustainable, except for one farm were pesticides were not applied. Yet, there seemed to be a trade-off between the application of pesticides and the possibility to have an income. This exemplifies the level of dependency on external inputs that small-scale agriculture has reached and the incorporation of the agroecosystems into the treadmill of production which demands the continuous purchase of new products to control pests; a cycle where pesticide use is gradually increased over time (Gliessman, 2015; Hedlund et al., 2020). The dependency on agrochemicals can be diminished by implementing ecological practices in favor of pest management, reducing the impact on health, environment, and the need for pesticides that become increasingly expensive every year. These practices that help to mitigate the dependency on pesticides include the use of more resistant varieties, increasing the special and temporal biodiversity with the implementation of crop rotation scheduling and intercropping schemes, the use of organic compounds, and the plantation of natural repelling plants, for example (FAO, 2019). This can also affect positively other elements evaluated within the CAET, like diversity and synergies, evidencing the interrelation between the elements of agroecology.

In summary, the current state of the small-scale agriculture in Guachetá evidences a series of issues that require joint action in order to be overcome. These problems must be tackled from multiple angles, and the diffusion of agroecological knowledge could play a central role in the achievement of more sustainable agriculture for the municipality. The potential practices to be implemented require the participation of different actors in order to promote an enabling environment that facilitates the participation of farmers in the governance of the land and a fair access to markets.

6. Conclusions

By means of implementing a TAPE assessment and conducting a qualitative data analysis, this study identified important constraints and challenges for the small-scale agriculture of Guachetá and the struggles that the peasant farmers currently face. Climate change seems to be a major challenge for the region and at the moment satisfactory measures to tackle its consequences do not seem to be in place. Also, the development of agriculture is impaired by an environment where there is a reduced responsible governance, circular and solidarity economy, and co-creation and sharing of knowledge due a to a lack of partnership, associative culture and joint action. Moreover, while exploring the common characteristics, practices and approaches, there was found evidence of a high dependency on agrochemical inputs leading to a low efficiency of the systems. All these conditions have repercussions in the ability of farmers to maintain a stable and reasonable income and in their capacity to overcome possible future perturbations. Consequently, there is no single solution to the problems faced by agriculture in the municipality, but systemic problems must be approached from different angles, understanding the complexity of the agro-ecosystems, the current needs of the peasant population, and the socio-ecological context in which farming takes place. Thus, there is a need to diffuse agroecological knowledge and implement its principles if sustainability is to be achieved. Subsequently, there is a wide range of possibilities for further research, since more detailed biophysical information is required; it is possible to investigate the potential to implement several practices that increase the efficiency of the systems (design of rotation calendars, use of different cultivars, breeds and local varieties, alternative management for pest control, rainwater harvesting possibilities, etc.); the issues related to learning, knowledge, communication and joint action between relevant stakeholders can be analyzed in more depth; and the dynamics of the markets and the food value chain deserve a detailed description, among other possible research opportunities.

7. Critical reflections

It was challenging to do this work for different reasons, but they were mostly related to the impossibility of being present while performing the interviews and surveys due to the pandemic outbreak. For this reason, it was not possible to conduct a complete TAPE assessment and possibly the number of farmers that could've been reached would be have been higher. This type of research requires frequent interaction with participants and "earning the trust" of the people to get answers that reflect their real perspectives, which can be even more challenging by having only remote contact. This also poses a limitation on understanding the situation or getting the whole picture. Additionally, the information gathered in order to evaluate the performance of the systems, could have been more detailed especially for 'Exposure to pesticides' and 'Income'. Similarly, the sample size for estimating 'Youth employment' might be too small, but this is because in the households assessed there were few peoples between 15 and 24 years old.

On the other side, there is the risk from miscommunication or misinterpretation due to several variables. The application of the TAPE surveys implied the translation of the questions from English to Spanish, but also in a language that is understandable for the different participants. Moreover, due to the nuances of the language there might have been situations where the interviewer and the interviewed could have a different understanding and interpretation of a single statement. This can also be related to the biases due to how one's own subjectivity can influence the research and the results. Even aware of this, the presented results of the qualitative analysis may be influenced by the own subjective experience of the researcher in term of what one considers more relevant. Having this in mind, there is always the opportunity to improve future work and learn from what can be done better.

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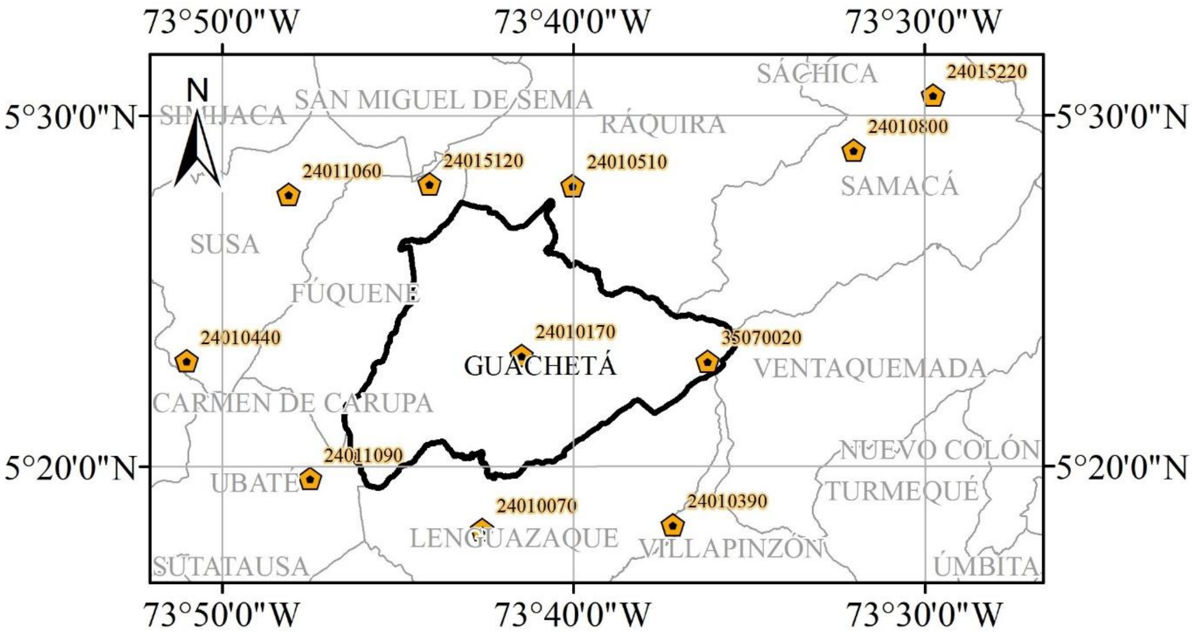
Appendix 1

Sources of climatic data

Information of the hydrometeorological stations and data collected.

Name of the station	Code	Municipality	Latitud	Longitude	Rain (mm)	Min. temp. (°C)	Max. temp. (°C)	Humid. (%)	Wind speed (m/s)	Sun (hours)	Time frame of available information
VILLA CARMEN	24015220	Samacá	5,509389	-73,495778					X		1991/04/29 - 2013/07/02
MINAS LAS	24010800	Samacá	5,483333	-73,533333	X						1991/01/01 - 2002/03/20
ISLA DEL SANTUARIO	24015120	Fúquene	5,467278	-73,734806	X	X	X	X		X	1962/01/01 - 2020/12/31
ZARZAL EL	24010510	Ráquira	5,466667	-73,666667	X						1991/01/01 - 2008/08/31
SUSA	24011060	Susa	5,462444	-73,801556	X						1991/01/01 - 2008/06/30
GUACHETÁ	24010170	Guachetá	5,385889	-73,691056	X						1992/01/01 - 2020/12/31
TRES ESQUINAS	24010440	Susa	5,383333	-73,850000	X						1991/01/01 - 2008/06/30
VENTAQUEMA-DA	35070020	Ventaquema-da	5,383056	-73,602889	X						1991/01/01 - 2020/12/31
UBATE GRANJA	24011090	Ubaté	5,327333	-73,791444	X						1991/01/01 - 2010/10/31
EL TRIANGULO - AUT	24010390	Lenguazaque	5,305306	-73,619306	X						1991/01/01 - 2008/08/31
LETICIA	24010070	Lenguazaque	5,303194	-73,709750	X						1991/01/01 - 2020/12/31

Spatial distribution of hydrometeorological stations.


73°50'0"W
73°40'0"W
73°30'0"W
5°30'0"N
5°20'0"N
N
SIMIJACA
SAN MIGUEL DE SEMA
SÁCHICA
RÁQUIRA
SAMACÁ
SUSA
FÚQUENE
GUACHETÁ
VENTAQUEMADA
CARMEN DE CARUPA
NUEVO COLÓN
UBATÉ
TURMEQUÉ
LENGUAZAQUE
VILLAPINZÓN
SUTATAUSA
ÚMBITA
24015220
24010800
24011060
24015120
24010510
24010440
24010170
35070020
24011090
24010070
24010390

Appendix 2

Questionnaires for interviews

Questionnaire for farmers

1. Is agriculture the principal means for the livelihoods of your household?

   O Yes.
   O No.

2. Do you consider you as a small-scale farmer / peasant?

   O Yes.
   O No.
   O I don't know / prefer not to answer.

3. What is the main product of your farm?

   O Milk.
   O Potatoes.
   O Onion.
   O Tomato.
   O Strawberry.
   O Other: ________________

4. The production is carried to out by:

   O Members of the household.
   O Members of the family and some hired workers.
   O Mainly hired workers.

5. What is the area of your farm?

   O Less than 1 hectare
   O Between 1 and 3 hectares
   O Between 3 and 10 hectares
   O Between 10 and 50 hectares
   O More than 50 hectares
   O I prefer not to answer.

6. Indicate how much do you agree with the following statements:

	Totally agree	Agree	Neither agree nor disagree	Disagree	Totally disagree

It is better to have a single product (crop or animal) than several.					
A greater variety of food was produced in the past.					
It is good to have natural spaces within your land.					
Climatic events have become more unpredictable.					
Is necessary continuous use of inputs to maintain the agriculture .					
You are proud of being a farmer / peasant, of your culture and tradition.					
The youth want to dedicate themselves to agriculture.					
Traditional knowledge is important for agriculture.					
Traditional knowledge has been lost.					
You feel the support of your community.					
You can trust the support of the government (local, departmental or national).					
The State and other entities (eg universities) share useful information / knowledge for your production.					
Your revenues are stable, allow pay debts, have conditions of decent living and save.					
The decisions of the household and production are the responsibility of the man.					
You share culture, traditions and identity with the peasants of the Cundiboyacense highlands					

7. Can you describe which are the major difficulties you faced as a farmer?
8. Form the following list, what are the main challenges / problems faced as a farmer? (select up to 3 and rate them in order of relevance) *

- ☐ Climatic events (droughts, floods, frosts).
- ☐ Pests and diseases.
- ☐ High cost of inputs (pesticides, fertilizers, seeds, animals, insemination, etc.).
- ☐ Low production.
- ☐ Low prices of the product.
- ☐ Low fertility.
- ☐ Supply of water.
- ☐ Other: ________________

9. What kind of support have you gotten from the government or any other organization?
10. How would you like to / should you be supported?
11. Have you received any kind of training for productivity and sustainability?
12. Do you know anything about ' Agroecology '? If yes, how would you define it?
13. Do you have any additional comments or questions?

Questionnaire for farmers' associations

1. What can you tell me about the association? What is the objective or the need to be covered?
2. What are the difficulties / challenges that confront the producers / farmers of the municipality? (Economy, profitability, prices of inputs, social aspects, climate, pests, soil, degradation of resources natural, etc.)
3. What is needed to improve the conditions of farmers?
5. What kind support provides the association to farmers?
6. What are the limitations of the association in terms of the support they can provide? Who else would help? How?
7. Indicate how much you agree with the following statements:

	Totally agree	Agree	Neither agree nor disagree	Disagree	Totally disagree
The government local provincial or national provides one timely and sufficient support to farmers.					
It's better that farmers specialize and a single product (crop / animal) rather than producing several.					
It's necessary purchase of inputs (pesticides, fertilizers, seeds, feed for livestock, insemination, etc.) to ensure good production.					
It is important to retain the traditional knowledge.					
It is required more training for farmers.					
The youth wants to dedicate themselves to agriculture.					
The farmers share culture, traditions and identity with the peasants of the altiplano Cundiboyacense.					

8. Do you know anything about ' Agroecology '? If yes, how would you define it?
9. Do you have any additional comments or questions?

Questionnaire for experts

1. In general, what problems related to sustainability does agriculture in Colombia face?
2. In your opinion, what are the specific challenges facing farmers in Guachetá or the Ubaté Valley?
3. Do you think that there is an efficient generation and dissemination of knowledge in relation to the demands and needs of the Colombian countryside?
4. What is needed to improve the food production system in Guachetá or the Ubaté Valley?
5. What type of support does the State offer? Are they oriented towards conventional agriculture?

Questionnaire for representatives of local authorities/entities

1. What is the entity's responsibility towards the agricultural sector?
2. What are the difficulties / challenges faced by producers / farmers in the municipality? (Economy, profitability, input prices, social aspect, climate, pests, soil, degradation of natural resources, etc.)
3. What kind of support is provided to farmers?
4. What else is needed to improve conditions for farmers?
5. What other support does the government provide (departmental, national)? (incentives, subsidies, access to credit, training / education, etc.)
6. What type of coordination is carried out with other public entities in charge of generating information / knowledge (ICA, Agrosavia, IGAC, IDEAM, etc.)? Private entities?
7. Does current food production allow the municipality to be self-sufficient?
8. Indicate how much you agree with the following statements:

	Totally agree	Agree	Neither agree nor disagree	Disagree	Totally disagree
The government local provincial or national provides one timely and sufficient support to farmers.					
It's better that farmers specialize and a single product (crop / animal) rather than producing several.					
It's necessary purchase of inputs (pesticides, fertilizers, seeds, feed for livestock, insemination, etc.) to ensure good production.					
It is important to retain the traditional knowledge.					
It is required more training for farmers.					

	Totally agree	Agree	Neither agree nor disagree	Disagree	Totally disagree
The youth wants to dedicate themselves to agriculture.					
The farmers share culture, traditions and identity with the peasants of the altiplano Cundiboyacense.					

9. Do you know anything about ' Agroecology '? If yes, how would you define it?
10. Do you have any additional comments or questions?

Appendix 3

Scores for each index of the 10 elements of agroecology

Element	Index	P1	P2	P3	P4	P5	P6	P7
1. DIVERSITY	1.1. Crops	2	4	3	0	4	4	2
	1.2. Animals	3	2	3	1	3	2	2
	1.3. Trees	1	1	0	1	2	2	3
	1.4. Diversity of activities, products and services	2	1	3	1	2	2	2
	General score	50,00 %	50,00 %	56,25 %	18,75 %	68,75 %	62,50 %	56,25 %
2. SYNERGIES	2.1. Crop-livestock-aquaculture integration	2	2	2	3	4	3	2
	2.2. Soil-plants system management	2	4	3	1	4	3	2
	2.3. Integration with trees	1	1	0	0	2	1	2
	2.4. Connectivity between elements of the agroecosystem and the landscape	2	1	0	0	1	1	2
	General score	43,75 %	50,00 %	31,25 %	25,00 %	68,75 %	50,00 %	50,00 %
3. EFFICIENCY	3.1. Use of external inputs	1	2	0	0	3	2	1
	3.2. Management of soil fertility	1	3	0	1	4	3	0
	3.3. Management of pests & diseases	1	1	0	0	3	2	0
	3.4. Productivity and household's needs	2	2	3	3	0	1	2
	General score	31,25 %	50,00 %	18,75 %	25,00 %	62,50 %	50,00 %	18,75 %
4. RECYCLING	4.1. Recycling of biomass and nutrients	4	4	3	3	4	4	2
	4.2. Water saving	0	0	0	1	1	1	1

Element	Index	P1	P2	P3	P4	P5	P6	P7
	4.3. Management of seeds and breeds	1	2	0	1	2	3	1
	4.4. Renewable energy use and production	1	1	1	1	1	1	2
	General score	37,50 %	43,75 %	25,00 %	37,50 %	50,00 %	56,25 %	37,50 %
5. RESILIENCE	5.1. Stability of income/production and capacity to recover from perturbations	1	1	2	1	1	1	1
	5.2. Mechanisms to reduce vulnerability	2	2	2	2	1	2	2
	5.3. Indebtness	2	2	3	2	4	4	2
	5.4. Diversity of activities, products and services	2	1	3	1	2	2	2
	General score	43,75 %	37,50 %	62,50 %	37,50 %	50,00 %	56,25 %	43,75 %
6. CULTURE & FOOD TRADITION	6.1. Appropriate diet and nutrient awareness	3	3	4	3	3	4	3
	6.2. Local or traditional identity and awareness	4	4	4	4	3	4	3
	6.3. Use of local varieties/breeds and traditional knowledge for food preparation	3	3	3	3	3	3	3
	General score	83,33 %	83,33 %	91,67 %	83,33 %	75,00 %	91,67 %	75,00 %
7. CO-CREATION & SHARING OF KNOWLEDGE	7.1. Platforms for the horizontal creation and transfer of knowledge and good practices	2	1	0	2	0	2	1
	7.2. Access to agroecological knowledge and interest of producers in agroecology	2	2	1	1	1	2	1
	7.3. Participation of producers in networks and grassroot organizations	3	1	1	3	0	3	2
	General score	58,33 %	33,33 %	16,67 %	50,00 %	8,33%	58,33 %	33,33 %
8. HUMAN & SOCIAL VALUES	8.1. Women's empowerment	3	3	3	3	4	4	4

Element	**Index**	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
	8.2. Labour	4	3	3	3	3	3	3
	8.3. Youth empowerment and emigration	1	1	1	1	1	2	0
	8.4. Animal welfare	3	3	3	3	2	3	2
	General score	68,75 %	62,50 %	62,50 %	62,50 %	62,50 %	75,00 %	56,25 %
9. CIRCULAR & SOLIDARITY ECONOMY	9.1. Products and services marketed locally	2	2	2	2	4	4	1
	9.2. Networks of producers, relationship with consumers and presence of intermediaries	1	1	0	1	1	3	1
	9.3. Local food system	2	2	1	1	2	1	1
	General score	41,67 %	41,67 %	25,00 %	33,33 %	58,33 %	66,67 %	25,00 %
10. RESPONSIBLE GOVERNANCE	10.1. Producer's empowerment	2	2	2	2	2	2	2
	10.2. Producer's organizations and associations	3	1	0	1	0	3	1
	10.3. Participation of producers in governance of land and natural resources	1	1	0	1	0	1	2
	General score	50,00 %	33,33 %	16,67 %	33,33 %	16,67 %	50,00 %	41,67 %

Appendix 4

Scoring core criteria

SECURE LAND TENURE	P1	P2	P3	P4	P5	P6	P7
Do you have any legal recognition of your land?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Do you percieve that your access to land is secure?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Do you have the rigth to bequeath or sell any of the parcels of the holding and to inherit land?	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Score	**Desirable**	**Desirable**	**Desirable**	**Desirable**	**Desirable**	**Desirable**	**Desirable**

INCOME	P1	P2	P3	P4	P5	P6	P7
Your income is increasing AND higher than the average income in the region							
Your income is stable AND equal to the average income in the region	X		X				
Your income is decreasing OR lower than theaverage income in the region		X		X	X	X	X
Score	**Acceptable**	**Unsustainable**	**Acceptable**	**Unsustainable**	**Unsustainable**	**Unsustainable**	**Unsustainable**

EXPOSURE TO PESTICIDES	P1	P2	P3	P4	P5	P6	P7
Uses synthetic pesticides	Yes	Yes	Yes	Yes	No	Yes	Yes
Uses class I pesticides (hihgly toxic)	Yes	No	No	No	No	No	No
Uses class II pesticides (moderately toxic)	Yes	Yes	Yes	Yes	No	Yes	Yes
Mitigation strategies when applying							
Mask	X	X	X	X		X	X
Body protection (glasses, gloves, etc.)	X	X	X	X		X	X
Special protection for women and children							
Visible signs of danger after spraying			X	X			
Community is informed of the danger		X	X	X			
Secure disposal of the empty containers after use	X						
Other							
Organic pesticides AND/OR other integrated techniques for pest management							
Cultural control	X				X		
Plantation of natural repeling plants						X	

EXPOSURE TO PESTICIDES	P1	P2	P3	P4	P5	P6	P7
Use of cover crops to increase biological interactions							
Favor the reproduction of beneficial organisms for biological-control							
Favor biodiversity and spatial diversity within the agroecosystem					X		
Use of organic compounds		X			X		
Chemical pesticides are more important than organic	X	X	X	X		X	X
Organic pesticides are more important than chemical					X		
Pesticides use in negligible, ecological management is more important					X		
Score	**Unsustainable**	**Unsustainable**	**Unsustainable**	**Unsustainable**	**Desirable**	**Unsustainable**	**Unsustainable**

DIETARY DIVERSITY	P1	P2	P3	P4	P5	P6	P7
Grains, white roots and tubers, and plantains	X	X	X	X	X	X	X
Pulses (beans, peas and lentils)	X	X	X	X	X	X	X
Nuts and seeds							
Dairy	X	X	X	X	X	X	X
Meat, poultry, fish	X	X	X	X	X	X	X
Eggs	X	X	X		X	X	X
Dark green leafy vegetables	X	X	X	X	X	X	X
Other vitamin A-rich fruits and vegetables		X	X		X	X	X
Other vegetables	X	X	X	X	X	X	X
Other fruits		X	X	X		X	X
Score	**Desirable**	**Desirable**	**Desirable**	**Desirable**	**Desirable**	**Desirable**	**Desirable**

YOUTH EMPLOYMENT	Male	Female	Total
Number of young people (mainly) working in the agricultural production of the system	0	1	1
Number of young people (mainly) in education/training	2	1	3
Number of young people not in education/training nor working in agriculture, nor in other activities	0	0	0
Number of young people (mainly) working outside but currently living in the system assessed	0	0	0
Number of young people who have left the community/village for lack of opportunities	0	1	1
Number of young people that would like to continue the agricultural activity of their parents	0	1	1
Number of young people that don't want to work in agriculture and would emigrate if they had the chance	2	1	3
Employment/activity score	80%		
Emigration score	50%		
Score	**65% = Acceptable**		

AGRICULTURAL BIODIVERSITY	**P1**	**P2**	**P3**	**P4**	**P5**	**P6**	**P7**
Number of crops, trees or other perennials	2	4	4	1	8	3	3
GINI index for crop diversity	0,52	0,75	0,75	0,00	0,88	0,65	0,62
Number of animal species/breeds	6	4	4	1	6	2	3
Total number of animals	18	18	95	12	57	19	19
GINI index for animal diversity	0,73	0,57	0,63	0,00	0,73	0,40	0,53
Beekeping score	0,5	0,5	0,5	0,5	0,5	0,5	0,5
Productive area covered by natural or diverse vegetation score	0,25	0,25	0	0,25	0,25	0,25	0,75
Presence of pollinators and beneficial animals score	0,66	1	0,66	0,66	1	0,66	1
Natural vegetation, trees and pollinators average score	0,47	0,58	0,39	0,47	0,58	0,47	0,75
Average GINI	**0,58**	**0,64**	**0,59**	**0,16**	**0,73**	**0,51**	**0,63**
Score	**Acceptable**	**Acceptable**	**Acceptable**	**Unsustainable**	**Desirable**	**Acceptable**	**Acceptable**