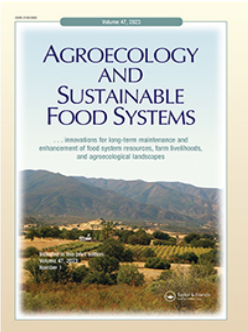

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Perspectives on agroecological transition: the case of Guachetá municipality, Colombia

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ABSTRACT

Specialization of agriculture in the Colombian Andes has increased smallholder vulnerability to climate change and global price fluctuations and has also affected the socio-economic and environmental conditions. Promoting sustainable agriculture in the region requires a holistic understanding of complex agroecosystems. This study identifies and analyzes the main challenges for agriculture and possibilities for agroecological transition of small-scale farms in Guachetá, Colombia. Using the Tool for Agroecology Performance Evaluation (TAPE), 10 elements of agroecology and core performance criteria were evaluated on seven farms. Several key actors were then interviewed, to triangulate data and understand current challenges and possible future pathways. It was found that drier climate and variations in rainfall patterns pose major challenges to current production systems. Limited possibilities for participation in land governance, lack of interest in agriculture among young people, and lack of access to markets hinder the development of sustainable agriculture. Current specialized practices in dairy and potato production are associated with reduced agricultural biodiversity and dependency on agrochemicals, leading to weak synergies and low profitability within agroecosystems. Implementation of agroecological principles and practices such as crop and income diversification and promoting joint action in agricultural development could help overcome sustainability issues in Guachetá.

KEYWORDS

Agroecology; agroecological assessment; TAPE; small-scale agriculture; climate change; participation

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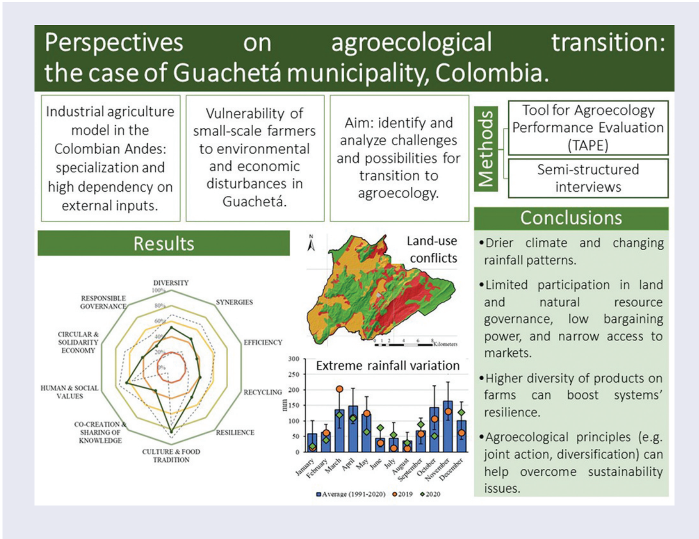

Introduction and background

In 2019, agriculture accounted for 16.6% of Colombia's employment and 6.7% of total GDP (OECD 2021). By 2018, about 19% of Colombia's population lived in rural areas, yet, low productivity has undermined the competitiveness of the Colombian agriculture sector, largely driven by infrastructure deficiencies, unequal access to land and land-use conflicts. Aiming for a significant increase in food production, the Colombian Government has heavily promoted intensive agricultural practices since the 1960s (in line with the Green Revolution). This resulted in small-scale farmers moving from self-sufficiency based on traditional food production knowledge to technology- and chemical-dependent agriculture. This change has impoverished rural communities, eroded social fabric and polluted natural resources (Anderson and Valdés 2008). The use of agrochemicals in combination with repeated monocultures diminishes soil fertility, making crop production more difficult and more expensive every year (Altieri and Nicholls 2005; FAO 2018). Improper use of pesticides has polluted soils, water resources and the air, so use of agrochemicals has come at a high price for Colombian farmers (Langrand 2021; Valbuena, Cely-Santos, and Obregón 2021).

Due to its highly developed dairy sector and its smallholder-based agricultural production, the Ubaté Province, located in central Colombia, is known as 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, made up of 10 municipalities. According to the 2018 census, Ubaté Province has over 129,500 inhabitants and covers an area of 1408 km^2 (TerriData 2020). The region's economy is largely based on livestock rearing, mainly cows for dairy production. All 10 municipalities show a high degree of specialization in livestock raising and potato (*Solanum tuberosum*) production (Carrillo 2017). In fact, livestock rearing for dairy production has been the main cause of landscape transformation in the province, manifested in logging of native forest and expansion of grassland area (Franco-Vidal et al., 2015). Other major crops grown are onions, tomatoes and strawberries (TerriData 2020). The region has also been immersed in the coal mining boom during the past two decades and mining has become another important economic activity (León 2018).

Traditional agricultural systems in the region have been severely affected by the industrialization of agriculture and by climate change. The past specialization of agriculture led to widespread livestock farming and potato cultivation, which resulted in an oversimplified landscape dominated by grasslands and lower diversity of agricultural products (Carrillo 2017; Franco-Vidal et al., 2015). These issues are also associated with a number of environmental impacts, including threats to local biodiversity and depletion of natural resources (Franco-Vidal et al., 2015). This is problematic because a system dependent on a few products is highly vulnerable to external threats and is less resilient in both ecological and economic terms (Gliessman 2015). In fact, fluctuations and drops in international market prices have reduced the overall profitability of agriculture, produced substantial losses, and created repeated scenarios of crises, especially among milk producers in 2013 (Vargas, 2015) and for potatoes farmers in 2020 (Rodriguez and Garcia 2020). Often, small-scale farmers have been driven to sell their products at very cheap prices, resort to unconventional means of distribution, and even sell their means of productions (land, cattle, machinery) (Rodriguez and Garcia 2020; Vargas, 2015). These factors, along with low living standards in rural areas, have contributed to discouraging parents from engaging their children in agriculture and promoting high migration to cities in search of better job opportunities and better living conditions, resulting in abandonment of the countryside and agricultural activities (León 2018; Trece 2019).

It has been suggested that climate change is also becoming a major issue for farmers in Ubaté Province (Carrillo 2017). There have been reports that the region is experiencing acute and serious negative climatic events, such as floods, droughts and inconsistent weather patterns. Floods during 2011 and 2012 caused a reduction in milk production down to 50%, with a 38% loss in the bovine population (La Villa 2020). Climate change in general poses major threats to food security world-wide and particularly in the Colombian Andes, exposes growers to price risks, and promotes migration to urban areas due to serious challenges related to rising temperatures (Núñez Rodríguez et al. 2021; Lozano-Povis, Alvarez-Montalván, and Moggiano-Aburto 2021). Temporary solutions, such as construction of levees to control floods, have been implemented to overcome some of the difficulties experienced in Ubaté Province (La Villa 2020), but there are clear signs of systemic problems within food production systems of the region. Thus, the region needs to develop alternative strategies and solutions for agriculture to increase resilience and reduce emissions (Carrillo 2017).

Facilitating transition toward more sustainable food systems requires a holistic systems thinking approach (Gliessman 2015). Agroecology is a discipline (science, practice, and social movement) that acknowledges the complexity of social and natural systems within the whole food production system, with their elements, interactions, and flows of matter, energy, and information (FAO 2018; Gliessman 2015; Wezel et al. 2009). Aiming to achieve a sustainable agricultural production, the theoretical agroecological framework offers the opportunity to meet food needs on a global scale, harness ecosystem services through the management of service-providing organisms, and achieve other social and environmental goals (Barrios et al. 2020; Bommarco, Kleijn, and Potts 2013; Tittonel 2014). Dealing with the question of sustainability evaluation of food systems and estimating the impact of possible agroecological transition requires a comprehensive understanding of the components, interactions, processes and emergent properties of those systems (Gamble, Wallace, and Thies 1996). In an attempt to provide an analytical framework to assess the multi-dimensional performance of agroecosystems, FAO developed the Tool for Agroecology Performance Evaluation (TAPE) as a way to support decision-making processes in the transition toward more sustainable or agroecological food systems (FAO 2019). The tool, consisting of three diagnostic steps and participatory analysis and interpretation of results, makes use of FAO (2018), 10 elements of agroecology and 5 key dimensions in sustainable food and agriculture (*environment & climate change*, *health & nutrition*, *society & culture*, *economy*, and *governance*) developed in 10 core criteria (FAO 2019). This analytical framework provides a good opportunity to understand and assess the state of agriculture for the Colombian context, particularly in Guachetá, one of the constituent municipalities of the Ubaté Province.

Despite the national relevance of the region in regards to agricultural production, there is a little or limited amount of information in the scientific literature about the state of agriculture in the Guachetá municipality or the Ubaté Province, and no studies that address this issue from an agroecological perspective. Moreover, this type of research can aid in gaining a holistic understanding of the challenges, risks, and potential pathways for the improvement of the overall state of agriculture in the study area and in other Colombian territories. Therefore, the aim of this study was to assess the current state of small-scale agricultural systems and identify opportunities for agroecological development in the Colombian Andes, using the case of Guachetá. Specific objectives of the present study were to:

1. Identify agro-environmental and socio-economic characteristics and contexts in Guachetá, by analyzing secondary information on the municipality.
2. Assess the sustainability of small-scale farming systems in Guachetá, using a multi-criteria assessment tool.
3. Triangulate and further abstract the sustainability assessment results by interviewing key stakeholders in the municipality's food systems.

Applying TAPE as an analytical framework to assess the multi-dimensional performance of the food system in Guachetá municipality was expected to help understand possible pathways for the transition to agroecology and enable evidence-based decision-making.

Methodology

This research applied a mixed methods approach. A series of semi-structured interviews were conducted and surveys were performed with farmers and other key stakeholders in Guachetá, to obtain their insights and perspectives on the state of agriculture in the municipality. The Tool for Agroecology Performance Evaluation (TAPE) developed by FAO (2019) was utilized during the interviews as an instrument to evaluate agroecological performance of the case farms. Interactions with the participants were held during February-March, 2021.Because of the COVID-19 travel restrictions, all interactions (initial contact, interviews and surveys) were held remotely (online or by telephone). Therefore, it was not possible to perform a full TAPE assessment for the systems analyzed, although the steps were implemented to a large extent.

Sampling and participants

To conduct the research, a process of respondents' identification, sampling, data collection and analysis was followed (Creswell 2013). A total of 16 respondents participated of the study: 10 small-scale farmers, two representatives of farmers' associations, a representative of a local government agency that provides technical assistance/advisory services for farmers, and three academic experts (within the fields of agriculture, soil science and agroecology) (Table 1). Such set of participants was established to assess different perspectives on the phenomena (Silverman 2010). For the purpose 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 farm area was ≤3 hectares. Participants were selected by convenience sampling (Voss, Tsikriktsis, and Frohlich 2002), recruiting those who could be accessed via distance methods. In a snowballing technique, the initial participants were

Table 1. Brief description of participants in this study ($n = 16$) (In parenthesis the gender and age of the farmers:(m) man, (w) woman, and (c) couple).

		Participation in study						
Group	ID	SS*	TAPE	Description				
Representatives	R1	X		Association of potato producers and cold climate agricultural products of Guachetá				
	R2	X		Association of milk and bovine producers Valle Verde of Guachetá				
	R3	X		Municipal Agricultural Technical Assistance Unit (UMATA)**				
Academic experts	E1	X		Former researcher in agrology and soil science. Experienced in direction of soil surveys, scientific research, environmental studies, and education.				
	E2	X		Former researcher in agrology and soil science. Experienced in leading education in environmental impact assessment and environmental sciences.				
	E3	X		Agronomist and researcher in agroecology. Experienced as director of education in biology and environmental sciences.				
Farmers/ producers				*Main source of income*	*Purpose of production****	*Main product*	*Farm run by:*** **	*Holding area (ha)*
	P1 (w, 40)	X	X	Agriculture	S	Potatoes	HM and OHL	<1
	P2 (w, 69)	X	X	Agriculture	S	Milk	HM	1-3
	P3 (m, 57)	X	X	Agriculture	S	Milk	HM and OHL	1-3
	P4 (m, 70)	X	X	Agriculture	S	Potatoes	HM and OHL	<1
	P5 (m, 55)	X	X	Wages in different activities	SC	Milk	HM	1-3
	P6 (w, 39)	X	X	Work in mines	S	Potatoes	HM	<1
	P7 (w, 38)	X	X	Agriculture	S	Potatoes	HM and OHL	1-3
	P8 (m, 30)	X		Work as machine operator	S&SC	Milk	HM	<1
	P9 (c, 61 & 60)	X		Agriculture	S	Milk	HM	1-3
	P10 (m, 64)	X		Agriculture	S&SC	Milk	HM	1-3

*SS = Semi-structured interviews; **The Municipal Agricultural Technical Assistance Unit (UMATA) is responsible for offering agricultural technical assistance and its objective is to aid small producers through advisory services; ***S: mostly for sale, SC: mostly for self-consumption, S&SC: equally for sale and self-consumption; **** HM: household members, OHL: Occasional hired/exchanged labor.

asked to suggest other relevant participants. Under this approach, the point of saturation was achieved when the same topics repeatedly appeared during the interviews, and the question did not yield new information. This corresponds to the theoretical understanding of the concept of saturation (Bryant and Charmaz 2007).

Assessment using the Tool for Agroecology Performance Evaluation (TAPE)

TAPE is a tool consisting of three diagnostic steps (steps 0, 1 and 2) and a participatory analysis of results (FAO 2019). Due to the limitations in the interaction with participants, this last part could not be implemented in full as stated in the methodology but instead semi-structured interviews were conducted to supplement the discussion (see subsection 2.3). Out of the 10 farmers participating of the study, seven were willing to take the surveys for two of the diagnostic steps (steps 1 and 2). The first step (Step 0) consisted of a literature review that was completed by accessing and analyzing mainly official data about the municipality. The biophysical characterization included soils, landforms, land cover, natural vegetation and climate (see Appendix A in Supplementary Material). The climate description was based on hydrometeorological data from 11 meteorological stations of the Institute of Hydrology, Meteorology and Environmental Studies, IDEAM (IDEAM 2021). Other information sources included the land use capability map of Cundinamarca (IGAC 2001a) and Colombia's national land-use conflict map (IGAC 2013). Land use capability maps in Colombia show permanent limitations of land that represent a risk of degradation, resulting in eight agrological classes that indicate maximum potential for land use (Classes I-VIII). In the land-use conflict map, the environmental supply (recommended potential use from agrological classes) and demand (current use related to land cover) are compared, resulting in a definition of concordance or discrepancy due to under- or over-utilization of the land (IGAC 2012). In addition, data were collected on some socioeconomic variables describing the population in Guachetá.

Step 1, Characterisation of Agroecological Transition (CAET), was based on the scoring of the 10 elements of agroecology: *diversity*, *synergies*, *efficiency*, *resilience*, *recycling*, *co-creation and sharing of knowledge*, *human and social values*, *culture and food traditions*, *responsible governance*, and *circular and solidarity economy*. For the CAET, 37 semi-quantitative indices (belonging each one to a particular element) were scored based on selected answers from five possible predefined options for each of the questions in the survey that matched each index. The scores of all indices belonging to a particular element were added together and the totals were standardized on a percentage scale for each element, revealing the strengths and weaknesses of the system.

In Step 2, core performance criteria, only six of the 10 core criteria were evaluated due to the impossibility of closer interaction with the participants. Calculation of *Productivity* and *Added value* would have required detailed and sensitive information that was not readily disclosed by the participants, or that they had not estimated themselves. For *Women's empowerment*, a set of conditions would have needed to be set for the interviews, while for assessing *Soil Health* both field and laboratory analyses would have been required. Thus, the core criteria considered here were *Secure land tenure, Income, Exposure to* *pesticides, Dietary diversity, Youth empowerment* and *Agricultural diversity*. The data from Step 2 were analyzed using a "traffic light" approach in which three sustainability levels were considered: desirable (green), acceptable (yellow) and unsustainable (red). The way in which the scoring system was applied depended on each core criterion evaluated, as stated in the description of the TAPE methodology provided by FAO (2019). Because the data for calculation of *Income* can be considered sensitive information and can be difficult to obtain, calculation of this criterion was based on approximate income values provided by the farmers.

Semi-structured interviews for qualitative analysis

A total of 16 semi-structured interviews were conducted, using mainly open questions selected according to the group or category in which participants were classified, i.e. farmers, representatives or experts (Table 1). Prior to conducting the interviews, customized questions (see Appendix B) were defined for each group, in order to map the perceptions of different stakeholders regarding the main challenges facing agriculture and gather information that could not be obtained from TAPE. The interviews were transcribed and the transcripts were analyzed further by thematic analysis (Boyatzis 1998; Denzin and Lincoln 2011), using the thematic coding method. A coding procedure was applied first, to reduce the texts to manageable proportions by selecting what was considered relevant relating to the research question (Auerbach and Silverstien 2003). Identified recurring views that had commonalities were then grouped into implicit topics, allowing structuring of the repeating ideas. These topics were re-organized into two larger theoretical constructs, resulting in development of a theoretical narrative that explained the major challenges for small-scale agriculture in the view of the participants.

These results were then analyzed and compared together with those from characterization of agroecological transition and from the review of the performance criteria, bearing in mind the context and enabling environment described in Step 0.

Results & discussion

The following sections present the results from characterization of the level of agroecological transition according to the 10 elements of agroecology (3.1), describe the performance of the seven systems assessed (3.2) and present the perspectives of key stakeholders (3.3).

Main characteristics of the region

The socioeconomic and bio-physical conditions in Guachetá are relevant for agriculture, including the heterogeneous landscape and specific climate features. Supplementary cartographic information can be found in Appendix A.

Biophysical environment

Topography and landforms. With an area of 17,900 ha (TerriData 2020), Guachetá lies approximately between 2540 and 3600 m.a.s.l., with a highly variable landscape. Flat areas with slope below 12% are mostly found to the west, while steep slopes higher than 75% are associated with mountain landscapes throughout the municipality (Figure 1). These landforms derive, respectively, from formation of a plains landscape containing fluvial-lacustrine terraces and floodplains and from a mountain landscape dominated by hogbacks, homoclinal ridges and hills (IGAC 2001b).

Climate. Temperature variation is low throughout the year. The maximum monthly temperature varies around 25°C, while the minimum temperature is often close to 6°C. The difference between the maximum and minimum temperature is highest in January, which has a higher likelihood of extreme variations in temperature within a day, along with frosts.

Annual precipitation is unevenly distributed and ranges between 800 mm (south) and 1126 mm (northwest), although the majority of the area receives less than 1000 mm. There is a bimodal precipitation pattern, with peaks during March-April and November (Figure 2).

Annual potential evapotranspiration was estimated here to be 1429 mm, which suggests a ratio between potential evapotranspiration (ETo) and

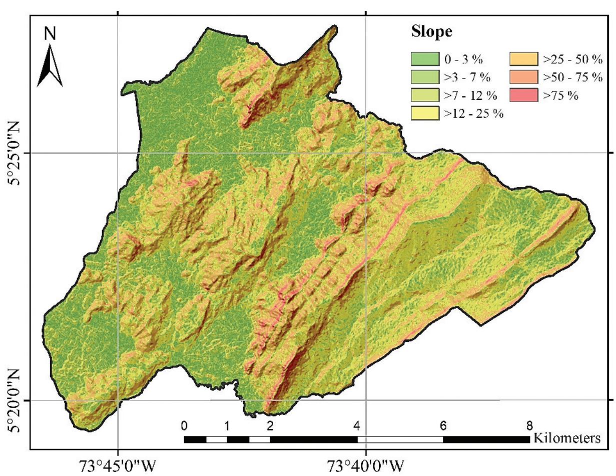

Figure 1. Topographical map of Guachetá municipality in Ubaté Province, central Colombia. Source: own elaboration based on DAAC (2011).

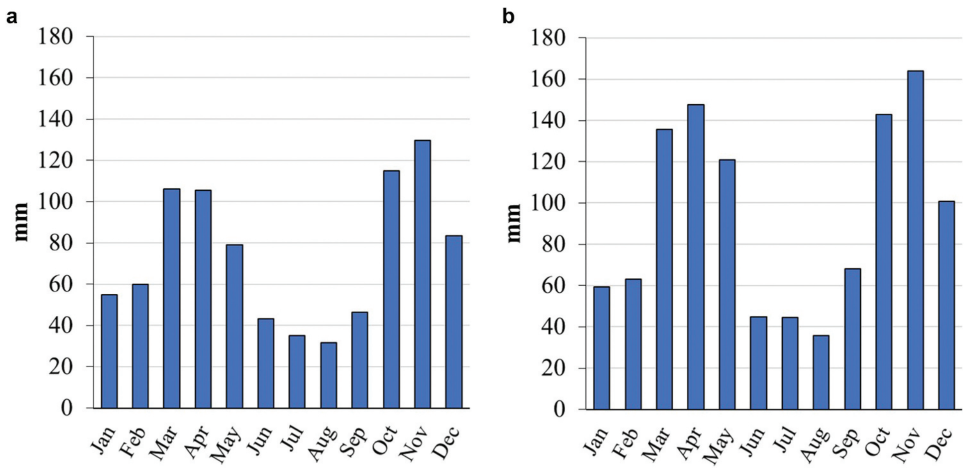

Figure 2. Mean monthly precipitation at the meteorological stations (a) GUACHETA [central zone] and (b) ISLA DEL SANTUARIO [northwest] in Guachetá.

precipitation (ETo/P) of between 1.3 and 1.6, depending on the location within the municipality. These values indicate a dry cold climate (IGAC 2014a), although a smaller share of the territory (above 3000 m.a.s.l.) can be considered wet and very cold (IGAC 2001b).

Vegetation and land cover. The dominant climate conditions and altitude support natural vegetation of low montane dry forest (IGAC 2014a). The major land use in the municipality is pasture, which along with other agricultural land occupies 64% of the total area (IDEAM 2014). Natural vegetation, represented by shrubs and/or herbaceous vegetation (27.7%), is mainly found in the east, where the high altitude and cold weather pose limitations for agriculture. The remaining land area consists of open spaces with little or no vegetation (4.5%), inland wetlands (1.9%), forest (1.6%) and artificial surfaces (0.4%).

Land use capability and conflicts

Adequate use of land (no land use conflict) occurs in 46% of the municipality, while 29% of the total area is agriculturally underutilized and 25% is overutilized (Figure 3). The most suitable agricultural land found in the area is of Class IV (32% of the area) and Class II (4%), but a large proportion of this land is underutilized. It is mainly located in flat zones on terraces, the floodplain and some hills, and is considered suitable for intensification of agriculture by integrating crop production and having intensive livestock raising with high-yielding pastures, requiring only supplemental irrigation and some conservation practices (IGAC 2014b). Considering the agroecological principle of making appropriate matches between production and the natural productive

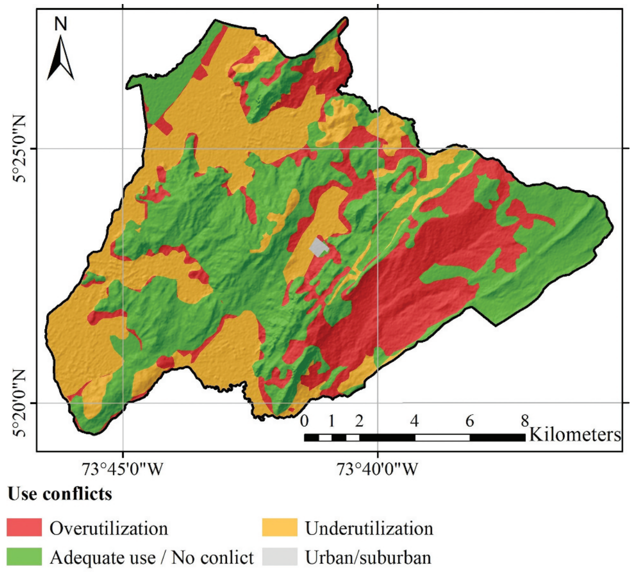

Figure 3. Land-use conflict map of Guachetá municipality. Source: own elaboration based on IGAC (2013).

potential and limitations of the land (Gliessman 2015), a sustainable approach for implementation of more intensive practices is that of ecological intensification (Tittonel 2014). Focusing on supporting and regulating services such as formation and conservation of soil, nutrient cycling and pollination would make it possible to harness these, contributing to agricultural production (Bommarco, Kleijn, and Potts 2013).

Around 41% of the land in Guachetá municipality is classified as Class VI, where the steepness of the slope and low rainfall during some seasons constitute major limitations. This land is only suitable for some semi-perennial or perennial, semi-dense and dense crops, agroforestry, and forestry, although extensive livestock rearing is possible if soil conservation practices are implemented (IGAC 2014b). Grazing livestock in areas with relatively high slopes has previously led to soil degradation (IGAC 2013).

Water bodies and protected areas are part of the remaining area (23%), along with Class VII and VIII land types, which are dominated by steep slopes, shallow effective soil depth, high erosion potential and poor rainfall. Class VII land is suitable for forestry for conservation purposes, but permanent multistratum vegetation cover is necessary. Productive forest and agroforestry systems can be established where there is sufficient effective depth, with soil conservation and water management practices. Class VIII land should only be used for nature conservation (IGAC 2014b), since the presence of livestock has caused over-utilization of this area.

If the above recommendations for land use are followed, a more diversified agricultural landscape and systems could be achieved within the municipality, in accordance with agroecological principles (Gliessman 2015). In other words, alternative land uses can lead to a less homogenous landscape (reflected in the analysis of land cover) and promote better integration of trees and greater connectivity between elements of agroecosystems and the landscape.

Socio-economic aspects

Of the 14,241 inhabitants in Guachetá municipality (TerriData 2020), 7722 live in rural areas (54.2%). Most households in the rural areas are productive units smaller than 1.0 hectare (49.1%) or between 1.0 to 3.0 hectares (27.2%). However, productive units larger than 10 hectares (less than 5% of households) occupy the majority of the land (64%), with only 15% of total land occupied by farms smaller than 3.0 hectares. Production of annual crops in the municipality is dominated by potatoes, which account for 83.6% (4144 t/year) of total annual vegetable production (TerriData 2020). Annual potato yield is estimated to be 16.19 t/ha, which lies below the national mean production level of 20.17 t/ha. Onions account for 14.1% of total annual vegetable production (699 t/year), but the yield of 18.39 t/ha is lower than the national average of 22.63 t/ha. There are no available records for milk production levels in Guachetá municipality.

Characterisation of agroecological transition (CAET) of the systems

The scores for each of the 10 elements of agroecology and for each system are presented in Table 2, while Figure 4 shows the results obtained from the CAET when the scores of the seven agroecosystems assessed were averaged.

The strongest element was *Culture & food tradition*, followed by *Human & social values* (Table 2). The finding on *Culture & Food tradition* indicated that participating farmers had access to appropriate diets, were aware of good nutritional practices and had respect for traditions and local identity, and that traditional food preparation was in place, with the use of local products. Scores for *Human & social values* were high because the indices for women's

Table 2. General scores* for the 10 elements of agroecology for each of the agroecosystems assessed on the seven small-scale farms (P1-P7) in Guachetá municipality.

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%**
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%**

*Scores below 50% indicate no agroecological transition, scores of 50–70% indicate transition to agroecology, and scores higher than 70% indicate advanced transition.

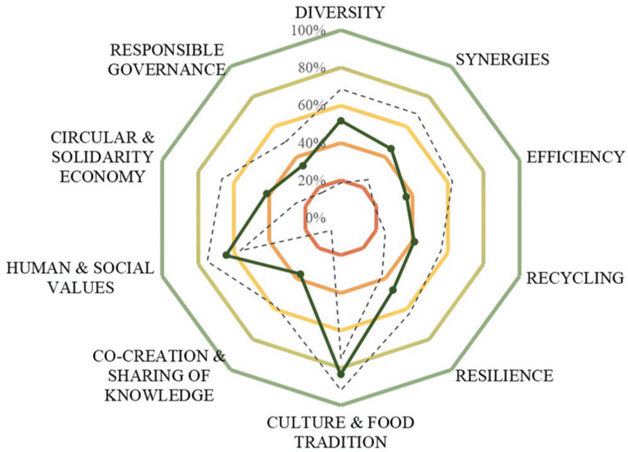

Figure 4. Radar diagram summarising the average CAET results for the seven small-scale farming systems in Guachetá municipality. Dotted lines indicate the range of variation.

empowerment and labor were relatively high, although the index for youth empowerment and emigration significantly lowered the overall score for this element. The index for animal welfare showed medium to relatively high scores.

Diversity had an average score slightly higher than 50% (Table 2). On one farm, crop and animal diversity were minimal, since production was based on monoculture and only one animal species was kept. Some farms had at least two or three crops on a significant cultivated area, while in the most diverse cases, at least four adapted crops were grown using intercropping within a spatially diversified area. Those farms also had at least two different species of animals. The index with the lowest scores among all farms was for presence of trees and other perennials, reflecting their absence or rare presence. These aspects and the limited number of products and services offered were the main factors lowering the score for diversity.

Similarly, the scores for *Synergies* were low due to the lack of integration of trees within the systems and poor connectivity with the natural landscape. The crop-livestock integration score was medium for most of the farms, because animal manure was often used as fertilizer and animals were mostly fed with homegrown produce. Higher integration indicated animals fed only with products from the farm and producing more than one service. Soil-plant system management differed between farms in terms of their practices. The soil was not left bare after harvest in any case, but in one case use of monocultures gave the system a low score, while the other farms practised soil conservation.

The element *Resilience* scored low, mainly due to unstable income and productivity. It showed higher variability in its scores due to more varied answers about indebtedness. For some farmers, debts constituted about half of their income, while others had no debts because they had never applied for financial support. The diversity of activities, products and services differed between the farms, ranging from only two or three productive activities to more than three activities and one service. The stability of income/production and capacity to recover from perturbations was low, since most of the producers indicated decreasing profit margins, variable production and little capacity to recover from perturbations. Regarding the mechanisms to reduce vulnerability, although in theory the farmers have access to loans, it is difficult to obtain a loan in practice. Insurances are also not common. The community might be supportive to a certain extent, but their capacity to help is limited.

Recycling also scored low (Table 2). There was no significant amount of self-produced and renewable energy consumption, since the farms were connected to the electric power supply in the municipality, which relies on thermal power stations (coal-fired) and hydroelectric power. The farmers also purchased gas and used animal traction to some extent. Various techniques for water harvesting or saving were not in place. However, the majority of the residues generated on the farms were recycled and little waste was burnt. The most notable differences between producers were in management of breeds and seeds, for which some depended completely on the market, giving them low scores, whereas for others the majority of genetic resources were self-produced.

Efficiency showed noticeable differences between farms, although the average value was very low. On the farm with the lowest scores, use of external inputs was high and all inputs were purchased on the market, whereas in other cases some inputs were produced on the farm. Management of pests and diseases on most farms scored low, since chemical pesticides were used regularly and use of biological products was limited. However, on a few farms, pest management was mainly done using organic practices with biological substances. The management of soil fertility showed high variability in scores among the farms. The lowest values were associated with regular use and dependency on synthetic fertilizers, while higher values were associated with organic practices. Productivity and household needs showed a negative relationship with the other indices, suggesting a trade-off between reduced use of external inputs and productivity, i.e. farmers who relied less on external inputs also had lower revenues. In some cases, production on-farm did not meet the basic needs of householders and they had to rely on alternative sources of income.

Responsible governance, *Co-creation & sharing of knowledge*, and *Circular & solidarity economy* were among the elements that showed the lowest average scores (Table 2). Differences in farmers' perceptions, relationships and involvement with a farmers' association were most evident when analyzing *Co-creation and sharing of knowledge*, the element with the most varied scores. Associations represent the main platform for horizontal creation and transfer of knowledge and good practices. Farmers who claimed that there were no available platforms for producers were those who were not involved with associations. In a similar way, the participation of producers in networks and grassroots organizations was very variable: one producer claimed to be isolated, with no relations with their community, while others were well interconnected. Concerning the access to agroecological knowledge and interest of producers in agroecology, some farmers showed agroecological principles in their practices and interest in spreading knowledge, while others had little understanding of agroecological principles and did not trust alternative agricultural practices.

Circular & solidarity economy showed relatively low scores. Inputs were often purchased from outside the municipality or the region, although some foods were locally available and there was exchange of goods and services between local producers to some extent. The index for networks of producers, relationship with consumers and presence of intermediaries scored low for the majority of the systems assessed, since although there were networks of producers, they did not function properly, there were little to non-existent relationships with final consumers and the intermediaries had control over the marketing process. Further, although local markets existed, only some products and services were marketed locally.

Responsible governance was the element with the lowest general scores. All the participants alleged that their rights were recognized and respected but their bargaining power was low, with little stimulation to improve their livelihoods or to develop their skills. Their perception on participation in decision making on governance of land and natural resources was highly varied, although all of the participants claimed that there are no fully operational mechanisms that allow producers to participate in governance. The farmers reported different degrees of involvement with farmers' associations. For some the role of the association was marginal and represented no significant support, while for others the association provided support for access to markets and other services.

Performance of agroecological systems

The results from Step 2 of the TAPE evaluation are presented in Table 3. *Secure land tenure* indicated a desirable state for all of the agroecosystems assessed. There was legal recognition of access to the land and the perception of the farmers was that it was secure and they had the right to sell, bequeath and inherit. Similarly, *dietary diversity* was desirable for all the households, since in all cases the participants indicated that at least 7 out of the 10 different food groups listed had been consumed in their households within the previous 24 hours.

Youth employment scored "acceptable" as a generalization of the systems (Table 3). Among the population aged between 15 and 24 years, one was currently working in agricultural production, the majority were currently receiving some kind of education and training, and one more had left the community due to lack of opportunities. Only one person showed interest in continuing with the farm run by their parents, while the others would emigrate given the chance or had already emigrated. The weighted score for this criterion was 65%, mainly because education or training is considered favorable for young people despite them generally not being willing to continue with agricultural production.

Agricultural biodiversity showed variable scores, although in most cases this criterion scored as "acceptable" (Table 3). Gini-Simpson index for crop and animal species, which is a default biodiversity indicator in the TAPE tool, was above 50% in six systems assessed. The index of natural vegetation, trees, and pollinators was low in most cases due to the small area covered by natural vegetation within the agroecosystems. Nevertheless, in all cases farmers reported significant or abundant presence of beneficial organisms. Farm P4 was a system in which crop production was dominated by monocultures and with only one animal breed, and thus the Gini-Simpson index was zero. In contrast, farm P5 had a high diversity of crops and animals, leading to Gini-Simpson score above 70%.

Table 3. Results on core performance criteria applied to individual systems on the seven participating small-scale farms (P1-P7) in Guachetá municipality.

CORE CRITERIA	P1	P2	P3	P4	P5	P6	P7
SECURE LAND TENURE	Desirable						
INCOME	Acceptable	Un-sustainable	Acceptable	Un-sustainable	Un-sustainable	Un-sustainable	Un-sustainable
EXPOSURE TO PESTICIDES	Un-sustainable	Un-sustainable	Un-sustainable	Un-sustainable	Desirable	Un-sustainable	Un-sustainable
DIETARY DIVERSITY	Desirable						
YOUTH EMPLOYMENT	Acceptable						
AGRICULTURAL BIODIVERSITY	Acceptable	Acceptable	Acceptable	Un-sustainable	Desirable	Acceptable	Acceptable

In terms of *Exposure to pesticides*, only farm P5 had a desirable state and the others were considered unsustainable for different reasons, including the use of highly hazardous Class I pesticides, lack of mitigation strategies and/or no use of organic substances or similar integrated practices. In contrast, P5 only used cultural control, by choosing resistant varieties, manually removing plants with signs of disease and implementing intercropping and crop rotations.

Finally, the criterion of *Income* proved to be unsustainable because most farmers reported that their income had declined over the years, although they did not think that it differed significantly from the average in the region.

Four of the core criteria could not be evaluated in this study. Two of these criteria, *Added value* and *Productivity*, require a detailed amount of data and information that could be considered sensitive, and thus it was not feasible to evaluate them by remote communication or assume a possible state. The third criterion, *Women's empowerment*, required a specific set of conditions to perform interviews with women alone which could not be achieved due to the constraints of this study. Altough the majority of interviews indicated that decision-making and participation in farming are agreed jointly by men and women (only in one case was it mentioned that the man was solely responsible for decision-making)), there is not enough evidence to categorize this criterion in a sustainability level. With regard to the fourth criterion, *Soil health*, none of the participants mentioned problems associated with "bad soils." According to IGAC (2001a), moderate chemical fertility can be inferred from the presence of organic soils in flat regions and good soil structure, although some steep mountain areas are subject to erosion. Thus the *Soil health* criterion is likely to have an overall acceptable state.

Main challenges identified by different stakeholders

The semi-structured interviews also revealed several important challenges faced by small-scale farmers. These were broadly grouped into two theoretical constructs (see Section 2.3): a) productivity and profitability issues and b) lack of collaboration and support. They were then further segmented into five topics, as discussed below.

Productivity and profitability issues

Climate-related factors affecting productivity. Environmental conditions are a major constraint to achieving higher productivity in the study region. These conditions are related to natural processes and possible effects of climate change.

"Verano" is too harsh. "Verano" refers to the dry seasons. Agriculture in the region is predominantly rainfed, as most farmers do not have access to

irrigation infrastructure or cannot afford the equipment. Thus, water scarcity is a major factor affecting productivity. One of the experts (E2) reported that Ubaté Province has an exceptionally dry climate in comparison with neighboring regions and that irrigation is required for agriculture to reach its full potential. However, the appropriateness of measures, practices and technologies to be implemented must be considered (Patnaik and Bhowmick 2018), meaning that the region should address the issues of water scarcity in relation to identified needs and practices adapted to the local context. An example of the implementation of agroecological principles in Colombia is cultivation of burley tobacco in Sucre (Ortega and Zambrano 2020), where use of adequate information for the development of crop calendars, mulching and establishing optimal planting times gave an improvement in overall sustainability. Likewise, rainwater harvesting can be an appropriate option as the region receives heavy rainfall concentrated to a few days, which also exacerbates soil erosion (Piemontese et al. 2020). Some of the lands deemed unfavorable for highly productive agriculture due to high slope gradient (*e.g.* Classes VI and VII) might actually be suitable for rainwater harvesting, by building contours and dykes. However, feasible and effective water harvesting systems need to consider both biophysical assessments and the socio-economic dimension, since for instance the location determines the possibility to implement rainwater harvesting measures such as terracing, storing rainwater in pits or obtaining water from streams (Piemontese et al. 2020).

Climate unpredictability. "*The climate is not the same as a few years ago; you can no longer plant potatoes in November*," said one of the potato farmers (P1). A dairy farmer (P10) said: "*You no longer know when it will rain. We have no alternatives if there is a lack of rain. Before there was more confidence in the timing*." These two statements show the difficulty farmers have in planning their crops due to uncertain rain patterns during the year and unexpected periods of frost, which they have experienced in recent years. Such events increase the risk of harvest losses and failed investment in cultivation.

These claims are consistent with our analysis of the variation in rainfall in the region during recent years (Figures 5 and 6). In 2011 and 2015, the region experienced the highest and lowest values of total annual rainfall, respectively, since 1962. Moreover, there was noticeable variation in total monthly rainfall (Figure 6). In 2019, total rainfall during March was notably higher than the average, but it dropped below the average in April. A more erratic situation was observed in 2020, when the first rainy season (March-May) showed drier conditions, rainfall during October was well below the normal range of variation and heavy rainfall was experienced during some days in late November, leading to monthly rainfall that was markedly higher than usual. Alterations in rainfall patterns have also been recorded in the Eastern Colombian Andes, with farmers in a neighboring region, Norte de Santander, reporting negative effects of climate change on agriculture via increased susceptibility to pests and diseases and increased water scarcity, among other problems (Núñez Rodríguez et al. 2021). In fact, several studies have reported that livelihoods and important crops such as potato, quinoa and maize in Colombia and other Latin-American countries are already considerably affected by rising temperatures resulting in higher evapotranspiration and water scarcity (Lozano-Povis, Alvarez-Montalván, and Moggiano-Aburto 2021; Núñez Rodríguez et al. 2021; Ortega and Zambrano 2020).

The results obtained in this study show that traditional peasant farming in Guachetá has undergone a gradual reduction in agricultural biodiversity, increasing dependency on external inputs and low integration within the elements of the agroecosystems and with the natural landscape (Figure 4). This has resulted in poor efficiency of agroecosystems, inadequate use of natural resources, undermining their ecological and economic basis,

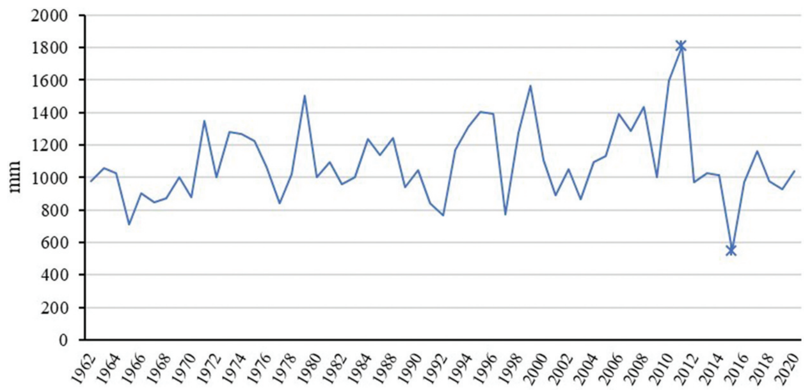

Figure 5. Total annual rainfall (mm) 1962–2020 at the station ISLA DEL SANTUARIO in Guachetá municipality. The highest and lowest values were recorded in 2011 and 2015, respectively.

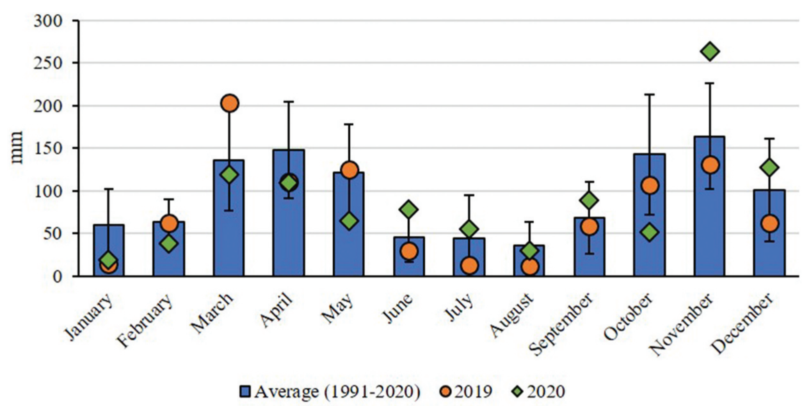

Figure 6. Mean monthly precipitation compared with total rainfall recorded for 2019 and 2020 at the station ISLA DEL SANTUARIO in Guachetá municipality (error bars represent standard deviation).

decreasing profit margins for rural communities and high vulnerability to climate change. Redesigning agroecosystems by promoting use of adapted varieties and breeds, reduced tillage, precision farming with efficient irrigation, rainwater harvest, agroforestry, crop diversification and rotation, modification of crop calendars, organic farming etc., could potentially help farmers deal with climate change, a deteriorating environment and low economic incentives (Jacobs et al. 2019; Ortega and Zambrano 2020). With regard to climate change, although some general guidelines for adaptation to climate change have been proposed in Colombia (DNP 2012; M.A.D.S 2018), there are still no clear measures or specific guidelines for agriculture. Thus, further efforts are needed to promote sustainable agriculture in the context of climate change.

Shift toward conventional agriculture. Many participants described a dependency on external inputs (both pesticides and fertilizers) and reported that this was not the case in the past. Many noted that their parents and grandparents did not use agrochemicals and employed alternative practices to manage pests, like the use of "*ají*" (chili pepper).

Use of external inputs. "*Nowadays we always need to spray to control pests*," remarked one of the farmers who needs to engage in other activities for his sustenance (P8). The need for pest control was a challenging factor frequently mentioned by the participants, especially with reference to production of potatoes and maintenance of pastures. There are several common pests and diseases in the region, but for potatoes the main one is Guatemalan potato moth (*Tecia solanivora*), while eor pastures, the most important pest is a bug (*Collaria columbiensis*) that "withers" the grass. This dependency is aggravated by the unsustainable exposure to pesticides reported in the performance analysis (Table 3) due to malpractices in their application.

There has been a shift in perceptions on how agricultural production should be carried out. Farmers felt that constant use of inputs is now mandatory, but also reported that it was becoming increasingly difficult to control pests and diseases even with increased use of pesticides. In their understanding, pesticides also come with a new "bug" or pest. In the words of one of the most experienced farmers (P2), "*when inputs were used, each one came with its 'virus' that in the future will be harmful.*" Some farmers regretted using agrochemicals because of negative environmental consequences and health effects, and felt that it would be ideal to shift toward the use of alternative methods to manage pests. However, farmers who used alternative practices and reported fewer problems with pests indicated that their production was mainly self-consumed in the household or was relatively small-scale and their main source of income came from other activities (P5, P6, and P8).

The dependency on inputs was reflected in low *Efficiency* of the systems (CAET), one of the elements with the lowest average values (Table 2). The use of pesticides was described as unsustainable (core performance criteria), except for one farm where pesticides were not applied. However, there seemed to be a trade-off between application of pesticides and the possibility for increased yield and income. This exemplifies the level of dependency on external inputs and the incorporation of agroecosystems into the treadmill of production, which demands continuous purchase of new products to control pests in a cycle where pesticide use gradually increases over time (Gliessman 2015; Hedlund, Longo, and York 2020).

Specialisation of farms in fewer products. Although the agricultural diversity was considered acceptable in most of the cases according to the systems performance analysis (Table 3) with a potential transition to agroecology (Table 2), two of the experts (E1 and E2) mentioned a decrease in the diversity of farm products toward only having milking cows and noted that family orchards, which were once common, are becoming rare. "*The sheep have disappeared. The home garden is rarely used and nobody sows* [other crops] *any more*," commented one of the experts on the current state of specialization in the region. These participants were of the opinion that having high diversity within farmland is good, as it spreads the risk, but they also felt that managing diverse systems was more complicated and posed a risk to their livelihood, while specialized systems seemed to be more reliable. There is thus a mismatch between current agricultural practices and how farmers actually think that agriculture should be carried out.

Low, decreasing and unstable profit margins. Low and decreasing profitability is a discouraging and demotivating scenario that leads farmers to reconsider their willingness to continue in agricultural production.

Rising costs. Several farmers (P1, P3, P4, P10, and R2) reported that agricultural inputs and services (*e.g.* milk cooling, rented machinery) are too expensive and require high investments to guarantee a minimum amount of production. Furthermore, farmers have to bear duties and taxes for imported agrochemicals without significant aid from the government. A farmers' couple (P9) mentioned that the price of concentrate feed for cattle had increased by 30% during the past couple of years due to various market conditions. Likewise, technologies that could improve production and the livelihoods of farmers are not economically available to small farms. Basic living costs are also rising yearly.

This dependency on agrochemicals can potentially be diminished by implementing ecological practices which favor integrated pest management, reduce negative effects on health and avoid the need for expensive pesticides. Practices that help to mitigate the dependency on pesticides include the use of more resistant varieties, increasing spatial and temporal biodiversity with the implementation of intercropping schemes and varied crop rotation, the use of organic compounds and planting natural pest-repelling plants (FAO

2019). These practices are also likely to have positive effects on other elements of evaluated CAET, like diversity and synergies (Table 2), reflecting the interrelation between the elements of agroecology (Barrios et al. 2020).

Fluctuating prices of agricultural products and no bargaining power. "*That the price* [of farm produce] *reflects the value of our work*" was a desire expressed by a farmers' couple (P9), reflecting the concerns of several others. Prices of agricultural produce are not sufficient to support farmers in the short and long run. Several participants recognized their disconnect from consumers and the dominant role of intermediaries in sales channels. The prices of the farm produce are imposed by these intermediaries, while farmers have no influence, regardless of the production costs. One farmer (P10) acknowledged the uneven bargaining power among actors in the value chain: "*Intermediaries earn three times as much as they pay for the produce.*"

Importing food from countries such as Ecuador, Canada, the USA and the Netherlands, without proper government intervention, was also viewed by the participants as causing drops in food prices. Products like potatoes were reported to receive very poor prices and production of crops was not considered as profitable as production of milk. Yet, the situation for milk producers was also critical, since milk prices never go up. "*Three years ago, one liter of milk was sold at 1,300 pesos* [0.33 USD] *and now it is sold at 1,190* [0.30 USD]" said an association representative (R2). Moreover, several farmers emphasized the constant threat of sudden price drops, which is consistent with a prevalent unsustainable income in the analysis of performance (Table 3). Demotivation amongst (potential) farmers was further exacerbated on comparing the wages in the agriculture sector with those in mining; a person working in the mines can earn more than twice as much as a farmer and has better social security conditions. This has most likely an effect on the willingness of your people to continue in agricultural activities, as explained in the analysis of performance of the agroecosystems. There have been similar findings in other regions of Colombia, like in Antioquia, where the prices of agricultural products in remote areas are controlled mainly by intermediaries, leaving a low profit margin for peasant farmers and causing high levels of poverty, migration and demotivation (Acevedo-Gonzalez and Múnera-Ramírez 2020).

Lack of producer networks and the disconnect between producers and consumers resulted in low scores for *Circular & solidarity economy* in the CAET (Table 2). More sustainable and equitable markets can only be guaranteed when there is support for local economic development (FAO 2018). These aspects should take special relevance within the context of an economic system heavily influenced by international trade. The experiences of the participants strongly suggest that the national government has been ineffective in stimulating and protecting smallholders from the international market challenges. Low resilience of the agroecosystems is related to unstable income and low capacity to recover from perturbations. Current conditions leave the small-scale farmers in a situation of high vulnerability, resulting in lack of interest in agriculture among young people, which poses a major threat to the development of small-scale farming (Carbone and Subioli 2011; Rodriguez-Lizano, Montero-Vega, and Sibelet 2020).

Actions to decrease the economic strain on farm households include facilitating access to local markets and reducing the number of intermediaries in the food supply chain. This can be done through introducing technological innovations such as software and apps aimed at supporting the sustainability of agricultural landscapes, which can potentially reduce the distance between producers and consumers (Inwood and Dale 2019; Shriram and Mhamane 2018). In addition, value co-creation processes that consider local contexts and realities could bring higher benefits for farmers (Barrios et al. 2020).

Debts, credits and taxes. Although the farmers reported having access to credit, they receive no subsidies and fear losing financial solvency in the event of variations in market values, drops in productivity, etc. The interest rates on available loans for small-scale farmers do not offer advantages in relation to other types of credit. "*In theory, a small producer has access to credit, but the peasant who asks for a loan and for some reason does not get enough* [from their production] *goes bankrupt, and the banks finish them off*," remarked one of the experts (E1). There was a general perception that taxes are very high and that there is very unfair treatment. Another participant reported that in order to pay their debts they had to sell their cattle cheaply and rent out their land, since they could not continue to use some of it for production.

Lack of support and collaboration between relevant stakeholders

Pessimism and distrust in institutions and organizations. There was general distrust in institutions and organizations, including farmers' associations. This had built up over time and was related to lack of effective support measures for development of agriculture, perceived corruption within organizations and public entities, and lack of representation of the interests of the rural population.

Perceived corruption and disinterest leading to insufficient and ineffective support for agriculture. All the participants agreed that national and local governments have not shown enough support for small-scale producers. Most farmers mentioned that they have never received any support from the government "*We have been forgotten, sometimes we have to do this 'with our nails'* (with almost no means)" said even the farmer who had the highest resilience and an acceptable income (P3). According to the participants, there is no evidence of government interest in rural development and food production. Investment, control, collaboration or aids are limited. There was also a general perception that the few aids offered by the government do not reach smallholders. Farmers explained how they do the paperwork to apply for support, but that the procedures do not work properly and that application can only be made through the associations. One farmer mentioned that there were too many populist promises during elections that were not kept and the only way to get some support was to get along with the politicians. Moreover, there was a lack of clear information on how government funds for agricultural development were utilized.

There was also distrust in farmers' associations and some claimed that their path had deviated. The aids that associations applied for did not always work, and when they did many people who initially did not have the will to cooperate took advantage of the money. Corruption is a common phenomenon in Colombia (Langbein & Sanabria, 2013), with different degrees of tolerance and acceptability (Martinez and Posada 2022), meaning that a bribe is somehow expected. The country scores 39/100 on the Corruption Perceptions Index (Transparency International n.d.), where low values are associated with highly corrupt countries.

Lack of leadership, representation and collaborative work. A common opinion among the farmers was that their interests were not represented on a larger societal level and that there were no leaders to represent peasant lifestyles. This was clearly evident from a remark by a farmer (P10): "*They* [governments] *do not know what hunger is, they do not know what it is to work in 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*." Many participants acknowledged the lack of peasant leadership and will to participate in communal projects. Some pointed out the need for strong cooperation and organization. Others indicated that there is no community culture or culture of cooperation and that getting common agreement is challenging. In many cases, the role of associations was perceived by the participants as marginal and mostly consisted of providing support to producers for access to the markets.

Feasible and effective implementation of agricultural practices requires assessments of both biophysical and socio-economic dimensions (Piemontese et al. 2020). Consequently, it is necessary to identify the prevailing socio-ecological conditions in order to achieve effective coordination between farmers and other relevant stakeholders. Possible measures to address the issues identified in this study would require the active participation of different actors in governance of the land, which was the weakest point identified by the CAET. Only an adequate enabling environment can facilitate implementation of measures, practices and technologies to overcome the problems. Creating an enabling environment requires developing governance mechanisms that are inclusive, transparent and accountable (FAO 2018). In contrast, the environment described by the farmers in the present study indicated that operational mechanisms for active governance of the land and the natural resources are absent. Thus, for agriculture that improves human well-being and quality of life, responsible governance mechanisms at different scales, from local to national level, need to be implemented, in accordance with the 10 elements of agroecology (FAO 2018).

Lack of mechanisms for coordination, communication, learning, knowledge transfer and exchange of information. Inadequate communication, cooperation and articulation between different relevant stakeholders have led to a situation where the possibilities for improving the conditions for agriculture in Guachetá are limited.

Decision-makers in positions of power ignore the struggles and reality of farmers. The aids that farmers can apply for are often not monetary, but in kind (*e.g.* agrochemicals), and do not meet their actual needs, as mentioned by the participants. "*Not that they give us the inputs, but that we can decide what to invest in*" said one of the farmers (P1), meaning that financial aid would be more relevant. This indicates a disconnect and lack of understanding between farmers and decision-makers. In the words of one representative (R3): "*Most of the projects are formulated by people who do not know the agricultural sector. They are formulated in an office in Bogotá where the needs of the countryside have not been taken into consideration.*" This situation highlights the need for participation and coordination with agriculturalists in governance and decision-making. While these findings suggest some degree of unawareness among decision-makers about the needs of the Colombian peasant population, application of principles of multi-stakeholder partnerships, such as effective communication and collaborative leadership (Brouwer et al. 2016), can aid in overcoming these issues.

Limited coordination between different official entities and farmers. The overall perception was that communication between relevant stakeholders within the agricultural sector is insufficient. There are several government agencies that deal with different aspects of environment, agriculture and rural development, but there seem to be disconnects or lack of coordination between them in developing relevant and efficient solutions. Although knowledge may be available to address specific issues, there is no dedicated work on improvement of agricultural practices or the well-being of small-scale farmers. Often there is no continuation of agricultural development projects after four years, because governance and administrative positions in the public sector change every four years and the determination to continue or start new projects depends on the vision of each administration.

Transition toward sustainable agriculture requires redesign of the systems themselves so that their functionality resembles ecological processes (Gliessman 2015). Notably, redesign of the systems cannot be performed only at farm level and it is desirable to transition to a socio-ecological regime that focuses on the goal of sustainable life. This requires a redesign of world views, institutions and technologies (Beddoe et al. 2009). Such evolutionary processes take time and require 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 (Brouwer et al. 2016). Thus, strengthening collaborative action in Guachetá could be the basis to tackle some of the important challenges that the current food system faces, since complex or systemic problems cannot be overcome by individual parties (Brouwer et al. 2016).

Lack of knowledge, training and education. Farmers in this study had insufficient information and training on sustainable agricultural systems, and the training that they received was often not relevant (*e.g.* specific resources and technologies that farmers lacked were required). According to out interviews and surveys, there is a strong need to implement technologies that allow sustainable development of agriculture. Farmers' associations engage in training of farmers, but their efforts and resources are limited. In the past, official agencies developed programmes to train farmers in the use of natural resources and production systems, but such knowledge and skills among farmers and trainers has been lost, according to one of the experts interviewed in this study. Despite Guachetá being located close to the capital, there seems to be insufficient knowledge and education among farmers in the municipality about sustainable farming practices. One of the farmers acknowledged a lack of information and guidance on soil science and its implications for agriculture. As mentioned by one of the experts, there is a need for more detailed information on soils. Existing knowledge about the condition of land and its uses is too general, which aggravates the issues related to optimal and sustainable use of natural resources.

An approach based on participation and collaboration can serve to promote and improve the *Co-creation & sharing of knowledge*, another element with a very low average score in the CAET (Table 2). 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 co-creation of knowledge that promotes uptake of agricultural innovations 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). As rural people's knowledge and skills emerge from practical experience in a local context, these can be highly specific and bound to that context (Scoones and Thompson 1994). Thus, dialogue and interaction between the knowledge of agriculturalists and the scientific knowledge in various institutions and universities can lead to creation and implementation of agroecological innovations that help cope with the challenges of the system (FAO 2018; Scoones and Thompson 1994). This type of collaboration which involves transdisciplinary engagement as a mutual learning process (Barrios et al. 2020) can speed up the generation of knowledge where it is lacking. Moreover, it can improve access to agroecological knowledge, leading to widespread diffusion and application of its principles (FAO 2019).

Conclusions

In this study, important new information pertaining to the challenges facing small-scale agriculture and opportunities for agroecological development of Guachetá was obtained by applying the TAPE tool and conducting complementary interviews with key stakeholders. This produced a multi-faceted picture of the agri-food system of the region and uncovered a series of issues that require collaborative action in order to overcome them.

Climate change, low integration of agricultural practices with the natural landscape and poor interconnection between elements of the agroecosystems were identified as major challenges in the region, affecting the social, environmental and economic sustainability of local farms. There was evidence of high dependency on agrochemicals and of farmers being trapped in a vicious cycle of agrochemical use to support productivity. In addition, the food supply chain seemed to benefit retailers and other middle actors, while ignoring producers' needs and also environmental pressures, price fluctuations and low prices for farm products. There appeared to be a lack of partnership, associative culture and joint action among the food system stakeholders. These factors, together with a low level of agroecological knowledge and education, have repercussions for the capability of farmers to maintain a stable and reasonable income and overcome possible future perturbations. Thus, the current food production and distribution systems have led to high vulnerability to external risks for individual farms. This indicates a need to switch from the current food systems, which are based on short-term objectives, to holistic development of farms and rural society by promoting agroecological practices.

There is no single solution to the problems faced by agriculture in Guachetá municipality, and they must be tackled from multiple angles. From the findings of this study, we think that there is not a sequence of events that should be followed, nor a specific set of steps that are to be taken. These issues should rather be addressed with the involvement of several actors in a participatory way. Diffusion of agroecological knowledge, together with collaborative action, could play a central role in creation of more sustainable agriculture in the municipality. Implementation of practices such as alternative land use and diversification of farming systems would require the participation of different stakeholders to promote an enabling environment for participation of farmers in land governance and fair access to markets.

Transmission of agroecological knowledge, adaptation to local contexts and enactment by farmers, advisors and government actors are essential actions for farmers and communities to reap the benefits of agroecology. This study also demonstrated the potential of agroecological practices at farm and food system level to generate rapid, fair and inclusive development that can be sustained for future generations. In addition, it revealed a need for detailed biophysical information to determine the potential for implementing practices which can increase the efficiency of the systems (such as design of rotation calendars, use of different cultivars, breeds and local varieties, alternative management for pest control and rainwater harvesting possibilities). Detailed studies on issues related to learning, knowledge, communication and joint action between stakeholders and the dynamics of the markets and the food value chain could be helpful in identifying specific pathways for small-scale farmers to transition to agroecology and escape from their current socio-technical lock-ins.

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