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Towards the agroecological production of Hass avocado (*Persea americana* Mill.) in the Eastern Colombian massif

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ABSTRACT: The Hass avocado is one of the five most consumed tropical fruits globally, and its production is associated with significant environmental and social impacts. Since 2013, the Colombian Horticultural Association has been promoting the implementation of sustainable practices in avocado cultivation. Through semi-structured interviews with key stakeholders and structured interviews with avocado producers in the eastern Colombian massif, this article analyzes advancement towards agroecological production using the socio-ecological systems framework. Ninety-four percent of interviewed producers indicated using at least one sustainability-oriented practice, with an average value of 0.57/1 in the dimensions of the system and resource units, stakeholders, governance, and interactions. The region stands out for its progress towards sustainable production.
Keywords: Huila; tropical agriculture; sustainability; social-ecological system.

Rumo à produção agroecológica de abacate Hass (*Persea americana* Mill.) no Maciço Oriental Colombiano

RESUMO: O abacate Hass é uma das cinco frutas tropicais mais consumidas globalmente, e sua produção está associada a impactos ambientais e sociais significativos. Desde 2013, a Associação Colombiana de Horticultura promove a implementação de práticas sustentáveis no cultivo de abacate. Por meio de entrevistas semiestruturadas com as principais partes interessadas e entrevistas estruturadas com produtores de abacate no maciço oriental colombiano, este artigo analisa o avanço em direção à produção agroecológica utilizando a abordagem dos sistemas socioecológicos. Noventa e quatro por cento dos produtores entrevistados indicaram utilizar pelo menos uma prática voltada para a sustentabilidade, com um valor médio de 0,57/1 nas dimensões sistema e unidades de recursos, partes interessadas, governança e interações. A região se destaca por seu progresso em direção à produção sustentável.
Palavras-chave: Huila; agricultura tropical; sustentabilidade; sistema socioecológico.

1. INTRODUCTION

1.1 Agroecological and sustainable production

Among the major challenges humanity faces is the search for how to produce food under sustainable schemes in scenarios of accelerated environmental change and its degradation. Agroecological production emerges as an alternative to progress on this path (WEZEL et al., 2020).

Agroecology is associated with producing food with lower environmental and social impacts (NEWTON et al., 2020). Agroecological practices aim to manage available resources, such as soil, water, flora, and fauna, more sustainably and to reduce dependence on agrochemical inputs in crop production (ALBARRACÍN et al., 2019). Thus, using cover crops, productive diversification, and reduced or no tillage, among other practices, highlights favorable outcomes in soil condition, carbon sequestration, and increased biodiversity.

Since 2013, Asohofrucol (Hortifruit Association of Colombia) has been promoting the implementation of a model called tropical agriculture in the horticultural sector. This model focuses on three pillars: soil protection and management, protection and management of fauna and flora, and plant nutrition.

Soil protection and management address aspects such as soil preparation through the no-till technique (direct seeding of crops), soil protection through the management of live vegetative cover (herbaceous plants), and dry organic matter such as mulch.

Fauna and flora protection involve strategies such as biological corridors, conservation of ecological niches on the farm, and planting native plants. Additionally, it includes monitoring and phytosanitary management with mineral broths such as sulfur-lime broth, which is composed of sulfur and lime and is recommended for managing phytopathogenic fungi and insects. Bordeaux mixture, based on copper sulfate and calcium hydroxide, is used as a fungicide and bactericide, and potassium soap that serves as an insecticide.

Finally, plant nutrition emphasizes using bioleach or microbial broths, liquid preparations with a diverse microbiological load and a supply of known minerals, fermented for a specified period (RAMÍREZ et al., 2023). It also includes mountain microorganisms, defined as microbial inoculants with a high population of fungi, bacteria and bokashi (solid fermented organic matter) (SARMIENTO et al., 2019).

1.2 The impact of avocado on global and national agriculture

Hass avocado is the fourth most consumed tropical fruit in the world, with a production of 6.5 million tons recorded in 2019, harvested from 735,174 hectares in the world.

Currently, avocados are grown in 69 countries located in tropical and subtropical regions. The Americas host 72% of the global avocado plantations. Colombia, contributing 11% to the global production, with 979,617 tons harvested from an area of 94,111 hectares.

In Colombia, the cultivated area for avocados increased from 13,204 hectares to 94,111 hectares from 2000 to 2021. Various avocado varieties are grown in the country, including Lorena, Trinidad, Booth-8, Fuerte, Trapo, Santana, Colinred, Ettinger, and Hass. The Hass variety has the largest planted area, accounting for approximately 25%, primarily located in regions with moderately cold climates.

The extensive production of avocados worldwide has prompted numerous investigations into their cultivation's environmental and socio-economic impacts. In Mexico, for example, avocado production is linked to deforestation. Cho et al. (2021) estimated that, between 2001 and 2017, approximately 20% of the deforestation in Michoacán was associated with avocado expansion. This region's landscape features forest fragments mixed with avocado crops, altering environmental conditions, soil chemistry, natural resources, biodiversity, and species populations (MONTERRUBIO et al., 2019). Additionally, avocado production is associated with water scarcity, impacting water access in local communities in Michoacán. There is a growing concern about ensuring equitable access in local communities to avoid heightened tensions arising from inequalities in access to this resource (POWERS, 2019).

On the socio-economic front, as avocados are exported fruits, their marketing is associated with higher prices and better product quality. However, accessing these export markets is challenging for small farmers; in Kenya, for example, access to avocado export markets positively correlates with larger-scale producers and robust training processes (AMARE et al., 2019).

In Colombia, some regions have recently engaged in avocado production. This is the case in the eastern Colombian massif, in the department of Huila, a region where avocados became one of the top 10 agricultural products only in 2022. Thus, avocado cultivation is a new activity in the region, primarily undertaken by small-scale farmers whose production is oriented towards the external market and uses agroecological practices promoted by Asohofrucol. To understand the progress towards agroecological production of Hass avocado cultivation in the eastern Colombian massif, in the southern part of Huila, Colombia, this document uses Socioecological Systems (SES) as a theoretical and conceptual framework that facilitates delving into existing relationships between ecological and socioeconomic systems through flows at different levels of organization and scales. Developed by Ostrom (2009) and expanded by McGinnis; Ostrom (2014), this framework allows for a better understanding of systems addressing both ecological and social systems, with equal depth and importance (BINDER et al., 2013). The framework also facilitates the comprehension of how these systems can achieve sustainability (HERRERO et al., 2018), especially in food systems (MARSHALL, 2015; VALLEJO, 2022).

This article operationalizes this framework for avocado cultivation in Colombia for the first time, offering key points on the system and resource units, governance, stakeholders, and interactions that must be addressed to move towards sustainability-oriented production.

2. MATERIAL AND METHODS

2.1. Study area description

The Colombian Massif, also known as the "Fluvial Star of Colombia" because it is the birthplace of the Magdalena River, the country's most important waterway, is located in Huila and other departments in southern Colombia, and is protected by the Central and Eastern mountain ranges. This area contains San Agustín and Isnos, two rapidly growing municipalities with an increasing area under avocado cultivation in the region (Figure 1).

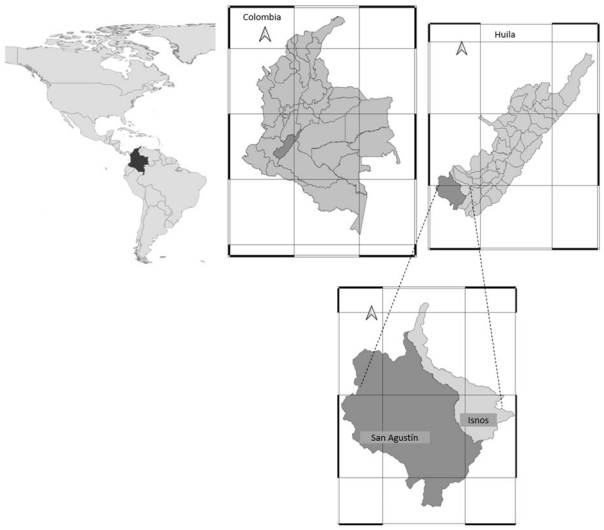

Figure 1. Study area in the east of the Colombian massif.
Figura 1. Área de estudo no leste do maciço colombiano.

San Agustín is located south of Huila, covering a territorial area of 1574 km², with an altitude of 1730 meters above sea level. The climate in San Agustín has been classified as premontane humid forest and low montane very humid forest Brand et al. (2021), with an average annual temperature of 18 to 24°C and rainfall of 1000 to 2000 mm annually for the humid premontane forest and average daily temperatures of 17°C or less and rainfall greater than 2000 mm for the very humid lower montane forest.

The population of San Agustín is 34,541 inhabitants, according to the projections of the 2018 census for the year 2023. 32.8% of the population lives in urban areas and 67.2% in rural areas. The economy is based on the agricultural sector and tourism.

The Municipality of Isnos has a cold and humid climate corresponding to a series of hills, mounds, and mesas comprising a characteristic landscape of hills with a moderately broken topography and slopes between 12 and

25%. Isnos receives 1458 mm of annual precipitation and average daily temperatures of 18°C. According to the 2018 census projections for the year 2023, Isnos is home to a population of 26,340 inhabitants, of which 23.7% reside in the urban area, while the majority, 76.3%, reside in the rural area.

2.2. Selection of variables to analyze agroecological production

The methodological trajectory commenced by selecting dimensions and variables that give information about the territory, guided by the socioecological systems framework proposed by McGinnis and Ostrom (2014). This framework has five crucial dimensions: The first is System and Resource Units (SRU), which are associated with the natural resources available in the territory. Second is Stakeholders and Productive System (SPS), which are the characteristics of the region's population. Third is Governance (G), which delves into decision-making processes, rules, norms, and land tenure. The fourth dimension is Interactions (I), which is related to the interactions and outcomes between variables, offering a perspective on the problems and conflicts present in the territory. Finally, the fifth dimension, Exogenous Conditions, relates to social, economic, political, and ecosystem characteristics.

Through a participatory approach and employing the expert consultation method, Herrera et al. (2022), an interdisciplinary team of researchers, identified a set of variables for analyzing the initial four dimensions. Table 1 outlines the variables and the associated elements utilized for each variable.

Table 1. Variables selected for the socioecological analysis.
Tabela 1. Variáveis selecionadas para a análise socioecológica.

Dimension	Variable	Structured interview with avocado producers	Semi-structured interview with key stakeholders
System and Resource Units (SRU)	Recognition of ecosystem services	Average number of recognized ecosystem services	
		Main recognized ecosystem services	
	Availability of water resources	The available water is sufficient for family needs during the summer period	Perception of water abundance
	Conservation areas	The producer states that he has conservation areas within his properties	Recognition of conservation areas at the local, regional, and national levels
Governance (G)	Land tenure	Type of declared tenure	Perception about the type of land tenure.
	Land area	Land area managed by the producer's family in hectares	Perception about the average household size
	Organization	Participation in local organizations	Recognition of local organizations in the area
		The number of annual meetings attended by the producer in an organization	
		Perception of the organization's functioning	
Stakeholders and Productive System (SPS)	Characteristics of avocado producers	Main economic activities generate income for the family	More relevant economic activities
		Average age of producers	
		Education level of the producer	
		Participation of members of the family in cultivation.	
		The producer states that having a home garden	
		Satisfaction with avocado cultivation	
	Characteristics of avocado cultivation	Average crop area	Limitations of the production system
		Age of the crop plants	
		Cultivar	
		Sanitary limitations	
		Reported system performance (t/year)	
		Commercialization	
		Number of certifications reported (BPA, GAP, exporting property)	
Interactions (I)	Environmental problems	Recognition of the negative impact of cultivation on the environment	Perception of the main environmental problems
	Social problems	The number of services that the home has	Perception of key stakeholders on the main social problems
	Sustainable practices in avocado cultivation	Average number of sustainable practices implemented per producer	Perception of key stakeholders on the use of sustainable cultivation practices
		Most used sustainable practices	
		Impact of practices on costs, performance, and quality	

2.3. Data Collection

Semi-structured interview formats were designed and applied to key stakeholders, and structured interviews were conducted with avocado producers in two municipalities of the Colombian massif. The semi-structured interviews with key stakeholders Schensul; Le Compte, (2013) followed a format with 16 questions distributed as follows: a) general information (date, location, name of the interviewee, institution, and position), b) system and resource units (services most relevant ecosystems, state of the water

resource, presence of conservation zones), c) stakeholders (main economic activities, arrival and importance of avocado cultivation), d) governance (land tenure, size of property, local organizations, stakeholders relevant in the territory), e) interactions (main environmental, social, productive problems and use of practices aimed at sustainability in avocado cultivation).

Sixteen interviews were conducted with representatives of local government bodies (2), leaders of local avocado producer organizations (8), environmental organizations (1), fruit marketers (2), trade union organizations (2), and academic and training organizations (1). These interviews took place between December 2022 and March 2023, were recorded, transcribed, and consolidated into a matrix to facilitate subsequent data analysis. All interviewees provided informed consent for both the recording and the use of the information.

The structured interview format for producers was collectively designed by an interdisciplinary team of researchers and consisted of 39 questions distributed across various categories: a) general information (date, location, name, identification number, contact information), b) socioeconomics (age, schooling, household size, total area of managed properties, economic activities, among others), c) natural resources (ecosystem services, impact of cultivation, conservation actions, etc.), d) productive system (information on seedlings, lot adaptation and transplant, agronomic management, sanitary management, irrigation and drainage, harvest, post-harvest, and infrastructure), and e) tropical agriculture practices (practices used for plant nutrition, soil protection, biodiversity and water).

55 structured interviews were conducted with avocado producers in January 2023, following non-probabilistic snowball sampling (Robinson, 2013). The interviews were systematized, and the data were analyzed using descriptive statistics (frequencies, percentages, and means) in Excel and R version 4.3.1 software.

2.4. Agroecological Production Index (API)

A multi-criteria indicator called the Agroecological Production Index (API) was calculated based on four dimensions of the socioecological systems (SES) framework: resource system and units, governance, stakeholders, production system, and interactions. A set of 18 variables distributed across the four dimensions was used in the analysis (Table 2). First, weighted values were assigned to the four main criteria categories to construct the index. The criteria within each category were then weighted based on their specific characteristics. Because the analysis variables were in different units and range gradients, three normalization techniques were used to reclassify each set of values according to each criterion in a range gradient between 0 and 1 (LESLIE et al., 2015).

The API equation consists of the sum of the products between the value of the normalized variables (Cj) and the weighted impact factor (βj) for each dimension of the socioecological system (Equation 1).

$$\mathrm{API} = \sum_{j=1}^{m} \beta_j C_j \qquad (01)$$

where: βj is the weighted value of criterion j, and Cj is the normalized value of criterion j.

The normalized values for each criterion (Cj) are the first values included in the API calculation process. The weighted impact factor of each criterion forms the second set. This is based on the fact that not all preselected criteria have the same impact on each farm's agroecological production. The supplementary material presents details on the index estimation.

Table 2. Variables selected for the agroecological production index.
Tabela 2. Variáveis selecionadas para o índice de produção agroecológica.

Dimension	ID	Variable
System and Resource Units	1	Average number of recognized ecosystem services.
	2	Perception of water availability all year round to meet family needs (domestic use and cultivation).
	3	The producer states that he has conservation areas within his properties.
Governance	4	Type of declared tenure.
	5	Land area managed by the producer's family in hectares.
	6	The number of annual meetings attended by the producer in an organization.
	7	Perception of the organization's functioning.
Stakeholders and Productive System	8	Household productive diversification
	9	Proportion of farm area cultivated in avocado.
	10	Family farming. Participation of household members in cultivation.
	11	The producer states having a home garden.
	12	Age of the avocado producer.
	13	Education level of the avocado producer.
	14	The yield of the productive system was reported last year.
	15	Number of certifications reported by the producer.
Interactions	16	The producer acknowledges the negative impact of cultivation on the environment.
	17	Number of sustainable practices implemented by the producer.
	18	Farmer's perception of the impact on costs, yield, fruit quality, and selling price of tropical agriculture practices.

3. RESULTS

Figure 2 synthesizes the main elements of the socioecological systems in the eastern Colombian Massif and the relevance and management of Hass avocado crops. The results for each dimension are described below.

3.1. System and resource units

The results of the semi-structured interviews showed that on average, the key stakeholders recognize between two and three ecosystem services, mainly those related to the

availability of water resources and the region's flora, as exemplified in the narratives below.

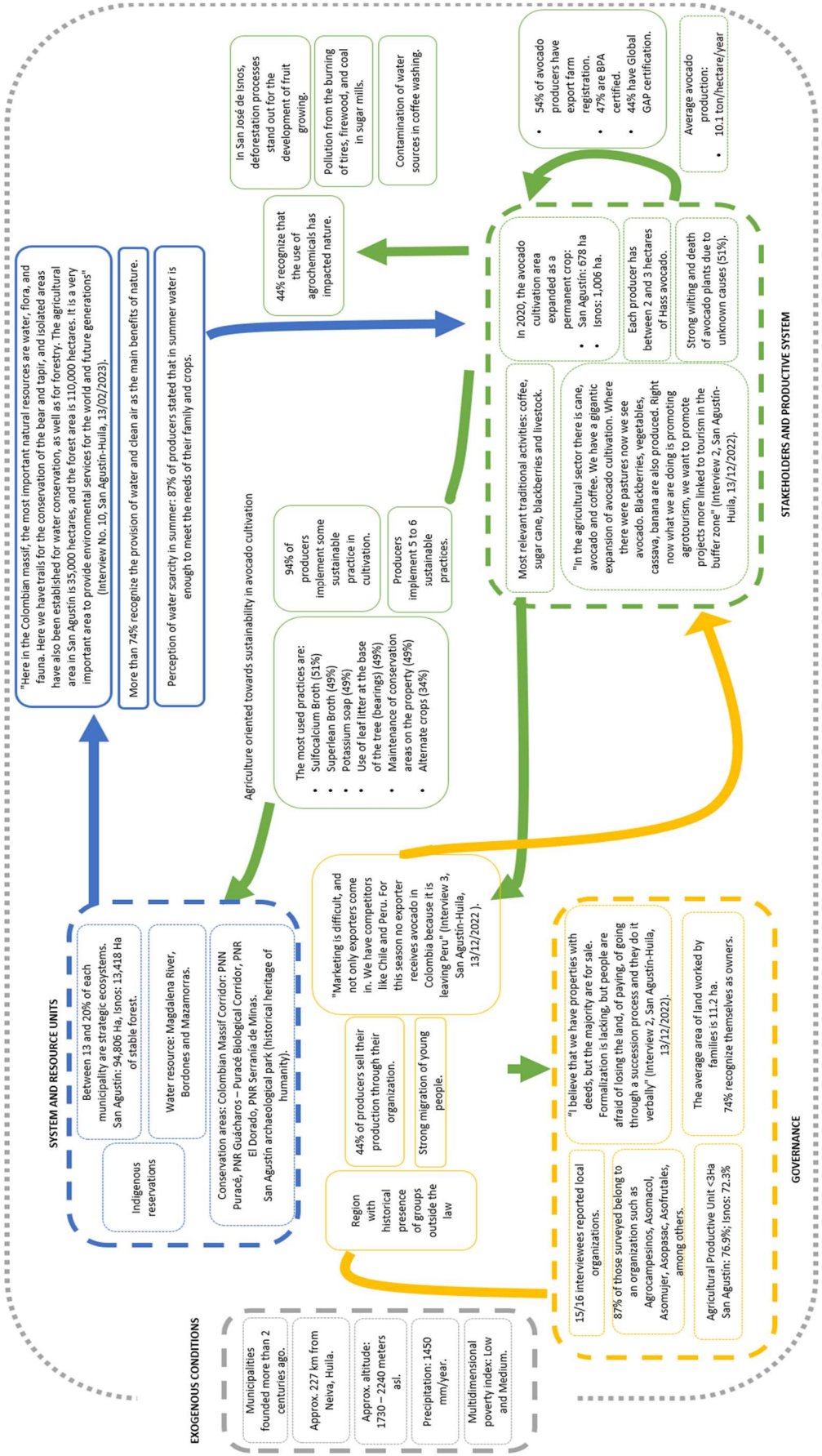

Figure 2. Avocado cultivation and socioecological systems in the eastern Colombian massif.
Figura 2. Cultivo de abacate e sistemas socioecológicos no maciço oriental colombiano.

"Here in the Colombian massif, the most important natural resources are water, flora, and fauna. Here we have trails for the conservation of the bear and tapir, and isolated areas have also been established for water conservation and forestry. The agricultural area in San Agustín is 35,000 hectares, and the forest area is 110,000 hectares. It is a very important area to provide environmental services for the world and future generations" (Interview No. 10, San Agustín-Huila, 13/02/2023).

The structured interview results reflect that, on average, avocado producers recognize between three and four benefits from nature. The most recognized benefits are the supply of water for domestic use and crops (74.6%), the quality of the air and oxygen supply (74.6%), wildlife protection (49.1%), provision of wild foods and firewood (36.4%), and climate regulation (30.9%).

About water resources, 68.8% of key stakeholders indicate that water resources are abundant or very abundant in the region. In addition, 87.3% of producers state that even during summer, the water is enough to meet the needs of the family and the crops.

Regarding conservation zones, 62.5% of the key stakeholders identified local conservation zones, highlighting the properties the municipality has acquired for water protection and areas that contribute to local aqueducts. Furthermore, 31.2% emphasize the existence of regional conservation zones such as the Guácharos-Puracé Biological Corridor, and 31.2% mention the relevance and presence of National Natural Parks (PNN Puracé, PNN Nevado del Huila). Additionally, in the structured interviews, 90.9% of producers affirm that protecting forests and water sources is as important as agricultural production, and 74.5% indicate owning land or areas designated for conservation.

3.2. Governance

When asked about land size, 81.2% of the key stakeholders indicated that areas smaller than five hectares are predominant. Moreover, tenancy is more often listed under the owner's name.

"90% of the producers, more or less, are owners of their plots, some have deeds, sound possession, purchase and sale documents" (Interview No. 8, Isnos-Huila, 13/12/2022).

Analyzing the properties' sizes based on structured interviews with producers revealed a heterogeneous distribution; the average surface area is 10.8 ha, while the median is 4 ha. Regarding land ownership, 75% of producers claim to be owners, 15% are tenants, and 9% report other forms of ownership.

Regarding organizational capacity, the semi-structured interviews revealed associativity is recognized and widely present in the region. 93.8% of the key stakeholders mentioned local productive organizations, and 50% cited local environmental organizations. However, they also emphasize that sometimes organizations are created to access public resources, and the organizations disintegrate once the resource is allocated.

"We as Asohofrucol serve here in Huila more or less 22 associations of producers in different product lines: passionflowers, avocado, cape gooseberry. Such as: Asomujer - Avocado Producers, APAIH - Avocado Producers, Asofruor - Blackberry Producers, Asocampesinos – Avocado Producers, Asomacol - Avocado Producers, Asofrutales - Avocado Producers, Asopasac - Avocado Producers, Apromora - Blackberry Producers" (Interview No. 8, Isnos-Huila, 13/12/2022).

In the structured interviews, 87.3% of producers say they are part of an organization. 81% of these producers perceive that the organization they belong to works well and estimate that, on average, they meet between seven and eight times per year.

3.3. Stakeholders and the production system

3.3.1. Characteristics of avocado producers

When investigating the main livelihoods, the semi-structured interviews illustrated that fruit and coffee are the most important crops, and 75% of key stakeholders pointed out the growing importance of avocado cultivation.

"The agricultural sector includes cane, avocado, coffee, blackberries, vegetables, cassava, banana, corn, and beans. Avocado cultivation is rapidly expanding, replacing pastures. Tourism is another line, right now what we are doing with the Ministry of Culture is promoting agrotourism, with those who are in the buffer zone, between the park and the productive zone" (Interview N°2, San Agustín-Huila, 13/12/2022).

Structured interviews with producers show that the main income-generating activities in the region are associated with non-agricultural rural income (45.5%) and avocado cultivation (72.8%). The average age of the interviewed producers is 47, with a recorded maximum age of 75 and a minimum age of 21. Regarding education, 33% of farmers had incomplete primary education, 20% had completed primary education, 7% had incomplete high school, and 24% had completed high school.

The average household size is 4 people, with approximately 48.5% of household members contributing to agricultural activities. Finally, 43.6% expressed satisfaction with avocado cultivation. The primary motivations for considering a change in the crop are linked to unstable profitability resulting from fluctuations in fruit prices and the emergence of wilting, contributing to increased tree mortality in the region (with no identified causal agent to date).

3.3.2. Characteristics of avocado cultivation in the eastern Colombian massif

The area cultivated by families in avocado is diverse; the data shows that the range oscillates between 0.3 and 5.5 ha. The average area is 1.5 ha, indicating a small size of the crops.

Most farmers consulted (89.1%) started planting avocados in the last 10 years. All crops are established with the Hass variety, with an average density of 186 plants per hectare. The main health limitations identified by producers were the *Monalonion* insect (*Monalonion velezangeli*) with 78%, mites (*Oligonychus yothersi*) with 38%, thrips insects (*Frankliniella gardeniae*) with 29%, and to a lesser extent, the disease caused by *Phytophtora* sp. (7%).

The average avocado production in southern Huila is 7.8 t/ha/year. This production level is typically attained through two (65.5%) or three harvests (14.5%). Producers categorize the fruit into first, second, and third qualities. On average, 82% is classified as first quality, 17% as second, and 1% as third.

Regarding fruit marketing, most producers (61.8%) indicated that they do not have a sales agreement with buyers,

while only 20% claim such agreements. Additionally, 43.6% mention making joint sales with their association. A significant portion, 38.2%, sells their fruit to intermediaries, and 36.3% to marketing companies focused on exports.

Lastly, regarding certifications, 54.5% of producers state that they have the exporter property registry, 47.3% state that they have the national Good Agricultural Practices certificate, and 43.6% have the Global GAP certification. Based on the semi-structured interviews, key stakeholders highlighted the significant presence of insect pests and diseases (43.8%), challenges related to fruit commercialization (37.5%), and the high costs of production inputs (31.2%) as notable limitations within the production system.

"Marketing and competition come in, not just exporters. The problem lies in international business, as competitors like Chile and Peru have regulations to access markets like the U.S. and the EU. Last year, no exporters accepted Colombian avocados during this season due to the Peruvian supply. This year, until this week, they weren't receiving either, but some exporters have now started buying." (Interview No. 3, San Agustín-Huila, 13/12/2022).

3.4. Interactions

Environmental concerns raised in the semi-structured interviews underscore the impact of agricultural activities on the environment (62.5%). Additionally, there is a strong emphasis on the extensive use of agrochemicals (50%) and the consequential impact on water resources (43.8%).

"The big problem is wastewater from coffee growers, as coffee washing water lacks septic tanks or treatment, polluting water sources and harming biodiversity. Another issue is sugar mills burning tires as fuel, a problem that persists despite administrative changes"(Interview No. 4, San Agustín-Huila, 12/13/2022).

From the structured interviews, it is noteworthy that 49% of producers perceive the negative impacts of avocado cultivation on the environment, mainly associated with using agricultural inputs. However, producers mentioned that the use of chemical synthesis inputs in avocado is decreasing. On the other hand, social problems include the effects of the armed conflict in rural areas, where poverty and distrust persist.

"San Agustín comes from an armed conflict, and we have sectors very affected by violence, and well, that's what we have the aftermath of, which are territories where you go, and you don't see the same development." (Interview No. 2, San Agustín-Huila, 13/12/2022).

The migration of young people and the shortage of labor in the countryside (31.2%) also stand out, along with issues associated with drug and alcohol consumption, and insecurity (31.2%).

"Today's young people are not going to use a pick and shovel, we need to renovate, have a two-wheel tractor, a tractor, here in San Agustín there are no tractors; strengthen companies, we are worried that we are going to be left with a food shortage having fertile land and soil because there is no one to work." (Interview No. 2, San Agustín-Huila, 12/13/2022).

3.3.3. Sustainable practices in the production system

The semi-structured interviews with key stakeholders revealed that 87.5% and 93.8% emphasize using biofertilizers and biopesticides as sustainable. Similarly, the structured interviews with producers indicated that, on average, each producer implemented between five and six sustainable practices in avocado crops over two years.

To enhance plant nutrition, 49% of producers said they use super-lean broth, and 18% mentioned using mountain microorganisms for crop fertilization. Based on their experience, the producers affirmed that this practice aids in fruit setting and contributes to the overall health of the crop. Additional practices included the application of liquid humus (14.5%), bioles (12.7%), and bokachi (9%).

The practices reported for soil protection include using mulch (49%) at the base of trees and managing herbaceous plant covers (34.5%). To protect biodiversity, farmers stated that they conserve forest patches that function as biological corridors (49%), use polycultures as systems that improve the productivity and sustainability of agroecosystems (34.5%), conserve ecological niches (27.2%), and plant native species on their properties (25.4%).

Regarding the phytosanitary management of the crop, producers applied sufocalcium broth (49%), potassium soap (49%), ash broth (21.8%), the use of insect monitoring traps (18%), and Bordeaux broth (16.3%).

After investigating the impact of these practices on production costs, fruit quality, and yields obtained, farmers strongly perceived that these practices reduce production costs (69%) and improve the quality of the fruit, mainly in terms of safety (40%).

3.5. Agroecological production index

Estimating the Agroecological Production Index (API) in avocado cultivation in this region revealed a shift towards a different production approach from conventional methods. Considering that the maximum value of the index per dimension is one, it is worth mentioning that values greater than 0.5 are observed in all dimensions, indicating significant interest and improvement in current practices (Figure 3). The importance of variables such as "water availability," "land ownership," and "organizational functioning" is emphasized, aligning positively with agroecological production.

4. DISCUSSION

4.1. Avocado cultivation in the socio-ecological systems of the eastern Colombian massif

To fully understand each analyzed dimension, it is crucial to consider external factors that influence the region's environmental, social, and productive aspects. These factors include the more than two centuries of history in each municipality. During this time, the armed conflict spurred the emergence of liberal and communist guerrillas, along with criminal gangs of conservative origin. These conflict dynamics intensified between 2002 and 2014, marked by the rise of paramilitarism and a faction of the Revolutionary Armed Forces of Colombia, the FARC. This period witnessed an increase in homicides, forced disappearances, massacres, displacements, and threats, with the rural areas being disproportionately affected. On a related note, this region's San Agustín Archaeological Park is material evidence of a pre-Hispanic past. Recognized by UNESCO in 1995 as a Cultural Heritage of Humanity, the park significantly promotes national and international tourism in the area.

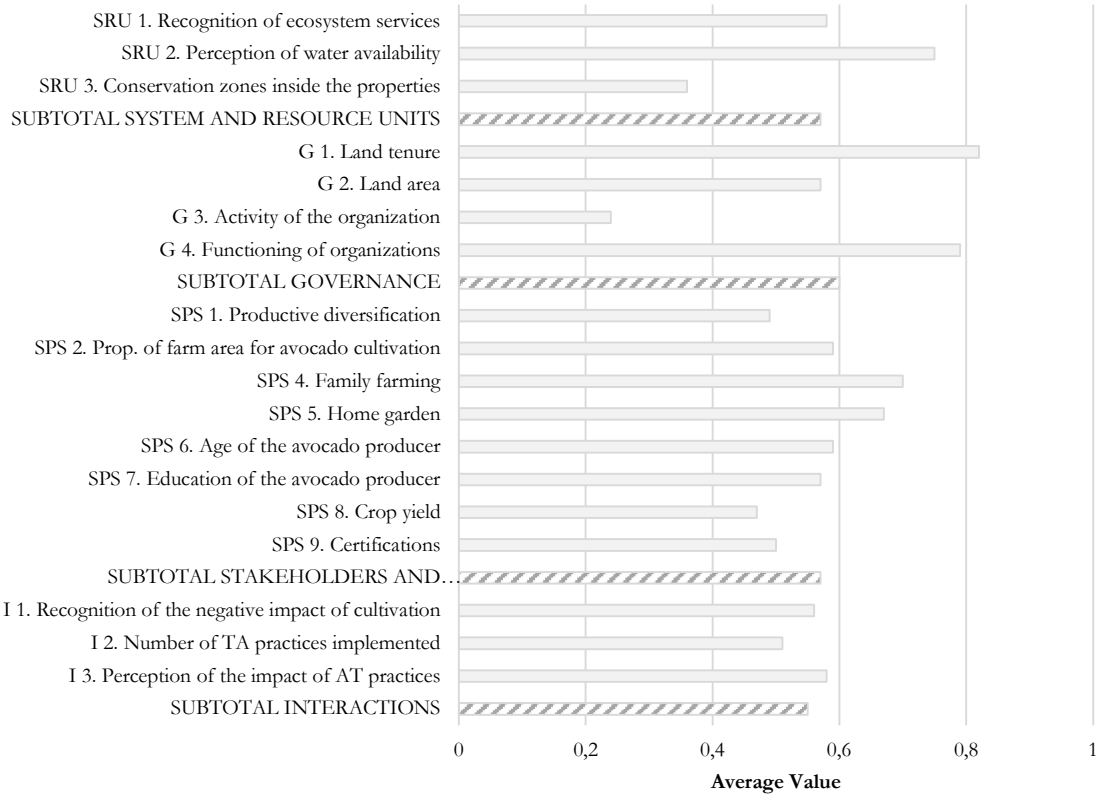

Figure 1. Results from the Agroecological Production Index - API.
Figura 1. Resultados do Índice de Produção Agroecológica - IPA.

The system and resource units underscored the presence of strategic ecosystems in the region, covering over 10% of the total surface area of the municipalities. The results of the interviews revealed a pro-environmental stance among respondents. Most (89.1%) farmers asserted their engagement in tangible actions to safeguard forests and water. These actions included conserving vegetation around water sources, managing reserves, and reforestation efforts. Designating protected areas on properties shows commitment to preserving resources, aligning with Maleksaeidi; Keshavarz (2019), who emphasize farmer engagement in conserving genetic resources and biodiversity.

Conserving strategic ecosystems is crucial for maintaining biodiversity in altered landscapes and ensuring the health and productivity of agricultural systems (SCHERR; MCNEELY, 2007). In the eastern Colombian massif, promoting sustainable agriculture is essential to ensuring ecosystem services like water quality, biodiversity conservation, and climate change mitigation. These practices must integrate ecosystem protection into avocado and crop production.

The governance system reflected that most farmers own their land, granting them access to and control this primarily agricultural resource. These municipalities boasted 15,290 Agricultural Production Units (UPAs), with over 70% having an area of less than three hectares. It's crucial to highlight the heterogeneous distribution of farm sizes revealed in the interviews. While the average surface area is 10.8 hectares, and the median is 4 hectares, it's noteworthy that the registered farm sizes vary widely, ranging from a minimum of 1 hectare to a maximum of 138 hectares.

Conversely, the global demand for Hass avocados has drawn foreign investors to acquire or lease land for production. While local farmers retain control over their lands, factors like infrastructure, public services, and access to agricultural inputs affect their efficient use.

Governance is also linked to the presence and actions of governmental and non-governmental entities. Local environmental and productive organizations play a crucial role in providing services to society, fostering horizontal relationships, building networks, and promoting decentralization among interdependent stakeholders (WACHHAUS, 2014). In the eastern part of the Colombian massif, over 87% of interviewed farmers reported an affiliation with at least one organization, influencing the agricultural technical services, training, and information they receive. However, producers emphasized the necessity of strengthening the collaboration between organizations and government entities, aiming to impact the regulation of fruit transaction prices.

The dimensions related to stakeholders emphasized the region's significant agricultural inclination, prominently featuring coffee crops (38%) and sugar cane (31.5%), alongside others like legumes, vegetables, and fruit trees. Avocado is between the third and fifth in terms of planted area. The conflict-driven dynamics in the region resulted in the involuntary migration of numerous farmers, heightened inequality in land ownership, and the disruption of networks within the territories (CUERVO et al., 2018). This, coupled with limited opportunities, social inclusion challenges, and a lack of relevant and accessible education, widens the gap between the rural and urban populations. The current study shows that the younger farmers under 30 years old are the least prevalent (10%), while those over 40 are the most predominant (27%).

Aligned with the perspective of Lozano (2022), education in the rural sector has gained significance in fostering peace,

equity, social construction, development, and sustainability in territories over the past two decades. Despite 42.1% of Colombia's population residing in rural areas, a substantial education gap persists between rural and urban areas. This aligns with the interview findings, where only 24% of respondents completed high school, with 53% distributed between completed primary school (20%) and incomplete primary school (33%). Nationally, educational inequality in the rural sector is closely linked to multidimensional poverty, which, in rural areas, is three times higher at 31.1%, compared to urban poverty at 11.5%.

Regarding the Hass avocado production system in Huila, there has been a notable increase estimated at 72.8%, from 1,957.5 to 3,382 hectares between 2020 and 2022. Approximately half of the Hass avocado crops are nearly 4 years old. These statistics align with the information gathered during interviews, which indicated that approximately 89% of the crops are less than 10 years old, with 49% less than 5 years old. The rise in Hass avocado cultivation can be attributed to Colombia's designation of this fruit as a Project of National and Strategic Interest since 2015, which aims to boost avocado exports to the United States, Japan, and China.

The average crop yield in Huila increased modestly from 10.20 to 10.96 t/ha/year between 2019 and 2022, reflecting limited progressive growth. Notably, in the study area, the average yield was 7.8 t/ha/year. Many Hass avocado producers in Huila lack experience in cultivation management. Since Hass avocados are primarily destined for export, effective technical management is vital to ensure high-quality fruit production and sustained plantation productivity through multiple harvest cycles.

Farmers in the region are concerned about tree withering, a problem linked to the wilt disease complex. This complex significantly affects avocado farming across Colombia, causing widespread impact and economic losses (RAMÍREZ et al., 2017). This problem is linked to various causal agents affecting trees' roots and vascular systems. From a biotic perspective, the oomycete *Phytophthora cinnamomi* (Rands) is considered the most critical pathogen, while from an abiotic perspective, hypoxia and anoxia are contributing factors (RAMIREZ et al., 2017).

Additionally, in this region, limited knowledge of soil preparation for crops contributes to tree withering and mortality. The compacted soils, previously used for livestock, may further exacerbate this issue. Other factors contributing to the decline in yields include the establishment of the crop without a prior soil analysis, changing climate conditions, and the presence of limited infrastructure for mechanization, collection, and processing.

Conversely, the region sees growing interest in certification for export, with Hass avocado viewed as a lucrative opportunity due to high international demand and exporters' presence. However, marketing remains challenging; only 20% of producers have sales agreements, and while 43.6% commercialize through associations, trust and formal buyer agreements are still developing.

4.2. Advances in the use of practices aimed at sustainable avocado production in the eastern Colombian massif

Ninety-four percent of those interviewed indicated that they have implemented sustainability-focused practices. Furthermore, there is a widespread perception that these practices contribute significantly to soil conservation, biodiversity, crop health, and human well-being.

Biopreparations are prominent among these practices for fertilization or crop health management. The consensus is that these microbiological and mineral solutions have positive environmental impacts and result in lower production costs.

Notably, the preparation of biopreparations is often documented in manuals and booklets, as seen in Mexico, Argentina, Peru and Colombia. Despite the growing interest in evaluating the effects of these products, research in this area remains limited.

Super-lean broth and mountain microorganisms were frequently mentioned among the commonly used biopreparations. Evidence suggests that super-lean broth enhances agronomic characteristics in various crops, promoting their growth and productivity (GONZÁLEZ et al., 2021). Its positive effects have also been assessed in forest plantations, demonstrating tree height and diameter improvements.

On the other hand, using mountain microorganisms is proposed as a beneficial practice for enhancing plant growth and health, leading to increased quantity and quality of production and improved resistance to pathogens and pests (Morocho; Leyva, 2019; Mesa, 2020). In bean cultivation, this practice is reported to boost yields in terms of pod and grain numbers (AGUILAR; MESA, 2019).

There is ongoing research about using mineral broths, such as Bordeaux broth, which farmers have employed as a fungicide, bactericide, and insecticide for several decades. Reports indicate its efficacy as a repellent against certain beetles that affect potatoes, tobacco insects, and corn grasshoppers (*Dalbulus maidis*). Additionally, Bordeaux broth has demonstrated control over nutritional deficiencies of calcium and copper.

Moreover, reports indicate the efficacy of calcium sulfide broth in managing phytopathogenic fungi and insects. This broth can be prepared manually or obtained commercially under 18% calcium polysulfide. Notably, favorable results are also attributed to potassium soap, recommended as an insecticide and acaricide for aphids (*Myzus persicae*), whiteflies (*Trialeurodes vaporariorum*), thrips (Thripidae), and red spiders (*Tetranychus urticae*), among others. Some research points to mortality effects on green-scale insects (*Pulvinaria psidii*), ranging between 82% and 100%.

5. CONCLUSIONS

In the eastern Colombian massif, socioecological systems underscore various elements, including system and resource units, governance, characteristics of the stakeholders, and interactions, all aligned with agroecological production in the cultivation of Hass avocado. Despite historical conflicts surrounding the territory, available natural resources, conservation efforts, organizational capacity, productive diversification, and adopting more environmentally friendly practices collectively signify notable progress toward sustainable production.

Using biopreparations for fertilization and sanitary management is a prominent practice in recent avocado crops. Well-managed biopreparations have shown to have multifaceted impacts, including a) enhancing nutrient contribution to plants, b) improving plant responses to diseases and pest insects, c) increasing crop yield, d) reducing costs in crop management, and e) enhancing soil quality by

elevating organic matter content and fostering the diversity of beneficial microorganisms. There is a need to strengthen technological advancements in preparing and applying biopreparations specifically tailored for avocado cultivation.

Despite these advances in agroecological production, Hass avocado cultivation in the region is grappling with rising tree wilting and premature tree mortality. To safeguard the crop and mitigate potential economic losses, there is a likelihood of increased use of agrochemicals in the region in the coming years.

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