

Diagnosis of Agroecological Practices in the Commune of Savalou, Tchetti District

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How to cite this paper: Ouikoun, C.G., Aholou, F.B.E., Ekpo, K.J., Yalinkpon, F., Agbangba, C.E. and Chougourou, C.D. (2026) Diagnosis of Agroecological Practices in the Commune of Savalou, Tchetti District. *Journal of Environmental Protection*, 17, 15-38.

<https://doi.org/10.4236/jep.2026.171002>

Received: November 22, 2025

Accepted: January 23, 2026

Published: January 26, 2026

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Abstract

Agriculture faces various challenges, including climate change, low productivity, loss of fertility, and disruption of supply chains. Agroecology emerges as an effective and reliable solution, taking an increasing place in agricultural development policies. In this context, the Tool for Agroecology Performance Evaluation (TAPE) was developed to assess the performance of agroecological systems and their contribution to the Sustainable Development Goals (SDGs). This study evaluated the level of agroecological transition of farms in Savalou, in the Tchetti district, using a sample of 123 farms based on the Krejcie and Morgan [1] method. Steps 1 and 2 of TAPE revealed a low level of transition, with only four (4) elements of agroecology out of 10 exceeding 60%. A more advanced level of transition was linked to responsible governance, better recycling, and increased synergy in the agrosystem. The systems show high exposure to class II and III pesticides, low agricultural biodiversity (Gini-Simpson index of 58%), and an added value of 318,000 CFA francs/year. The scores for human and social values, food cultures, and circular economy positively influenced the Women's Empowerment in Agriculture Index (WEAI: 69.04%) and income estimated at 756,000 CFA francs/family labor unit/year. The level of transition of farms impacts their performance. In conclusion, TAPE proves to be a useful tool to support producers in the adoption of sustainable agroecological practices.

Keywords

Diagnosis, Agroecological Practices, Productivity, Culture, Benin

1. Introduction

Food insecurity has become a major global concern. There is a consensus that the current food system does not meet basic needs, particularly regarding hunger, malnutrition, decent agricultural livelihoods, and environmental impact [2]. Approximately 850 million people suffer from hunger, half of whom are small farmers living in rural areas. Many of those who are not food insecure experience an erosion of their income and autonomy [3].

In West Africa, agriculture represents 30% of GDP and employs more than 50% of the active population [4]. In Benin, this sector is crucial, representing 70% of the active population and contributing 36% to national GDP as well as 88% of export revenues [5]. Fertile soils are essential for food security, and sustainable intensification of agriculture is necessary to produce more on less surface area. However, soil degradation, caused by unsustainable agricultural practices, limits this capacity and exacerbates hunger and poverty [6]. Approximately 33% of land is moderately or severely degraded, affected by erosion, pollution, and poor management, resulting from various factors, including increased land pressure and crop intensification [7].

Since the 1970s, food production in sub-Saharan Africa has not kept pace with population growth, resulting in a drastic decline in productivity [8]. In Benin, fighting poverty and food insecurity has become crucial, particularly in rural areas, where low agricultural productivity constitutes a major obstacle [9]. Climate change, which particularly affects West Africa, aggravates these challenges, negatively influencing soil fertility and, consequently, food security [10].

Faced with these challenges, it is essential to adopt sustainable agricultural practices, such as agroecology, which aims to restore soil fertility while producing efficiently [11]. Agroecology positions itself as a promising alternative for the sustainable development of production methods. To address the challenges of declining modern agriculture, a profound transformation is necessary at several levels [12]-[14]. This study aims to diagnose agroecological practices in the Tchetti district, within the commune of Savalou, to facilitate the transition to sustainable and environmentally friendly agriculture.

2. Materials and Methods

2.1. Study Area

The study sector is the Tchetti district located in the commune of Savalou in the Collines department in Central Benin (**Figure 1**). The commune of Savalou lies between 7° 35' and 8° 13' North on the one hand and 1° 30' and 2° 6' East on the other. It shares its borders with the communes of Dassa-Zoumè and Glazoué to the east; Djidja to the south, Bantè to the north, and the Republic of Togo to the west over approximately 65 km (North-South boundary). It extends nearly 58 km from west to east and covers an area of 2674 km², representing 2.37% of the national territory. With an annual growth rate of 3.7%, the commune of Savalou is subdivided into fourteen districts, four of which are urbanized: Aga, Agbado, Attakè, and Ouèssè,

and comprises seventeen city neighborhoods and fifty-two (52) villages. During the 2013 census (RGPH-4), the commune had 144,549 inhabitants [15]. The commune of Savalou belongs to a region subject to both equatorial influences and influences from the alternating Guinean-type regime. This is the zone where the influences of the southwest monsoon and the continental trade wind called the northeast harmattan fade away. This situation is manifested in the distribution of rainfall, which is marked by the appearance of two rainy seasons from March to July and from September to November; two dry seasons; the first from December to March and the second corresponding to the decline in precipitation in August. The average rainfall is 1150 mm. However, this rainfall varies from year to year between 864 and 1637.3 mm. Temperatures are high throughout the year with minimums ranging between 23°C and 24°C and maximums varying from 35°C to 36°C. This variability constitutes a constraint on the choice of different agricultural activities.

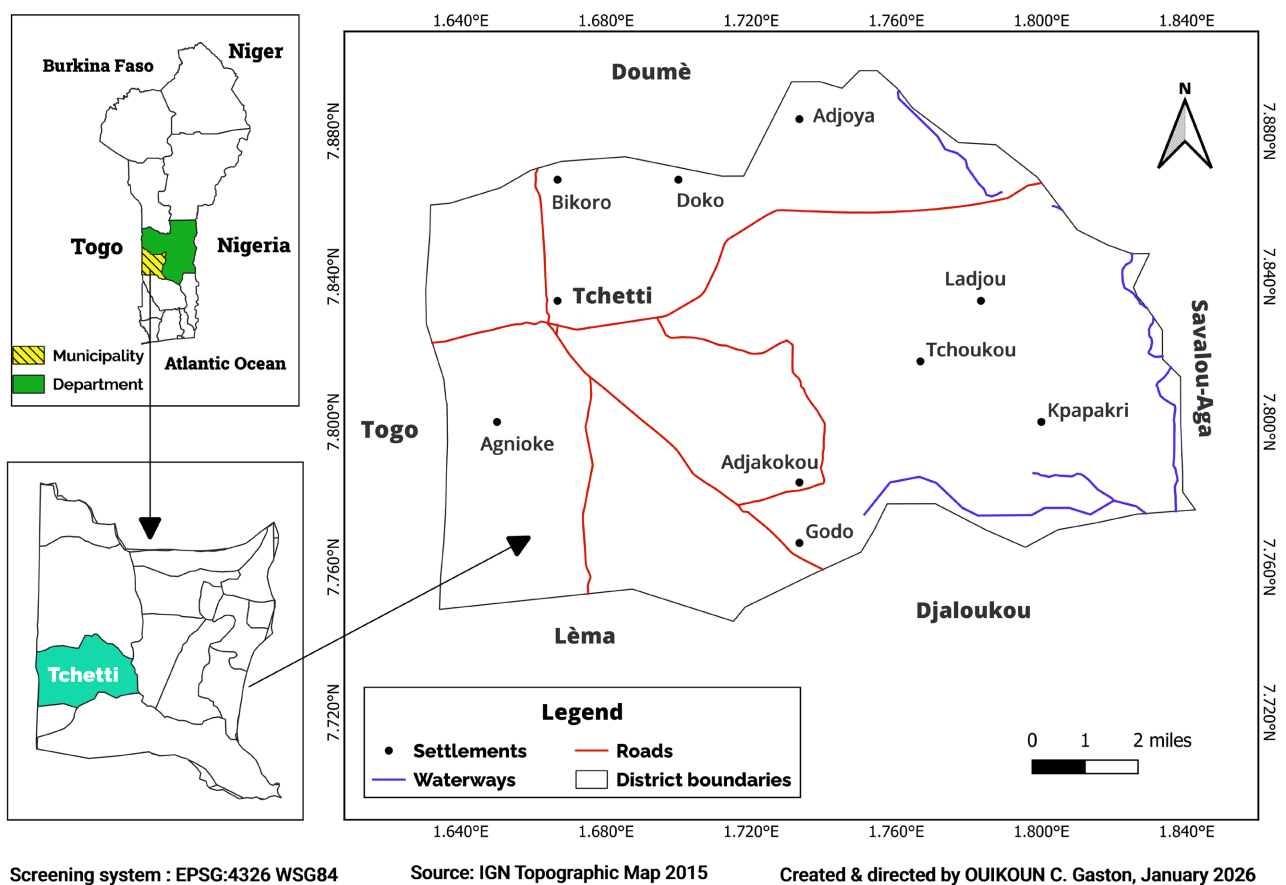


Figure 1. Geographic map of the commune of Savalou.

The most widespread soils are tropical ferruginous soils with areas of concretion in places. Hydromorphic soils and vertisols are also distinguished. Analysis of these different soils shows that they are not particularly fertile except for vertisols, which, moreover, require adequate technical means for their development.

Other very widespread types of soils generally have low water retention capacity and are poor in mineral salts such as nitrogen and phosphorus. This limits the choice of crops on the immense available cultivable lands. Several plant formations are distinguished. The vegetation is composed, in places, of gallery forests, dry dense forests, semi-deciduous forests, clear forests, wooded savannas, shrub savannas, and saxicolous savannas. The fauna consists of small savanna game, notably grasscutters, rabbits, and some savanna species such as duikers and francolins. The economy of the Commune of Savalou operates through several activities. These include agriculture, livestock farming, fishing, trade, handicrafts, transport, firewood exploitation, and processing of agricultural products. Activities such as tourism and industry are very poorly represented [16].

2.2. Methods

A survey-diagnostic approach, based on the Tool for Agroecology Performance Evaluation (TAPE) developed by FAO [12], was used. TAPE guidelines and protocols are described in detail by Bicksler *et al.* [17] and Mottet *et al.* [18]. The steps (Step 1 and Step 2) were preceded by a literature review or participatory exercise constituting the preliminary step called Step 0. It allowed contextualization of the target territory and the main drivers that can create an enabling environment for agroecological transitions. This contextualization grounds the study in place, time, scale, and cultural, ecological, and political factors to provide a territorial overview. Steps 1 and 2 are the basic analytical steps, followed by participatory analysis, validation, and interpretation of results (Step 3).

2.2.1. Characterization of the Agroecological Transition (CAET)

The Characterization of Agroecological Transition (CAET) describes the current level of transition of the evaluated systems toward agroecology. This description is based on the 10 elements of agroecology proposed and validated by FAO governing bodies [12]. These elements are disaggregated into 37 semi-quantitative indices with 4 transition levels [17], which take the form of descriptive scales ranging from 0 to 4 [18]. These scales are well aligned with the 13 principles of agroecology [2], as well as with other sustainability indicators [19]. To illustrate this point, for example, the “Synergy” element is characterized by the indices (sub-elements) of livestock-aquaculture integration, soil-plant system management, integration with trees (agroforestry, silvopastoralism, agro-silvopastoralism), and connectivity between agrosystem elements and the landscape. For each of these indices, a score ranging from 0 to 4 is assigned. These results are calculated to obtain a total score for synergy in the form of a percentage, allowing judgment of the system’s state concerning this element. The same method is applied to all 10 elements.

2.2.2. Evaluation of Performance Criteria

▪ Land Tenure Security

Equitable access to land and natural resources is essential to achieve social jus-

tice and gender equality, but also to encourage long-term investments essential for protecting soils, biodiversity, and ecosystem services and strengthening resilience to systemic stress factors. The transition to agroecology could be linked to changes in farmers' land tenure and/or mobility security for pastoralism. Thus, this study focuses on the following criteria: existence of legal recognition of land access; existence of an official and nominative document; perception of security of land access; existence of the right to sell, bequeath, and inherit land, always disaggregated by sex. SDG indicator prescriptions require sex-disaggregated data.

▪ **Productivity**

Total factor productivity is obtained from the total quantity of products/production at the farm or territory scale (crops, livestock, forestry, aquaculture) and the total quantity of inputs such as land, capital, and labor, but also resources such as water and nutrients [20] [21]. To overcome variable mass units, production is aggregated in terms of value (quantity multiplied by price). The agricultural land area of the farm corresponds to the area used for agriculture. The indicators take into account the number of people working on the farm, *i.e.*, the total number of active people on the farm (family and paid labor in full-time equivalent (FTE), with children under 12 years considered as 1/2 FTE). Thus, it is calculated by the following method (Equation (1)):

$$TFP = \frac{\text{Products (crops + livestock + forestry + aquaculture)}}{\text{Inputs (land + capital + labor + water + nutrients)}} \quad (1)$$

with TFP: Total Factor Productivity, and products and inputs are measured in price equivalence to be added.

Thresholds for Productivity per Hectare (ha):

Productivity can be affected by external factors such as abrupt climate changes, market disruptions, pests, or diseases. Resilience is the ability of a system to recover after a shock and return to a state of stability. It is an emergent property that depends on system characteristics and their mode of operation. For example, diversification and integration of subsectors can help producers reduce their vulnerability in case a crop, livestock species, or other product experiences difficulties. Reducing dependence on external inputs can also reduce producers' vulnerability to economic risks. These improvements can significantly strengthen the resilience and stability of household productivity over time.

▪ **Income**

The economic viability of farms is an essential element for ensuring their sustainability. Average income was calculated by subtracting expenses from gross revenues. Both elements were calculated by taking into account the following data: - Net family income calculation [22] is obtained from the following formula (Equation (2)):

$$\text{Family income (R)} = \text{GP} - \text{CIT} - \text{CLCs} - \text{IB} - \text{D} \quad (2)$$

with GP: Gross product (value of agricultural production: crops, livestock, aquaculture, forestry) (+subsidies); CIT: Cost of inputs and taxes (seeds, fertilizers,

pesticides, animal feed, veterinary services); CLCs: Cost of wage labor; IB: Loan interest and land rental cost; D: Depreciation of machinery and equipment.

Income thresholds

It is possible to use a perception-based method, as for sub-indicator 2 of SDG 2.4.1. If applicable, proceed as follows to evaluate the income criterion:

- **Green (desirable):** Perception that income is increasing and is above average income in the region;
- **Yellow (acceptable):** Perception that income is stable and equals the average income in the region;
- **Red (unsustainable):** Perception that income is decreasing and is below the average income in the region.

▪ **Added value**

Income analysis can be supplemented by adding value [23] after subtracting subsidies and income from land rental or other assets, and adding taxes, loan interest, and wages paid to labor. It was calculated using the following formula (Equation (3)):

$$\text{Added value}(Va) = R - SR + CLCs + IB \quad (3)$$

With R: Net family income; SR: Subsidies and rental income; CLCs: Cost of wage labor; IB: Loan interest and land rental cost.

Thresholds for added value:

- **Green (desirable):** Gross added value per family worker $> 1.2 \times$ median gross added value in a similar agroecosystem (drawn, e.g., from farm monitoring systems) OR (if not available) $> 1.2 \times$ national agricultural GDP per agricultural worker (FAOSTAT);
- **Yellow (acceptable):** Gross added value per family worker $< 1.2 \times$ median gross added value in a similar agroecosystem (drawn, for example, from farm monitoring systems) AND $> 0.8 \times$ median gross added value in a similar agroecosystem OR (if not available) $< 1.2 \times$ national agricultural GDP per agricultural worker (FAOSTAT) AND $> 0.8 \times$ national agricultural GDP per agricultural worker (FAOSTAT);
- **Red (unsustainable):** Gross added value/family worker $< 0.8 \times$ median gross added value in a similar agroecosystem (drawn, e.g., from farm monitoring systems) OR (if not available) $< 0.8 \times$ national agricultural GDP per agricultural worker (FAOSTAT).

▪ **Pesticide exposure**

Chemical pesticides are used on farms to control pests. Nevertheless, they can damage not only the environment but also human health. Agroecology promotes the use of biological pesticides to eliminate the use of chemical pesticides. In our study, according to the TAPE methodology, pesticide exposure is measured according to different criteria: the quantity of organic and synthetic pesticides applied, their level of toxicity, the use of mitigation measures when applying pesticides, and the use of beneficial practices for ecological pest management.

Thresholds for pesticide exposure:

- **Green (desirable):** The quantity of organic pesticides used is \geq the quantity of synthetic pesticides used AND class I and II pesticides (highly and moderately toxic) are not used AND at least 4 mitigation techniques among those identified are implemented during chemical pesticide application OR chemical pesticides are not used AND organic pesticides AND/OR other integrated pest management techniques are used.
- **Yellow (acceptable):** The quantity of synthetic pesticides used is greater than the quantity of organic pesticides used, producers do not use class I pesticides (highly toxic), at least four mitigation techniques among those identified are implemented during chemical pesticide application, and organic pesticides and/or other integrated techniques are also used.
- **Red (unsustainable):** Producers use extremely dangerous pesticides (class I) and/or illegal pesticides, OR producers use class II and/or III pesticides (moderately toxic and slightly or relatively non-toxic) and fewer than 4 mitigation techniques among those identified, OR producers use chemical pesticides.

- **Dietary diversity**

Minimum dietary diversity scores for women [24] consist of a simple count of the 10 food groups consumed during the previous 24 hours: grains, white roots and tubers, and plantains; pulses (beans, peas, and lentils); nuts and seeds; dairy products; meat, poultry, and fish; eggs; dark green leafy vegetables; other vitamin A-rich fruits and vegetables; other vegetables; and other fruits. Women are considered indicative of the household's nutritional situation, and these data are collected from them.

Thresholds for the dietary diversity index:

- **Green (desirable):** Dietary diversity score ≥ 7
- **Yellow (acceptable):** Dietary diversity score ≥ 5 and < 7
- **Red (unsustainable):** Dietary diversity score < 5 .

- **Women's Empowerment**

Women represent nearly half of the agricultural workforce. They also play a vital role in household food security, dietary diversity, and health. Yet they remain economically marginalized and exposed to violations of their rights, and their contributions are still rarely recognized. For example, agroecology strongly emphasizes the importance of human and social values and focuses on reducing gender inequalities in developing countries by offering more opportunities to women and allowing them access to the same resources as men [25]. The Women's Empowerment in Agriculture Index (WEAI) is a survey-based index designed to measure the empowerment, agency, and inclusion of women in the agricultural sector. This phase of the questionnaire is intended only for the main woman of the household. It addresses six criteria, namely: participation in productive decisions, asset ownership, access to credit, control over income use, group membership, and workload.

Thresholds for Women's Empowerment:

- **Green (desirable):** WEAI $\geq 80\%$

- **Yellow (acceptable):** WEAI $\geq 60\%$ and $<80\%$
- **Red (unsustainable):** WEAI $< 60\%$.

- **Youth Employment Prospects**

In this case, TAPE follows the approach of SDG indicator 8.6.1 and collects data on the proportion of youth (aged 15 to 24) not in education, employment, or training. These data are then compared to the number of youths working in the agricultural sector (within the evaluated system), the number of youths in school, the number of youths working outside the evaluated system, and the number of youths who have emigrated. These data are combined with young people's perception of agricultural work, asking them whether they wish to continue their parents'/family's activity or whether they would emigrate if they had the opportunity. Where possible, collection of these data should be disaggregated by sex to better highlight differences between boys and girls of different ages. The criterion corresponds to the unweighted average of two indices (employment and emigration), calculated separately using indicators, scores, and weighting.

- **Agricultural biodiversity**

To calculate this index, the TAPE tool offers a methodology based on counting cultivated species and varieties, recording the relative surface area occupied, as well as counting animal species and breeds to calculate a Gini-Simpson index of crop and animal diversity. These results are then calibrated by an index measuring natural vegetation and the presence of pollinators. A Gini-Simpson diversity index is then calculated for both crops and animals (Equation (4)).

$$I = 1 - D = 1 - \sum p_i^2 \quad (4)$$

where p_i is the abundance and i is the proportion of individuals in the i -th species

Thresholds for agricultural biodiversity:

- **Green (desirable):** Average score $\geq 70\%$
- **Yellow (acceptable):** Average score $\geq 50\%$ and $<70\%$
- **Red (unsustainable):** Average score $< 50\%$.

- **Soil health**

Soil is a fundamental element at the base of agriculture. Soil health is a major factor in the perspective of sustainable and resilient agriculture. It depends on numerous factors such as the quantity and quality of organic matter present in it. To estimate soil health, the TAPE tool uses the SOCLA (Sociedad Científica Latinoamericana de Agroecología) indicator. It is based on 10 criteria to best estimate soil health. Each criterion is assigned a score ranging from 1 (least desirable) to 5 (most desirable). Scores of 2 and 4 are assigned to intermediate situations. The 10 SOCLA indicators of soil health are: soil structure, degree of compaction, soil depth, residue status, color, odor and organic matter, water retention, soil cover, signs of soil erosion, presence of invertebrates, and finally microbiological activity. Once all indicators have been evaluated, they can be presented individually in a radar chart.

2.2.3. Determination of Sample Size

There are different formulas for calculating the required sample size depending on whether the target population is finite or infinite. In the case of species, the cotton farms monitored by AIC in the commune number 180. For a confidence level of 95% and a commonly used sampling error margin of 5%, the formula for determining sample size by Krejcie and Morgan [1] was used (Equation (5)):

$$S = \chi^2 NP(1-P) / [d^2(N-1) + \chi^2 P(1-P)] \quad (5)$$

with S = sample size; χ^2 = the table value of chi-square for 1 degree of freedom at the desired confidence level; N = the known population size; P = the proportion of the population (assumed to be 0.50 since this would provide the maximum sample size); d = sampling error margin.

2.2.4. Data Collection

The study was conducted in the Tchetti district, and the chosen producers are those monitored by the Interprofessional Cotton Association (AIC) in the context of cotton production. In total, 123 producers were interviewed; consequently, the study concerned 123 farms. Data were collected from October 10 to 30, 2022, using TAPE questionnaires, guidelines, and protocols [17]. To facilitate the work, the questionnaire was digitized using the KoBo Toolbox application. The questionnaire includes both surveys and field observations. This includes data such as a description of the main socioeconomic, environmental, and demographic characteristics and contexts of the systems, such as location, household size, productive assets, agroecological zone, geomorphology, forests, land access, staple products, and regional production systems. It also includes a description of enabling (or disabling) elements of the environment for ecological transition. Finally, data to be collected from the farm/household for agricultural performance evaluation relate to information such as land tenure, productivity, income, added value, pesticide exposure, dietary diversity, women's empowerment, youth employment, biodiversity, and soil health.

2.3. Statistical Analyses

Raw data collected from the KoBoToolbox application were extracted into an Excel database and analyzed using descriptive statistics in R software, following the approach proposed in the TAPE methodology.

3. Results

3.1. Transition Levels of Agroecological Systems

3.1.1. Step 0: Farm Characteristics

All farms produce cotton. A large majority of them also cultivate soybeans, peanuts, maize, cowpea, rice, yam, pepper, and some, in more limited numbers, grow pigeon pea, doïwé, and cassava. Cashew crops are also very present. Farmers mostly practice crop rotation as a cultural practice, and only a few practice monoculture. Regarding animals, poultry farming, such as raising chickens and guinea

fowls, is practiced. We also have duck production and sheep/goats. For livestock, cattle are raised by a few producers. Most crops and animals are destined for sale, and a minority are for self-consumption.

3.1.2. Environmental Challenges Encountered in the Area

Soils are most often confronted with flooding and drought. The survey period was a period of intensive rainfall. It was noted that rains not only affect certain lands but also delay agricultural activities. Moreover, the presence of numerous rivers in this commune makes certain lands easily floodable (**Figure 2**). Consequently, yields are affected. Also, crops are sometimes ravaged by water, destroyed, or carried away. Beyond environmental problems, other problems were highlighted by some producers. They claim that soils are increasingly infertile. Another problem addressed was pastoralism. Animals constantly destroy crops, making farmer-herder conflicts frequent. Others claim that combating these negative aspects of pastoralism is difficult because many of these herders manage herds belonging to fellow farmers.



Figure 2. Shows some images illustrating certain challenges of our study area: (a) the Gbogui bridge, (b) a portion of a farm flooded by rainwater, (c) and (d) fields flooded by rain.

3.1.3. Public Policy and Market Context Influencing Agroecological Transition

Public policies and market contexts that support or limit agroecological transition were identified.

- **Local markets:** there is a local market in Tchetti, where producers market their products, thus allowing inhabitants to supply themselves;
- **Field schools:** the adoption of agroecological practices can be influenced by factors such as access to information, profitability, or the profitability that the producer thinks they can derive from it. Therefore, to support agroecological transition, a group of farmers meets at a given frequency under the direction of a trained facilitator. During these sessions, they observe and compare two plots throughout an agricultural campaign. One plot follows conventional local methods while the other is used to experiment with what could be considered “best practices.” They experiment and observe; they present their findings during a plenary session, followed by discussion and planning for the coming weeks. This practice allows farmers to decide what works best through their trials and observations and thus adopt these practices they deem better if possible;
- **OGAs (Ordinary General Assemblies):** these are groupings of producers, meetings during which they make assessments, present progress reports, and decide on the course of action for the smooth running of agricultural activities.

3.1.4. Different Actors of the Agroecological Transition System

Certain actors who interact with producers advocate for sustainable land and natural resource management and participate in promoting agroecology. The producers who were the subject of this study are those monitored by the Interprofessional Cotton Association (AIC). It brings together producers, ginners, and agricultural input distributors and has the mission of facilitating relations between sector actors and consultation with the State. It also has the mission of managing and monitoring all activities and functions related to the proper functioning of the cotton sector. It ensures, for example, cotton research, training and technical supervision of producers, production and distribution of seeds, and quality control of seed cotton. They organize field schools and encourage producers to sow improving and fertilizing plants in their fields, such as *pigeon pea and mucuna* (Figure 3), and to better manage harvest residues. They avoid burning them so that they can serve again for soil enrichment and promote better use without abuse of chemical fertilizers, because not all soils need, for example, the same dose of urea and NPK (nitrogen, phosphorus, potassium). The TAZCO Project is a project aimed at the sustainable improvement of family farm incomes in cotton-growing areas of Benin. Specifically, the project aims to support a sustainable ecological, economic, and social transition of cotton-based production systems through the conduct of diagnostics and experimentation with agroecological practices adapted to the specificities of territories.



Figure 3. Improving plants: (a) *Clotalaria retusa* (b) *Cajanus cajan*.

3.2. Step 1: Characterization of the Agroecological Transition

Figure 4 presents the CAET results of the 10 elements for the 123 farms. According to the results obtained, five of the 10 elements have high average scores and are the most advanced in the agroecological transition, with only four agroecology elements out of 10 exceeding 60%.

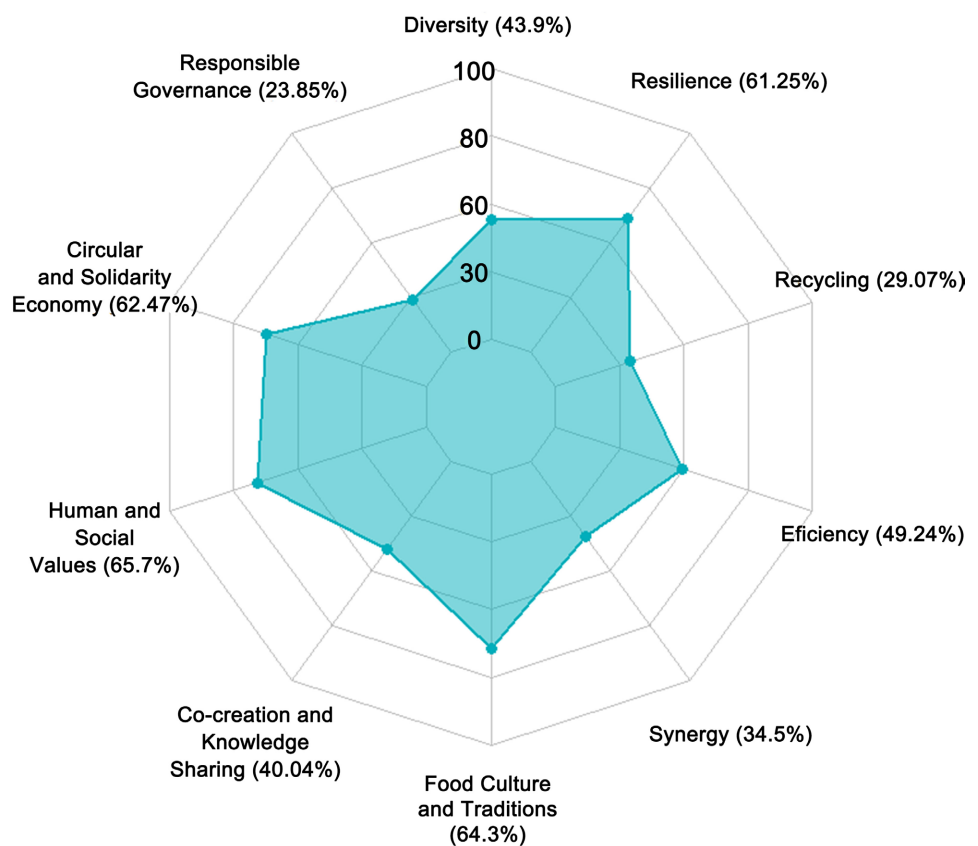


Figure 4. CAET visualization of 123 farms in Savalou (Benin) after establishing a transition typology.

The synergy score (34.5%) indicates notably low levels of integration between different components of the agroecosystem and low use of ecological pest and dis-

ease management techniques. Animals are not always fed with products produced on the farm or through grazing, and their manure is rarely used for fertilization. Moreover, they heavily depend on the market to acquire inputs for agricultural production. Soils are not always covered with crop residues or cover crops. Soils are therefore exposed to minimal disturbances, and the practice of rotation or use of intercropping is not always done, or only on part of the land. Concerning agroforestry, silvopastoralism, and agro-silvopastoralism, the scores indicate low integration with a limited number of trees offering a single product or service. Regarding the connection between agroecosystem elements and the landscape, it is mostly average.

For recycling (29.07%), it is noted that the score for renewable energy is 0% for farms, indicating a total absence of recourse to this type of production, which inevitably lowers the average. Moreover, the score for water management is low because they have no equipment or management system. Regarding seed management, the majority of farms produce their own seeds or exchange their genetic resources locally. However, more than half of producers do not recycle waste from harvests and dispose of it by burning.

The average scores in terms of diversity (43.9%) and efficiency (49.24%) reveal that these farmers produce very few crops and animals conventionally. This means that on average they produce a slightly above-average number of crops adapted to local conditions and climate change with significant cultivated areas. The average efficiency score can be explained by the greater use of synthetic fertilizers.

Co-creation and knowledge sharing (40.04%) suggest that this group does not have sufficient knowledge about agroecology and that there are few producers among them willing to apply agroecological practices and principles within their farms or aware of the existence of these practices.

Responsible governance (23.85%), meanwhile, suggests that producers are generally poorly organized, and there is a general lack of empowerment among farmers. Regarding access to knowledge about agroecology and producers' interest in this subject, the average results are lower. This means that knowledge about agroecology is still quite limited. Producers seem more interconnected within local communities but only often participate in events. Producers' rights are thus globally recognized and respected for both women and men. For both samples, they generally have the ability to improve their livelihoods and can be stimulated to develop their skills. Regarding producers' participation in land and natural resource governance, the scores are quite low. However, they have high scores in the element describing the link to food sovereignty (Food Culture & Traditions, 64.3%), which describes the social aspect of agroecology, suggesting average food security situations. This means they have achieved some food security but with less diversification and in larger quantities. Good nutritional practices are known but not necessarily applied. They obtained a high average score for knowledge of local identity, which means they generally respect local traditions or rituals. Re-

garding the use of local varieties or breeds and knowledge of traditional practices for food preparation, farms obtained fairly high average scores. This means that the majority of food consumed comes from local varieties.

The circular and solidarity economy element (62.47%) shows a tendency to market agricultural production in local circuits and territorial markets with a strong link between producers and consumers. Therefore, there are local and territorial markets, and farmer associations and organizations that support producer empowerment. The majority of products are sold locally. At the level of the producer network sub-element, consumer relationships and the presence of intermediaries, operational distribution networks exist and include women in most cases, and there is a direct relationship with the consumer, although intermediaries also sometimes intervene. Also, an equal share of food and inputs are purchased locally or outside the community. Products are processed locally, and exchanges between producers are regular.

The percentage of 65.7% obtained for human and social values shows that they attach importance to them because the role of women, for example, is considered in decision-making processes and the importance of social values. Women are completely involved but do not necessarily have access to resources. In general, working conditions are decent, with essentially family agriculture giving access to capital and the decision-making process. Regarding youth empowerment and their emigration, average scores are low. This finding indicates that young people consider agriculture too hard and would like to emigrate. For animal welfare, animals do not generally suffer from hunger or stress and pain at slaughter. Resilience, meanwhile, gives a percentage of 61.25% and implies that the evaluated farms are less vulnerable and therefore more or less financially stable. They seem more advanced in their transition at the resilience element level. Incomes are generally stable. The majority claimed not to have debt, and their recovery capacity after shocks remains good. Access to credit and insurance is also available for cotton producers.

3.3. Step 2: Performance of Agroecological Systems in the Commune

The performance criterion is focused on the characterization of farm conditions using the traffic light approach recommended by the TAPE tool.

3.3.1. Land Tenure Security

Figure 5 presents producers' perceptions and rights regarding land tenure.

The results reveal that only 1.63% of the 123 producers have legal recognition of their land equally for both sexes (0.81%). For land access, 90.24% of producers, including 32.52% women and 57.72% men, have secure land access despite the absence of legal recognition. Regarding the right to transfer one of the plots of their farms, the percentages obtained are 59.35% for men and 25.20% for women. The distribution of producers having the right to inherit land is 85.99%, of which 58.54% are men and 28.46% are women.

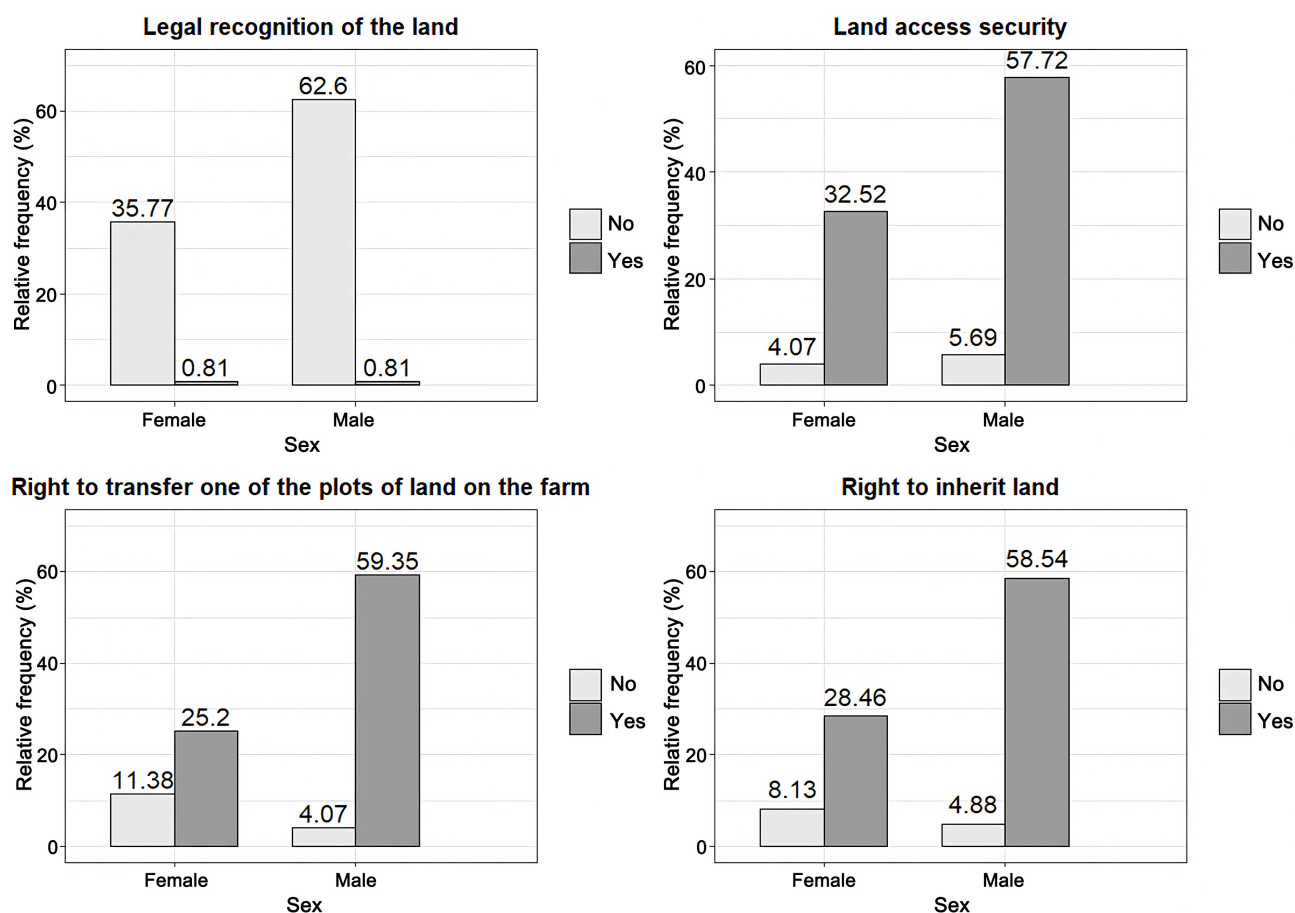


Figure 5. Land tenure: perception and rights.

3.3.2. Productivity

The Total Factor Productivity (TFP) is 1.24, indicating that for 1 FCFA of input invested, the farms generate 1.24 FCFA of production. This value, while positive, remains modest and reflects the productivity challenges faced by smallholder farmers. Farms are exposed to risks such as drought and flooding. Moreover, the results show that producers spend a lot on purchasing inputs such as chemical pesticides and organic fertilizers. The use of these inputs increases producers' vulnerability to chemical risks.

3.3.3. Income

The income obtained is 756,000 CFA francs per family labor unit per year, which is qualified as acceptable. This is the perception that income is stable and equals the average income in the region. Respondents mostly confirmed that their income is stable and has increased compared to the last three years.

3.3.4. Added Value

The added value is 318,000 CFA francs per year. The significant discrepancy between the net income and the added value is primarily due to the substantial deductions for subsidies and rental income (SR), as per Equation (3), and the subsequent addition of costs for wage labor and interest/rent (CLCs + IB). This indi-

cates that while gross revenues might be high, the net value generated and retained within the farm operation itself is considerably lower after accounting for external financial flows. Producers do not sufficiently diversify their sources of income.

3.3.5. Pesticide Exposure

Figure 6 presents the level of pesticide use on the evaluated farms. The majority of farms use chemical pesticides. Several pesticides are specifically used on cotton at different treatment stages and specific times.

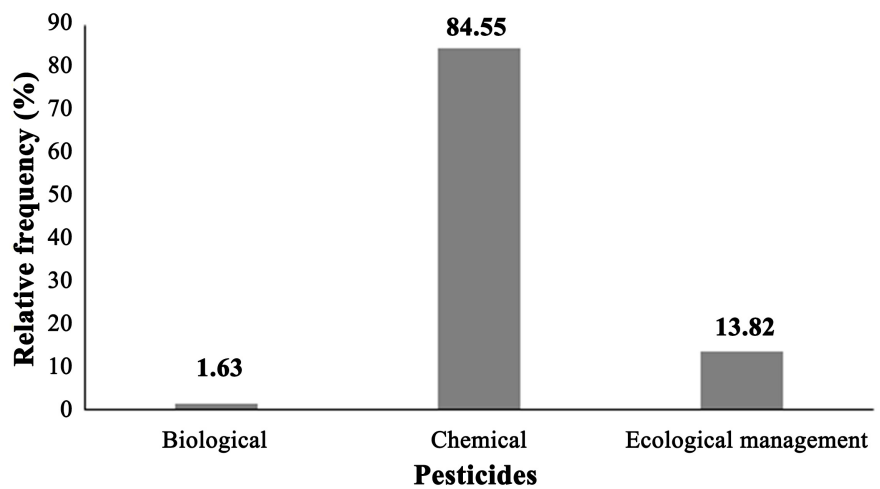


Figure 6. Level of pesticide use in production.

It emerges from this figure that 84.55% of producers use chemical pesticides (**Figure 7**) in their production. On the other hand, 13.82% of producers practice ecological pest management and 1.63% practice biological management. This level of pesticide use places producers in the red, reflecting high exposure to pesticides, a consequence of unsustainable conditions. Average expenses for organic pesticides are 45,804.35 FCFA/year compared to 15,019.23 CFA francs/year for chemical pesticides. The low cost of chemical pesticides justifies producers' attraction to their use.



Figure 7. Chemical pesticides encountered in fields: (a) Pyro FTE 672 EC, (b) Thunder 145 Q-TFQ, (c) Cotonix 328 EC.

3.3.6. Dietary Diversity

The minimum diversity score equals 3, which qualifies as red, corresponding to unsustainable conditions. In general, respondents present a relatively low dietary diversity score. It should be noted that the consumption of dairy products is very uncommon, except for cow cheese. The consumption of legumes and fruits is also quite rare, with few people having declared consuming them in the previous 24 hours. The most consumed foods are meat and pounded yam.

3.3.7. Women's Empowerment

The calculated Women's Empowerment in Agriculture Index (WEAI) is 69.04%, which is qualified as yellow, corresponding to acceptable conditions.

3.3.8. Youth Employment Prospects

This criterion was not evaluated due to the very low presence of youth in households.

3.3.9. Agricultural Biodiversity

Figure 8 presents the percentage of productive area covered by natural or diversified vegetation. The results show a percentage of 58% for "small" natural and diversified vegetation, 40% for "significant" vegetation, 2% for "abundant" vegetation. The evaluated systems present a low percentage of natural and diversified vegetation.

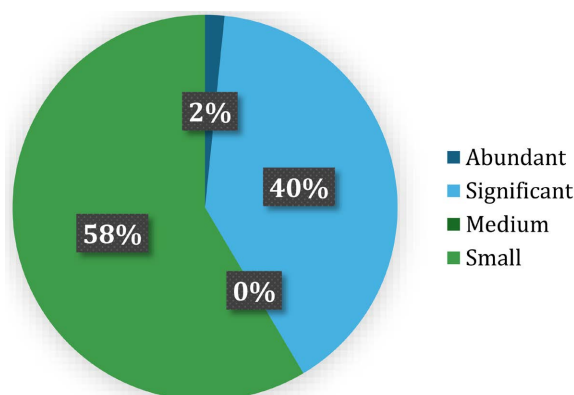


Figure 8. Productive area covered by natural or diversified vegetation.

Information collected on the presence or absence of bees within these 123 farms reveals that no producer practices beekeeping and, consequently, bees are not raised within the agroecosystem (**Figure 9**).

Nevertheless, the observed percentages are 52%, showing that bees are widespread within the agroecosystem, versus 48% that are rare within the agroecosystem.

Figure 10 reflects the presence of pollinators and other beneficial animals within the agroecosystem. Out of the 123 farms, the percentages obtained for importance and abundance are 52% and 48%, respectively. This means that approximately half of the surveyed producers (59) do not have pollinators and other ben-

eficial animals within their farms.

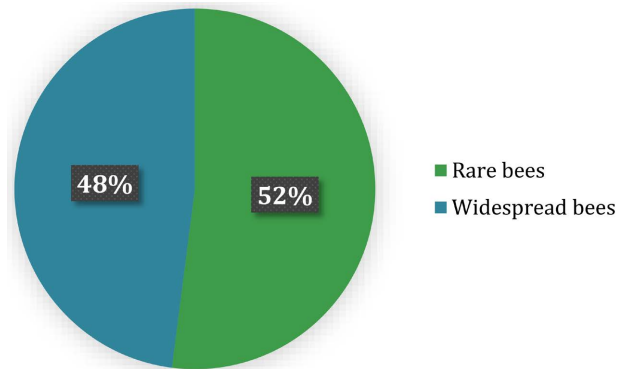


Figure 9. Beekeeping.

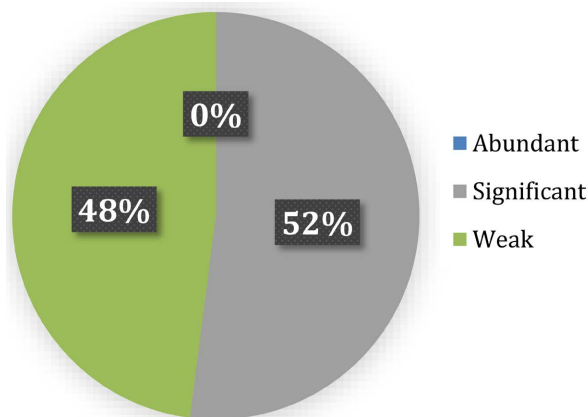


Figure 10. The presence of pollinators and other beneficial animals within the agroecosystem.

The index called “Natural vegetation, trees and pollinators” is 15.48%. The Gini-Simpson index of farm crops is: $1 - 0.11 = 0.89 * 100 = 89\%$.

The final agricultural biodiversity score (58.16%) is the unweighted average of the Gini-Simpson index for crops (89%) and the “Natural vegetation, trees and pollinators” index (15.48%). Animal diversity was not included in the final average as livestock were found to be minimal and non-diversified across the majority of farms, contributing negligibly to the overall biodiversity score. We are therefore in the Yellow zone, which corresponds to acceptable conditions.

3.3.10. Soil Health

Figure 11 presents soil health indicators. Observation of the figure reveals that only two indicators present a percentage above average: residue status (51.73%) and soil cover (50.09%). These results generally reflect unsustainable conditions for soil health. This could be due to the environmental challenges of the area. Nevertheless, these results should be taken with caution, as soil health specialists and analyses ranging from sampling to laboratory analysis would be needed to truly assess soil health.

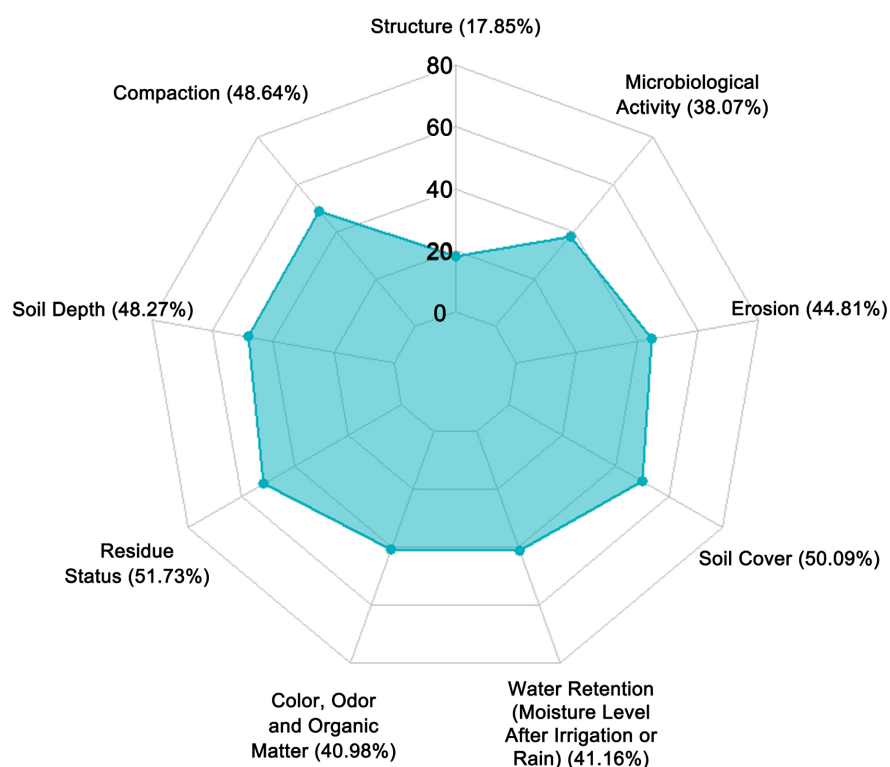


Figure 11. Visualization of soil health indicators.

4. Discussion

Faced with the environmental and economic challenges of conventional agriculture, transitioning to agroecology often requires producers to adopt a new set of practices that enhance ecosystem services and reduce environmental footprints. Overall, farms display a low level of transition, as indicated by the average scores obtained for the Characterization of Agroecological Transition (CAET), with only four (4) of the ten agroecology elements exceeding 60%. Higher scores in CAET (70, 80, or even more) would reflect strong implementation of agroecological practices and principles [26] [27].

In terms of performance, farm scores generally correspond to their level of transition, particularly in environmental and economic dimensions. These farms display low scores concerning pesticide exposure, added value, income, and dietary diversity. The high use of chemical pesticides and fertilizers inevitably impacts their income, which confirms their level of transition [28] [29]. The large discrepancy between the net family income (756,000 CFA/FLU/year) and the much lower added value (318,000 CFA/FLU/year) highlights that a significant portion of the gross revenue is not retained as value generated by the core farming activity. This is primarily due to substantial deductions for subsidies and rental income, indicating a dependency on external financial support. This underscores that the economic resilience of these farms may be more fragile than the net income figure alone suggests. They also depend on external inputs from outside markets. Producers who employ less non-family labor, particularly their children, obtain

higher yields through reduced expenses. Farms advanced in agroecological transition rely heavily on family labor, engaging almost all families in the farm [30] [31]. The high reliance on family labor is compatible with the calculated income per family labor unit, as the income represents the total net revenue distributed among a relatively small number of resident family members engaged in the farm work. This structure minimizes cash expenditures on hired labor, thereby increasing the net revenue share per family unit.

Agriculture is the main activity of this region, and few producers have secondary activities, which limits added value. Regarding food security and nutrition, dietary diversity is low. Several factors explain this: farmers most advanced in their agroecological transition present increased availability of diverse edible products on their farm [32] [33], which generally contributes to better dietary diversity [33] [34]. Moreover, these farms spend less on food for self-consumption, being more self-sufficient [35]. They are also better connected to local markets, increasing their chances of marketing their production and accessing food products they do not cultivate [36].

A notable finding was the very low presence of youth in the farming households, preventing the evaluation of youth employment prospects. This has profound implications for the sustainability of these agricultural systems. It suggests ongoing rural out-migration, potentially leading to future labor shortages and an aging farmer population. This trend threatens the intergenerational transfer of knowledge and the long-term viability of farming in the region.

Access to land, often transmitted from generation to generation, is valued. The belief that selling can lead to risks results in a good score for land tenure. Women are mostly involved in decision-making processes, as indicated by the Women's Empowerment in Agriculture Index (WEAI) score. The circular and solidarity economy element is crucial for agroecological transition, confirming the FAO and INRA theses [36] [37] on the strong link between agroecology, logical transition, dissemination, and the development of local markets. Farms advanced in agroecology benefit from increased food security [38] and can even achieve food sovereignty [39] [40].

Public policies should favor a transition toward agroecological production systems, ensuring better availability of diversified foods and greater resilience to shocks [41]. These policies must be accompanied by interventions aimed at connecting farmers to markets and establishing effective local markets, thus ensuring an outlet for agroecological producers and accessibility to diversified foods throughout the year [36]. These sustainable market institutions not only strengthen producers' food security but also encourage the adoption of agroecological practices by responding to consumer concerns about food quality [37].

The public sector plays an essential role in providing political and physical spaces to support local and territorial markets, thus promoting co-creation and knowledge sharing in sustainable agricultural matters. However, youth perceive few employment opportunities in agriculture. Agroecology can offer decent jobs

in a diversified and healthy environment, stimulating skills development and learning [42] [43].

In light of these results, it appears that farms do not have very high performance, with few criteria displaying high scores. These results can, however, be used to encourage and effectively help other farmers in their agroecological transition. Adoption of new practices would allow a transition from a conventional system to a more agroecological system, thus improving performance and environmental, social, and economic sustainability. The study also demonstrates that, thanks to its analytical framework based on the 10 elements of agroecology, TAPE constitutes a powerful tool to support agroecological transitions and establish links between agroecological transition and different dimensions of sustainability in food systems. Nevertheless, certain limitations of TAPE were identified, notably the importance of adapting questionnaires to the local context before data collection, particularly regarding economic information, women's contributions, and soil characteristics. Moreover, diachronic analysis is necessary to confirm certain results.

5. Conclusion

Agroecology positions itself as a relevant response to the health challenges of the current food system. This study demonstrates that the Tool for Agroecology Performance Evaluation (TAPE) constitutes an innovative framework for assessing the agroecological transition and multidimensional sustainability of agricultural systems. The low application of TAPE in the study area indicates that farms are less advanced in their agroecological transition. By combining the results of steps 1 and 2 of TAPE, it is possible to obtain performance evidence that supports the design of agroecological projects. This study informs decision-makers about the importance of promoting agroecology to ensure food security and sovereignty.

Conflicts of Interest

The authors declare no conflict of interest regarding the publication of this paper.

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