Agroecology TPP

Benin country report on Measuring Agroecology and its Performance (MAP)

TAPE application in the context of the GIZ global project Soil Protection and Rehabilitation for Food Security (ProSoil)

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The Transformative Partnership Platform on Agroecology (Agroecology TPP)

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Abbreviations and acronyms

Agroecology TP	Transformative Partnership Platform on Agroecology
BMZ	Bundesministerium für wirtschaftliche Zusammenarbeit und Entwicklung (German Federal Ministry for Economic Cooperation and Development)
CAET	Characterization of Agroecological Transition
CFS	Committee on World Food Security
CIFOR	Center for International Forestry Research
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement (French Agricultural Research Centre for International Development)
DeSIRA	Development Smart Innovation through Research in Agriculture initiative of the EU
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GIZ	Deutsche Gesellschaft für Internationale Zusammenarbeit (German development agency)
ICRAF	International Centre for Research in Agroforestry (World Agroforestry)
LDSF	Land Degradation Surveillance Framework
MA	Measuring Agroecology and its Performance
MCT	Mercury cadmium telluride
ProSilience	DeSIRA project Enhancing Soils and Agroecology for Resilient Agri-food Systems in Sub-Saharan Africa, implemented by GIZ and embedded in ProSoil
ProSoil	GIZ global project Soil Protection and Rehabilitation for Food Security
Stats4SD	Statistics for Sustainable Development
TAPE	Tool for Agroecology Performance Evaluation

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The Measuring Agroecology and its Performance (MAP) project is a collaborative initiative aimed at fostering agroecological transitions by generating evidence of agroecological contribution to societal goals. The MAP project is funded by the German Federal Ministry for Economic Cooperation and Development (BMZ), co-funded by the European Union (EU) and supported by the Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH. In the MAP project, the Tool for Agroecology Performance Evaluation (TAPE) was applied in Benin, Ethiopia, Kenya and Madagascar in the context of the EU-funded DeSIRA project Enhancing Soils and Agroecology for Resilient Agri-food Systems in Sub-Saharan Africa (ProSilience), which itself is embedded in the GIZ global project Soil Protection and Rehabilitation for Food Security (ProSoil).

The application of TAPE in four municipalities of Benin – Za-Kpota, Bantè, Sinendé and Kandi – was made possible through the Benin office of the Center for International Forestry Research and World Agroforestry (CIFOR-ICRAF), with the support of the Food and Agriculture Organization of the United Nations (FAO) for the comprehensive training of the enumerators. We appreciate the invaluable contribution of the CIFOR-ICRAF Soil and Land Health team in Nairobi, who played a crucial role in soil sample collection and analysis. The entire data management process was efficiently conducted using online data platforms, thanks to Statistics for Sustainable Development (Stats4SD), which was also responsible for data cleaning, analysis, and quality assurance. We also extend our gratitude to the Benin ProSoil project teams, the farmers, the enumerators and the key informants for their patience and cooperation throughout the data collection process and during the country stakeholders' meetings.

Executive summary

The Soil Protection and Rehabilitation for Food Security (ProSoil) project aims to promote food security through the protection and rehabilitation of degraded soils, with a particular interest in assessing the performance of agroecological practices in the intervention areas. The proposed collaborative work between ICRAF and GIZ leveraged activities of the Metrics Project and resulted in evidence generation through the collection and processing of robust and harmonized data on the levels of agroecological transition and the multidimensional performance of agroecology at farm/household and territorial levels by using the Tool for Agroecological Performance Evaluation (TAPE).

Since 2015, ProSoil has been empowering communities to address environmental and food-security challenges by implementing interventions, such as agroforestry, conservation agriculture, soil and water management, integrated pest management, and policy advice. Through effective collaboration with smallholder farmers, experts and decision makers, ProSoil has fostered a landscape transition towards sustainable farming practices. TAPE results from 120 farms that actively participated in ProSoil activities were compared with 120 farms that had not participated in ProSoil activities. To specifically assess the contribution of agroecology to improved soil health within ProSoil farms, as opposed to the comparison farms, TAPE was complemented with the Land Degradation Surveillance Framework (LDSF) methodology to gain more detailed insights into the contribution of agroecological integration to physiochemical soil characteristics.

The key findings of Step 0 (enabling environment) from TAPE show that an average household size is nine (±3 standard deviation) persons. The women and girls represent about 49.80% of the total number of household members older than 15 years of age. This demonstrates the need to consider women's empowerment in building vulnerable communities' resilience. The average land size dedicated to agricultural production is 5 hectares (ha), with 2 ha for natural vegetation and 0.6 ha for pastureland per household. The findings also show that 54% of the ProSoil beneficiaries' land was used for two to three crop varieties, while less than 40% of the non-beneficiaries adopted multiple varieties in their farmland. Moreover, a third of households (33%) also have livestock. About 15% of households produce fruit trees to harvest oranges, mangoes, cashew nuts and other fruits. A small minority (4.58%) cultivate trees for timber and non-timber forest products (NTFP), while about 46% of households adopt the mono-cropping approach, and 54% diversify their agricultural products. The institutional and policy environments in Benin are favourable for the development of agroecological practices from sub-national to national level since decision makers have developed various documents emphasizing the relevance of agroecological practices for sustainable development in the agricultural sector.

The Characterization of the Agroecological Transition (CAET) of Step 1 of TAPE revealed that households actively involved in ProSoil activities have a significantly higher overall CAET score (56%) than households in the comparison group (40%). The interquartile range (IQR) is 60–75 for the ProSoil group and 30–45 for the comparison group. The analysis of the transition level for each of the 10 elements of agroecology shows that the average CAET score of the comparison group for all elements is less than 50%, except for the Culture and food tradition element, which had scores of 50% to 60%. Furthermore, the difference in the overall CAET score between the ProSoil and comparison groups is greater on Co-creation and knowledge sharing, Responsible governance, and Synergies. This implies that these dimensions are very sensitive and determinant in agroecological transition. The project significantly contributed to the capacity building of the beneficiaries. The collective actions and information sharing between beneficiaries has played a central role in the development and application of agroecological innovations in the targeted sites.

Regarding the performance of agroecology in Step 2 of TAPE, the ProSoil group's positive and linear relationship between agroecological transition levels and the total value of agricultural products is best explained by the average positive correlation between the CAET score and income from crop sales. The relationship between the Gini-Simpson diversity index (GSI) for livestock versus the CAET scores reveals that for the ProSoil group, the more the GSI increases, the more the total CAET score increases, up to a threshold of 65%, from where the index starts to decline. The correlation coefficient is significantly positive between the number of ecological pest-management practices and the total CAET score (0.55), Resilience (0.60), Co-creation and knowledge sharing (0.49), as well as Circular and solidarity economy (0.50). There is a near-linear relationship between the women's empowerment score and the total CAET score in the ProSoil group, with A-WEAI (women's empowerment score) above 60%. However, this relationship is curve-shaped for the comparison group, with a minimum A-WEAI of around 7.5% and a maximum A-WEAI of about 55%. This demonstrates the important role that the agroecological approach plays in women's empowerment.

The transition to an agroecological system can be compromised by a lack of adequate documents to secure the land being used. Forty out of the 120 households – or 33.33% – in the ProSoil group have their farms in agroecological transition. Only 10.83% of the ProSoil beneficiaries hold the title deed, the certificate of customary tenure, the certificate of occupancy, or are registered with a certificate of hereditary acquisition. About 22.5% asserted that they inherited the land without title, which may compromise their ownership on the land. Fortunately, the land tenure issue has been considered by ProSoil since the beginning of the project, and this indirectly led to the record number of beneficiaries who have at least one document attesting to their ownership of the land. These efforts need to be strengthened with new initiatives in the country to continue increasing and consolidating the progress made so far.

The key recommendations and suggestions of the participants:

- Make available all materials that are useful for the TAPE application.
- Build the technical capacity of various actors to use TAPE.
- The GIZ team should follow up and promote collaboration to provide strong backup for statistical agriculture services at the national level.
- Carry out analysis of economic performance and provide more explanation of how agroecological practices have a positive impact on the local economy.
- TAPE did not present carbon sequestration as a crucial aspect relevant to the country's international commitments. There is a need to consider this perspective when conducting the project in Benin since more actions have been taken with respect to tree planting and other agroecological practices.

1 Introduction

African farmers face multiple challenges due to climate change impacts on agricultural productivity (CIFOR 2023). These farmers have become more vulnerable to these impacts, hence agroecology has been proposed to strengthen the resilience of the landscape and of their communities (Sinclair et al. 2019). However, the viability of agroecological practices for African farmers has been questioned (Namirembe et al. 2022). In that setting, the Soil Protection and Rehabilitation for Food Security (ProSoil) project aims to promote food security through protection and rehabilitation of degraded soils, with a particular interest in assessing the performance of agroecological practices in the intervention areas. The proposed collaborative work between ICRAF and GIZ leveraged activities of the Metrics Project and resulted in evidence generation through the collection and processing of robust and harmonized data on the level of agroecological transition and the multidimensional performance of agroecology at farm/household and territorial levels, using the Tool for Agroecological Performance Evaluation (TAPE).

TAPE is a participatory tool that was developed by the FAO (2019) with the aim of harmonizing not only the often-scattered evidence relating to the impacts of agroecology on agricultural production systems, but also to harmonize the approaches to evaluating the multidimensional performance of agroecological systems. This report presents the results of the TAPE tool as part of the Soil Protection and Rehabilitation for Food Security (ProSoil) programme implemented by GIZ, commissioned by the German Federal Ministry for Economic Cooperation and Development (BMZ), and co-financed by the European Union, through the DeSIRA initiative.

This report presents the results of evaluated agroecological practices at the farm and household level in the target areas of the ProSoil project using the TAPE tool. The report also presents the soil properties to assert the project's contribution to the soil fertility of the ProSoil group's farmers in the targeted sites. These results will be shared with relevant stakeholders at the local and national levels, including decision makers through the validation workshop.

Objectives

The main objectives of this application of TAPE in the context of ProSoil were:

i. to assess the degree to which participation in ProSoil activities resulted in increased agroecological integration at farm/household level.
ii. to assess how participation in ProSoil activities resulted in differing multidimensional farm/household performance, taking the multifunctionality of agriculture into account.
iii. to assess how the level of agroecological integration at farm/household level correlates with multidimensional farm/household performance, taking the multifunctionality of agriculture into account.
iv. to provide evidence of soil fertility to confirm the role of agroecological practices in the resilience of ecosystems and of communities.

2 The ProSoil project in Benin

The global project Soil Protection and Rehabilitation for Food Security (ProSoil) stems from the BMZ special initiative One World – No Hunger, which launched in 2014. ProSoil aims to disseminate sustainable approaches for the promotion of soil protection and the rehabilitation of degraded soils with a broad impact.

Initiated in 2015, the ProSoil project aimed to enhance food security and address the impacts of climate change by restoring degraded farmlands through the implementation of climate-smart agroecological practices. Through key practices such as agroforestry, conservation agriculture, soil and water management, integrated pest management, and the relevant policy advice, ProSoil has effectively collaborated with smallholder farmers, experts, and decision makers, helping landscapes transition to agroecology in the beneficiary regions of these target countries (GIZ 2021). Embedded within the ProSoil project, the Enhancing Soils and Agroecology for Resilient Agri-food Systems in Sub-Saharan Africa (ProSilience) project – also implemented by GIZ – aims to build on ProSoil outcomes by advancing agroecological transitions to enhance the climate-adapted, productive and sustainable transformation of agriculture and food systems in low- and middle-income countries (GIZ 2020).

ProSoil aims to implement sustainable soil protection and rehabilitation approaches on a large scale in the 18 intervention communes in Benin. The project received co-financing from the EU and BMZ to implement the ProSilience project. ProSilience stems from the EU initiative Developing Smart Innovation through Research in Agriculture (DeSIRA), which has the overall objective "to contribute to a productive, sustainable and climate-adapted transformation of agriculture and food systems in low- and middle-income countries. Through this project, agroecological approaches are implemented on a large scale in selected cooperation countries in order to protect soils in the interest of the environment and climate and to restore soils that have become non-fertile.

The ProSoil project supports smallholder farmers who learn to protect their land from erosion using agroecological and climate-smart methods as well as to restore and preserve soil fertility. To this end, it offers training and advice to farmers and agricultural extension workers. By working with public institutions, scientists, researchers, the private sector and civil society, the programme creates the overall conditions that promote change in agricultural and food systems, placing this theme on the political agenda at the heart of institutions and society. This helps promote food security and makes an important contribution to "land degradation neutrality," which is a Sustainable Development Goal of the United Nations. The programme further anchors this knowledge in the curricula of educational institutions and encourages exchanges between participating institutions and countries. The ProSoil project therefore aims to help enhance the protection and rehabilitation of degraded soils to foster sustainable production in the project's nine targeted municipalities in Benin, and specifically to disseminate soil-protection and rehabilitation techniques to producers there.

The achievements include:
- 3,000 additional producers grouped in 400 farmers' organisations are affected, 50% of whom are women
- Rice and soybean yield increased by 25%
- 2,120 ha of rehabilitated and protected land and 12 ha of plots planted using SRI technology
- 300 million CFA francs (USD 504,000) of income distributed per year to producers

The expected effects include the dissemination of innovative techniques for integrated soil-fertility management, in particular the introduction of combinations of legumes in rotation; the use of organic matter and supergranulated urea; the partial reconstitution of soil fertility; as well as an increase in yields, incomes and productivity.

The objective of ProSilience is to strengthen the agroecological transition towards sustainable agri-food systems in the targeted countries. It focuses on three domains:
- The adoption of technical and socioeconomic measures linked to innovation in agroecology is reinforced with partners in the target countries.
- The policy and research framework for the agroecological transition is improved.
- National stakeholders use co-created knowledge and data on agroecology and share them nationally and internationally.

In Benin, the project operates in 90 selected villages in nine communes across four departments (the commune of Za-Kpota in the Zou department; Savalou, Bantè, Dassa and Glazoué in the Collines department; Sinendé and N'Dali in the Borgou department; Kandi and Banikoara in the Alibori department).

In reference to these objectives, this study provides assessment results about the performance of agroecological practices implemented in the target communes in Benin.

3 Methodology

3.1 Sampling strategy and data collection

From the project's nine communes of intervention targeting four agroecological zones (AEZ) of the country, the sampling consisted of at least one commune per agroecological zone. The commune of Za-Kpota was selected in AEZ 6, the commune of Bantè in AEZ 5, the commune of Sinendé in AEZ 3, and the commune of Kandi in AEZ 2. In addition to this criterion, the selected communes were the targeted sites of the ProSoil project. The four communes are spread over one department in the south, two departments in the centre and two departments in the north of the country: Kandi in the department of Alibori; Sinendé in the department of Borgou; Bantè in the department of Collines, and Za-Kpota in the department of Zou.

The typology adopted for interview consisted of classifying the respondents into two groups. The first group included those who have implemented the agroecological practices tested by ProSoil, and the second group represented the control group, where the farmers did not apply the agroecological practices (Table 1). These two groups are referred to as ProSoil and Comparison group, respectively, in the presentation of the results.

Table 1. Distribution of households (HHs) interviewed by commune/subdistrict

Department	Commune	AEZ	Subdistrict (arrondissement)	No. of interviewed HHs		Total
				ProSoil	Comparison group	
Alibori	Kandi	2	Bensékou	00	03	60
			Donwari	00	26	
			Kassakou	30	01	
Borgou	Sinendé	3	Fô-Bouré	07	00	60
			Sekere	15	15	
			Sikki	08	00	
			Sinendé Centre	00	15	
Collines	Bantè	5	Agoua	07	00	60
			Akotoligbé	8	00	
			Koko	8	00	
			Pira	07	30	
Zou	Za-Kpota	6	Houngomè	08	00	60
			Kpakpamè	08	15	
			Za-Kpota centre	07	15	
				07	00	
					Total	**240**

The data were collected from 240 households (HHs) with the sampling structured in such a way that group responses were obtained in equal measure: 50% from the beneficiaries of the ProSoil group and 50% from the comparison group of farmers. In each commune, at least 60 HHs were interviewed following the above-mentioned distribution.

The south of Benin is characterized by an equatorial climate with two dry seasons (November to March and mid-July to mid-September) and two rainy seasons (April to mid-July and mid-September to October). Northern Benin is characterized by a Sudanian and Sudano-Sahelian climate with two seasons, including a single rainy season from May to October.

Table 1 shows the distribution of the HHs interviewed per subdistrict or subcommune, namely "arrondissement," in each commune.

3.2 TAPE tool for assessing agroecology performance

The Tool for Agroecology Performance Evaluation (TAPE), developed by FAO (2019), was used for this study and implemented in four steps:

Step 0

After the recruitment of enumerators, training was held with the support of an FAO expert on data collection approaches across the three steps of TAPE. An approach to interact with the communities before the questionnaire stage was also developed by the FAO expert. Two enumerators were deployed in each commune and the selected villages of the communes (Table 1).

This is a preliminary step that consists of collecting relevant information relating to the description of the considered production system. This includes a description of the main socioeconomic, environmental and demographic characteristics and contexts of the systems, such as location, household size, productive assets, agroecological zone, landscapes, forests, access to land, commodities produced, and agricultural exploitation in the region. Step 0 also includes a description of the enabling (or disabling) environment for agroecological transition, at higher scales than the system assessed (e.g. provincial or national). For example, these environments included the inventory of relevant policies for agroecology (favourable or limiting); the institutional and legal frameworks; marketing structures for various types of products; as well as sociocultural, environmental and/or historical drivers.

After selecting the villages with the extension service technicians of the selected communes in close collaboration with the ProSilience project team, the second point of contact was with the chief of each village to request their assistance for interviews with the selected respondents. Before the questionnaire was administered, consent to participate in the questionnaire was requested. The overall aim of the questionnaire was explained as well as the key time that will be spent during the questionnaire stage. The relevance of soil data collection in the field of each household was also explained.

Step 1

This step consists of characterizing the levels of agroecological transition (CAET) of the production system based on the 10 elements of agroecology: diversity, synergies, efficiency, recycling, resilience, culture and food traditions, the co-creation and sharing of knowledge, human and social values, the circular and solidarity economy, and responsible governance (FAO 2018). The CAET aims to measure the level of multidimensional sustainability of the agricultural exploitation studied. To do this, the 10 elements are disaggregated into 36 indices (FAO 2020) with descriptive scales at five transition levels (scores from 0 to 4), which include the 13 principles of agroecology. The final scores are then converted into a transition percentage for each item. The final CAET score is the result of the average transition score across all 10 elements (FAO 2021). These scores were calculated first for all regions surveyed, then for each region surveyed and finally for each element of agroecology mentioned above. In each case, the CAET score was presented for each production system category, i.e. ProSoil system and Comparison group system.

The agroecological transition categorization scale according to Lucantoni et al. (2021) was adopted in this study as follows:

- For a CAET score <= 50%, the production system is said to be non-agroecological.
- For 50% < CAET score <= 60%, the production system is considered to be in emerging transition.
- For 60% < CAET score <= 70%, the production system is considered to be in transition towards agroecology.
- For a CAET score > 70%, the production system is considered to be agroecological.

Step :

This step measures the impact of agroecological transition levels assessed in Step 1, on the multidimensional sustainability performance of the production system by considering the five dimensions of sustainability: governance; economy; health and nutrition; society and culture; and environment. Ten core performance criteria distributed across the sustainability dimensions were used to assess the relationship between the dimensions and the overall CAET score. These criteria, as well as the indicators used for their evaluation, are presented in Annex 1 (FAO 2019).

Step 3

Carries out a final analysis with a participatory interpretation of the results.

3.3 Soil sampling technique using the Land Degradation Surveillance Framework (LDSF)

The TAPE questionnaire was customized to offer comprehensive insights into soil health to determine the efficacy of ProSoil interventions as well as the contribution of agroecological integration in enhancing soil health. The Land Degradation Surveillance Framework (LDSF), developed by ICRAF, was applied in soil sampling and analytics to this effect. The LDSF provides a hierarchical sampling design, ensuring local relevance while creating predictive models with global applicability. In each of the 240 selected farms, a centroid point (subplot 1) was purposively selected as a good representation of the soil status in the entire productive farm under investigation (Figure 1).

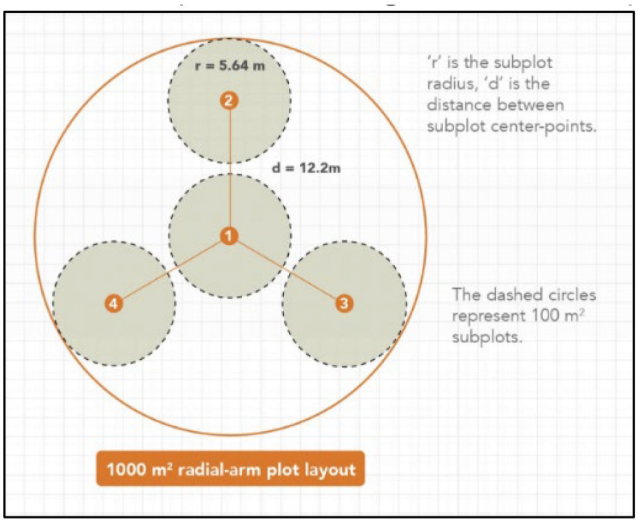

Figure 1. Soil sampling plot layout. Extracted directly from the ICRAF 2023 LDSF Field Manual

Source: https://www.cifor-icraf.org/knowledge/publication/25533

An additional three subplots were then delineated at a maximum of 12.2 m, and distributed at 120, 240 and 360 degrees around the centroid subplot (Figure 1). Two composite soil samples – topsoil (0–20 cm) and subsoil (20–50 cm) – were then extracted using soil augers from the four subplots, resulting in two soil samples per farm.

Likewise, the soil's microbial activities were assessed using hydrogen peroxide, and the outcome was evaluated on a qualitative Likert scale of 3. Soil samples were then analysed using a mid-infrared (MIR) spectroscopy technique combined with machine learning. Spectral measurements for the soil samples were acquired using a Bruker FTIR HTS-XT spectrometer fitted with a high-sensitivity liquid nitrogen-cooled mercury-cadmium telluride (MCT) detector. The prediction model was then validated using the wet chemistry method.

3.4 The TAPE data analysis methods

Analysis of the TAPE data conducted by Stats4SD was completed entirely in RStudio. The process can be split into three key components: analysis of CAET scores; analysis of the relationship between CAET scores and performance indicators; and analysis of the collected soil samples.

Firstly, both overall CAET and individual dimension scores were plotted using box and violin plots to demonstrate the differences in distributions between the two comparison groups. This was accompanied by the results of t-tests to assess whether the difference in means was statistically significant. Lastly, the mean individual dimension scores of the two groups were plotted on a radar chart.

For the assessment of the relationships between CAET and performance, each indicator was generally analysed using four techniques:

- A scatterplot with total CAET score and the indicator fitted with a moving average line, split by the two comparison groups. Where possible, an additional plot split by region was included. For monetary indicators, the scale was transformed to a log10 scale to account for uneven distributions and high figures.
- A table of Spearman's rank correlation coefficients between the indicator and CAET scores (both overall and dimensions) was created, split by the comparison groups.
- A t-test of means between the comparison groups
- A non-parametric test of medians between the two groups

Both means and medians were tested in general. For instance, monetary variables are better suited to median testing due to the likely skewed distributions. Where indicators are reported as binaries (i.e. using a toxic pesticide, in poverty etc.), frequency tables with chi-square test of association results were provided.

3.5 The soil data analysis

For the soil sample data, the analysis was similar to the indicator assessments. Scatterplots with moving averages accompanied box and violin plots and tables of means, medians, standard deviations and interquartile ranges. This was conducted on the three key measures of pH, soil organic carbon, and total nitrogen. Additional tables for summary statistics on other measurements, including potassium and boron, were provided. The p-values of t-tests comparing with the averages of the two groups were included. A split by region was also available for much of the analysis.

4 Results

4.1 Step 0: Context of the study

4.1.1 Location of the intervention area in relation to the agroecological zones

Benin is subdivided into eight agroecological zones (AEZ), considering the spatial distribution of pedoclimatic conditions, agricultural systems and land use dynamics. The selected communes for this study were presented as situated in each agroecological zone (Figure 2) of the country:

- The commune of Kandi is in the cotton-growing zone of north Benin (AEZ 2), characterized by a Sudanian or even Sudano-Sahelian climate, with an annual rainfall of 800–1,200 mm and only one rainy season. The soil types of the region are ferruginous, vertisols, or hydromorphic.
- The commune of Sinendé is in the food-producing zone of south Borgou (AEZ 3). The climate is Sudanian with rainfall of 1,100–1,200 mm. The dominant soils are lixisols.
- The commune of Bantè is in the cotton-growing zone of the AEZ 5 (Figure 2). It is the largest agroecological zone, with an area of 31,712 km^2. The climate is Sudanian-Guinean with two rainy seasons, but a tendency towards the Sudanian type with only one rainy season. Annual rainfall varies from 800 mm to 1,500 mm. This zone belongs to the transition zone between the south and the north of the country.
- The commune of Za-Kopta is in the *barre* land agroecological zone (AEZ 6). This area is characterized by a Sudano-Guinean type. The rainfall pattern varies from 800 mm to 1,400 mm. The soil types are mostly ferralitic, formed on the Continental Terminal and depleted.

In AEZ 2, 3 and 5, agricultural systems are essentially composed of food crops such as rice, sorghum, corn and yam, and cotton. The subsistence agricultural system is often conducted in pure crop rotations; in agroforestry with species such as *Adansonia digitata*, *Bombax costatum, Lannea microcarpa, Parkia biglobosa, Sclerocarya birrea, Vitellaria paradoxa, and Blighia sapida*; or associated with pastoral activities of sheep and cattle. The *barre* land zone, for its part, is characterized by vegetation dominated by savanna. The agricultural systems are mainly subsistence

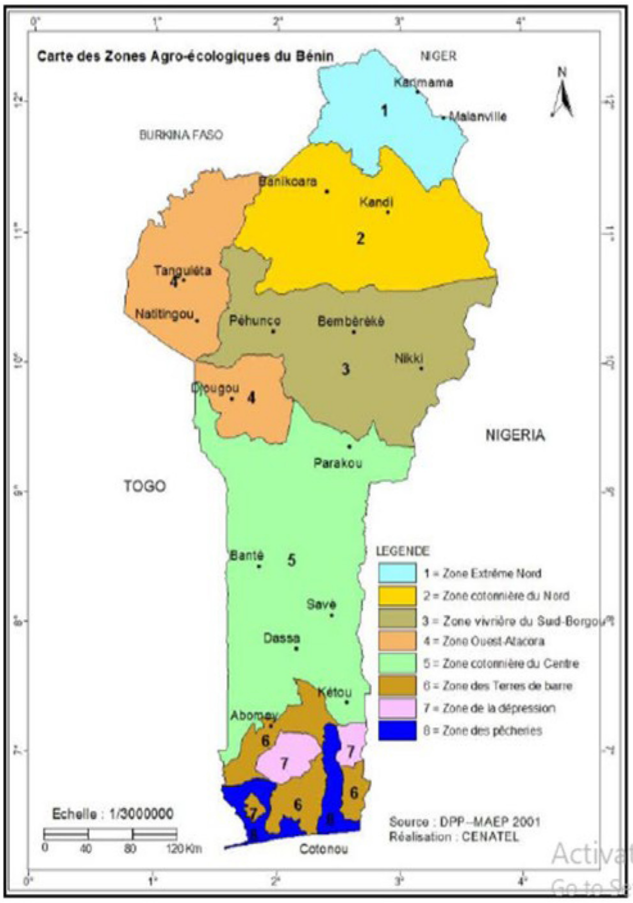

Figure 2. Map of agroecological zones in Benin showing the distribution of communes.

Source: DPP-MAEP, 2001

crops, including sorghum, yams, beans, peanuts, corn and cassava. There are also agroforestry systems based on natural forest species or forest plantations of exotic species, such as *Tectona grandis*, *Eucalyptus camaldulensis, Mangifera indica, Azadirachta indica* and *Acacia auriculiformis*. These systems are also very widespread over the landscape.

4.1.2 Characteristics of the surveyed households

The pattern analysis of the household profile shows an average of nine persons per household. The household size ranges from six to 13 persons, with the maximum recorded in the department of Alibori and the minimum in the Zou department. Women and girls represented about 49.80% of the total number of household members older than 15 years of age. This demonstrates the need to consider women's empowerment in building the resilience of vulnerable communities.

4.1.3 Size of agricultural exploitation and land use systems

On average, the area of land used for agricultural production per household is around 5 ha. Natural vegetation covers 2 ha and around 0.6 ha is devoted to pasture areas. The distribution of these areas by commune shows that households located in the commune of Alibori have a larger area for agricultural production, justifying Alibori's status as the largest department of Benin (23%) with widespread agricultural lands dominated by extensive production systems (Figure 3).

An estimated average of the various land use systems proportionally represents 64% of the total area for agricultural production, 27% for natural vegetation, 4% for permanent grazing areas, and 5% for common grazing areas, based on the survey's data from households (Figure 4).

Almost all households (99%) produce various crops and plant products (Figure 5). The cropping systems analysis revealed that few producers (ProSoil and Comparison group) have a monoculture production system across all agroecological zones. Most of the producers devoted their land to two or three crops with significant cultivated areas; about 54% of Comparison group producers and less than 40% of ProSoil households were in this category. In the same communities of these agroecological zones, more than 27% of the beneficiaries of ProSoil dealt with more than three crops, with significant cultivated areas adapted to the local climatic conditions, while only 21% of Comparison group households adopted the same type of cropping systems. There were no Comparison group producers of more than three crops of different varieties adapted to the local climatic conditions, and we noticed that at least 10% of the ProSoil beneficiaries have high adaptive capacity to deal with various crop varieties on their lands.

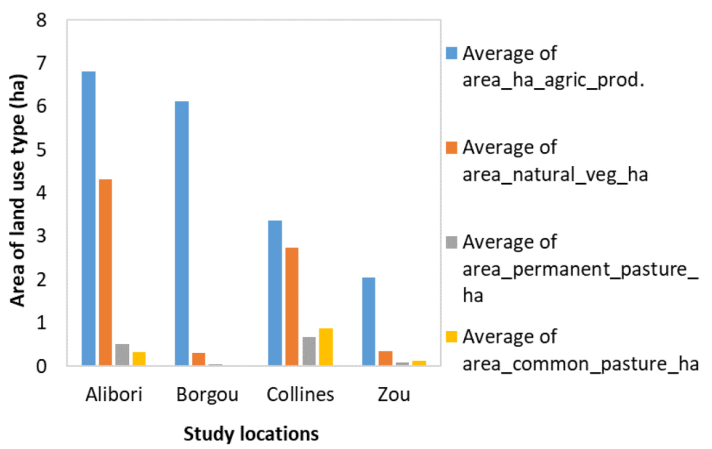

Figure 3. Area by type of land use systems in each commune

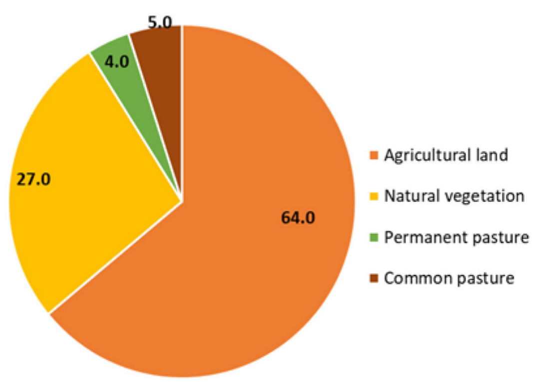

Figure 4. Proportional analysis of cropping systems

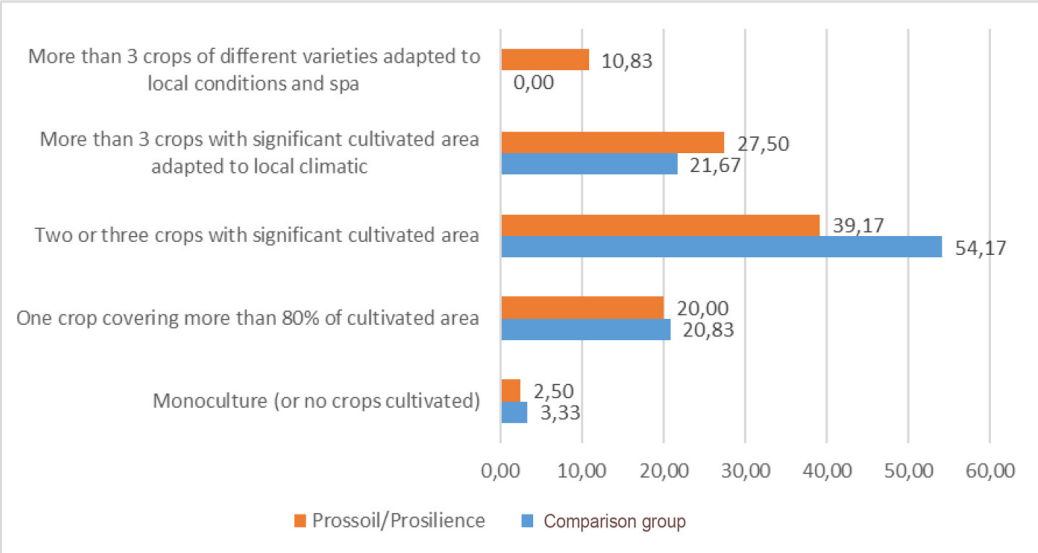

Figure 5. Proportion of households per number of agricultural products

Moreover, a third of households (33%) also have livestock. Around 24% of households produce fruit trees. A minority produce trees for timber and non-timber forest products (NTFP), while about 46% of households adopt a single agricultural product, and 54% diversify agricultural products.

4.1.4 Enabling environment

Sustainable development and environmental issues, including climate change, are integrated into Benin's national development policies. As part of the action programme called Benin Revealed (2016–2021), the government adopted its National Development Plan (Plan National de Développement, 2018–2025) and its first operationalization document, the Growth Program for Sustainable Development (Programme de Croissance pour le Développement Durable, 2018–2021). These development policy documents provide important tools for planning and aim to achieve the Benin 2025 Alafia vision, the UN Sustainable Development Goals and the aspirations of the African Union Agenda 2063. Sustainable development is placed at the heart of public action, reflecting the desire of the Beninese government to meet the challenges facing the country.

The National Development Plan addresses environmental and climate change issues. These aspects are specifically developed within the framework of National Strategic Objective 3, which focuses on the sustainable management of the living environment and the emergence of regional development poles. The conditions for the development of agroecological practices are favourable at both the subnational and national level thanks to the various policy documents developed by Benin's government.

4.1.5 Existing legal and policy frameworks (including climate change)

Benin has implemented several policies and strategies in the field of the environment, agroecology and climate change. These include the National Climate Change Management Policy; the Biodiversity Strategy and Action Plan; the National Climate Change Plan; Adaptation to Climate Change; the National Disaster Risk Reduction Strategy; the Low Carbon and Climate Resilient Development Strategy; the National Air Pollution Control Strategy; the Nationally Determined Contribution; the First, Second and Third National Communications; the National Forestry Policy; the National Wildlife Management Strategy; the Conservation and Protected Areas Management Strategy; the National Strategy for the Management of Rural Timber Markets; the Forest Code; and the National Strategy for Reforestation. These documents demonstrate Benin's efforts to address environmental and climate change issues, including adopting agroecological practices, mitigating and adapting to climate change, conserving biodiversity, reducing disaster risks, developing a low-carbon economy, combating air pollution and managing forest resources.

4.2 Step 1: Characterization of agroecological transition (CAET)

4.2.1 Overall analysis of the CAET score

Analysis of agricultural exploitation with regard to CAET score revealed that households actively involved in ProSoil activities have a significantly higher overall CAET score (56%) than Comparison group households (40%), (Figure 6a). The interquartile range of the ProSoil group is roughly 60–75, while it is just 30–45 for the comparison group.

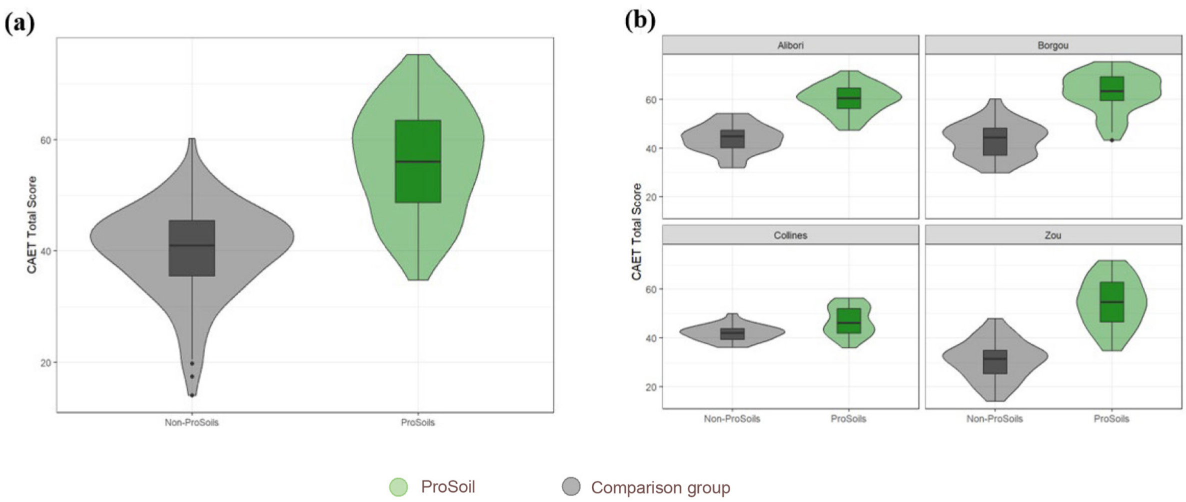

Figure 6. (a) Overall CAET score and (b) by department, ProSoil and Comparison group agricultural exploitation

4.2.2 Analysis per department/commune

ProSoil agricultural exploitation in the Borgou department had the highest CAET score (62.7%), followed by Alibori (60%), Zou (54.3%) and Collines (47%), (Figure 6b). The commune-specific analysis revealed that the ProSoil systems of the Sinendé commune in the department of Borgou, and of the Kandi commune in the department of Alibori had CAET scores of 62% and 60%, respectively. The commune of Bantè in the department of Collines had a CAET score of about 42% for Comparison group producers and about 47% for ProSoil households. The commune of Za-Kpota in the department of Zou shows a CAET score of about 31% for Comparison group producers and about 54% for the ProSoil group.

The communes of Kandi and Djougou can be considered to be in transition towards agroecology for the beneficiaries of the project.

The results of this analysis confirm that the application of ProSoil practices had significantly positive impacts on the CAET scores.

4.2.3 Analysis per element of agroecology

The analysis of transition level for each of the 10 elements of agroecology shows that the average CAET score of Comparison group systems for all elements is less than 50%, except for the Culture and food tradition element, which had a CAET score of 50% to 60%. Furthermore, the difference in overall CAET score between the ProSoil and Comparison groups is greater for the elements Efficiency, Recycling, Co-creation and sharing of knowledge, and Synergies. This implies that these dimensions are very sensitive and determinative in the transition to agroecology. Thus, particular emphasis should be placed on the agroecological practices of these elements to strengthen agricultural exploitation (Figure 7). Great progress has been recorded with the Co-creation and sharing of knowledge element, thus validating the efforts of the ProSoil project. Indeed, the project has made significant contributions to the capacity building of its beneficiaries. The joint production and information sharing between the beneficiaries has played a central role in the development and application of agroecological innovations in the targeted sites, helping address the challenges faced by the farmers. These actions have indirectly contributed to improving other elements of agroecology on the farmland of the beneficiary households.

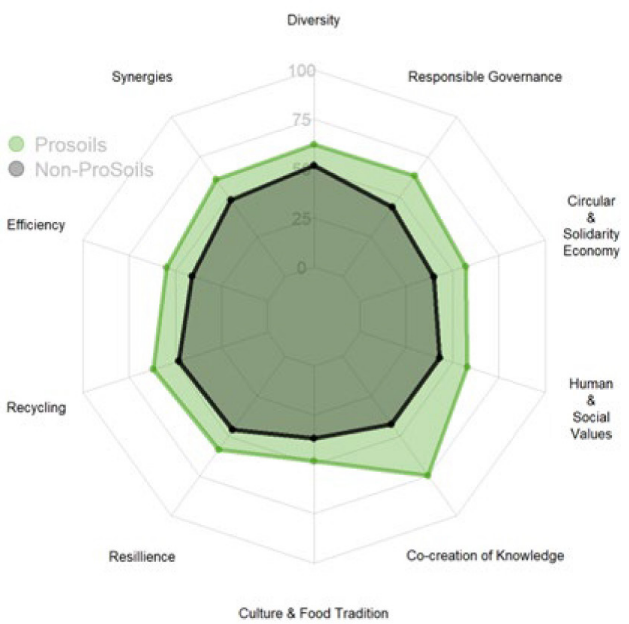

Figure 7. Standardized CAET score for the 10 elements of agroecology and difference in score between the ProSoil and Comparison groups

The average CAET scores of ProSoil systems for the elements Culture and food tradition, Co-creation and sharing of knowledge, Human and social values, and Circular and solidarity economy range from 60% to 70% (Figure 7). These elements are characterized by intermediate levels that do not allow a complete transition to agroecology. Indeed, in terms of culture and food traditions – and with regard to diet and nutritional awareness – almost 72% of producer households were characterized by medium-term food sufficiency, but also by diversity of food. These households also have sound knowledge of good nutritional practices, but do not always apply them. There is no food self-sufficiency as 36% of surveyed households still obtain most of their food outside the household farm. Regarding food and traditional heritage, 33% of households use both exotic and local varieties – seeds and breeds for food consumption – and have knowledge of traditional practices for food preparation. However, the traditional food knowledge and practices are not sufficiently preserved and promoted from generation to generation. Similarly, 23% of households claimed to produce half of the animal seeds and breeds, while the other half comes from the market. In general, there are still efforts that need to be made to consolidate and preserve the local and traditional food heritage.

It is necessary to adopt more approaches to demonstrate the positive impacts of agroecological practices, through field schools, for example, which would involve the producers themselves. Furthermore, the virtual absence of platforms or functional mechanisms for the Co-creation and sharing of knowledge – mentioned by 15% of producers – would limit efforts aimed at agroecological transition.

In terms of Human and social values, 55% of producers affirm that women do not have access to resources. These producers say women's associations exist but are not fully functional, thus hindering women's empowerment. Also, 39% of producers have limited access to financial capital and decision-making processes.

The economy is characterized by local marketing of agricultural products and/or services (35%); limited relationships between producers and consumers (20%); and existing but poorly operational and partially inclusive producer networks (25%). A significant portion of agricultural inputs come from outside the territory; agricultural products are partially processed locally, and there is little commercial exchange between local producers (36%).

The average CAET score for ProSoil systems is between 50% and 60% for the elements Responsible governance, Efficiency, Recycling, and Resilience; and is less than 50% for both the Diversity and Synergies elements. These scores indicate low diversity of plant and animal products. In fact, 17% of producers have a single crop covering most of the cultivated area, and 53% do not have livestock at all. Similarly, 19% of producers say they have few trees on the cultivated area, and 50% say their income is generated by only one type of product or service, or by a limited number of activities that produce a small number of products from the farm.

The low level of diversity explains the low level of synergies observed. The low presence of livestock in agricultural exploitation leads to a virtual absence of integration of crops and livestock. The low proportion of producers who raise animals (20%) indicates that the animals are mainly fed with food purchased outside the agricultural territory. Weed management practices are unknown or not applied due to a lack of access to suitable production inputs. The integration of agroforestry, silvopastoralism or agrosilvopastoralism practices is accountable only for 32.5% of producers.

Finally, we can deduce that the use of CAET for the evaluation of agroecological transition levels made it possible to identify the agroecology elements that offer more opportunities for a complete transition, as well as the elements for which more in-depth studies need to be carried out.

4.2.4 Cross-analysis of the CAET score per agroecological zone (AEZ) and per element of agroecology

The cross-analysis by agroecological zone (AEZ) and by agroecological element showed that the average CAET scores of all agroecological elements of the Comparison group are less than 50% in all AEZ. Only the ProSoil groups of AEZ 2 (Commune of Kandi) and AEZ 3 (Commune of Sinendé) received CAET scores of between 60% and 70% for all elements, except for Diversity and Synergies. Also noteworthy is that the CAET score of the ProSoil group for the Culture and food traditions element was greater than 70% (Table 2).

4.2.5 Statistical correlations between the 10 elements of agroecology and the overall CAET score

The correlation analysis between the overall CAET score and the scores of the 10 elements of agroecology revealed that although all the elements of agroecology are positively correlated with the overall CAET score, the production practices that increased efficiency, strengthened resilience and enhanced human and social values in ProSoil systems, compared with Comparison group systems, are the most positively correlated with the overall CAET score (Table 3). These results would imply that the improvement in the overall level of agroecological transition would be more conditioned, among other things, by:

- promoting mechanisms to reduce vulnerability and improve the capacity of agricultural exploitation to adapt to environmental risks, including climate change.
- increasing agricultural diversity, which also contributes to resilience.
- efficient practices for managing soil fertility, pests and diseases.
- increasing productivity and meeting the needs of agricultural households.
- strengthening the capacities of women.
- improving working conditions.
- reducing social inequalities.

4.3 Step 2: Analysis of the multidimensional performances of agroecology

4.3.1 Economic dimension

There is an almost linear relationship between the levels of agroecological transition and indicators of the economic dimension, particularly in terms of productivity; expenditure for the purchase of inputs; total added value; and the sale of crops, animals, agroforestry products and other agropastoral activities.

Total productivity

The positive linear relationship between agroecological transition levels and total value of agricultural products, observed for ProSoil systems (Figure 8), is best explained by the average positive correlation between the CAET diversity score and the total value of animal production, with a correlation coefficient of 0.55. The correlation coefficient between agroecological transition levels and the total value of agroforestry products and animal products is less than 0.20 but is between 0.335 and 0.38 for total productivity per person, and per hectare.

Value added

There is a positive linear relationship between agroecological transition levels and total expenses for the purchase of inputs (seeds, fertilizers, pesticides, equipment, etc.), especially for ProSoil group systems. This is explained by the average and significant positive correlation that exists between total expenditure and the CAET score of the Diversity indicators (0.53), Synergies (0.47) and Resilience (0.52).

Table 2. Mean values and standard deviations of CAET scores for each AE element, by Comparison and ProSoil groups, within each AEZ

	AEZ 2				AEZ 3				AEZ 5				AEZ 6			
10 AE elements	**Comparison**		**ProSoil**		**Comparison**		**ProSoil**		**Comparison**		**ProSoil**		**Comparison**		**ProSoil**	
	Average	Std*	Average	Std	Average	Std	Average	Std	Average	Std	Average	Std	Average	Std	Average	Std
Diversity	40	16	47	17	39	10	52	18	41	7	40	10	31	10	54	14
Synergies	42	11	49	13	35	11	59	17	53	9	48	10	27	11	53	17
Recycling	48	11	64	10	40	14	59	14	26	7	28	11	36	23	55	21
Efficiency	44	11	55	8	37	7	62	13	56	9	59	12	44	21	61	14
Resilience	47	6	62	6	47	8	61	11	45	7	46	9	28	9	47	10
Culture and food traditions	56	6	61	10	62	10	75	12	48	11	56	15	40	12	60	11
Co-creation and sharing of knowledge	30	8	69	6	30	18	64	11	29	13	46	15	12	8	51	13
Human and social values	46	8	64	7	52	7	65	6	37	7	43	8	32	12	56	14
Circular and solidarity economy	46	9	64	10	53	9	69	9	46	10	55	13	27	13	53	10
Responsible governance	39	9	65	10	37	14	61	9	38	8	47	11	33	10	54	12
Total CAET score	44	6	60	6	43	7	63	8	42	3	47	6	31	8	54	10

*Std: Standard deviation; AE: agroecology; AEZ: Agroecological zone; AEZ 2: Cotton zone of north Benin; AEZ 3: Food-growing zone of south Borgou; AEZ 5: Cotton-growing zone of the Centre; AEZ 6: Agroecological zone of *barre* lands

Table 3. Correlation coefficients between the overall CAET score and the score of the 10 elements of agroecology

Elements of agroecology	Coefficient of correlation (ProSoil)	p-value (ProSoil)	Coefficient de correlation (Comparison group)	p-value (Comparison group)
Diversity	0.68	< 2.2 e-16	0.68	< 2.2 e-16
Synergies	0.68	< 2.2 e-16	0.57	5.933e-12
Efficiency	0.73	< 2.2e-16	0.55	6.75e-11
Recycling	0.46	8.58e-08	0.40	6.037e-06
Resilience	0.85	< 2.2e-16	0.86	< 2.2 e-16
Culture and food traditions	0.62	3.195e-14	0.55	4.959e-11
Co-creation and sharing of knowledge	0.71	< 2.2e-16	0.64	2.291e-15
Human and social values	0.79	< 2.2e-16	0.65	1.082e-15
Circular and solidarity economy	0.61	1.322e-13	0.75	< 2.2 e-16
Responsible governance	0.68	< 2.2 e-16	0.61	7.75e-14

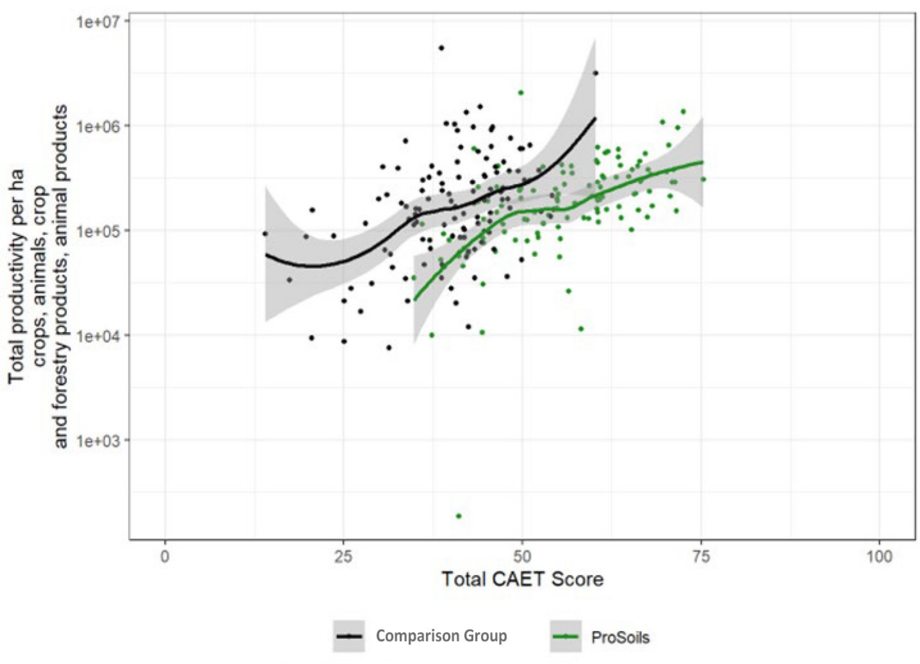

Figure 8. Relationship between CAET score and total agricultural productivity

The relationship between agroecological transition levels and total added value is positive and linear for the ProSoil group, while it tends to decrease for CAET scores of 40% to 55% for the Comparison group (Figure 9). This is mainly explained by the negative relationship between the CAET score and the value added per hectare and per person, when the CAET score is between 30% and 55%.

The relationship between agroecological transition levels and value added to gross value (VA/GVP) is positively linear for both ProSoil and Comparison group systems.

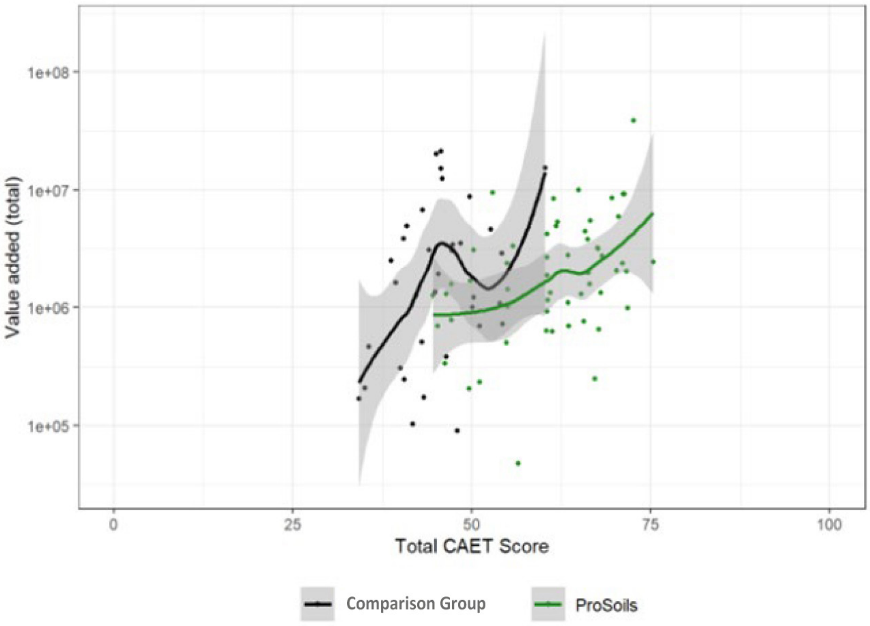

Figure 9. Relationship between CAET score and total value added

Net income from agropastoral activities

There is a positive linear relationship between the CAET score and income from the sale of crops and animals (Figure 10a), from agropastoral activities (Figure 10b) and from the sale of agroforestry products. When net income from the sale of crops, animals and pastoral activities increases, the total CAET score increases. This indicates, on the one hand, that the incomes of the producers surveyed come mainly from the sale of agricultural, animal and agroforestry products. On the other hand, it suggests that the increase in net income from agricultural activities broadly contributes to the achievement of agroecological transition, especially since the sale of these products is significantly higher in ProSoil systems than in Comparison group systems. Furthermore, agricultural income comes more from the sale of crops and animals than from the sale of agroforestry products. Indeed, the contribution of forest products to total income is seasonal for both the ProSoil group and the Comparison group, and very few households earn income from forest products. In addition, the sale of animal products is the most correlated with indicators of the agroecological transition, showing a positive and significant correlation coefficient of 0.57 with the CAET score of the Diversity indicator, 0.54 with the CAET score of Resilience, and 0.54 with the total CAET score.

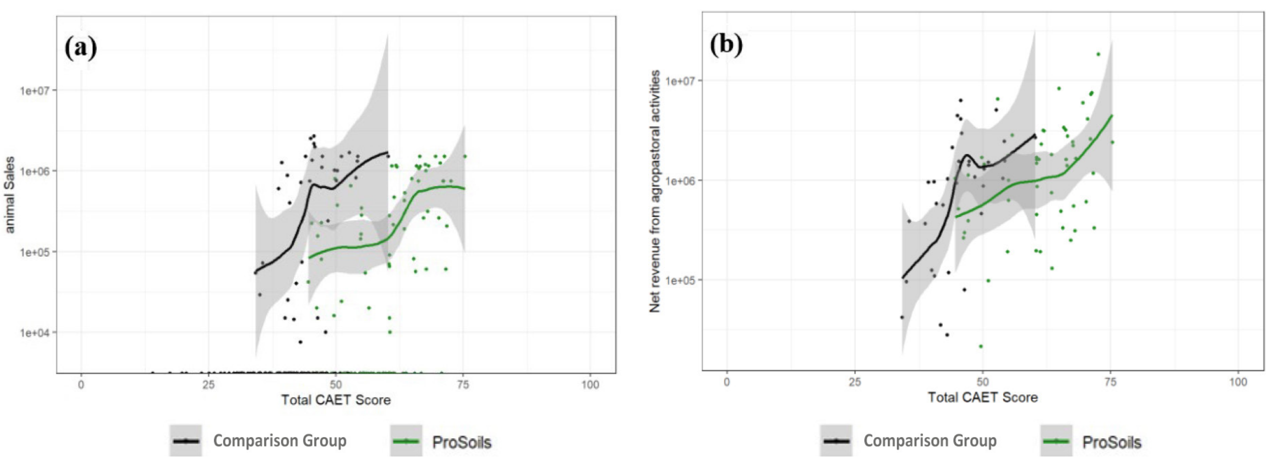

Figure 10. Relationship between total CAET score and (a) animal sales; and (b) net income from agropastoral activities

4.3.2 Environmental dimension

The environmental dimension was assessed using five indicators characterizing the performance criterion of agrobiodiversity and 11 indicators characterizing the soil health of production systems.

Agrobiodiversity

The relationship between the Gini-Simpson diversity index (GSI) of the animals and the CAET scores (Figure 11a) reveals that for the ProSoil group, the more this index increases, the more the total CAET score increases, up to a threshold of 65%, where this index begins to decline. This confirms that the diversity of animal species in the production system contributes positively to the agroecological transition of production systems. The average positive correlation coefficient (0.54) between the GSI index and the Diversity indicator further supports the positive relationship between this index and the total CAET score.

Unlike in the case of the animal diversity GSI, there is a positive relationship between the CAET score and the natural vegetation and pollinator diversity GSI for ProSoil agricultural exploitation (Figure 11b), having a CAET score of > 50%. But the correlation between these two indicators is very weak (0.03).

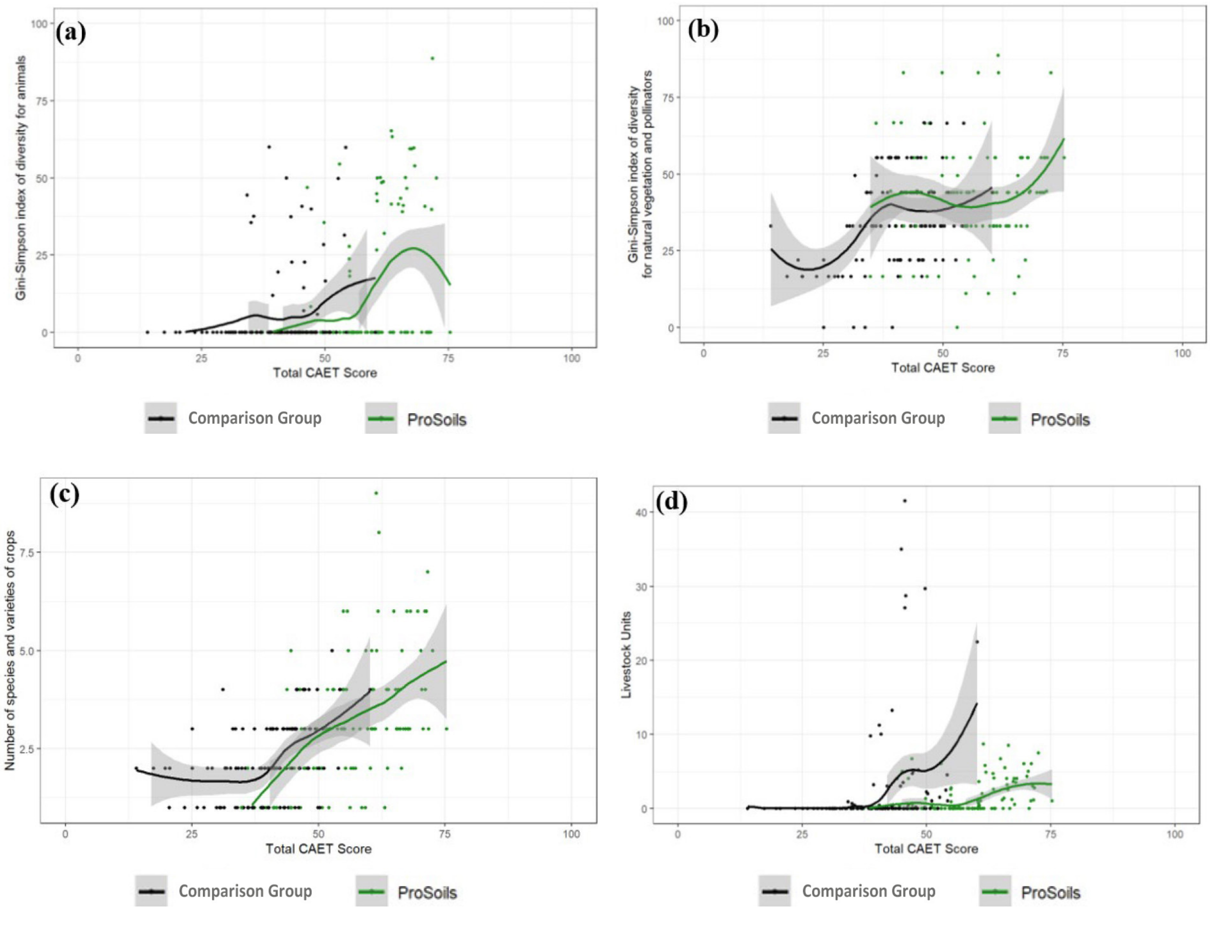

Figure 11. Relationship between the CAET score and: (a) the Gini-Simpson diversity index (GSI) of animals, (b) GSI of natural vegetation and pollinators, (c) the number of species and crop varieties, and (d) the number of breeding units, for the ProSoil and Comparison groups.

Soil health

There is a significant difference in the median value of the indicators of soil cover, soil erosion and the presence of microbial activity between the ProSoil and Comparison groups. However, this difference is not significant between the median value of the soil health index of the two groups.

For CAET scores of 62.5% to 75%, the total CAET score increases with increasing soil cover in ProSoil systems. This would indicate that soil cover is necessary for achieving the agroecological transition. The increase in the level of agroecological transition also goes hand in hand with the increase in the indicator of the presence of invertebrates in the soil. These organisms undoubtedly contribute to microbial activity and boost soil fertility. When we consider the soil health index, it tends to increase with CAET scores, up to a threshold of 60%, after which they remain stable for the ProSoil group (Figure 12). But there is no significant difference between the median soil health index values of the ProSoil and Comparison groups.

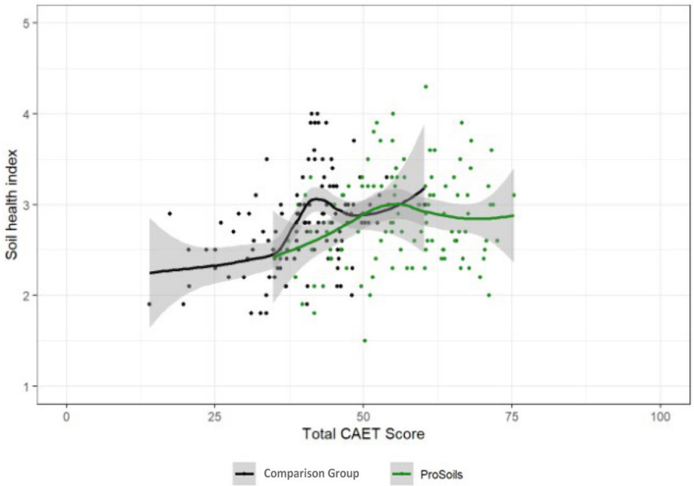

Figure 12. Relationship between CAET score and soil health index

4.3.3 Health and nutrition dimension

The health and nutrition dimension of sustainability was assessed by considering indicators of pesticide exposure – the quantity of chemical and organic pesticides used; the toxicity level of the pesticides used; the area of land on which pesticides are applied; the use of mitigation strategies; the implementation of practices for the ecological management of pests – and dietary diversity (number of food groups consumed, scale of experience of food insecurity, and expenditure for purchasing food).

The analysis shows that the quantity of chemical fertilizers, the number of mitigation strategies, ecological pest-management practices, and the integrated pest management score are the only indicators of pesticide exposure for which the median value in the ProSoil group is significantly higher than that in the Comparison group. In addition, the correlation coefficient is significantly positive between the number of ecological pest-management practices and the total CAET score (0.55), Resilience (0.60), Co-creation and sharing of knowledge (0.49), and Circular and solidarity economy (0.50). Thus, the agroecology elements Resilience, Co-creation and sharing of knowledge, and Circular and solidarity economy particularly contribute to the adoption of ecological practices for pest management, thereby reducing producers’ exposure to pesticides.

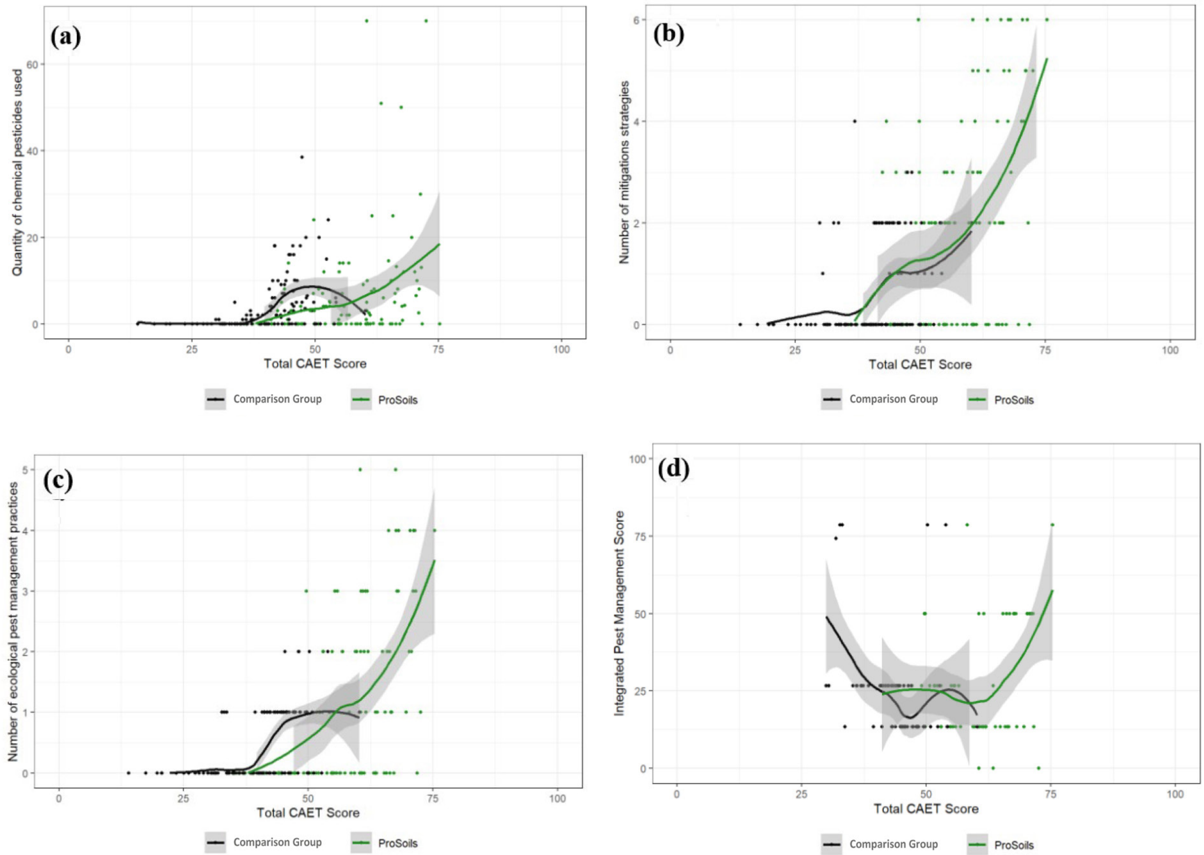

Figure 13. Relationship between CAET score and (a) quantity of chemical pesticides used, (b) number of mitigation strategies adopted, (c) number of ecological pest-management practices, and (d) integrated pest-management score

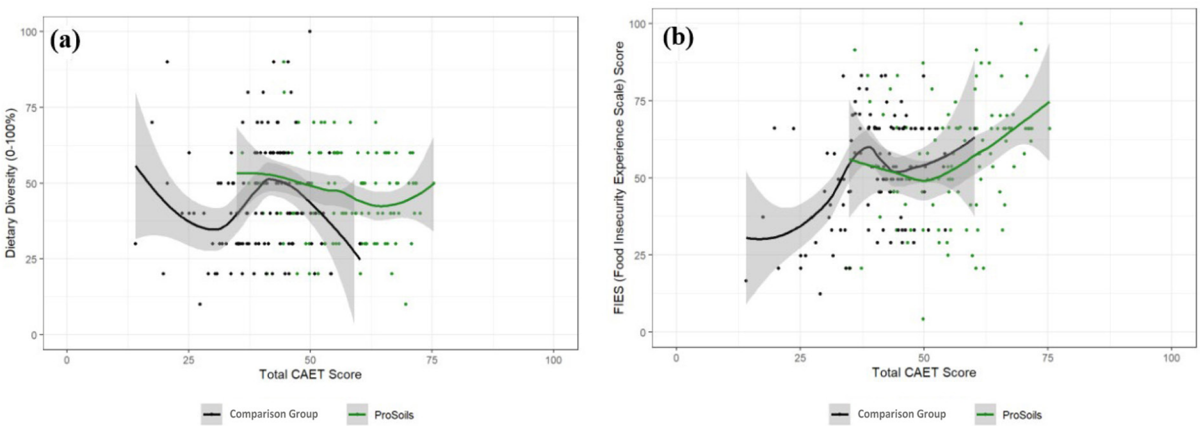

Figure 14. Relationship between CAET score and (a) dietary diversity score and (b) Food Insecurity Experience Scale (FIES)

Regarding food security and nutrition, it is interesting to note that higher CAET scores are positively correlated with reduced food insecurity but not with increased dietary diversity (Figure 14). Hence, while agroecology contributes to increased agrobiodiversity in this case study, this does not necessarily result in a more diversified diet. Further, the median value of the food insecurity experience scale (FIES) is significantly higher for households actively participating in ProSoil activities compared with the Comparison group (Figure 14b).

4.3.4 Social dimension

The assessment of the social dimension of sustainability was made based on indicators that made it possible to measure the empowerment of women and young people. Figure 15a shows that there is a near-stagnant relationship between the women's empowerment score and the total CAET score for systems in the ProSoil group, while this relationship is positive for Comparison group systems with a lower CAET score of 30%, and negative for Comparison group systems having a CAET score greater than around 40%. Additionally, there is a significant difference between the median values of women's empowerment scores of the ProSoil and Comparison groups. Women's empowerment has therefore contributed to the agroecological transition of ProSoil systems compared with Comparison group systems.

As for the youth empowerment criterion, the analysis demonstrates that the average value of the youth employability score for the ProSoil systems does not differ from the score for the Comparison group (Figure 15b). The employability of young people does not seem to have contributed to the agroecological performance of ProSoil systems.

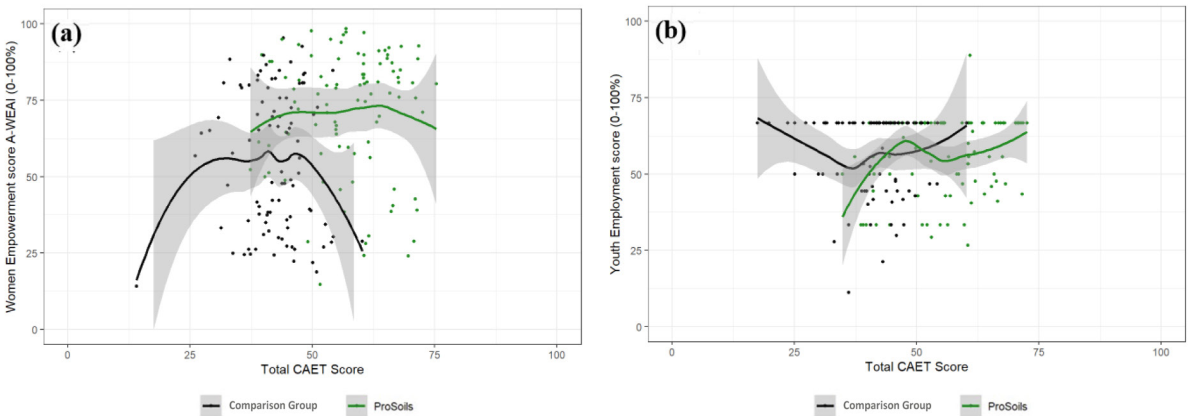

Figure 15. Relationship between the CAET score and (a) the women's empowerment score; and (b) the overall youth empowerment score

4.3.5 Governance dimension

The analysis of Table 1 revealed that the transition towards agroecological systems can be compromised due to the lack of adequate documents to secure the land. A third of the ProSoil beneficiaries (40 out of 120 households) have their farm in agroecological transition (Table 4). Only 10.83 % of the beneficiaries hold the title deed, the certificate of customary tenure, the certificate of occupancy, or are registered with a certificate of hereditary acquisition. The remaining 22.5 % asserted that they inherited the land without title, which may compromise their ownership of the land.

These results indicate that there is a need to provide incentives for the long-term investments that are necessary to protect soil, biodiversity and ecosystem services, while increasing resilience to system stressors on the land of the beneficiaries. Fortunately, the land tenure issue has been addressed by ProSoil since the beginning of the project, and this indirectly plays a key role in the record number of beneficiaries who have at least one document that attests to their ownership of the land. This effort needs to be strengthened to continue increasing the number of beneficiaries with land tenure documentation.

Table 4. Characterization of agroecological transition and land security

	Title deed		**Certificate of customary tenure**		**Certificate of occupancy**		**Registered will or registered certificate of hereditary acquisition**	
	Comparison group	ProSoil	Comparison group	ProSoil	Comparison group	ProSoil	Comparison group	ProSoil
< 50%	10.83	3.33	22.50	4.17	0.83		3.33	6.67
50%–60%		3.33	3.33	7.50				3.33
60%–70%		4.17	0.83	0.83		0.83		5.00
> 70%		2.50		2.50		0.83		

	Registered certificate of perpetual / long-term lease		**Registered rental contract**		**Secure mobility corridor**		**Others**	
	Comparison group	ProSoil	Comparison group	ProSoil	Comparison group	ProSoil	Comparison group	ProSoil
< 50%							54.17	15.00
50%–60%							4.17	15.00
60%–70%								22.50
> 70%								2.50

5 Soil properties at the farm/ household level

5.1 Topsoil properties at the farm/household level

The pattern analysis of the topsoil properties globally (for the whole set of samples) shows the low level of soil organic carbon (SOC) in the topsoil and asserts the overuse of agricultural land in the targeted communes.

On the other hand, SOC may be increased at the farm level of the ProSoil project since the CAET shows that the beneficiary farmers are moving towards agroecological transition.

Table 5. Topsoil summary statistics

Statistic	N	Min	Pctl(25)	Median	Mean	Pctl(75)	Max	St. Dev.	Interpretation based on the median
pH (-)	240	5.31	6.15	6.46	6.51	6.8	8.92	0.55	Moderately Acidic
SOC (%)	240	0.05	0.38	0.54	0.66	0.78	3.06	0.42	Very Low
TN (%)	240	0.02	0.04	0.04	0.06	0.06	0.21	0.03	Very Low
m3.Al (mg/kg)	240	271.89	443.89	535.82	544.3	615.19	953.82	134.34	Very High
m3.B (mg/kg)	240	0.07	0.16	0.24	0.33	0.37	2.32	0.29	Very Low
m3.Ca (mg/kg)	240	3.12	313.23	587.93	895.49	1,076.62	7,508.28	1,029.98	Optimum
m3.Fe (mg/kg)	240	40.09	82.35	105.7	108.84	130.86	220.33	33.41	Very High
m3.K (mg/kg)	240	4.24	41.08	65.26	74.55	92.71	327.22	51.5	Very Low
m3.Mg (mg/kg)	240	16.56	78.01	115.15	143.38	159.12	767.06	112.98	Very High
m3.Mn (mg/kg)	240	2.61	96.7	127.02	136.4	171.74	378.62	60.37	Optimum
ExAc (cmolc/kg)	240	0.17	0.22	0.25	0.26	0.28	0.62	0.06	Very Low
PSI (-)	240	19.98	31.9	40.83	41.7	48.84	109.06	13.29	Optimum
CEC cmolc/kg	240	2.27	4.15	5.37	7.37	8.98	34.23	5.12	Very Low
Clay (%)	240	11.96	20.86	24.59	26.16	30.5	55.62	7.85	Optimum
Silt (%)	240	0.76	15.16	18.1	17.92	20.87	30.84	4.68	Moderately Low
Sand (%)	240	23.41	48.91	56.54	55.92	63.43	82.62	10.9	Moderately Low

5.2 Subsoil properties at the farm/household level

The SOC on the subsoil follows the same trend as in the topsoil (Table 6).

Table 6. Subsoil summary statistics

Statistic	N	Min	Pctl(25)	Median	Mean	Pctl(75)	Max	St. Dev.	Interpretation based on the median
pH (-)	240	4.93	5.96	6.31	6.34	6.69	8.18	0.53	Moderately Acidic
SOC (%)	240	0.06	0.3	0.44	0.52	0.66	1.79	0.3	Very Low
TN (%)	240	0.02	0.03	0.04	0.05	0.06	0.15	0.02	Very Low
m3.Al (mg/kg)	240	339.49	505.32	609.98	633.34	737.66	1,106.79	162.8	Very High
m3.B (mg/kg)	240	0.02	0.14	0.2	0.26	0.31	1.33	0.19	Very Low
m3.Ca (mg/kg)	240	0.22	253.47	483.45	735.75	906.4	5,059.01	760.65	Moderately Low
m3.Fe (mg/kg)	240	7.03	72.66	95.08	97.81	115.84	228.75	34.64	Very High
m3.K (mg/kg)	240	2.6	44.9	66.7	71.84	90.05	325.6	41.38	Very Low
m3.Mg (mg/kg)	240	38.33	87.86	121.3	158.11	178.52	977.83	120.64	Very High
m3.Mn (mg/kg)	240	22.51	102.92	129.77	148.36	178.62	403.6	69.61	Optimum
ExAc (cmolc/kg)	240	0.15	0.23	0.26	0.28	0.31	0.6	0.07	Very Low
PSI (-)	240	23.74	38.98	47.5	51.89	62.59	112.59	17.11	Optimum
CEC cmolc/kg	240	2.7	4.36	5.81	7.69	8.74	26.09	5.08	Very Low
Clay (%)	240	13.53	25.08	30.78	32.26	39.11	66.37	9.96	Moderately High
Silt (%)	240	7.49	15.49	17.87	17.78	20.62	29.36	3.87	Moderately Low
Sand (%)	240	16.89	41.5	51.21	49.95	57.89	75	11.55	Moderately Low

6 Descriptive statistics for assessing elements of soil fertility across the farms of ProSoil and comparison groups

A soil sample of the target sites comprises the soils from the farms of ProSoil beneficiaries and from the farms of the control group. The soil samples collected from these farms are the best way to test whether agroecological practices can provide a range of elements to plants (Table 7). A soil test is a chemical method of estimating the capacity of the soil to supply nutrients. The technologies used for the soil sample analysis have helped determine what nutrients are in the soil. The descriptive statistics of Table 7 provide the key elements of the soils.

Table 7. Descriptive statistics for the key elements of soil fertility at farm level

Measure	Group	Mean	Median	Standard Deviation	Interquartile range (IQR)	T-test result (p-value)
CEC.cmolc/kg	Comparison	8.4	5.3	6.5	4.0 - 11.5	0.003
	ProSoil	6.9	5.8	3.5	4.4 - 8.3	
ExAc.(cmolc/kg)	Comparison	0.3	0.2	0.1	0.2 - 0.3	0.658
	ProSoil	0.3	0.2	0.1	0.2 - 0.3	
PSI.(-)	Comparison	46.5	42.5	17.8	34.5 - 54.9	0.935
	ProSoil	46.7	44.2	15.2	36.2 - 55.6	
SOC.(%)	Comparison	0.6	0.5	0.4	0.3 - 0.7	0.650
	ProSoil	0.6	0.5	0.3	0.3 - 0.7	
TN.(%)	Comparison	0.1	0.0	0.0	0.0 - 0.1	0.833
	ProSoil	0.1	0.0	0.0	0.0 - 0.1	
m3.Al.(mg/kg)	Comparison	585.5	558.6	169.0	458.9 - 683.3	0.860
	ProSoil	588.2	567.7	143.7	484.7 - 667.4	
m3.B.(mg/kg)	Comparison	0.3	0.2	0.3	0.2 - 0.4	0.003
	ProSoil	0.3	0.2	0.2	0.1 - 0.3	
m3.Ca.(mg/kg)	Comparison	976.7	486.0	1,264.5	234.4 - 1178.7	0.006
	ProSoil	708.8	585.1	499.6	370.8 - 908.6	
m3.Fe.(mg/kg)	Comparison	107.3	106.5	37.8	77.8 - 131.4	0.044
	ProSoil	100.5	97.0	32.2	79.1 - 117.0	

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Table 7. Continued

Measure	Group	Mean	Median	Standard Deviation	Interquartile range (IQR)	T-test result (p-value)
m3.K.(mg/kg)	Comparison	84.0	72.8	54.5	46.6 - 108.4	0.000
	ProSoil	67.0	61.8	39.8	42.4 - 86.0	
m3.Mg.(mg/kg)	Comparison	178.0	119.6	154.9	87.1 - 211.5	0.000
	ProSoil	132.2	120.3	73.1	83.5 - 155.6	
m3.Mn.(mg/kg)	Comparison	143.0	132.6	60.1	101.1 - 172.5	0.016
	ProSoil	129.1	117.9	58.9	91.5 - 155.4	
pH.(-)	Comparison	6.5	6.4	0.6	6.1 - 6.8	0.044
	ProSoil	6.4	6.4	0.5	6.0 - 6.7	

7 Correlation between CAET score and soil indicators

The CAET scores and the soil cover show a strong relationship with a CAET score higher than 65%, confirming that agroecological practices contribute to high soil cover on the farms that are in transition or are already agroecological.

In the same order, soil erosion – which is a severe degradation problem that endangers the achievement of Sustainable Development Goals – has been estimated. The findings show a strong decrease of the soil erosion index while the CAET score increases, demonstrating the key role of agroecological practices in limiting erosion, which affects agricultural production by reducing soil fertility via topsoil translocation, leading to soil quality deterioration (Figure 16b).

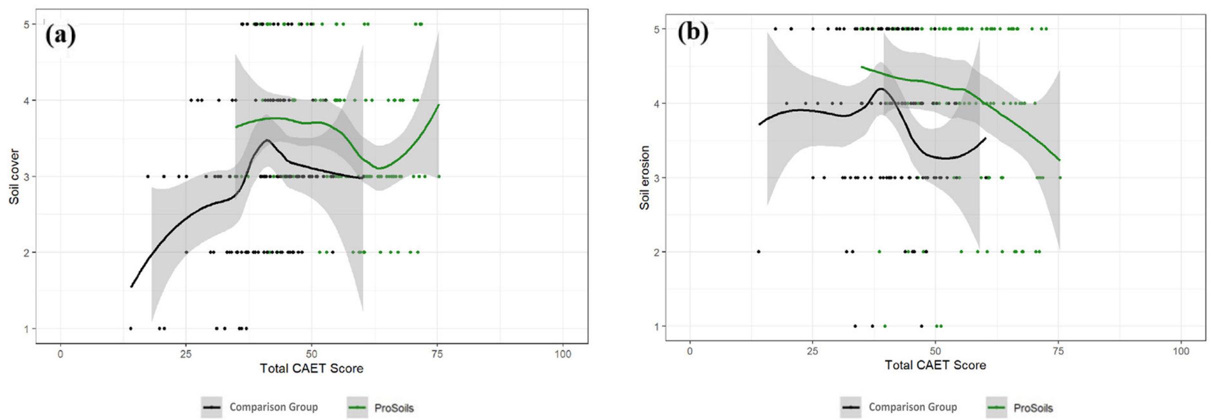

Figure 16. Relationship between CAET score and the soil cover (a), and soil erosion (b)

8 Conclusions

The use of CAET for the assessment of levels of agroecological transition made it possible to identify the agroecological elements that offer more opportunities for a complete transition, and the elements for which more in-depth studies should be carried out.

The major lessons to be learned after using the CAET:

- Analysis of the average total CAET score revealed that the ProSoil group is in transition (with a score of 56%) while the Comparison group is not agroecological (score of 40%).
- Only the ProSoil systems of the commune of Sinendé in the department of Borgou (CAET score = 62.7%) and the commune of Kandi in the department of Alibori (CAET score = 60%) can be considered as in transition towards agroecology.
- Overall, the difference in the overall CAET score between the ProSoil and Comparison groups was greater for the elements Efficiency, Recycling, Co-creation and sharing of knowledge, and Synergies. This implies that these dimensions are very sensitive and determinative in the transition to agroecology.
- The scores for the Diversity and Synergies elements were less than 50%, demonstrating low diversity of plant and animal products. Low diversity of agricultural products is associated with low synergy between crops and livestock and low resilience.
- The elements of Culture and food tradition, Co-creation and sharing of knowledge, Human and social values, and Circular and solidarity economy of ProSoil systems are in emerging transition towards agroecology. More than 70% of households are characterized by medium-term food sufficiency, but also by insufficient dietary diversity. These households have a sound knowledge of good nutritional practices, but do not always apply them.
- Knowledge about good traditional food practices is not sufficiently preserved and promoted from generation to generation.
- More than 20% of producers are still unaware of agroecological principles or do not have confidence in these principles, thereby limiting the adoption of agroecological practices even though they are known to producers.
- Platforms or functional mechanisms for the co-creation and sharing of knowledge are almost absent, thereby limiting efforts aimed at agroecological transition.
- Women's empowerment is hampered because women do not have access to productive resources and are not part of fully functional women's associations.
- Around 40% of producers have limited access to capital and decision-making processes.
- The economy is characterized by local marketing of agricultural products and/or services (35%), limited relationships between producers and consumers (20%), as well as existing but poorly operational and partially inclusive producer networks.
- Production practices that increase efficiency, strengthen resilience and enhance human and social values in ProSoil systems, compared with Comparison group systems, would most favour agroecological transitions.
- The economic performance of ProSoil systems was boosted most by the total value of livestock production, and the sale of crops and animals. An increase in the total value of livestock production induces an increase in the CAET diversity score, which would improve resilience and synergies.

- In the environmental dimension, the level of agroecological transition tends to increase with soil cover; the presence of invertebrates in the soil; microbial activity; and soil health. Agricultural practices favouring soil cover reduce the evaporation of soil water and create soil humidity and temperature conditions favourable to microbial activity. All these factors contribute to soil fertility, which will increase agricultural productivity.
- From the analysis of the performance of the health and nutrition dimension, we can conclude that the implementation of pest-mitigation and ecological-management strategies increases the total CAET score of agricultural exploitation and above all contributes to resilience, the co-creation and sharing of knowledge, and the circular and solidarity economy.
- In the social dimension, it was noted that women's empowerment contributed more to the agroecological transition of ProSoil systems, compared with Comparison group systems. Therefore, the actions already taken in this direction should be reinforced.

9 Recommendations

Based on the lessons learned, the following recommendations can be made:

- Overall, several efforts have been made to boost agroecological transitions in ProSoil systems. However, these efforts should be strengthened to achieve a complete transition so that the systems are closer to an agroecological system model.
- Producers should benefit from more institutional support for social integration and access to production inputs, in order to create favourable conditions for the practice of various income-generating activities. For example, capacity building for producer associations targeting the production of NTFPs could increase opportunities to diversify agricultural products.
- Emphasis should be placed on the agroecological practice elements of Efficiency, Recycling, Co-creation and sharing of knowledge; and Synergies to strengthen production systems.
- Generally speaking, efforts still need to be made to consolidate and preserve the local and traditional food heritage.
- More approaches to demonstrating the positive impacts of agroecological practices – through field schools, for example – could be adopted to involve producers.
- Improving the overall level of agroecological transition would be conditioned, among other things, by:
  - promoting mechanisms to reduce vulnerability and improve the capacity of agricultural exploitation to adapt to environmental risks, including climate change.
  - increasing agricultural diversity, which also contributes to resilience.
  - efficient practices for managing soil fertility and pests.
  - increasing productivity and meeting the needs of agricultural households.
  - strengthening the capacities of women and improving working conditions.
  - reducing social inequalities.
- The levels of agroecological transition could also be improved by implementing strategies aimed at promoting diversity (cultural, animal, natural vegetation); the resilience of species and crop varieties against environmental risks; and the co-creation and sharing of knowledge about agroecological practices aimed at protecting plants and biodiversity.
- Integrated pest management should be promoted to boost agroecological transitions.
- Strengthen women's empowerment to boost agroecological transitions in ProSoil production systems.

Key recommendations and suggestions of the participants from the validation workshop:

- Make available all materials that are useful for TAPE application.
- Build technical capacity of various actors to use TAPE.
- The GIZ team should follow up and promote collaboration to provide strong backup for statistical agriculture.
- Carry out analysis of economic performance and provide more explanation of how agroecological practices have a positive impact on the local economy.
- TAPE did not present carbon sequestration as a crucial aspect relevant to the country's international commitments. There is a need to consider this perspective when conducting the project in Benin since more actions have been taken with respect to tree planting and other agroecological practices.

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Annex

Annex 1. Sustainability measurement indicators in TAPE Step 2 – by performance criterion and sustainability dimensions

Dimensions of sustainability	10 core criteria of performance	Measurement indicators in standard version of TAPE Step 2
Governance	Secure land tenure	Existence of legal or traditional recognition of land
		Existence of legal or traditional recognition of mobility for pastoral people
		Perception of secure access to land (or secure mobility)
		Right to sell / inherit / bequeath land
Economy	Productivity	Quantity of crop and forestry products produced
		Quantity of animals and livestock products produced
		Monetary value of agropastoral production
		Gross value of agricultural production (per ha, per person)
	Value added	Total expenditures for purchase of seeds, fertilizers, pesticides, machinery
		Total expenditures for the purchase of livestock
		Value added (per ha, per person)
		Value added on gross value of production (VA/GVP)
	Income	Revenue derived from crop and forestry products
		Revenue derived from animals and livestock products
		Revenue derived from other activities
		Financial expenditures
		Net revenue from agropastoral activities per person and per household
		Net revenue from agropastoral activities after taxes and subsidies per person and per household
		% of revenue derived from crops and livestock
		% of people below the poverty level
		Depreciation
		Expenditures for wages

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Annex 1. Continued

Dimensions of sustainability	10 core criteria of performance	Measurement indicators in standard version of TAPE Step 2
Environment	Agrobiodiversity	Gini-Simpson index of diversity for crops
		Gini-Simpson index of diversity for animals
		Index of diversity for natural vegetation and pollinators
		Number of species and varieties/breeds of crops and animals
		Livestock Unit
	Soil health	10 indicators of soil health (structure, compaction, depth of superficial soil, status of residues, colour and odour, presence of organic matter, water retention, soil cover, soil erosion, and microbiological activity)
Health and nutrition	Exposure to pesticides	Quantity of chemical pesticides used
		Quantity of organic pesticides used
		Level of toxicity of the pesticides used
		Area of use of pesticides
		Use of mitigation strategies when applying pesticides
		Implementation of practices for the ecological management of pests
	Dietary diversity (and food security)	Number of food groups consumed
		Food Insecurity Experience Scale (FIES)
		Expenditures for purchase of food per capita
Social	Women's empowerment	Production decisions, decisions on income, perception of decision making, leadership, time use, access to credit for both men and women
		Gender Parity Index
		% of women living and working on the farm
		All social indicators disaggregated by gender
	Youth empowerment	Youth employment opportunities
		Youth emigration and willingness to emigrate or work in agriculture
		% of youth living and working on the farm
	Others	Number and composition of the household
		% of the family employed on farm
		% of children working on farm

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The Measuring Agroecology and its Performance (MAP) project is a collaboration to generate evidence of how agroecology can contribute to societal goals. The project assessed the performance of agroecology in Alibori, Borgou, Collines and Zou Departments (Kandi, Sinendé, Bantè and Za-Kpota) in Benin, which have been part of the GIZ global project, Soil Protection and Rehabilitation for Food Security' (ProSoil), since 2015. For this purpose, the Tool for Agroecology Performance Evaluation (TAPE), as well as the Land Degradation Surveillance Framework (LDSF) were applied on 120 farms that participated in the global project, and on 120 non-participating farms as a control group.

Key findings show that 54% of participating farms used two to three crop varieties on their land, while less than 40% of the control group adopted multiple varieties. Households actively involved in ProSoil activities have a significantly higher overall CAET score (56%) than those in the control group (40%). There is a positive and linear relationship between agroecological transition levels and the total value of agricultural products in the ProSoil group. There is also a strong relationship between the Gini-Simpson diversity index for livestock versus the CAET scores for the ProSoil group. The transition to an agroecological system can be compromised by a lack of adequate documents to secure the land being used.

In summary, programmes supporting sustainable farming practices like ProSoil can enhance agroecological integration. Alongside strong support of policymakers, such programmes help improve economic, environmental and social outcomes. Indeed, the study site should increase agroecological practices to consolidate progress.

About the Agroecology TPP

The Agroecology TPP convenes a broad group of scientists, practitioners and policymakers working together to accelerate agroecological transitions. Since its official launch on 3 June 2021, the TPP has begun addressing knowledge gaps across eight domains that will support various institutions and advocacy groups in key decision-making processes. Its online COMMUNITIES are open to all, providing spaces for members to co-create knowledge, share insights and experiences on various agroecological themes, building collaborative networks with local communities and research bodies to drive agroecological progress for food systems transformation.