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Biodiversity and Food Diversity of Farms Using Agroecology in Benin Cotton Areas

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Abstract

Farms biodiversity and food diversity of agricultural households are evaluated to understand some agroecology effects on cotton farms. This is a part of socio-economic analysis of the agroecological transition underway in cotton zones of Benin. The surveys covered 509 farmers in 5 municipalities: Banikoara, Kandi, Ouassa-Pèhunco, Parakou and Savalou. Data collected are crops diversity, livestock diversity, natural vegetation, trees and pollinators of each farm and the various food consumed within 24 hours before the survey on each farm. Scores obtained by farm on each criterion were used to calculate the farm biodiversity index and household food diversity index; and the averages by type. Student's Chi--square test and Kruskal Wallis multiple comparison test were used to compare index averages, to analyze difference between farm types according to their "Test" or "Control" status. Analysis based on "Tool Agroecology Performance Evaluation (TAPE)" method shows that surveyed farms are unsustainable (biodiversity index <50%) regardless of status, except farms of type 5 Test which have a better result and significantly different from the Controls. But their diet remains acceptable (5≥food diversity index<7); difference observed on most types except 1 and 4. This means that agroecology is not yet bearing full fruit in the study areas and that farming households are still vulnerable to food insecurity. However, there are clear differences between the types of farms and differences between individuals of the same type. These few disparities observed highlight the potential of agroecology to improve households' food situation if the process is intensified.

Keywords: agroecology, biodiversity, food diversity, TAPE tool, crop diversity, animal diversity

1. Introduction

The second United Nations Sustainable Development Goal (SDG 2) is to end hunger, achieve food security, improve nutrition and promote sustainable agriculture by 2030 (United Nations (UN), 2017). However, the proportion of the undernourished population has increased from 10.4% in 2006 to 15.1% in 2017 (West and Central African Council for Agricultural Research and Development (CORAF), 2021). In Benin, data from the National Institute of Statistics and Economic Analysis (INSAE, 2017) show that 14.1% of households still have inadequate food consumption regarding frequency and food diversity. Rural households are the most affected by this phenomenon of food and nutritional insecurity; however, food occurs in rural areas. Therefore, the situation targeted by SDG 2 remains intact in West Africa.

According to the regional agricultural policy document of the Community of West African States (CEDEAO, 2015), one of food insecurity causes in West Africa is the liberalization of the agricultural sector under structural adjustment, which has not provided this sector with the support that can enable it to ensure populations food security.The same source indicates that the low productivity that characterizes the sub-region's agricultural sector, linked to severe environmental constraints, makes it impossible to resolve the food security concern. Solving this problem, therefore, involves supporting the agricultural sector and improving agricultural productivity.

To address the food security challenge, Berton, Billaz, Burger & Lebreton (2013) think that it is necessary to make a profound transformation of production methods and move towards a sustainable approach that seeks to maintain or restore soil fertility. This transformation no longer be a simple adaptation of productivity models of the green revolution to reduce their ecological impact but also a profound reform of food systems as a whole

(Dury, Bendjebbar, Hainzelin, Giordano & Bricas, 2019).

An honor point must be on diversifying agricultural production. Indeed, FAO (2019) states that biodiversity is necessary to produce enough nutritious food in a world characterized by climate change, an ever-growing population and changing diets. Gaillard, Verger, Dury, Dop & El Ati (2022) support this FAO statement. According to those authors, there are systematic positive correlations between farm production diversity and diet diversity. Enhancing agricultural production diversity to contribute to food diversity requires adopting agricultural practices that promote agricultural diversification. This calls for agroecological practices, which are essentially based on using biodiversity and ecosystem services for agricultural production (Hainzelin, 2015 in FAO, 2015). Indeed, agroecology is an integrated approach that contemporarily applies ecological and social concepts and principles to designing and managing food and agricultural systems (FAO, 2018). Other beneficial ecosystem services derived from the biodiversity generated by agroecology are mentioned in the literature: air nitrogen fixed by nodule species such as Gliricidia present in coffee plantations under agroecological management; additional savings made by farms under agro-ecological management due to ecosystem services as biodiversity; etc. (Lanka, Khadaroo et Böhm, 2017).

Basically, agroecology aims to generalize agricultural and food production methods that make food and nutritional security compatible, to address environmental emergencies and reduce development inequalities between countries and people (Temple & Sourisseau, 2019). One of agroecology principles is that ecological knowledge can be combined with local culture and agricultural experience inherent in traditional agricultural production systems (FAO, 2015). It seems clear that agro-biodiversity, i.e. the diversity of crops and livestock, food and nutrition security, are key indicators in a transition process to agroecology.

Since 2017, Benin has been engaged in agro-ecological transition project to gradually reach all production systems in the country's cotton zones (MAEP, 2020). After five years of agro-ecology project implementation in some pioneer municipalities, this study is to assess the production diversity (crops and livestock) and its link with the level of food diversity in the agricultural households involved.

2. Materials and Methods

2.1 Study Area

There are 51 municipalities in the cotton areas of Benin (MAEP, 2020). However, the municipalities selected for data collection for this study are Banikoara; Kandi; Ouassa-Péhunco; Parakou; and Savalou. These municipalities were selected for having served as pioneer areas for supporting agroecological transition in cotton areas of Benin since 2017.

Municipalities of Banikoara and Kandi are located in the Northern-East Sudanese agro-climatic zone MAEP (2018). They are characterized by tropical ferruginous soil and a dry climate with a single rain season of 5 to 6 months. The annual rainfall average is between 700 and 1100 mm. The dominant crops in that area are cotton and maize. It also has a large herd of cattle, sheep, goats and poultry. The municipality of Ouassa Péhunco is located in Sudanian agro-climatic zone of the North-West. It is characterized by a single rain season and an annual average of 700 to 900 mm. It constitutes a sliding zone of livestock and cotton farming. The municipalities of Parakou and N'Dali are located in the Sudanese agro-climatic zone of the Center-Northern. They are characterized by a rainy season with an annual average of 1200 mm. There is a strong presence of yam and soybean crops with a little cotton. Finally, Savalou municipality is located in the southern Sudano-Guinean agro-climatic zone. It is characterized by two rainy seasons and an annual average of 1400 mm. Cotton crop is practiced on small lands, alongside cassava, maize and cowpea.

Figure 1. Geographical location of TAZCO municipalities in Benin

Source: Survey, 2021

2.2 Materials

The following data were collected : types of farms; crops on the different plots of the farm; animals raised; natural vegetation around the farm, presence of trees and bees (pollinators); beneficiary status or not of the project for agro-ecological transition support in the cotton areas of Benin (TAZCO); foods consumed in the last 24 hours.

The collection tools used were essentially digitalized questionnaires on the KoboCollect application, smartphones, interviews and observations. Control producers were randomly drawn from the 2019 cotton producers' database of interprofessional cotton association (AIC) of Benin.

Types of producers encountered in the study area are five and are described in Table 1.

Table 1. Descriptive summary of farm types in cotton areas of Benin

Types	Age	Household size	Land Capital(ha)	Annual cultivated field (ha)	Cotton part (%)	Average income (FCFA)	Food expenditure (FCFA)
Type 1: Cotton farms of agro-pastoralists	44	13	14.3	10.44	39	1 531 907	1 144 444
Type 2: Cotton farms of smallproducers	40	9	10.4	7.2	55.8	737 420	1 696 105
Type 3: Cotton farms of middle Producers	41	28	14.2	8.9	43.8	2 281 108	2 179 625
Type 4: Cotton farms of wide Producers	46	15	19.6	15.2	41.5	6 185 662	1 440 460
Type 5: Mechanized cotton Farms	42	12	9.,7	5.4	62	1 601 579	1 591 520

Source: Surveyed, 2021

2.3 Methods and techniques

- ✓ ***Sampling***

The sampling method considers the involvement of the farms surveyed in the TAZCO implementation since 2017. Those involved constitute the group of Tests and the others, the group of Controls.

All 300 producers involved in the project (Tests) were surveyed. To have parity in the overall sample, 300Controls were selected: hence the sample size of 600 farm managers. But during the survey, a total of 509 available farm heads were reached out of 600 planned, including 32 women. The sampling was therefore based on two approaches: the full consideration of Test farm managers and random selection of Control farm managers from a list of producers from villages other than those of the Tests within a radius of more than 5 km. The annual averages of the Controls are similar to those of the Tests. Table 1 shows the distribution of farm managers surveyed.

Table 2. Number of respondents by the municipality and by gender

Municipalities	Tests			Controls			TOTAL
	Men	Women	Total 1	Men	Women	Total 2	
BANIKOARA	48	2	50	62	1	63	113
KANDI	47	3	50	52	0	52	102
PARAKOU	51	0	51	38	0	38	89
PEHUNCO	41	3	44	56	3	59	103
SAVALOU	39	10	49	43	10	53	102
TOTAL	226	18	244	251	14	265	509

Source: Survey, 2021

Test farms surveyed represent approximately 48% of the total sample against 52% for the controls. Women's farms make up 7% of the Test sample against a proportion of 5% in the Control sample. This sample satisfies the objective of parity between test and control and includes both men's and women's farms.

- ✓ ***Analysis***

"Tools agroecology performance evaluation (TAPE)" of FAO (2021) which is based on several indicators, including farm biodiversity and agricultural household food diversity. This method has been used by Bicksler, Mottet, Lucantoni & De Rosa (2020) and Mottet et al. (2020) to assess agroecology. It is adopted in this study to assess the biodiversity and food diversity indicators of farms engaged in agroecology in cotton areas of Benin. Data collected were put into a matrix in Excel 2013. Then the various calculations of sum, square sum and average, as well as the tests of equality of the averages between test and control types, were performed in Stata/SE 14.0.

Farms' biodiversity

The evaluation method consists of counting the species and varieties cultivated, listing the relative areas occupied, and the species and animal breeds in each farm surveyed. Then, the Gini-Simpson index of crop and animal diversity is calculated. The expression of this index is as follows:

$$1 - D = 1 - \sum P_i^2$$

With: Pi, the proportion of species I in crops or animals on the farm, i.e. the number of species I counted out of the total number for all species; D, the diversity of the exploitation, which is the square sum of the proportions of species Pi. That means D=∑Pi2.

The calculation is made separately for plants and animals. Those results are then combined by an index that measures natural vegetation and the presence of pollinators determined by the average of the importance (scores between 0 and 1) of beekeeping; of production land covered by plants; and of pollinators' presence of the farm survey. It is determined according to the grid in table 3.

Table 3. Evaluation grid for the “Natural vegetation, trees and pollinators” index

Indicator	Response	Score
Beekeeping	No	0
	Yes, wild	0.5
	Yes, breeding	1
Productive land covered with naturalvegetation	Absent	0
	Small	0.25
	Medium	0.5
	Important	0.75
	Abundant	1
Presence of pollinators and auxiliaryanimals	Absence	0
	Weak	0.33
	Important	0.66
	Abundant	1

Source: FAO, 2021

The farm's "Natural vegetation, trees and pollinators" index is obtained by calculating the average of the scores collected for the indicators in the grid. The averages of both Gini-Simpson index relating to crops and animals and of the third index are used to assess agricultural farm’s biodiversity criterion. It expression is as follows:

$$Biodiversity\ of\ T(i) = \frac{\sum(1-\mathrm{D})/\mathrm{ni(Plant)} + \sum(1-\mathrm{D})/\mathrm{ni(Animal)} + \sum\mathrm{Index\ of\ Natvege/ni}}{3}$$

with Ti: type of farm surveyed.

The results obtained by type of producer surveyed were compared between Test and Control types.

Farms food diversity

The Dietary Diversity Index is a qualitative measure of food consumption that captures the variety of foods available to households and is also an approximate measure of dietary adequacy at the individual level (FAO, 2021). To determine this index, the TAPE model recommends 10 food groups consumed 24 hours before the survey. Foods consumed by producers were classified according to these food groups. The list of foods cited by respondents is as follows: maize; rice ; sorghum; Tubers (roots, tubers and plantains); cowpea; oil; protein (meat, fish and eggs); fruits and vegetables (pulses, nuts and seeds, dark green leafy vegetables, other fruits and vegetables rich in vitamin A, other vegetables, and other fruits). The dietary diversity index should be calculated by simply counting the number of foods consumed by the farm household surveyed during the period indicated out of the ten groups. By the way, the number of foods cited by respondents (08) is less than the ten recommended by TAPE model; the calculation of this indicator consisted of determining the proportion of the number of foods consumed in the list obtained. The average food diversity index by type of surveyed farm was calculated and compared between Test and Control types.

3. Results

3.1 Agricultural Diversification

Table 4 presents the average of surveyed farms’ Gini-Simpson index and an average of the surveyed farms’ NaturalVegetation index by type.

Table 4. Crop and livestock diversity on surveyed farms

Type	Status	Observation	Animal Diversity	Crop Diversity	Natural vegetation, trees and pollinators
1	Test	89	0.4	0.4	0.3
	Control	85	0.4	0.4	0.3
2	Test	95	0.2	0.3	0.3
	Control	52	0.2	0.3	0.3
3	Test	32	0.2	0.5	0.4
	Control	28	0.3	0.3	0.4
4	Test	25	0.0	0.5	0.4
	Control	83	0.1	0.4	0.4
5	Test	3	0.1	0.7	0.5
	Control	17	0.2	0.3	0.4

Source: Survey, 2021

Table 5 shows the surveyed farms' biodiversity index per type and the comparisons between test and control types.

Table 5. Biodiversity index of the types of farms surveyed and comparison of index

Type	**Statut**	**Obs**	**Mean**	**Std. Dev.**	**Min**	**Max**
1	Test	89	0.37 NS	0.11	0.07	0.58
	Control	85	0.38	0.11	0.06	0.61
2	Test	95	0.28 NS	0.13	0.06	0.53
	Control	52	0.28	0.14	0.06	0.58
3	Test	32	0.34 NS	0.10	0.06	0.53
	Control	28	0.34	0.11	0.10	0.58
4	Test	25	0.29 NS	0.11	0.06	0.51
	Control	83	0.29	0.12	0.06	0.61
5	Test	3	0.42**	0.02	0.40	0.45
	Control	17	0.30	0.12	0.12	0.49

**** Significant at 1%; ** Significant at 5%; * Significant at à 10%; NS Non-Significant*

Source: Survey, 2021

Table 5 shows that the 5 types of exploitation have a biodiversity index of less than 0.5. Chi2 test of Student shows no significant difference between test and control farms of types 1;2;3 and 4. But the test farms of type 5 have better biodiversity than control farms of type 5.

Kruskal Wallis test made shows the results in Table 6.

Table 6. Comparison of biodiversity index of the Test farms

TYPE	**OBSERVATION**	**RANK SUM**
1	89	13261.5
2	95	9335.5
3	32	4290.5
4	25	2507.5
5	3	740

Chi2 = 29,962 ; ddl=4 ; p = 0,0001<0,05

Source: Survey, 2021

Test results and probability obtained show a significant difference between the biodiversity index of types of Test surveyed farms at 5% threshold.

3.2 Diet Diversification

Table 7 shows the dietary diversity index of surveyed farms per type, which are the average of the index obtained perfarm of the same type. Comparisons of this index according to the status of the exploitation per type are also presented.

Table 7. Dietary diversity index

Type	Statut	Obs	Mean	Std. Dev.	Min	Max
1	Test	89	0.58 ^{NS}	0.25	0.25	1
	Témoin	85	0.52	0.19	0.25	1
2	Test	95	0.60**	0.20	0.00	1
	Témoin	52	0.71	0.28	0.25	1
3	Test	32	0.62**	0.25	0.25	1
	Témoin	28	0.53	0.15	0.25	1
4	Test	25	0.74 ^{NS}	0.17	0.25	1
	Témoin	83	0.74	0.20	0.13	1
5	Test	3	0.50	0.22	0.25	0.63
	Témoin	17	0.82***	0.15	0.50	1

*** Significant at 1% ; ** Significant at 5% ; * Significant at 10% ; NS Non Significant

Source: Survey, 2021

From the results in table 7, the 5 types of farms have a food diversity index that is at least acceptable (greater than 50%). Some of them have a desirable index. The level of food diversity of farm types does not depend on their test or control status (within the same type, some tests have a better index and controls that are better). At types 1, 2 and 4, there is no difference between the test and control; on the other hand, at type 3, the test farms have a significantly better index than the controls. At type 5, it is rather an index of controls that are better.

Table 8. Comparison of the dietary diversity index of the Test farms

TYPE	OBSERVATION	RANK SUM
1	89	8975.5
2	95	12651.5
3	32	4009.5
4	25	3987.5
5	3	266

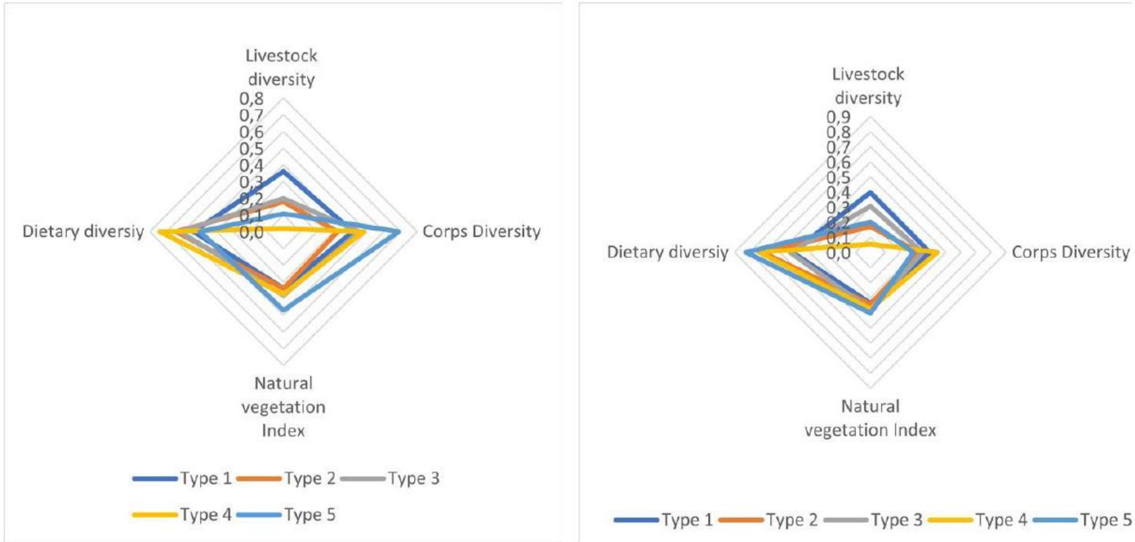
Chi2 = 18,158; ddl=4 ; p= 0,0011<0,05

Source: Survey, 2021

The dietary diversity index of test farms in table 8 was compared using the Kwallis test. The results show that thetypes of surveyed farms have significantly different dietary diversity indexes.

3.3 Relationship between Biodiversity and Food Diversity

Figure 2 schematizes the correlation between the different components of the farm's biodiversity and the food diversity of the household. It allows to comparison types according to their Test or Control status.



Test Control

Figure 2. Biodiversity trajectory and food diversity of surveyed farmsSource: survey, 2021

Those trajectories of farm types displayed in Figure 2 highlight nuances that have not been perceived through the statistical analyses. It can be seen that: trajectories of farms of type 1 and 2 are the same for the four analysis criteria regardless of the status (Test or Control); type 3 farms show better animal diversity in the Controls but better food diversity in the Tests; type 4 look the same but with better dietary diversity in Tests than Controls.On the other hand, farms of type 5 have a non-super-posable trajectory. Tests have better crop diversity and a medium food diversity, while controls have better food diversity with medium crop diversity. Type 1 farms (agro-pastoralists) have better animal diversity than the other types.

4. Discussion

4.1 Biodiversity and Farm Resilience

Analysis of the results shows that the surveyed farms do not have acceptable biodiversity, the acceptability threshold being at least 0.5 of the biodiversity indices (FAO, 2021). Therefore, climatic variations can have severe consequences on some of these farms that do not have enough alternatives. Indeed, biodiversity creates a typical habitat, including specific species and dynamic relationships that stabilize an ecosystem (Ramzan et al., 2021), unlike another less diversified one, even if microclimates remain strongly linked to regional climate (Majeed et al., 2020; De Frenne et al., 2021). This justifies that farms with diversified crops are more resilient than monoculture farms. This conclusion is also in line with Soussana (2015) for whom, the expanded adaptive potentialities of agroecology translate into species diversification of sharing the same space, which gives the agroecosystem resistance and resilience.

By dissociating elements of biodiversity, we realize that farms of type 5 (farms with a good level of mechanization) have good crop diversity. This great diversification capacity of farms of type 5 is acquired from the ease with which they carry out cropping operations than the others. This gives these farms a greater ability to adapt to climatic variations (soil preparation and rapid sowing after a rain, for example) than other farm types.

The same trend was observed in Mali by De la Croix et al. (2011) for whom, farms that are agricultural equipped to work in Niger basin of Mali are more diversified in crops than those in arid environments. Therefore, farms with good mechanization in the study area will better respond to the principle of biodiversity advocated by agroecology and, thus, food diversity. But they are not the only ones; the farms of agro-pastoralists (type 1), which have better animal diversity than the others, also have better crop diversity and are therefore predisposed to food diversity due to diversified access to food.

Despite the observed performance of some farm types on components of biodiversity, none of the farm's types surveyed had, at the same time, good animal diversity, good crop diversity and a good level of natural vegetation. This means that these farms in the cotton areas are not yet resilient enough because of limited alternatives to facing exogenous shocks. But the minimum and maximum values observed in the calculated highlight some existing disparities between individual farms.

Generally, there is not good biodiversity on studied farms and those involved in agroecology do not stand out with a significant difference. That situation is due to the short duration of agroecology implementation in cotton areas (4 years of implementation since TAZCO project start). Dugué (2012) shows that the return on investment regarding agroecological practices sometimes takes several years. Moreover, even if other similar actions had taken place in these regions before, they have not yet succeeded in solving the problem of farm biodiversity, according to the results obtained.

Therefore, it seems clear that to improve cotton farms resilience, it is necessary to intensify the agroecology movementto promote its proper dissemination and wider adoption.

4.2 Dietary Diversity and Farmer Resilience

The dietary diversity index calculated in this study show an overall acceptable level of dietary diversity on surveyed cotton farms (index between 5 and 7) (FAO, 2021) while the biodiversity index for the same farms is globally under the acceptability threshold (unsustainable). These results contradict the norm where the most desired levels of dietary diversity are those supported by good farm biodiversity. The goal of having compatible agricultural and food production systems in agroecology (Temple and Sourisseau, 2019) has not yet been achieved on these farms. Indeed, production diversity on the farm is normally positively correlated with household diet diversity (Gaillard et al., 2022). That link between agricultural production and food security is schematized by Dury, Vall and Imbernon (2017) for whom, production contributes in two ways to food security: making food available (direct consumption) and facilitating financial access to feed (purchase of feed from production income). The last apprehension is adapted to food production. Cash crops can only contribute to food security by strengthening financial access to food and justifies the contradiction observed in the study area where the main crop of the production systems of the farms surveyed is cotton.

Cotton is a cash crop whose outlets are secured and farmers rely on its income to finance their other needs. Its production could then attract more farmers to the detriment of food crops; which creates the lack of biodiversity on farms. This hypothesis is confirmed by a recent study showing that cotton currently occupies 43% of the area in major producing municipalities such as Banikoara (Westerberg, Golay, Houndekon & Costa, 2017). Thesame observation is made in Tchad, where cotton is criticized for competing with cereals impoverishing soil, and monopolizing the peasant labor force at key times in the cropping calendar (Magrin, 2000).

Although, cotton income can help producers to meet their food needs through purchasing, it must be ensured that this income is adequate for this purpose. Unfortunately, the average income from cotton without input subsidies in Banikoara municipality (Benin) is around 51,300 FCFA/ha (Westerberg et al., 2017); which is insufficient to meet smallfamily farms food needs over one year.

Farmers are therefore not yet very resilient to food insecurity risk, despite the food diversity currently observed. It can be concluded that the best way to access food for people living in rural areas physically is to diversify their agricultural production to cover most of their food needs. This is confirmed by Pouliot (2008) for whom people of disadvantaged areas have limited physical access to food when their mode of access is based on the purchase.

5. Conclusion

Analysis of farm biodiversity and households' food diversity in cotton areas has made it possible to assess the levels of farms resilience face to climate variations and farmers' resilience to food insecurity. The analysis method used is based on the tool agroecology performance evaluation (TAPE) proposed by FAO, which corrects the shortcomings noted in the old methods for evaluating farms agroecological performance.

Comparisons made show no significant differences between farms involved and those not involved in agroecology. Overall, effects of agroecology are not yet very noticeable in these areas. But the different index values obtained by farm highlight disparities and mean that some farms are more advanced in agroecology than Others. There are also significant differences between index obtained for the various types of exploitation. This explains why the level of agroecology engagement depends partly on farms socio-economic characteristics.

Differences between farms and farm types taken in isolation suggests good biodiversity in cotton farms, if agroecology actions continue for a long time. This biodiversity will induce a more sustainable food diversity that will contribute to food security in the study area.

This study highlights that the results of the agroecology process, which is still quite mixed in the cotton areas studied, prove that the previous actions have not yet achieved their objectives. This means that Benin would benefit from the intensification of agroecology throughout all over the territory, given the advantages of this production approach for food security. It serves as a reference for measuring future agroecology progress in cotton areas of Benin.

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