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Diversity of soil fertility management options in maize-based farming systems in northern Benin: A quantitative survey

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Introduction: Maize-based production systems in Sub-Saharan Africa are largely based on family farming, which is characterized by low-input, nutrient-mining agriculture and practices. These systems usually promote soil degradation through loss of organic matter and erosion. The present study characterizes farms and main soil fertility management options in maize-based farming systems of the northern Benin.

Methods: The study was conducted in the municipalities of Malanville, Banikoara and Bembèrèkè. We sampled randomly and interviewed 262 maize farmers, and the statistical analysis (distribution of means and frequencies, chi-square, ANOVA, etc.) was performed.

Results and discussion: The results show that maize farming characteristics and socioeconomic conditions (land use and labor, production activities and land allocation, institutional arrangements on land, access to labor and capital, etc.) were diverse across locations and exhibited a wide variation within locations. Several practices were used for the management and sustainable maintenance of soil fertility in maize production systems in northern Benin: maize-legume intercropping, cotton-maize rotation, and mineral and organic fertilizers application. Most of farmers occasionally or regularly used mineral fertilizers (95.4%), followed by legume-cereal rotation/ intercropping (51.9%). Overall, 23.6% and 58.4% of farmers consistently used mineral fertilizer over the last 5 and 10 years, respectively. The amount of applied mineral fertilizer did not significantly vary between locations with an average (applied day after sowing, DAS) of 131.7 $\pm$ 13.7 (22 $\pm$ 8 DAS), 58.7 $\pm$ 9.6 (44 $\pm$ 5 DAS) and 164.7 $\pm$ 25.4 (38 $\pm$ 11 DAS) kg ha^{-1} for NPK, urea and Mix NPK + urea, respectively applied at, and days after sowing. Most farmers spread the fertilizer around the plants without covering with soil particles. Manure was applied exclusively to food crops through transporting and corralling (28.2%); and most farmers also used manure from their own livestock while few farmers used cattle corralling. Farmyard manure was mainly spread (100% of respondents) on the surface before plowing at the beginning of the rainy season. Maize farmers applied mineral fertilizer based on the level of initial soil fertility (naturally fertile or poor, degree of erosion etc.) and fertilizer purchase costs. Manure was not widely used as an alternative to chemical fertilizers; therefore, farmers need more strengthening and technical assistance on the production of organic fertilizers and manure storage. The findings are useful for policymakers on encouraging the successful

implementation of sustainable soil fertility management strategies of maize-based farming systems in northern Benin.

KEYWORDS

diversity, management practices, soil fertility, maize, northern Benin

1 Introduction

Agricultural sector is the backbone of the economy of the majority of countries in sub-Saharan Africa (SSA). It accounts for about 30%–50% of gross domestic product (GDP), and is the main source of income for more than 60% of the population, and provides more than 40% of export earnings (FAOSTAT, http://faostat3.fao.org/). However, the population is mainly poor and suffers from food insecurity (Khonje et al., 2015), especially the smallholder farmers that are the majority of agricultural farmers (over 90% of food produced on the African continent) for whom rainfed agriculture is very important (Beyene & Kassie, 2015). Thus, the development of agricultural sector by supporting small farmers could help to reduce food insecurity, poverty and therefore contribute to economic development.

Maize is the main crop and food base for most farmers in SSA, especially in Benin. It represents about 75% of the cereal production in Benin (Pomalégni et al., 2016). In northern Benin, maize comes in second position after cotton as a subsistence and cash crop, and tends to become first after the fall and inconvenience experienced by the cotton industry in the recent years. In terms of cultivated area, maize and cotton come first, followed by others cereals (sorghum, millet, etc.), legumes (groundnuts, cowpeas, soybeans, groundnut, etc.), (Badou et al., 2013). Maize production has increased remarkably in recent decades due to demand from neighboring countries, including Nigeria and Niger. The volume of production exceeded 750,442 tons in 2000 and reached 1,611,615 tons in 2020 (FAOSTAT, http://faostat3.fao.org). For a long time, maize production and consumption was limited in the south of the country, but maize crop has spread recently to the northern regions (mainly cotton production areas).

As part of the Strategic Plan for Development of the Agricultural Sector (PSDSA) adopted in 2017, the Government of Benin has promoted eight food crops (maize, rice, cassava, yam, pineapple, cashew nuts, oil palm) as essential component of its approach to agricultural production diversification, and to further reduce food insecurity and poverty. As part of this plan, maize is a strategic crop to improve the livelihoods of smallholder farmers (MAEP, 2017). Thus, increasing maize productivity would be strategically valuable for increasing export earnings and improving national food security. Despite its importance, maize productivity however remains largely unsatisfactory with very low yields (between 585 and 1400 kg ha^{-1}) well below potential (FAOSTAT, http://faostat3.fao.org). This is mainly due to the declining soil fertility and recent climate change (Yegbemey et al., 2014).

Today, the degradation and decline of soil fertility are serious problem for most area of SSA. This issue is the result of strong demographic growth observed in several countries of the African continent, poor management of soil fertility, reduction in the duration of fallows, etc. The increase in population and decline in soil fertility have given rise to conflicts between farmers and herders, which increase the risks of food insecurity (Baco et al., 2008). In Benin, the northern part records loss of human lives from these conflicts practically every year. Courts and other judicial institutions (gendarmeries, police stations, etc.) continue to receive complaints from both parties on a daily basis. These violent conflicts are due to the fact that farmers looking for fertile land, have occupied land reserved for pasture. The cattle owner, unhappy to see their grazing areas decrease or almost non-existent, the latter graze their animals in the cropping fields. Despite the fact that Benin is one of the twenty African countries that have given their agreement to take part in the joint program entitled Soil Fertility Initiative (SFI) launched at the World Food Summit held in Rome in 1996 during which the World Bank made a commitment with its partners, in particular the FAO, the decline in soil fertility remains a crucial issue for the emergence of agriculture (Vanlauwe et al., 2017).

In response to this, local populations have developed a number of techniques over many generations to preserve and restore soil fertility (Coulibaly et al., 2018). Through research efforts, several soil fertility management technologies have been developed, tested and made available to extension services through a techno-economic approach known as "technology transfer" (Djenontin et al., 2002; Adégbola & Adekambi, 2006). Farmers reveal that intensive practices introduced by research and extension to correct or improve soil management practices sometimes have a negative impact on their farms. The practices introduced are not always adapted to local conditions, which leads to their failure since they are too expensive and not very suitable for producers (Abdoulaye et al., 2012). Therefore, soil fertility management is a key element to focus on, since it is a prerequisite for food security and sustainable production and livelihoods in developing countries. In addition, studies on traditional soil fertility management practices are largely absent or the existing literature is aging. Therefore, it is necessary to understand and characterize the current soil fertility management strategies to guide efforts towards targeted recommendations. Hence, before going to site-specific soil management recommendations, information concerning farms characteristics and soil management practices is very pertinent. This is practically helpful to verify the limitations the current practices and suggest alternative fertilization approaches.

The objective of the current study is to characterize current farming systems and farmers' indigenous soil fertility management strategies with a focus on cattle manure and mineral fertilizer in maize-based farming systems of the northern Benin.

2 Materials and methods

2.1 Study area and selection of agro-ecological zones

The republic of Benin is located in tropical West Africa, between 6°30° and 12° N and 1° and 3°40 E. This study was conducted in the Borgou-Alibori department, which accounts for 3 of the 4 agro-

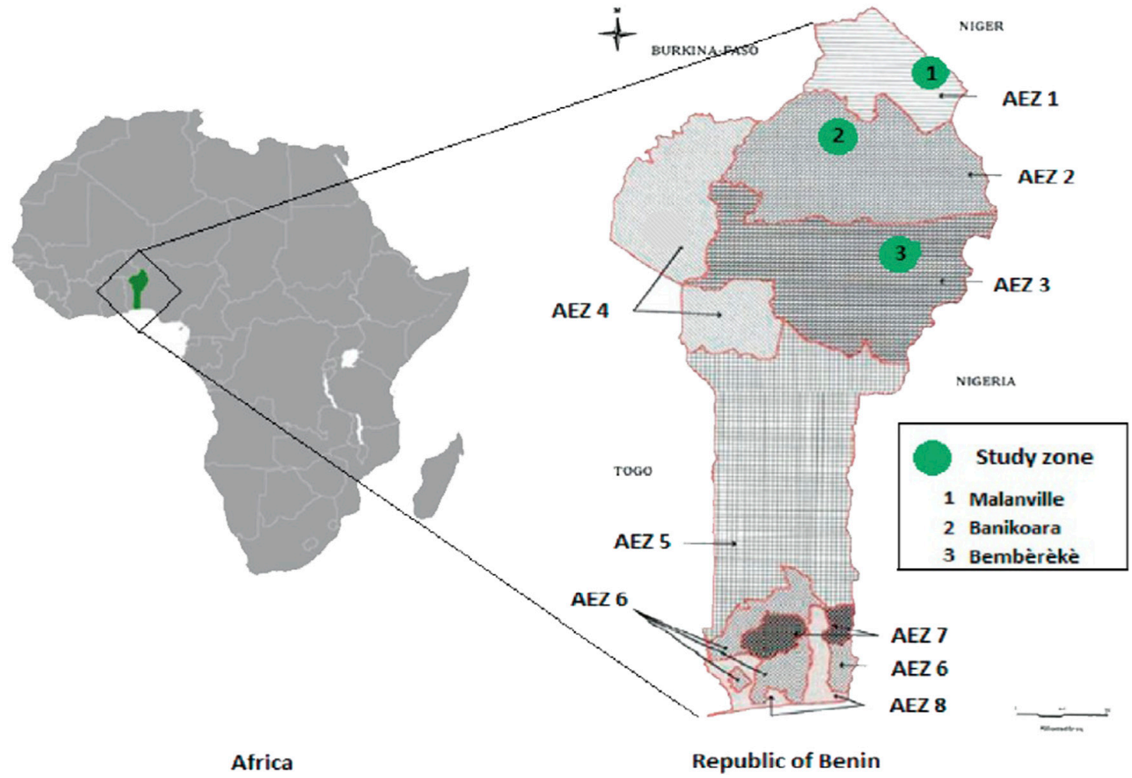

FIGURE 1
Study area. Source: Adapted from Yegbemey et al. (2014).

TABLE 1 Main biophysical characteristics of the selected locations.

Variables	Unit	Sites		
		Bembèrèkè	Banikoara	Malanville
Agro-ecological zone		III	II	I
Altitude	m	449	300	200
Geographic coordinates	Degree	10° 13′ 30″N, 02° 40′ 05″E	11° 18′ 00″N, 2° 26′ 00″E	11° 52′ 00″N, 3° 23′ 00″E
Rainfall				
Annual rainfall	mm	1114.71	932.64	904.9
Rain season		April to October	May to October	May to October
Temperature				
Annual mean	°C	28.5	27.8	30
Annual maximum	°C	38	39	40
Annual minimum	°C	19	18	20
Soil type (dominant)		Ferruginous and tropical soils	clay soils, graveled soils, clayey-sandy soils, clay-graveled soils	Soil, ferruginous; clayey, alluvial, silty, muddy soils
Population density	Hab/km^2	39	56	56
Dominant cropping systems		Cotton, maize, soybean, sorghum, cowpea, yam	Cotton, maize, soybean, sorghum, millet, cowpea, rice, yam, cassava	Rice, vegetable crops, maize, cotton, sorghum

ecological zones (AEZ) of northern Benin (Figure 1). This area is considered as the basket of food and cash crops, implying the major role of agriculture in the livelihoods of the rural population. The rainfall distribution across the whole region is mono-modal, characterized by a long dry season and a short rainy season that allow only one cropping season per year (Table 1).

The study area was located in the extreme North-Benin (AEZ 1), the cotton zone of northern Benin (AEZ 2) and the food-growing zone of Sud-Borgou (AEZ 3). Agriculture is the main source of income for the majority of the population of these three areas. Indeed, Zone 1 (AEZ 1) included together the municipalities of Malanville and Karimama, and Zone 2 (AEZ 2) the municipalities of Nikki, Pèrèrè, Kalalé, Bembèrèkè, N'Dali, Sinendé, Péhunco and Kouandé. They are characterized by humid Sudanese climate, with a rainy season from May to October and a dry season from November to April.

Located in zone AEZ 1, the average altitude of the municipality of Malanville is 200 m above sea level. It extends between 11.5° and 12° latitude from North to South for over 50 km and from east to west for 60 km. The climate of this municipality is Sudano Sahelian type marked by a dry season from November to April and a rainy season from May to October. The average rainfall recorded in recent years is 904.9 mm. The temperature varies between 20°C and 40°C. the main dominant soils are ferruginous soils; clayey, alluvial, silty, and muddy soils.

The commune of Banikoara is located in the AEZ 2 zone and between 10° 50′ and 11° 45 Nand between 2° and 2° 55' E. It is characterized by an annual rainfall with an average of 932.64 m. The average annual temperature is 27.8°C. Its climate is savanna type with dry winter of the northern Sudanese climatic zone with two seasons: a rainy season which occurs from May to October with an upswing of the monsoon and a dry season from November to April with the predominance of the harmattan which is a dry and dusty wind coming from the Sahara. The main soils encountered in the town are clay soils, graveled soils, clay-sandy soils, and clay-graveled soils.

As for the municipality of Bembèrèkè, located in AEZ zone 3, it is between 09° 58′ N and 10° 40′ N and between 02° 04′ E and 03° 00′E with an altitude of 449 m. It is characterized by a climate of the South Sudanese continental type which gradually passes to the North Sudanese type in the far north. This climate is characterized by a single dry season from November to March and a rainy season from May to October with peaks in July and August depending on the year. The average annual rainfall is 1,114.71 mm. Its temperature varies between 38°C and 19°C. The main types of dominant soils are ferruginous and tropical soils.

TABLE 2 Socio-economic and demographic characteristics in the whole study area.

A) Qualitative variables	n	%
Sex		
Male	252	96.2
Female	10	3.8
Marital status		
Single	8	3.1
Married	249	95
Divorced	5	1.9
Ethnic group		
Bariba	169	64.5
Dendi	64	24.4
Others	29	11.1
Religion		
Endogenous religion	13	5
Christian	86	32.8
Muslim	163	62.2
Level of education		
Not	129	49.2
Primary	56	21.4
Secondary	56	21.4
University	05	1.9
Others	16	6.1
Contact with an extension service (yes)	194	74

B) Quantitative Variables	Mean	Standard deviation
Age (Years)	43.52	11.59
Household number	15.07	9.49
Education of the head of household (Years)	3.38	4.39
Experience in agriculture (Years)	19.67	9.62

2.2 Selection of study sites and farms

For the purpose of choosing the respondents, a three-stage sampling method was adopted. Firstly, three representative municipalities–Malanville, Banikoara, and Bembèrèkè (out of eight municipalities in the whole department)–belonging to three different AEZs, were purposively selected based on their importance in agriculture in Benin. The second stage was a sampling of two/four representative villages (belonging to different districts) within the three municipalities, selected with the support of agricultural extension officers following the criteria of the importance of maize farming and the easiest accessibility during the survey time. As a result, the villages of Koara-tédji and Isséné in Malanville, Bonhanrou, and Ounet in Banikoara, and Guéré, Pédarou, Ina center and Guessou-sud in Bembéréké were selected. Within each village, 32 to 36 farming households were randomly sampled by using random systematic sampling (through the table of random numbers) after a rapid census of all farmers in the selected villages. Practically, the agricultural extension officer identified all farmers in each village and assigned a number to each of them. Later on, they were selected, using the table of random numbers. Data collected using a semi-structured questionnaire are related to the general socio-economic characteristics (i.e., age, education level of the farmer and his family, the main occupation of the farmer, access to credit, land ownership, and farm wealth), the main farming system characteristics (total household members, farm size, land use rights, family labor availability), maize production system and the current soil fertility management strategies and rationality.

2.3 Calculations and data analysis

The number of family members employed permanently and those who worked on the farm either full- or part-time was used to determine family labor. The number of temporarily hired laborers was not accounted for. The quantity of amendments (manure and mineral fertilizer) applied to maize crops was quantified on a seasonal basis. Applied N–P–K and urea fertilizers on fields were reported by farmers in bags of 50 kg and converted into kg ha-1. Farmyard manure

TABLE 3 Descriptive statistics (mean and standard error in parenthesis) for system characteristics.

Locations	Malanville	Banikoara	Bembèrèkè	Average	*p*-value
Total land size(hectare)	18.2 (1.4)	16.1 (1.4)	12.3 (0.9)	15.5 (1.2)	0.001*
Total cropped land (hectare)	16.7 (1.3)	14.1 (1.3)	10.0 (0.9)	13.6 (1.2)	0.023*
Total annexed land (hectare)	1.5 (0.6)	2.0 (0.6)	2.3 (0.4)	1.9 (0.5)	0.524
Total household size	17.9 (1.2)	19.8 (2.1)	12.8 (1.0)	16.8 (1.4)	0.001*
Family labor	10.1 (0.8)	9.1 (1.4)	8.4 (0.7)	9.2 (1.0)	0.285
Land: labor ratio (LLR)	2.9 (0.5)	1.8 (0.5)	3.0 (0.3)	2.7 (2.0)	0.168
Total livestock (TLU)†	3.7 (0.9)	6.0 (0.9)	4.5 (0.6)	4.7 (2.7)	0.180
Total number of cattle (TLU)	3.1 (0.5)	4.5 (0.8)	2.3 (0.8)	3.3 (0.7)	0.127
Total land (TLU ha^{-1})*	0.2 (0.1)	0.3 (0.2)	0.2 (0.1)	0.2 (0.1)	0.396
Cropped area (TLU ha^{-1})	0.2 (0.1)	0.4 (0.2)	0.2 (0.1)	0.3 (0.1)	0.262

†Tropical livestock unit: sum of the animals with loading cow = 0.7/goat = 0.1/chicken = 0.01/pigs = 0.2/sheep = 0.1; *Significant difference with $p < 0.05$.

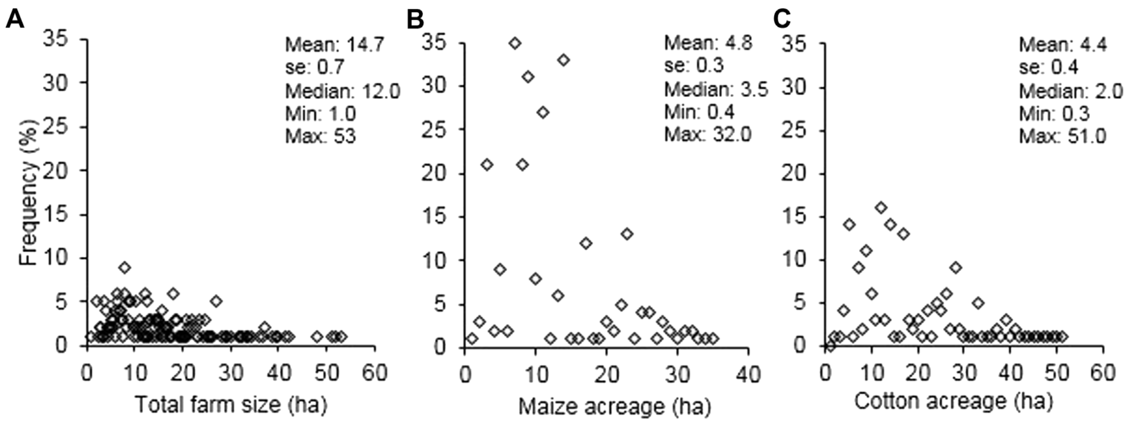

FIGURE 2
Frequency distribution of total farm sizes **(A)**, maize **(B)**, and cotton **(C)** acreage.

quantity applied by farmers was recorded in local units of measure (number of carts) and converted to kg ha^{-1} dry matter according to the ratio proposed by Azouma et al. (2007) for the study zone. Prior to analysis, data were carefully checked for outliers using descriptive statistics, boxplots, and correlation analysis. Graphical analysis of residuals was employed to test for normality and homogeneity of variances using the Shapiro Wilk W Test and Bartlett's test, respectively. Comparisons across sites in terms of socio-economic and land use and management indicators were done through the calculation of descriptive statistics. The statistical significance of relations between locations and soil fertility management practices were assessed by two-tailed Pearson correlations. Comparisons between locations in terms of farmyard manure and mineral fertilizer quantities were done using a linear mixed effect model with location considered as fixed effects, and farmers as random variables to broaden the conclusions to the general region. Significant differences were compared at $p < 0.05$). All analyses were done in IBM SPSS Statistics version 21.

3 Results

3.1 Farmers' socio-economic and demographic characteristics

Most of the respondents of the study area were men of 43 years on average (Table 2). The level of education was 3 years on average, while the average experience in agriculture was about 22 years. The household had 15 people on average, with 9 people doing agricultural activities.

3.2 Farm characteristics and socio-economic diversity across locations

3.2.1 Land use and labor

The total land size and cropped area were significantly different among locations (p <0.01; Table 3), and the largest farms was located

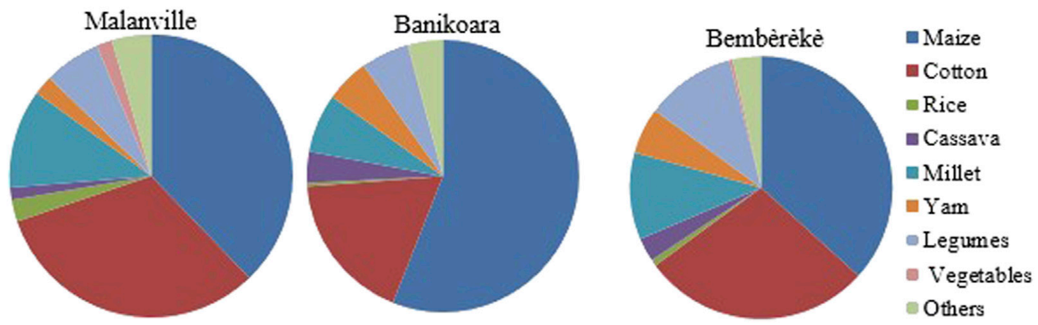

FIGURE 3
Percentage of acreage (%) for the selected crop in northern Benin by location.

TABLE 4 Indicators of production activity and resource allocation across locations.

Indicators	Malanville	Banikoara	Bembèrèkè	Average	*p*-value
No. of crop species grown	5.1 (0.2)	5.2 (0.2)	6.1 (0.1)	5.7 (0.1)	<0.001*
Av. No. of fields farm^{-1}	9.8 (0.7)	9.2 (0.7)	7.5 (0.5)	8.5 (0.4)	0.022*
Av. size of the fields (ha)	1.1 (0.1)	0.8 (0.2)	1.2 (0.1)	1.1 (0.1)	0.151
Food crop acreage (ha)	7.1 (0.7)	8.8 (0.7)	8.4 (0.5)	8.2 (0.4)	0.185
Maize acreage (ha)	4.0 (0.6)	4.7 (0.6)	5.2 (0.4)	4.8 (0.3)	0.206
Income from maize (%)	51.9 (1.3)	46.6 (2.2)	49.1 (1.1)	49.2 (1.5)	0.076
PMTE (%)	55.9 (3.6)	48.6 (6.1)	53.1 (3.0)	52.6 (0.3)	0.570
Cotton acreage (ha)	7.8 (0.7)	8.0 (0.7)	1.1 (0.5)	4.4 (0.4)	<0.001*
% area with food crop	68 (2.9)	82.2 (2.9)	71.8 (2.0)	73.4 (1.5)	0.012*
Ranking of consumption crops	1st	Maize	Maize	Maize	
	2nd	Millet/Sorghum	Yam	Legumes	
	3rd	Legumes	Millet/Sorghum	Yam and cassava	
Ranking of income-generating crops	1st	Cotton	Cotton	Cotton	
	2nd	Maize	Maize	Maize	
	3rd	Rice	Cassava and Yam	Legumes	

Av. No. average number; Tot. No. total number; *Significant difference with $p < 0.05$. The numbers in brackets indicate standard errors.

in the municipalities of Malanville (18.2 ha) and Banikoara (16.1 ha). Most of the surveyed farms (155 out of 262) had less than 10 ha, with a median of 12.0 ha and an average of 14.7 ha (Figure 2). No significant difference of land area occurred among sites, i.e. fallow and unused land (1.9 ha on average) (Table 3).

The average size of the households was significantly higher in Banikoara (19.8 persons) than in Malanville (17.9 persons) and Bembèrèkè (16.8 persons), while the number of family members working on full time did not significantly differ among sites (9.2 persons on average). No significant differences of land:labor ratio (LLR, in ha person-1; i.e., the number of adults working on the farm per unit area of land available per family) occurred among locations, with an average of 2.7 (Figure 2) and LLR wide varied within locations (not shown). Small LLR indicates land limitation, whereas large values may indicate labor limitation, particularly for hand-hoeing. The average total livestock (TLU), the total number of owned cattle (TLU), and the cattle density (which indicate potential manure availability per area cropped) did not significantly differ among locations.

3.2.2 Production activities and land allocation

Agriculture was the main income-generating activity for about 93.7% of the farmers across sites (of whom 82.5% in crop production and 11.2% in livestock-related activities). Non-farm activities (e.g. hand-works, commerce, services, etc.) were performed as the main income-generating activity by 6.3% of the farmers.

The most important food crops were maize (*Zea mays L.*), sorghum/millet (*Sorghum bicolor/Pennisetum glaucum L.*), and legumes such as cowpea (*Vigna inguiculata L.*), groundnuts (*Arachis hypogaea L.*) and soybean (*Glycine max L.*), while rice

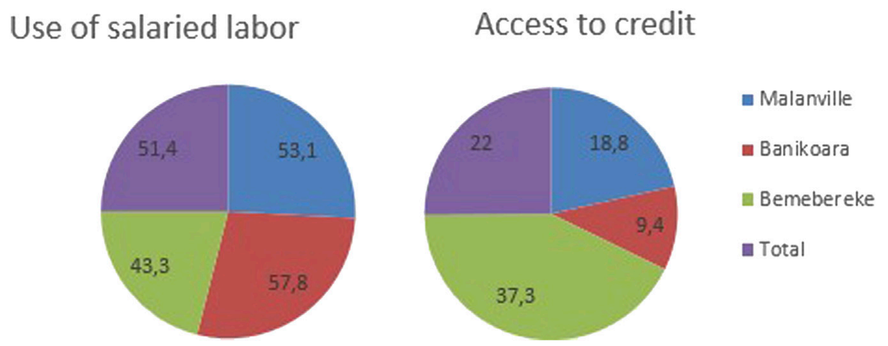

FIGURE 4
Access to the production factors: labor and capital.

(*Oryza sativa*), cassava (*Manihot esculenta Crantz*) and yam (*Discorea spp*.) were generally less important (Figure 3). Cash cropping was restricted to cotton in the study area. In most cases, maize was the main consumed food followed mainly by millet/sorghum and legumes (soybean and cowpea). However, some differences existed in the dominant staple crops and food habits across locations (Table 4). Selling of cash crops such as cotton ranked first among the income generating activities, followed by food crops such as maize, legumes, rice, cassava and yam (not necessarily surpluses).

Farmers produced at least five different crop species (Table 4). The number of crop species grown per farm varied across locations, related to agro-ecological conditions and market access opportunities, and less to land availability. The number of fields per farm was significantly larger in Malanville (9.8) and Banikoara (9.2) than in Bembèrèkè (8.5). The size of crop land, the food crop acreage, maize acreage, the percentage of the household income from maize and the part of income from maize in total expense of the household did not significantly differ among locations (Figure 3). Cotton acreage and the proportion area with food crop showed significant difference among locations. Farmers in Banikoara and Malanville grow more cotton (7.8 ha and 8.0 ha respectively) than those in Bembèrèkè (1.1 ha). Lower frequencies of fields with food crops were recorded in Malanville (68%) and higher frequencies occurred in Banikoara (82.2%) and Bembèrèkè (71.8%).

3.2.3 Institutional arrangements on land

The institutional arrangements on land mainly refer to property rights that entitled farmers different rights on land use. In the study area, farmers had access to land through three main ways: inheritance (66% of the cases), pledge (17% of the cases) and gifting (8% of the cases) (Table 4). In addition, access to land through renting also occurred in the study area, especially in Malanville. The land ownership gave farmers various rights on land. About 82% of the farmers had land ownership, that is most of the respondents had the right of cutting/planting trees on their fields (87%) and the right of giving land in inheritance (84%). These two rights were typical features of land ownership in northern Benin. Indeed, only the sole owner of land is allowed to cut/plant trees in the field or give pieces of land in inheritance. Others rights were also found in the study area, especially the right to rent land (74%) and the right to sell land (65%).

3.2.4 Access to the production factors: Labor and capital

Farmers also need two main important production factors for agricultural activities: labor and funds (Figure 3). The labor sources was from family and wage labor, and funds was raised from the household's assets (materials and machines of production, cash, etc.) and extra money from credit. About 51.43% of farmers employed workers for farming. The agricultural wage labor was permanent or temporary; and the workers were hired from Atacora—neighboring department—or Burkina Faso in case of permanent agricultural wage labor, and from the youth in the village in the case of temporary workers. On average, about 7 persons were available for family labor within the households.

The access to credit in the study area was low, since only 22% of the respondents had access to credit (Figure 4). The lowest access rate to credit (9.4%) occurred in the municipality of Malanville and the highest in the municipality of Banikoara (37.3%), followed by Bembèrèkè (18.8%). The unique institution of micro-finance in the study area was CLCAM (Caisses Locales de Crédit Agricole Mutuel), which was difficult to access by the farmers because of the lack of guarantee.

3.3 Distribution of current soil fertility management practices among farmers

The level of use of the different soil fertility management practices did not vary among study areas, except for corralling practice, crop residues restitution and legume-cereal rotation/intercropping (Table 5). Large number of farmers (95.4%) occasionally or regularly used mineral fertilizers. Manure was applied exclusively to food crops through transporting and corralling, and 16.8% of farmers used a transported farm yard manure as fertilizer. On average, 9% of the surveyed farmers corralled their farms, but this practice was more used in Malanville (11%) and Banikoara (9.8%). Most of farmers practicing crop rotation (28.9%) mainly involved three crops (maize and cotton or legumes) whereas some had a broader range of choices. Since maize and cotton are the major crops in the farming systems in northern Benin, the other crops were most of the times cultivated in intercropping or rotation with the main crops. The average length of a crop rotation cycle was 2.5 years. Moreover, 29.7% and 17.2% of farmers leave their crop residues on the fields after harvest in Malanville and Bembèrèkè, respectively; while only 4.7% report this

TABLE 5 **Institutional arrangements on land.**

	Malanville		Banikoara		Bembèrèkè		Total
	Frequency	Percentage	Frequency	Percentage	Frequency	Percentage	
Inheritance	41	64.1	53	82.8	80	59.7	174 (66.4%)
Gifting	5	7.8	4	6.3	12	9	21 (8%)
Renting	6	9.4	3	4.7	5	3.7	14 (5.3%)
Buying	0	0	1	1.6	8	6	9 (3.4%)
Plegde	12	18.8	3	4.7	29	21.6	44 (16.8%)

TABLE 6 **Descriptive statistics (percentages/mean) of current use of soil fertility management practices.**

Use of nutrient resources (% of farmers)	Malanville	Banikoara	Bembèrèkè	Average	*p*-value
Mineral fertilizer application	93.8	100.0	94.0	95.4	0.132
Corralling	10.9	9.8	6.1	9.0	0.028
Farmyard manure application	12.5	21.9	16.4	16.8	0.361
Compost application	0.0	4.7	1.5	1.9	0.135
Crop residues restitution	29.7	4.7	17.2	17.2	0.001
Manure and mineral fertilizers combined used	0.0	0.0	3.7	1.9	0.088
Fallowing	12.5	20.3	14.9	15.6	0.452
Legume-cereal rotation/intercropping	25.0	65.6	58.2	51.9	0.001
Cotton-cereal rotation	21.9	14.1	12.7	15.3	0.232

practice in Banikoara. Only 15.5% of the surveyed farmers had completely fallowed their land for 3 or more years, and 8% of the farmers used legume-maize rotation/intercropping.

3.4 Farmyard manure use

Almost half of the farmers (47%) used farmyard manure from their own livestock, 18% collected manure freely from dairy farms and fulani camps, while 8% and 11% got manure in exchange for crops at harvest and make corralling contracts, respectively (Table 6). Some farmers (16%) buy manure from dairy farms because they do not have their own livestock and do not find free to collect them. Four 4) application methods were found in this study: broadcasting on the soil surface before plowing, broadcasting on the soil surface after plowing, and heaping around the crop and banding after sowing with incorporation in soil. All the farmers (100% of respondents) spread manure on the surface before plowing at the beginning of the rainy season to facilitate decomposition after the first rains. Around 71% of organic manure users never parked cattle compared to 28% who did so either occasionnaly, every year, every 2 years or every 3 years.

3.5 Current mineral fertilizer use

3.5.1 Types and amount

Among the 95% of farmer using mineral fertilizers, 23.6% and 58.4% used it consistently over the past 5 and 10 years, respectively; 13.6% used it frequently during the last 3 years, and 4.40% used it occasionally. About 74% applied mineral fertilizer for 10 years in Malanville. Farmers used mainly three different mineral fertilizers application practices in maize fields: single use of compound NPK (43.5%) mainly the cotton-formula applied at 15–21 days after sowing (DAS) accompanied by the applicationof urea (41.9%) at 40–45 DAS, and mixed application of the two fertilizers (53.4%) applied once at 40–45 DAS (Table 7). The quantity of applied mineral fertilizer did not significantly vary among study localities for each practice, with an average of 132 ± 13.7, 59 ± 9.6 et 165 ± 25.4 kg ha^{-1} for NPK, Urea and Mix NPK + urea, respectively.

3.5.2 Application methods for each type of mineral fertilizer

The whole farmers applied spot-broadcasting method in the study area. This method consists of spreading little fertilizer at the foot of the plants, with or without incorporation into soil, using two slightly different techiniques depending on the age of the applier. Adults spread fertilizers around the plant while children put fertilizers on one side. Urea or mix NPK + urea application was immediately followed by weeding-ridging according to most of the farmers. The full-broadcasting method was found in Banikoara (about 6% of respondents) and used only with NPK (Table 8). Except the mixed application method, the date of application of NPK and urea did not significantly vary among study sites (not shown). On average, farmers applied NPK and urea at 22 ± 8 and 44 ± 5 days after sowing, respectively.

TABLE 7 Distribution of respondents according to their source of supply and B) frequencies of farmyard manure application.

A) Manure source						
Study areas	Own livestock	Free collection	Collection in exchange for harvests	Corralling contracts	Purchase	Total
Malanville	5(7%)	2(3%)	4(5%)	3(4%)	1(1.35)	15(20%)
Banikoara	10(14%)	6(8%)	1(1%)	1(1%)	5(7%)	23(31%)
Bembèrèkè	20(27%)	5(7%)	1(1%)	4(5%)	6(8%)	36(49%)
Total	35(47%)	13(18%)	6(8%)	8(11%)	12(16%)	74(100%)
B) Frequency of manure application						
Study areas	Occasionally	Every year	Every 2 years	Every3 years	Every 4 years	Total
Malanville	4(27%)	2(13%)	3(20%)	5(33%)	0(0%)	15(20%)
Banikoara	3(13%)	4(17%)	6(26%)	10(44%)	0(0%)	23(31%)
Bembèrèkè	5(14%)	4(11%)	8(22%)	14(39%)	5(14%)	36(49%)
Total	12(16%)	10(13%)	17(23%)	29(40%)	5(7%)	74(100%)

TABLE 8 Mineral fertilizer quantity used (kg ha^{-1} ± standard error) and B) application methods across sites.

A) Mineral fertilizer quantity used (kg ha^{-1} ± standard error)				
	Banikoara	Bembèrèkè	Malanville	Mean
NPK	127 ± 14.9	124.96 ± 11.3	143 ± 14.9	132 ± 13.7
Urea	54 ± 11.2	57 ± 7.7	65 ± 10.1	59 ± 9.6
Mix NPK + urea	157 ± 27.0	168 ± 18.1	170 ± 31.0	165 ± 25.4

B) Application methods, n (%)					
		Banikoara	Bembèrèkè	Malanville	Total
NPK	Full-broadcasting	1 (5.9)	0	0	1 (0.9)
	Spot-broadcasting without incorporation	10 (58.8)	43 (74.1)	13 (41.9)	66 (62.3)
	Spot-broadcasting with incorporation	6 (35.3)	15 (25.9)	18 (58.1)	39 (36.8)
Urea	Full-broadcasting	-	-	-	-
	Spot-broadcasting without incorporation	12 (66.7)	43 (71.7)	14 (43.8)	69 (62.7)
	Spot-broadcasting with incorporation	6 (33.3)	17 (28.3)	18 (56.3)	41 (37.3)
Mix NPK + urea	Full-broadcasting	-	-	-	-
	Spot-broadcasting without incorporation	38 (86.4)	40 (60.6)	11 (39.9)	89 (64.5)
	Spot-broadcasting with incorporation	6 (13.7)	26 (39.4)	17 (60.7)	48 (35.5)

3.5.3 Rationalities in mineral fertilizer application

Maize farmers applied mineral fertilizers based on the level of initial soil fertility and fertilizers purchase costs (Table 9). Farmers will use fertilizer in Banikoara when the soil is naturally poor. In the study area, 84% of farmers used fertilizers on the naturally fertile soil and 87% did not use fertilizer on eroding soils to avoid nutrients loss. Farmers reduced or increased the amount of fertilizers depending on soil conditions and their financial capacity. On naturally fertile soils, 89% of farmers using fertilizer lowered the amount to sustainably benefit from the soil fertility. In contrast, 92% of farmers increased the amount of fertilizer (sometimes double or triple) on naturally poor soils. When soils are eroded and fertilizer costs are high, 64.7% and 84.4% of farmers will reduce the amount of fertilizer (Table 9).

4 Discussion

4.1 Farm characteristics

The characterization of farmers and farming systems is quite important to get a broad idea on the primary data set and the environment of the study area. Farmers cultivated several crops

TABLE 9 Rationalities in mineral fertilizer application, n (%).

Conditions	Study areas	No	Yes	Total
Naturally fertile soils	Malanville	7 (10.9)	57 (89.1)	64 (24.4)
	Banikoara	11 (17.2)	53 (82.8)	64 (24.4)
	Bembèrèkè	24 (17.9)	110 (82.1)	134 (51.1)
	Total	42 (16)	220 (84)	262 (100)
Naturally poor soils	Malanville	3 (4.7)	61 (95.3)	64 (24.4)
	Banikoara	0	64 (100)	64 (24.4)
	Bembèrèkè	6 (4.5)	128 (95.5)	134 (51.1)
	Total	9 (3.4)	253 (96.6)	262 (100)
Eroded soils	Malanville	52 (81.3)	12 (18.8)	64 (24.4)
	Banikoara	59 (92.2)	5 (7.8)	64 (24.4)
	Bembèrèkè	117 (87.3)	17 (12.7)	134 (51.1)
	Total	228 (87)	34 (13)	262 (100)
High fertilizer cost	Malanville	14 (21.9)	50 (78.1)	64 (24.4)
	Banikoara	22 (34.4)	42 (65.6)	64 (24.4)
	Bembèrèkè	47 (35.1)	87 (64.9)	134 (51.1)
	Total	83 (31.7)	179 (68.3)	262 (100)

including maize, cotton, millet/sorghum, rice, yam, cassava, legume, and vegetables. These results are consistent with the findings of Yegbemey (2014), who reported that the farmers are not specialized in producing only one crop over time in the same study area. They use to combine, at a time, different crops or change the cropping pattern over time.

Most of maize farmers also cultivated cotton and claimed land ownership, which allows them to have access to agricultural credit if they hold the evidence. Indeed, inheritance was the main access mode to land, an important factor for agricultural production. This ownership right by farmers was similar to that held by maize farmers in southern and central Benin (Akpo et al., 2015). The low area of cultivable land for women in the study area was due to the difficulty of women to access land. On the social level, very few women have the right to inherit land in northern Benin, because they were more present in households and most of them were involved in the processing of agricultural products.

4.2 Soil fertility management options

Maintaining soil fertility could be a concern for farms with the continuous cultivation of cotton and maize in northern Benin. A total of 10 soil fertility management practices were found in the study area including maize-legume combination, use of mineral fertilizers, cattle parking, animal droppings, compost/household waste, return of crop residues, combined use (mineral and organic fertilizer), fallow practice, cotton rotation—maize, and maize-legume rotation. These results are similar to those of Coulibaly et al. (2012) regarding cotton-maize rotation, maize-legume combination and abandonment of fallow in cropping systems in western Burkina Faso.

Farmers applying crop rotation/intercropping are likely to adjust their agricultural calendar to cope with climate variability. Crop rotation/intercropping practice is considered as an adaptation option to rainfall variability since this practice allow to reduce the risk of losing the production of all crops. Indeed, these results are consistent with those obtained by Yabi et al. (2016) who reported that the rotation and intercropping of appropriate crops is a traditional practice, endogenous to the population of northern Benin and represents one of the most adopted strategies for adaptation to climate change in cropping systems. Labiyi et al. (2018) also found that the practice of intercropping and crop rotation has a positive and significant impact on net margin and on average labor productivity. Thus, intercropping could increase the net margin by 0.32% per hectare, and the average labor productivity increased the price of a man/day by 0.26%. Maize-legume intercropping/rotation and cotton-maize rotations are the main practices implemented by producers in the study area. These practices correspond to those adopted in central and western Burkina Faso (Koulibaly et al., 2010). In addition, the cultivation of legumes allows the fixation of nitrogen, which is an essential element for the regeneration of soil nutrients (Labiyi 2018). Roussy et al. (2015), reported that intercropping allows producers to increase the level of fertility of cultivable soils through the cultivation of legumes, which allows the fixation of nitrogen (essential nutrient of soils). However, cotton-cereal rotation, a predominant practice in cropping systems in central and western Burkina Faso, is reported to cause land depletion (Koulibaly et al., 2010).

The present study reveals that very few farmers (17.20%) applied crop residue restitution in their cropping systems. This low rate of application is explained by the lack of knowledge of the effects of the biomass of these residues in restoring soil fertility. The decomposition of these biomasses contributes to the improvement of crop yields. These results agree with those obtained by Badou et al. (2013) in the center of Benin through a study on the effects of different modes of soybean residue management on maize yield. Indeed, these authors suggested that the increase in maize yields is due to the improvement in soil structure through decomposition of soybean biomass in the soil. In contrast, Koulibaly et al. (2010) reported a gradual decline in soil chemical properties with the duration of soil cultivation regardless of the crop residue management. Koulibaly et al. (2010) thus concluded that the management of crop residues leads to a drop in crop yields regardless of the management in Burkina Faso. This result is in disagreement with that obtained in the present study. However, harvest residues are used to constitute litter in the parks and their decomposition in mixture with animal excreta results in manure which is then spread on the plots to be regenerated and their burial takes place at the start of wintering (Djenontin et al., 2003). Likewise, Autfray et al. (2012) mentioned that in Mali, the management of crop residues are buried in the soil with bedding from parks associated with 25% of the total production of cattle feces.

Fallowing in maize-based cropping systems was very low (15.6%), since this is disappearing in the cultivation habits in Northern Benin. This decline can be due to a decreasing availability of arable land within the territory of Northern Benin. Banikoara, where the cropping intensity was highest due to the cotton cultivation, fields were subjected to partial fallow much more frequently than fields located on the other localities. However, the use of this practice according to Blazy et al. (2011) combined with other rotational crops can control pests and reduce the use of pesticides. But the current adoption levels appear low and contrasted depending on the type of farm. Producers no longer adopt this practice because of land constraints as a result of demographic pressure which is increasing. This finding confirms those of Jouve (1991) who reported that as soon as land pressure increases, the long tree fallow regresses. So the need to replace shifting cultivation with sedentary cultivation systems becomes necessary.

In the study area, more than 95% of farmers occasionally or regularly used mineral fertilizers. In general, the applied fertilizer rates by maize growers were lower than those recommended by extension agents, which are 150 kg/ha NPK and 50 kg/ha urea. This reduction of the dose depends on the quantity available on the market and varies between zones. In this area, cotton cultivation by maize growers was a mean of easy access to mineral fertilizers because these fertilizers are mostly subsidized by the government. These producers take advantage of growing cotton by diverting some quantities of subsidized fertilizer to maize, which justifies the small quantity of mineral fertilizers applied to the maize crop. These producers also did not respect the period of application of fertilizers because they apply fertilizers according to its availability and period of acquisition on the market. The same opinions were highlighted by Pouya et al. (2013) on cotton production in central and western Burkina Faso. Most growers spread mineral fertilizers around plants without covering them with soil. According to Sale et al. (2014), the use of organic manures on farms was a strategy for adapting to soil chemical changes. The relative high quantities of manure applied in the study locations can be explained by the proximity to Niger and Burkina Faso. The results obtained are consistent with those of Assogba et al. (2012) in terms of the average amount applied per hectare (number of cart per hectare). Very few projects and NGOs take into account the importance of organic manures in their popularization of soil fertility in Benin, which means that many farmers are using this practice. There is also a lack of manure storage (34.4%), transportation and enforcement (26%), poor sanitation (34.4) and problems quantity and not enough production (29.4%) which also justify the low level of organic manures use in production systems. According to farmers, it took about 8–10 cartloads of cow dung to ensure a good level of fertilization of the plot of 1 ha (1 ha) throughout the crop cycle, we can estimate this amount to about 640–800 bowls. Assuming that the payload of a cart used to transport cow dung was approximately 976 kg, according to estimates by Azouma et al. (2007), we can estimate the amount of cow dung transported per basin and per polyester bag at 12–36 kg each. Due to the significant distance (sometimes more than 2 km) which separates the fields from the place of production/ harvest of the organic manure, the fertilization of the plots through cow dung and other organic matter was a daunting task. Most women, as well as men without oxen and carts, found themselves in a situation where fertilization remains problematic, especially when considering the multiple household tasks that women often have to perform.

5 Conclusion

The purpose of the study was to characterize farms and main soil fertility management options in maize-based farming systems of the northern Benin. The studied farms differed in land area, labor and financial resources, and potential nutrient availability, which affected land use and soil fertility management. Most of the farmers were mainly smallholder with an average land holding of 5 ha (including fallow and land not in use) of land to organize the agricultural activities. Based on the land allocation, maize was the most important crop. Maize-based farming systems in northern Benin integrated diverse practices for soil fertility management such as: 1) endogenous practices (fallow, corralling, farmyard manure application, legume-cereal rotation/intercropping, cotton-cereal rotation etc); 2) improved practices (mineral fertilizer application, composting, integrated manure and fertilizer use, etc). The main practice to improve/maintain soil fertility was mineral fertilizer and legume-cereal rotation/intercropping, but the rates of fertilizer were far below those recommended or required to ensure good maize yields. With subsistence farming as the most important to poor, improving soil fertility for maize production in these fields will directly enhance their life. In the transition to sustainable production systems, using locally available organic fertilizers could be well developed and the constraints could be lifted. However, to obtain a better insight into the farming systems and the diversity of soil fertility management options, some complementary studies should be conducted especially the typology that may underlie structure of farming system heterogeneity, the complex and dynamic coexistence of diverse farm households in space and time. This can be done by classifying farms into groups that have common characteristics in order to support the implementation of a more tailored approach for sustainable soil fertility management strategies in maize-based farming systems in northern Benin.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

PT: funding acquisition, conceptualization, and methodology; PT, FA, and FT: investigation, analysis, and writing—original draft. FA and NO: methodology, writing—review and editing. RY and JY: review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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