Vol. 15(2), pp. 14-25, July-September, 2024
DOI: 10.5897/JSSEM2024.0936
Article Number: A456DD472485
ISSN: 2141-2391

http://www.academicjournals.org/JSSEM

Journal of Soil Science and Environmental Management

Full Length Research Paper

Typology of producers and determinants of yields in cassava cropping systems in Benin

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Received 26 March, 2024; Accepted 6 August, 2024

In Benin, cassava (*Manihot esculenta*) is a crop heavily involved in agro-industry and plays an important role in maintaining food security. However, cassava cultivation systems remain traditional with yields that are far below the potential yields. To understand this fact, a survey was conducted among 585 cassava producers in the agroecological production zones (Ouèssè, Bantè, Djidja, Dassa, Kétou, Djakotomé, Klouékanmey, Zakpota, Dangbo, and Adjohoun) with a semi-structured questionnaire. Quantitative and qualitative data were collected and they were related to soil fertility management practices, production constraints, and developed solutions to avoid or to minimize effects of these constraints. A regression tree was built to analyze the data collected. The areas allocated to cassava production are generally less than 1 ha in the agro ecological zones surveyed. Five cassava cropping systems are observed in the study area. The variables "commune'' (p=0.001) and "level of education'' (p=0.02) significantly determine farmers' choice of the system. Cassava importantly contributes to the household income with high significant difference (p<0.0001) in cultivated areas per commune. The high yields of cassava roots are obtained with the use of improved variety and mineral fertilizer. From the constraints observed, transhumance comes first in agroecological zone 5, the lack of specific fertilizer for cassava cultivation in agroecological zone 6, and the decline in soil fertility in agroecological zone 8. Future investigations in soil fertility should focus on the implementation of fertilizer recommendations for cassava cultivation in Benin, and raise awareness on the existence and use of improved varieties.

Key words: Food security, integrated soil fertility management, tubber root crop.

INTRODUCTION

One of the major challenges of the coming decades is to feed a world population estimated by 2050 at 9.3 billion people (Ozor et al., 2014; Faostat, 2017) while preserving a healthy environment for future generations (Lall and Mengistae, 2005). Indeed, the strong demographic growth observed has led to a reduction in cultivable areas

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and difficulties in in meeting the quantity and quality of the food needs of the populations (Čičková et al., 2015). Sub-Saharan Africa is a region with a high prevalence of malnourished and undernourished people (FAO, 2014) In Benin, 74% of households face food insecurity and protein is the main missing nutrient in most diet (Munthali et al., 2018). To deal with these problems related to food crisis in the world, increasing food supplies through national production undoubtedly remains an important objective for developing countries. The new agricultural policies adopted by Benin have led to the creation of (depending on the agroecological zones) Agricultural Development Poles (PDA). Each of these poles contains one or two key sectors around which others gravitate. Among the key sectors is cassava.

Cassava (*Manihot esculenta* Crantz) appears to be a strategic crop for maintaining food security of populations as well as reducing poverty in the world (Latif and Müller; FAO, 2018; Sivamani et al., 2018). It is the 4th most cultivated crop in the world after maize and rice (FAO, 2018), it can grow on poor soils (due to its tolerance to such condition), is easy to harvest (El-Sharkawy, 2004), and is resilient to current climate change and variability (Karume et al., 2022). In Africa, and mainly in developing countries where malnutrition is rampant, cassava is the second source of calories in the human diet (Kayiwa et al., 2021). In Benin, cassava is mainly grown in the center and south of the country where it is a staple food for the local population. In this country, it accounts for 8.3% of the agricultural GDP (STAT, 2015). It ranks second among cultivated crops in terms of sown areas and first place among roots and tubers (54% of the area and 59% of total production). The average production of fresh cassava in Benin was 387 kg/capita and reached more than 700 kg/capita in the most producing regions of the Ouémé, Plateau, Zou and Collines (Soulé et al., 2013). This production generates a commercial sector with a large artisanal processing sector that provides various products (garri, chips, tapioca, lafun, starch) (Vernier et al., 2018). Despite this importance, the yields obtained are much lower than the potential yields (Ezui et al., 2016; Parmar et al., 2017).

The potential yield is 80 t/ha according to the researchers, while the average yield worldwide is 12.8 t/ha (FAO, 2017). Therefore, there is a need for research to compensate for this yield gap in order to significantly increase cassava production in the country (Vanlauwe et al., 2014; Ravi et al., 2021).

For this reason, we would like to know what factors influence cassava production in cropping systems and what tactics growers might implement to increase their yields. The purpose of this study was to determine how to increase yields as well as the elements that explain the yield gap seen in cassava cropping systems.

The authors begin with the theory that the primary causes of this yield discrepancy in cassava cropping systems within the agro ecological production zones are variations in soil fertility management techniques.

MATERIALS AND METHODS

Study environment

This study was conducted in three agroecological zones namely cotton farming zone of central Benin (agro ecological zone 5, Ouèssè, Bantè, Djidja, Dassa, and Kétou), the *"terre de bare"* zone (agro ecological zone 6, Djakotomé, Klouékanmey and Zakpota) and the zone of alluvial soils along the Oueme valley (agro ecological zone 8, Dangbo and Adjohoun). In these three zones, cassava is one of the main grown crops.

The cotton farming zone of central Benin is characterized by a sudano-guinean climate type, which sometimes tends toward sudanian climate. This transition zone has two rainy seasons in the south and one in its northern part. The average annual rainfall is between 1000 and 1200 mm. The Ferric and Plintic Luvisol are dominant soil types in this area. The area bears predominantly tree/shrub savannah vegetation dominated by *Panifia ohieri* species (Gbemavo et al., 2010).

The *"terre de bare"* zone has a subequatorial climate type with two rainy seasons with 900 to 1200 mm of water per year in the west and 1100 to 1400 mm of water per year in the east. The average annual temperature is 26.5°C and the soil types are acrisols (FAO, 2014) on clayey-sandy sediment of the continental terminal, with deep profiles and easy to work but chemically poor.

The zone of alluvial soils along the Oueme valley is characterized by a subequatorial climate with four seasons including two dry and two rainy seasons. The average rainfall is 1177 mm and the average temperature is 23°C. The soil types are acrisols and hydromorhic with grassland, grassy savannah, raffia swamp, and mangrove vegetation.

Sampling method and data collection

The sample size was determined by normal estimation of the binomial distribution (Dagnelie, 1998): $N= ((U_{1-a/2})^2 \times p\ (1-p))/d^2$, with U_1-α ⁄ 2 the value of the normal random variable for the probability value of 1-α ⁄ 2, α being the risk of error.

For α = 5% the probability 1- α ⁄ 2 = 0.975 and we have U_1-α ⁄ 2 = 1.96. p is the proportion of producers who cultivate cassava in the study area, with a margin of error (d) estimated at 5%. The p value is determined using an exploratory phase at the start of the survey. A total of 585 cassava producers were surveyed, composed of 276 producers in the agroecological zone 5, 178 producers in the agroecological zone 6 and 131 producers in the agroecological zone 8 by the random and simple identification method. This method consists of selecting individuals who are cassava growers without taking other considerations into account.

Data were collected using a semi-structured questionnaire configured on a smartphone with the KoboCollect application. Quantitative and qualitative data were collected. The collected data were related to the socio-economic characteristics (age, sex, production experience, cultivated area, contribution to household income, cropping practice) of the producers, soil fertility management practices, perception of producers on the soil fertility level, production constraints and the solution developed. Yield squares of 16 m^2 were placed in producer fields to estimate root yields at harvesting. Harvest samples were taken and oven-dried at 65°C to constant weight for the estimation of dry matter. The formula Ps×10000/16 was used to calculate the root yield with Ps as the dry weight of root harvested in the field after drying in the oven. The yield was in $t.ha^{-1}$

Statistical analysis

The statistical analysis was carried out with R software version 4.3.1. The FactoMineR (Husson et al., 2016) and Factoextra (Kassambara et al., 2017) packages were used to perform multiple correspondence analysis followed by hierarchical ascending classification on data related to integrated soil fertility practices in cassava cropping systems.

Variables such as, variety used, tillage method, type of tillage, use of organic fertilizer, use of mineral fertilizer, use made of cassava leaves, use made of the stem, intercropping and crop rotation were chosen as variables for the typology of the producers.

Factorial correspondence analysis was carried out using the correspondence analysis (CA) function of the FactoMineR package (Husson et al., 2016) to analyze the relationships between cropping systems and the socioeconomic characteristics of producers. The rpart (Therneau et al., 2019) and partykit (Torsten et al., 2019) packages were used to build the regression tree model to identify the determinants of cassava yield in the study area. The Constraint Pairs Matrix was used to describe cassava production constraints by agroecological zone. This matrix measures the proportion of farmers who rank one constraint over another. Thus, one constraint is more limiting than the other is when more than 50% of producers consider it as such.

In addition, the overall classification of constraints in an area is a function of the number of times the constraint is identified as more limiting. Differences in cassava area growing across agroecological zones were assessed using Kruskal-Wallis test followed by Dunn's test with Bonferroni as a method of fitting Bonferroni's probability with the rstatix package (Kassambar and Mundt, 2020) since these data did not follow a normal distribution. A nominal polytomous regression was used to determine the adoption of cropping systems and this with the socioeconomic variables of the producers.

RESULTS

Socioeconomic characteristics of cassava producers

Table 1 presents the socioeconomic characteristics of the producers surveyed in the three agroecological zones. Men dominate in cassava production.

The age of the producers varied from 21 and 80 years with a mean of 50 years. In addition, producers involved in cassava production are mostly young.

Cassava cultivation has a very important contribution to the household income for the majority of producers. In the cotton farming zone of central Benin and in the zone of alluvial soils along the Oueme valley, the producers are mostly indigenous, while in the *"terre de barre"* zone, there is a significant proportion of migrants (15.69% of respondents). Almost 87% of the producers do not belong to any farmer organization with an experience in cassava cultivation which generally does not exceed 10 years. In general, 92% of the producers surveyed in the study area have a total available area of less than 10 ha, 6% have a total available area between 10 and 20 ha and 2% a total area greater than or equal to 20 ha. The areas devoted to cassava cultivation in the three agroecological zones were generally less than 1 ha. Inheritance (56.58%) is the dominant mode of land acquisition observed in the study area.

Typology of cassava producers surveyed regarding integrated soil fertility management practices

The soil fertility management practices observed among producers in the three agroecological zones essentially were: crop rotation, intercropping, supply of mineral and organic fertilizers, incorporation of dry cassava leaves into the soil during plowing.

The results of the multiple correspondence analysis followed by the hierarchical classification showed five dominant cassava cropping systems in all of the agroecological zones covered (Figure 1).

The first system includes producers using improved varieties of cassava, using of mineral fertilizer and cassava leaves are used as vegetables.

This group of producers does not apply organic fertilizer.

The second group of producers was those using improved varieties of cassava, practice intercropping and crop rotation, use cassava leaves as vegetables but do not apply organic or mineral fertilizers. The third group includes producers who do not associate or rotate crops and use cassava leaves as green manure. The fourth group included producers using local varieties and cassava leaves as fodder, intercropping and applying organic fertilizers. They do not use mineral fertilizer and do not rotate crops.

The last group was these producers using local varieties and cassava leaves as organic fertilizers and does not practices crop rotation.

The hierarchical classification showed that systems 2 and 5 are the most adopted in the study area (44.4 and 30.6% of the producers surveyed respectively) (Figure 2). The nominal polytomous regression (Table 2) showed that only the district and the educational level of the producer significantly determine the choice of the cassava cultivation system for producers.

The factorial correspondence analysis carried out from the typology data shows that the first two axes summarize more than 50% of the information relative to the diversity of cropping systems regarding the different municipalities surveyed (Figure 3).

The cropping system 1 is common in Dangbo while the cropping system 2 is common in the districts of Kétou, Bantè, Ouèssè and Zakpota.

The cropping system 3 is dominant in the districts of Djidja and Klouékanmè while cropping system 4 is dominant in the district of Adjohoun.

Finally, the cropping system 5 is mostly found in the districts of Djakotomey and Dassa-Zoumè.

Producers who adopt cropping systems 1, 4 or 5 believe that cassava production has an important contribution to the household income.

However, those who adopt cropping systems 2 and 3 consider that cassava production has not an important contribution to household income. The Kruskall-Wallis test carried out shows that the choice of cropping

Table 1. Socio-economic characteristics of cassava producers surveyed.

Variable	Term	Percentage of respondent		
		ZAE 5	ZAE 6	ZAE 8
Sex	Women	19.5	37.91	3.09
	Men	80.48	62.09	96.91
Age (years)	0-50	74.10	69.93	61.86
	50-70	22.31	27.45	36.08
	≥70	3.59	2.61	2.06
Origin	Native	94.82	84.31	98.97
	Migrants	5.18	15.69	1.03
Educational level	None	65.74	77.12	59.79
	Primary	22.31	13.73	30.93
	Secondary	11.95	9.15	9.28
Membership of a farmer organization	Yes	13.15	23.53	1.03
	No	86.85	76.47	98.97
Experience (years) in cassava cultivation	<10	35.46	41.18	55.67
	10-20	28.29	31.37	26.80
	≥20	36.25	27.45	17.53
Area (ha) available for agriculture	<10	81.67	95.42	100.00
	10-20	13.55	4.58	0.00
	≥20	4.78	0.00	0.00
Average area (ha) sown per year	<6	75.30	96.08	100.00
	06-11	11.95	1.31	0.00
	≥ 11	12.75	2.61	0.00
Area (ha) allocated to cassava	<1	49.80	66.01	59.79
	01-02	23.51	30.72	40.21
	≥2	26.69	3.27	0.00

ZAE 5: Cotton farming zone of central Benin; ZAE 6: “terre de barre” zone; AEZ 8: zone of alluvial soils along the Oueme valley.

systems is not a function of the area sown.

However, a high significant difference ($p<0.0001$) was observed at the level of areas sown with cassava by district. Indeed, the producers of the Collines department followed by those of Ouémé have a higher coverage than producers of the other districts.

Determinant of cassava yield level in the studied agroecological zones

Figure 4 shows variation in cassava root yields during the growing season of 2017, 2018 and 2019 according to the agroecological zones. This variation was obtained by calculating the average of the yield estimates provided by the producers surveyed over the three previous years (2017, 2018, and 2019). There is no significant ($p = 0.236$) difference between cassava root yields obtained during each growing season within the same agroecological zone but there is a difference in yield between the different agroecological zones. The average yield ranged from 10 ±1.2 to 12 ± 0.8 t ha^{-1} and 5 ± 1.6 t ha^{-1} in the cotton farming zone of central Benin, the “terre de bare” zone and the zone of alluvial soils along the Oueme valley, respectively.

The results of the regression tree (Figure 5) showed that the high cassava roots (20 t. ha^{-1}) yields were obtained with the use of improved variety and mineral

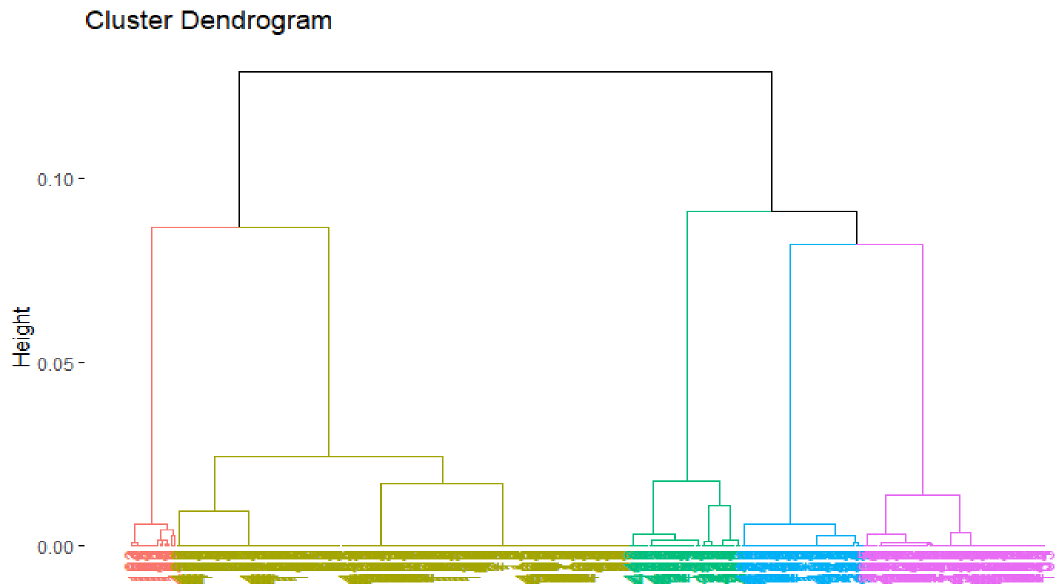

Figure 1. Dendrogram relative to producer groups.

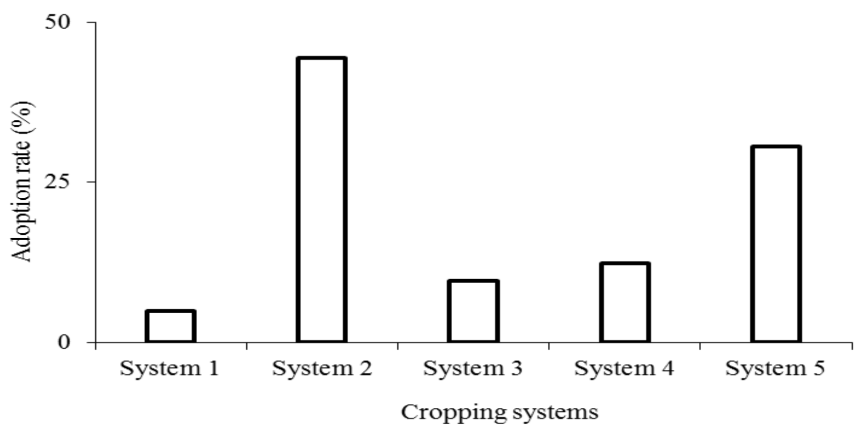

Figure 2. Adoption of cassava cropping systems.

Table 2. Nominal polytomous regression on the determinants of adoption of cropping systems.

Variable	Coefficient	Probability
District	-3.58	0.001***
Cassava area	1.4	0.74^{ns}
Sex	-0.8	0.25^{ns}
Age	1.7	0.53^{ns}
Main activity	-0.9	0.08^{ns}
Member farmer organization	0.6	0.14^{ns}
Experience in cassava production	-1.5	0.11^{ns}
Land tenure mode	0. 8	0.62^{ns}
Household size	1.2	0.50^{ns}
Educational level	2.1	0.02*
Contribution of cassava to household income	-1.1	0.43^{ns}

*Significant at the 5% level; ***significant at the 1‰ level; ns: not significant.

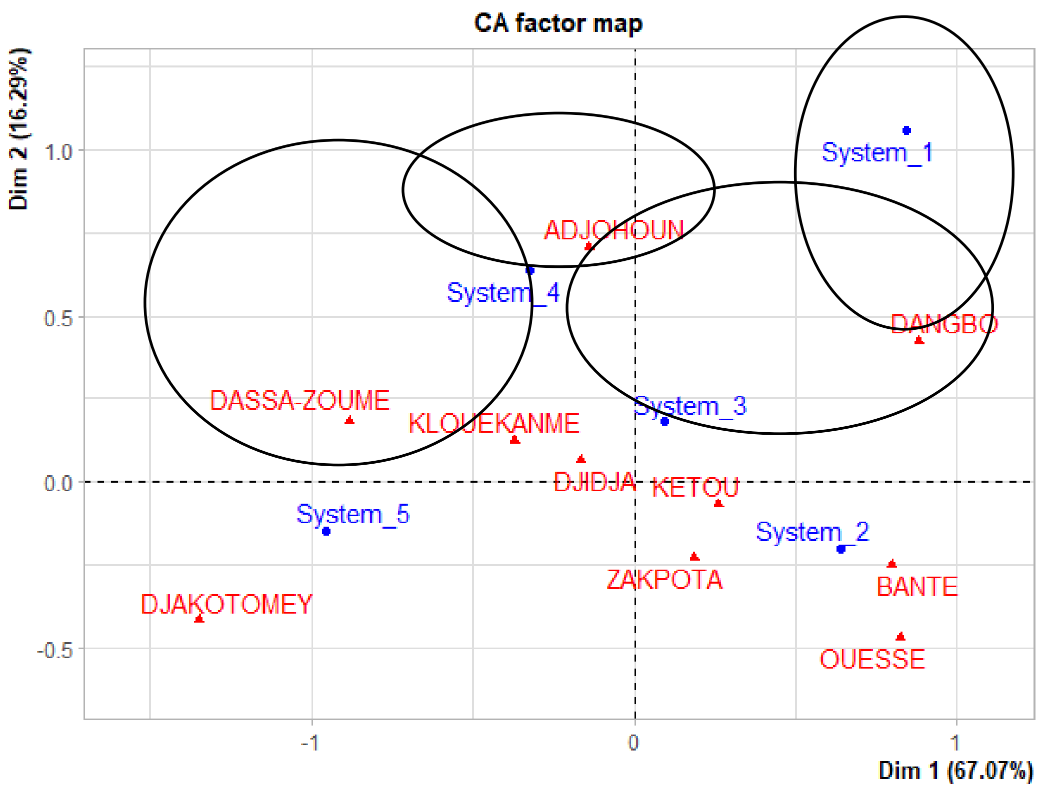

Figure 3. Distribution of the cropping systems by district.

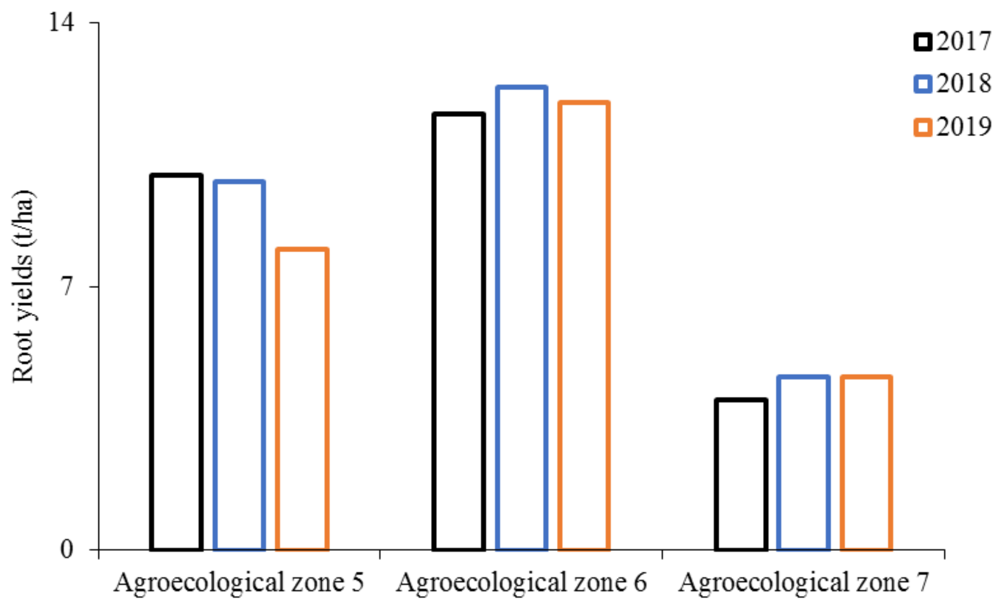

Figure 4. Average cassava yields in the agro ecological zones covered.

fertilizer. Moreover, the local varieties combing with the application of organic fertilizers with crop rotation can induce a yield close to 20 t.ha^{-1}.

In general, the supply of combined organic and mineral fertilizers with improved varieties increases the root yield of cassava in the agroecological zones covered.

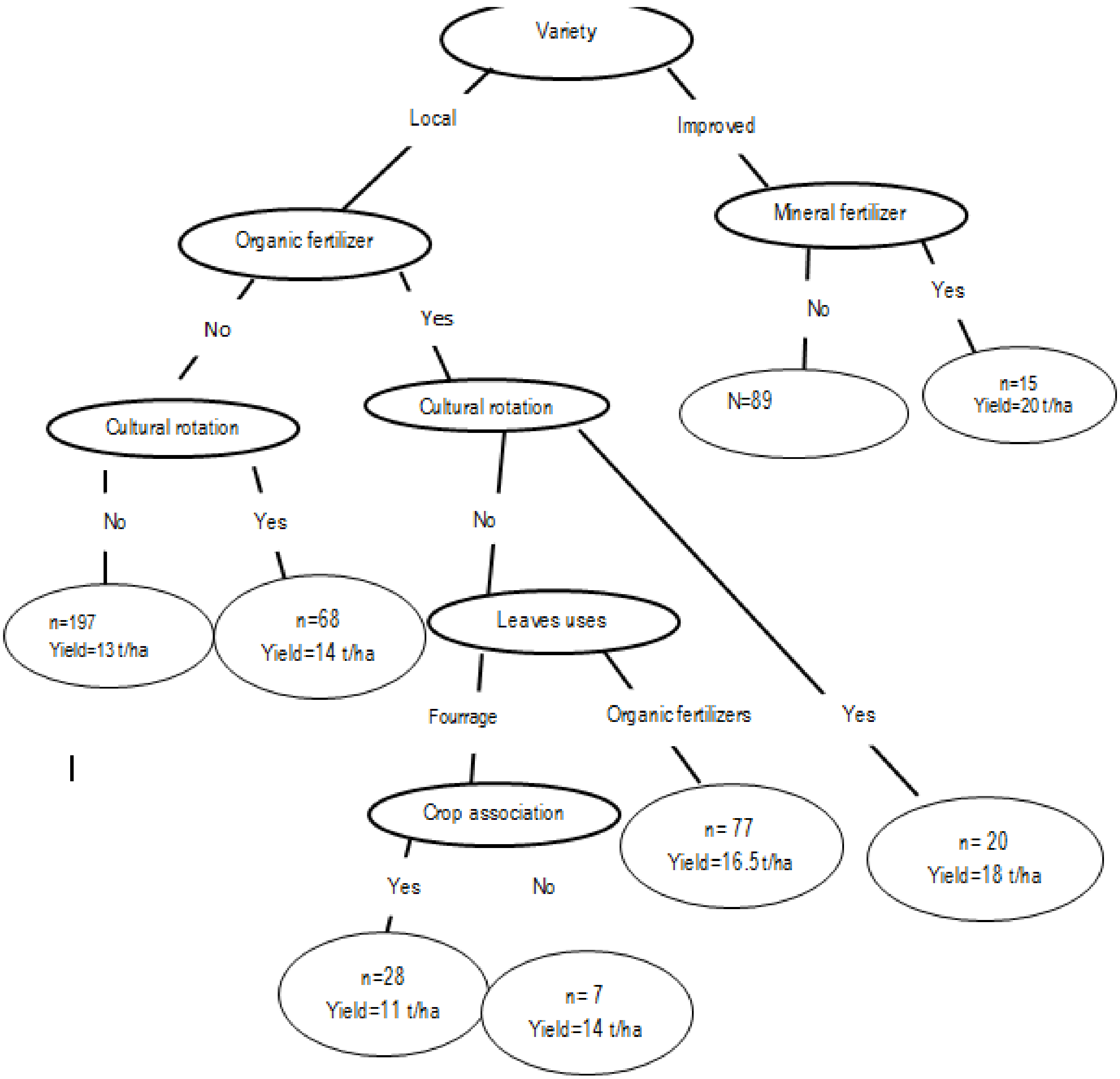

Figure 5. Regression tree model of the determinants of cassava yield in the surveyed areas.

Constraints related to cassava production in the agroecological zones

The analysis of the matrix of production constraint regarding the agroecological zone is presented in Tables 3, 4 and 5. Based on this matrix, the constraints of cassava production in the cotton farming zone of Central Benin are in order of importance: transhumance > declining soil fertility > unavailability of improved varieties > weed invasion > early drought > lack of fertilizer > high cost of labor > late rain. In the Table 4, the constraints are ranked in the following order: lack of specific fertilizer > declining of soil fertility > early drought > transhumance > unavailability of improved varieties > high cost of labor > weed invasion > late rain.

Finally, in the zone of alluvial soils along the Oueme valley the constraints reported by cassava producers are ranked as follow: declining soil fertility > weed invasion > high cost of labor > transhumance > lack of specific fertilizer > unavailability of improved varieties > early drought > late rain.

In all of the studied agroecological zones, the decline of soil fertility with the lack of specific inputs was constraints that all cassava producers faced.

Table 3. Matrix of production constraints for cassava in the cotton farming zone of central Benin.

Transhumance	Declining soil fertility	Unavailability of improved variety	Lack of specific fertilizer	High cost of labor	Weed proliferation	Late rain	Early drought
0.00	55.06	60.67	73.03	75.28	69.66	70.79	73.03
44.94	0.00	65.17	74.16	78.65	75.28	73.03	74.16
39.33	34.83	0.00	66.29	62.92	64.04	58.43	58.43
26.97	25.84	33.71	0.00	55.06	46.07	50.56	48.31
24.72	21.35	37.08	44.94	0.00	49.44	50.56	49.44
30.34	24.72	35.96	53.93	50.56	0.00	51.69	51.69
29.21	26.97	41.57	49.44	49.44	48.31	0.00	48.31
26.97	25.84	41.57	51.69	50.56	48.31	51.69	0.00

Table 4. Matrix of production constraints of cassava in the “terre de bare” zone.

Lack of specific fertilizer	Declining soil fertility	Early drought	Transhumance	Unavailability of improved variety	High cost of labor	Weed proliferation	Late rain
0.00	62.50	69.08	71.71	77.63	73.68	73.03	74.34
37.50	0.00	61.18	62.50	66.45	74.34	72.37	74.34
30.92	38.82	0.00	58.55	58.55	60.53	57.24	59.21
28.29	37.50	41.45	0.00	56.58	61.84	63.82	64.47
22.37	33.55	41.45	43.42	0.00	65.79	67.11	67.76
26.32	25.66	39.47	38.16	34.21	0.00	51.97	56.58
26.97	27.63	42.76	36.18	32.89	48.03	0.00	53.95
25.66	25.66	40.79	35.53	32.24	43.42	46.05	0.00

DISCUSSION

Soil fertility management practices, cropping systems effects on cassava yields in the agroecological zones surveyed

Cassava is one of the major staples crops in sub-Saharan Africa and its production involved men as well as women. The socio-economic characteristics of producers in the study area shown that men mainly cultivate cassava because they hold the majority of arable land. According to Balogoun et al. (2014) and Mor-Mussery et al. (2020), land rights make women’s access to land more restricted according to customary rule and it is men who inherit land from their parents.

The typology carried out with the soil fertility management data showed that there are five cassava-cropping systems with different soil fertility management systems and the cropping systems 2 and 5 being the most implemented in the study area. There are major disparities in the ranking of soil fertility management strategies between communities and areas (as reported by characteristics of each system).

This could be due to variations in agricultural land pressure, ethnic diversity, crop culture, soil condition, rainfall or farming practices. Differences in soil fertility management strategies between regions surveyed reflect different soil fertility management needs, different availability of animals, particularly oxen, availability of resources and tradition. In these two dominant cropping systems, combined organic and mineral fertilizers are not used. Intercropping and crop rotation were cassava fertilization practices in those major cropping systems. The absence of cassava fertilization can be attributed to the fact that, in contrast to other food crops, cassava is flexible in

Table 5. Matrix of production constraints of cassava in the zone of alluvial soils along the Oueme valley.

Declining soil fertility	High cost of labor	Early drought	Weed proliferation	Transhumance	Lack of specific fertilizer	Unavailability of improved variety	Late rain
0.00	71.34	76.22	75.61	78.05	82.32	84.76	83.54
28.66	0.00	55.49	45.73	53.05	57.93	56.71	62.80
23.78	44.51	0.00	46.34	53.66	60.37	61.59	63.41
24.39	54.27	53.66	0.00	57.93	67.07	68.29	62.80
21.95	46.95	46.34	42.07	0.00	56.71	63.41	54.27
17.68	42.07	39.63	32.93	43.29	0.00	53.66	49.39
15.24	43.29	38.41	31.71	36.59	46.34	0.00	51.22
16.46	37.20	36.59	37.20	45.73	50.61	48.78	0.00

terms of planting and harvesting times and is drought tolerant. In Benin, cassava is the second most widespread crop behind maize. Cassava is the largest crop in mixed cropping systems; it is present on a wide range of markets and is a stable source of income and food, so it represents a form of food security for many households (Jarvis et al., 2012). These observations were noted as part of this study.

The two dominants cassava cropping systems are more implemented in the cotton farming zone of central Benin because producers in this area still have enough cultivable land which allow them to practice crop rotation and combine other crops (particularly legumes) with cassava while respecting the acceptable spacing between crops. The fact that cassava is intercropped or in rotation with legumes allows it to benefit from the atmospheric nitrogen fixed by the legumes or to benefit from the residual effect of nutrients of the previous crops fertilized with mineral fertilizer which they could not fully benefit from. The reasons why this is possible are that cassava is a plant that is highly tolerant to drought and also to conditions of severe soil fertility decline (Tomlinson et al., 2018). The benefit of cultivating cassava is that it can generate high yields under low-fertility, water-stressed conditions according to farmers. Nonetheless, growing cassava in sloping, hilly and arid areas pose a high risk in terms of erosion. According to farmers, fallowing cassava is a cropping practice that improves soil fertility (Saidou, 2006). This perception on the part of farmers is explained by the fact that during the vegetation period, the canopy of cassava branches protects the soil against erosion factors (rain and wind). In addition, there is a high production of biomass which is very rich in macronutrients and which, by decomposing with the roots, regenerates the soil. However, this would not be a strict fallow in the sense of the term, since throughout this period cassava grows. In extensive cassava systems, biological activity, especially of earthworms, is intense and the producers attribute this to a fertile soil (Saïdou et al., 2004) which would be beneficial. Native biological soil practices are feasible land use approaches for maintaining soil fertility (or reducing soil fertility loss) using low external input technologies within the socio-economic and cultural framework that prevails. In addition, cassava produces a lot of litter that protects the soil against runoff. It is the microclimate created by this that explains the intense activity of earthworms.

Despite these potential advantages, Saidou (2006) has shown that the production levels of subsequent crops are not as high. Similarly, even when these benefits are observed, soil fertility levels remain low in cassava cropping systems, and there is therefore a need to introduce integrated soil fertility management practices.

In the cropping system 5 farmers used organic fertilizers, but no crop rotation is practiced in the agroecological zone 6 (Zakpota, Klouékanmè, and Djakotomey) where land is not available enough compared to the department of Collines and where other crops are more considered than cassava in terms of economic importance for the producer. Cropping system 1 characterized by the use of improved varieties and mineral fertilizer only is less adopted by producers in the study area but widely practiced in the zone of alluvial soils along the Oueme valley. This is due to the collaboration of producers with some NGOs working in this area. Producers generally use NPK and urea at respective doses of 150 and 50 $kg.ha^{-1}$ in order to increase cassava yield (Mugwe and Otieno, 2020). But these doses remain low according to the nutrient requirements of cassava to expect yields close to potential (Vanlauwe et al., 2014; Omondi and Yermiyahu, 2021).

Production constraints and cassava yield improvement strategies in Benin

The yield obtained in Benin and generally in Africa remains far below the yields achieved by agricultural research in Africa which is closed to 60 kg.ha^{-1} (Odedina et al., 2012). Despite the diversity of cassava cropping systems, yields remain low, especially as the results show that nutrient inputs are very limited. These different yields do not allow producers to make cassava production profitable and generate enough profits to ensure the repayment of the loans contracted for the establishment of the crop. Cassava plays a major role in households' food and income security in another country. Although several efforts have been made to address low yield in cassava production through the use of improved technologies adoption level of such technologies by farmers has not been high. This finding suggest that cassava does not deplete soil and a careful selection of cassava crop cultivars in extensive farming systems can be useful in maintaining reasonable yields. The regression results showed that the use of improved varieties combined with adequate fertilization practices would be adequate to obtain high root n yields of cassava. The decline of soil fertility and the limited use of mineral fertilizers are the factors that explain these results in the context of this study. Mineral fertilization of cassava is a strategy that significantly improve root yield in areas with low soil fertility (Dagbenonbakin, 2005; Ezui et al., 2016; Byju and Suja, 2020). In addition, the regression tree model showed that supply of mineral fertilizers combined with the use of improved varieties ensures good yields. It is shown that improved varieties have good nutrient use efficiency, which makes the application of mineral fertilizers more profitable than local varieties (Kishore et al., 2021; Pushpalatha and Byju, 2022). In this context, the establishment of fertilizer doses for balanced cassava nutrition would be essential in order to improve the yields of roots and leaves in these production areas, especially since the lack of specific cassava fertilizers has been reported as constraint (Luar et al., 2018; Omondi and Yermiyahu, 2021). The establishment of these new fertilizer formulas should take into account micronutrients, which are factors that limit the effectiveness of macronutrients (Faki et al., 2021; Anago et al., 2023), especially since micronutrient deficiencies in African's soils are currently very high (Kihara et al., 2020). But to confirm this, it would be interesting to carry out future studies to assess macro- and micronutrient deficiencies in the soils of cassava-growing systems. The results also showed that transhumance is a major problem in the study area. Cattles can damage cassava fields (total destruction) which often lead to the abandonment of cassava cultivation by some producers and to the loss of certain traditional cassava varieties. A concrete framework for managing transhumance would be ideal in order to limit the low uptake of yield improvement technology, especially as it is recognized that institutional constraints hinder the introduction of innovations (Saidou, 2006).

Although farmers believe and assert that cassava could help maintain soil fertility (Saïdou et al., 2004; Adjei-Nsiah et al., 2004), formal mainstream research has sometimes asserted that cassava leads to soil impoverishment. However, some authors claim that cassava depletes the soil, which seems to be partly based on evidence that cassava grows on the poorest soils. This could be a case where correlation is not a good guide to cause. Another explanation could be that cassava is grown on these soils because it is able to tolerate (and subsequently extract) lower levels of nutrients than most other crops (Howeler, 2001). In itself, the contrast between scientific assertions and farmers' comprehensions is worth exploring. Cassava's ability to grow on poor soils is due to the fact that cassava is highly mycotrophic, based on its ability to form arbuscular mycorrhizae (AM) (Cardoso and Kuyper, 2006). Farmers believe that the resulting improvement in crop yield is due to cassava's potential to produce large quantities of leaf litter which, as it decomposes, enhances soil fertility. In this context of diversity of cropping systems and with the positive influence of soil fertilization under cassava cropping systems, it would be wise to assess the nutrient deficiencies of these soils in order to implement fertilization strategies that take into account the nutrients that are important for cassava cropping in the areas surveyed.

Conclusion

Cassava cultivation is an activity essentially dominated by men and a crop that provides significant income to producers. The cultivated areas are larger in the cotton farming zone of central Benin. Producers in the study area regarding soil fertility management techniques practice five cassava-cropping systems. These cropping systems are characterized by low or no fertilizer use.

Variables such as improved varieties, use of mineral fertilizers, use of organic fertilizers and crop rotation were factors determining cassava yields in the agroecological zones covered. This confirms our hypothesis that the differences in soil fertility management practices in cassava cropping systems in the agroecological production zones are the main factors that explain this yield gap since cassava soil fertilization practices differ according to the systems identified. Assessing the nutritional deficiencies of cassava cropping system soils will make it possible the establishment of a balanced fertilizer formula and the use of improved cassava varieties adapted to each agroecological zones were areas that future researches can explore to guarantee sustainable cassava yields in Benin.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

ACKNOWLEDGEMENTS

The authors thank the Improvement of Smallholder Agricultural Productivity (PAPAPE/SAPEP-Benin) of Benin National Agricultural Research Institute (INRAB), funded by the Islamic Development Bank (IDB) and Benin Government for the financial support of the present research program.

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