Journal of Agriculture and Environment for International Development - JAEID 2025, 119 (2): 41-58
DOI: 10.36253/jaeid-17093

Typology of *Cajanus cajan* cultivation systems in Benin, West Africa

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Submitted on: 2024, December 25; accepted on 2025, July 10. Section: Research Papers

Abstract: Pigeon pea farms are heterogeneous, applying varied cropping systems. In this context, the study of the typology of farms taking into account the cropping systems they adopt is of practical importance for the implementation of targeted and effective technological interventions. The objective of this research is to identify and characterize the pigeon pea cropping systems practiced in Central Benin. A field survey was conducted among 240 pigeon pea producers randomly selected in the communes of Bantè, Glazoué and Ouèssè. Principal Component Analysis (PCA), Chi-square test of independence, analysis of variance (ANOVA) and multinomial logit regression were used to analyze the collected data. Three types of cropping systems were identified. The first system, adopted by 31.25% of farmers, is characterized by pure stand cultivation, the use of herbicides and a reduced frequency of manual weeding. The second system, chosen by 47.08% of participants, is characterized by mixed cultivation with maize, legumes (soybean, peanut), or other crops (cassava, yam, market garden crops and sometimes in cashew plantations), without the use of herbicides but with a moderate frequency of manual weeding. The third system, adopted by 21.67% of farmers, is characterized by mixed cultivation with maize, the use of herbicides and a limited frequency of manual weeding. These systems have varying levels of economic performance and appear to be specific to each municipality. Factors such as available agricultural area, Mahi ethnicity, and location within the Glazoué and Ouèssè communes significantly influence the choice of these systems. The results advocate for promoting pure stand systems and improved varieties to optimize yields across all cultivation systems.

Keywords: Typology, Crop systems, Cajanus cajan, determinants, Benin

Introduction

Pigeon pea (*Cajanus cajan*) is one of the major edible grain legumes widely used globally in human diet (Kinhoégbè *et al.,* 2022; Yang *et al.,* 2020). It is emerging as a versatile food legume of critical importance, acting as a lifeline for resource-limited farmers in tropical and subtropical regions of Asia, Latin America, and Africa (Chanda Venkata *et al.,* 2019). Mature seeds of pigeon pea exhibit remarkable nutritional composition, including 18.8% protein, 53% starch, 2.3% fat, 6.6% crude fiber, and 250.3 mg minerals per 100 g. In addition, pigeon pea is frequently used in traditional medicine, with its leaves, flowers, roots and seeds, to treat various conditions of the skin, liver, lungs and kidneys (Hardev, 2016). As a perennial shrub, pigeon pea is distinguished by remarkable tolerance to drought conditions, high biomass production mainly used as fodder, and significant contribution of nutrients and moisture to the soil (Fossou *et al.,* 2016; Njira *et al.,* 2012). The main producing countries are India and Myanmar which account for 83% of the total production, followed by African countries such as Malawi, Tanzania, Kenya and Uganda, contributing 14% of the overall production (Makena *et al.,* 2022).

Pigeon pea farms are heterogeneous with varying capacities, needs and resources (Namuyiga *et al.,* 2022). This diversity implies variable adoption of agricultural technologies (Adjobo *et al.,* 2020). Such inherent variability often influences farmers' response to various practices aimed at improving agricultural productivity and natural resource management (Goswami *et al.,* 2014). In this context, studying farm typology considering the cropping systems they adopt is of practical importance for implementing targeted and effective technological interventions. Typologies provide a basis for simplifying farming systems and diversified analyses (Collier *et al.,* 2012). They help group diverse farms into coherent similar categories, thereby facilitating the inference of certain characteristics (Musafiri *et al.,* 2020). Developing a typology represents an essential step in any realistic assessment of the challenges and opportunities facing farmers, contributing to the proposal of appropriate technological solutions, policy measures and a comprehensive environmental assessment (Andersen *et al.,* 2007; Goswami *et al.,* 2014).

In Benin, pigeon pea occupies an essential place in the lives of rural households, being used not only as a staple food and in traditional medicine, but also as a source of income (Zavinon *et al.,* 2020). This plant is also used for soil preservation and weed control in agricultural fields (Dansi *et al.,* 2012; Kinhoégbè *et al.,* 2020). Knowledge of pigeon pea cultivation systems is essential to promote this crop in the country, as it will make it possible to propose technologies adapted to farms, optimize production and promote this plant with multiple uses. This study aims to characterize pigeon pea farms in Benin. It stands out from previous studies by an innovative approach that takes into account the specificities of farms, in particular cropping systems, to propose adapted technological solutions and improve agricultural productivity and natural resource management.

Materials and Methods

Study area

The study was conducted in the Collines department, in central Benin in West Africa. Located between Togo to the west and Nigeria to the east, it is bordered to the north by the departments of Donga and Borgou, and to the south by those of Zou and Plateau. Agriculture represents the main subsistence activity for local populations (DGCS-ODD, 2019; INSAE, 2016). Although pigeon pea is cultivated in several departments including Plateau and Couffo (Ayenan *et al.,* 2017), Collines department accounts for the majority of national production according to official statistics (MAEP-DPP, 2020). In addition, the fourth General Population and Housing Census (RGPH4) indicates that the population of this territorial entity increased from 535,923 inhabitants in 2002, with a density of 38 inhabitants per km2, to 717,477 inhabitants in 2013, with a density of 52 inhabitants per km2. This population growth combined with the fragility of ecosystems makes the sustainable use of natural resources essential, becoming one of the main challenges in this region (DGCS-ODD, 2019). Due to this growing importance of pigeon pea cultivation in this region, combined with the challenge of sustainable management of natural resources, the classification of farms according to the cropping systems adopted is of delicate importance for appropriate support.

In this department, discussions were held with grassroots development agents, extension agents of the Territorial Agency for Agricultural Development (ATDA) to identify three communes (Bantè, Glazoué and Ouèssè) of importance in terms of pigeon pea production. These are areas that have hosted trials and experiments on the cajanus cajan as part of the Soil Protection and Rehabilitation for Food Security (ProSol) project, the project to support the agro-ecological transition in cotton-growing areas (TAZCO), the Multisectoral Food, Health and

Nutrition Project (PMASN) and the Early Childhood Nutrition and Development Project (PNDPE). These projects aimed to improve yields and enhance the crop's nutritional potential. Within these communes, the study villages were selected on the basis of a summary census of pigeon pea producers carried out during an exploratory phase. Thus, three (3) villages were chosen per commune. The geographical location of these study villages is illustrated in Figure 1.

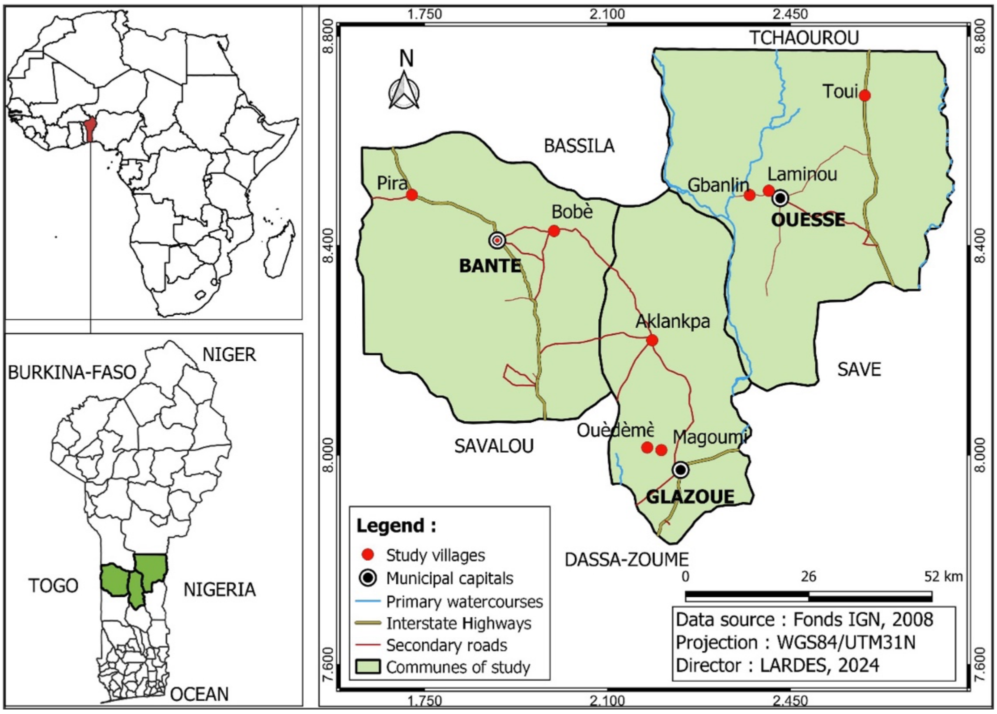

Figure 1. Geographic location map of the study villages

Finally, the less important flows are reflected in the scarce participation of Inca berry goods in international markets, highlighting a notable weakness of this value chain and the need for the prompt intervention of the public and private sectors to reverse the situation and improve the contribution of the Inca berry to the national GDP.

Sampling

The observation units of this research are the farms producing pigeon peas. Using a sampling frame from the summary census carried out during an exploratory phase, the random sampling technique was applied to select the farms surveyed. This sampling technique is widely recognized and used in many scientific studies because of its ability to ensure good representativeness of the population studied, by offering each individual the same chance of being selected (Bandara *et al.,* 2016; Biswas *et al.,* 2021; Chou and Chou, 2019; Far and Rezaei-Moghaddam, 2018; Sultana *et al.,* 2020).

This approach thus adopted made it possible to reach 80 pigeon pea producing farms in each commune. This sample size per commune is considered reasonable, in accordance with the recommendations of Kwak and Kim (2017) who estimate that a sufficiently large population requires a sample of at least 30 individuals to be representative.

Data collection

Primary data for this study were collected in July 2023. Individual interviews were conducted using a structured questionnaire, which had been pre-tested and appropriately adjusted.

Household heads of the 240 sampled farms or their representatives (usually the oldest person on the farm in their absence) were interviewed. Data collected covered the 2022-2023 agricultural season and included socio-economic characteristics of the farms and pigeon pea farming systems. The survey questionnaire was digitized and administered through direct interview through the KoboCollect mobile application by well-trained interviewers. Direct observation and information triangulation techniques were used to ensure the reliability of the responses provided by the respondents.

Theoretical approaches and data analysis

Understanding the complexity, diversity and dynamics of agriculture involves understanding agricultural systems. Although farms share some common characteristics, they are not all the same. Within a given agricultural system, farms may practice very similar cropping systems and belong to the same category, or belong to different categories but be highly complementary or not (Mazoyer and Roudart, 1997). This implies significant diversity between and within regions and countries, whether in terms of backgrounds, histories, environments or ways of operating of farmers (Lowder *et al.,* 2016). Under these conditions, a typology is now classic for development actions at the regional or national scale. The typology is a way to capture and understand the diversity of farms especially family farms, and it constitutes a means to design interventions and guide appropriate policy approaches (Alvarez *et al.,* 2014; Guarín *et al.,* 2020). In accordance with Cochet and Devienne (2006), “the history of agricultural development interventions shows that there can be no effective action, at the regional level, without prior and in-depth knowledge of the dynamics of the agrarian system and the diversity of farms”.

The basic principle of the typology is to group households that share similar characteristics to form a distinct “type” that can be compared with other “types”. The aim is to identify agricultural technologies or other development interventions that may benefit one type but not another, in order to target agricultural innovations appropriately (Hammond *et al.,* 2020). The typology thus becomes a decision-making tool that allows targeted interventions according to the specific problems of each agrarian system.

In the agricultural sector, statistical typologies are widely used due to their simplicity and flexibility (Akpatcho *et al.,* 2022; Freguin-Gresh and Razafimahefa, 2016; Kuentz-Simonet *et al.,* 2013; Mwabila *et al.,* 2023). Various approaches, such as Principal Component Analysis (PCA), Multiple Correspondence Analysis (MCA), Discriminant Factor Analysis (DFA), Mixed Data Factor Analysis (MDFA), as well as classification methods such as K- means and Hierarchical Ascending Classification (HAC) can be used to generate different types of typologies (structural typology based on the means of production available on the farm; functional typology based on the sequence of decision-making by the farmer to achieve his production objectives; typology based on performance criteria which are often coupled with the two previous ones; analytical typology constructed from the selection of discriminating indicators whose information comes from the farms themselves; statistical typology obtained by factor analyses of available empirical data; etc.) (Akpatcho *et al.,* 2022; Bélières *et al.,* 2017). Some of these approaches rely solely on quantitative data, while others integrate a set of quantitative and qualitative data (mixed data). In this study on pigeon pea farming systems, Principal Component Analysis (PCA) was chosen due to the nature of the variables associated with these systems. This method has proven to be particularly appropriate for farm typology, as evidenced by several previous research works (Adjobo *et al.,* 2020; Ayedegue *et al.,* 2020; Koné and Fok, 2021).

Typology of pigeon pea cultivation systems

The Principal Component Analysis (PCA) was based on variables or indicators deemed most likely to generate performance disparities between farms (Azonkpin *et al.,* 2018; Zongo *et al.,* 2016). In accordance with the work of Adjobo *et al.* (2020), Ayedegue *et al.* (2020), and Koné and Fok (2021), the following steps were followed for the PCA:

- The first step was to select potential variables while discarding those that showed significant correlations between them. (Koné and Fok, 2021) recommend maintaining a limited number of modalities for the typology criterion in order to guarantee its operationality. This step made it possible to retain the variables described in Table 4. It is important to note that the preselection of these variables was based on the observations made in the field during the survey.
- Depending on the variables selected, the farms were projected along the factorial axes.
- Then, the Hierarchical Ascending Classification (HAC) allowed to determine the different classes of pigeon pea crop systems and to classify them into more homogeneous types.
- The chi-square test of independence and analysis of variance (ANOVA) were used to describe the different classes of cropping systems obtained.

The economic analysis of the cropping systems was conducted using a differential approach that took into account the specificity of each cropping system. For pure crops, all production costs were allocated to pigeon pea, including soil preparation, seed purchase, labor for sowing, maintenance measures (manual and chemical weeding), plant protection, and harvesting operations. In the intercropped systems, cost allocation was carried out using a proportional estimation method by the farmers themselves, taking into account the area occupied by each intercrop, the approximate share of input consumed, and the labor time dedicated to each species. This approach makes it possible to isolate the specific economic performance of pigeon pea while taking into account interactions within mixed systems (Kermah *et al.,* 2017).

Modeling farm membership in cropping systems

The multinomial logit regression model was used to analyze the determinants of pigeon pea farms' membership in cropping systems. This model is an extension of binary logistic regression, suitable for multi-class classification problems (Madani *et al.,* 2022). It produces robust estimates by changing the probability between 0 and 1 to record odds ranging from negative infinity to positive infinity, as it applies the transformation of the dependent variable into a continuous variable (Ameh and Lee, 2022). The multinomial logit works by choosing one group as the base category that serves as a reference for the other groups. Therefore, all comparisons of the dependent variable are made against this base category, thus creating a reference point for the analyses (Greene, 2012; Madani *et al.,* 2022). The following equation presents the mathematical form of the cropping system membership model:

$$\begin{cases} P_1(Y_1 = 1/n) = \alpha_1 + \alpha_{11}X_1 + \alpha_{12}X_2 + \cdots + \alpha_{1k}X_k + \varepsilon_1, \\ P_2(Y_2 = 3/n) = \alpha_2 + \alpha_{21}X_1 + \alpha_{22}X_2 + \cdots + \alpha_{2k}X_k + \varepsilon_2. \end{cases}$$

With:

- P_1 and P_2 : Respectively the probabilities of choosing culture systems 1 and 2;
- k : The number of independent variables;
- α_i : The vector of coefficients of the parameters associated with the nth crop system;
- X_k : The $k^{ième}$ independent variable;
- n : The number of possible responses for the explained variable (n=3);
- ε_i : The centered Gaussian random variables associated with the nth crop system;
- α_{ik} : The regression coefficient associated with the nth crop system and the kindependent variables.

The influence of each independent variable on the cropping system is assessed using the likelihood ratio (LR) statistical test (Abdulhafedh, 2017). After identifying the logit equations and estimating the model parameters using the maximum likelihood method, it becomes essential to assess the statistical significance of the coefficients obtained. Indeed, multinomial regression coefficients only provide the direction of the effect of the independent variables on the dependent variable (Ameh and Lee, 2022; Greene, 2012).

Marginal effects represent the most relevant estimates of the impact of a unit change in an independent variable (predictor) on the dependent variable. In multinomial logit regression, the marginal effect of an explanatory variable (predictor) is the partial change in the probability of the event relative to the predictor of interest (i.e., the change in the probability of the event in response to a unit change in the predictor) (Abdulhafedh, 2017; Long and Freese, 2006). Marginal effects were estimated and the significance threshold for the probability is set at 10%.

In addition, socioeconomic and demographic characteristics were considered as potential predictors, given that various research studies have demonstrated their ability to differentiate farms (Alshurideh *et al.,* 2017; Budiastutik and Nugraheni, 2018; Granja *et al.,* 2018; Jain *et al.,* 2018). Modeling was performed using Stata software.

Results

Socioeconomic and demographic characteristics of producers

The socioeconomic and demographic characteristics of the respondents are presented in Table 1. It is clear from this table that the majority of the respondents (75%) are male, while 87.50% are married and 61.67% have never attended a formal school. In addition, 39.58% are part of a producer group centered around a specific crop. Regarding the average age of the producers, it is 45 (±10.95) years, with an average agricultural experience of 22 (±12.66) years and a specific experience in the production of pigeon peas of 7 (±7.31) years. As for their farms, the average agricultural land they have is 10.26 (±8.66) hectares, with an average size of 10 (±7.21) people per household, of which 6 are actively involved in agricultural activities.

In terms of pigeon pea production, the figures indicate that producers invest on average 81,184.47 (±65,370.87) CFA francs per hectare to achieve an average yield of 752.57 (±600.66) kilograms, which gives them a net profit of 297,534.6 (± 261,045.8) CFA francs.

Table 1. Socioeconomic and demographic characteristics of respondents

QUALITATIVE VARIABLES	TERMS AND CONDITIONS	ABSOLUTE FREQUENCY	RELATIVE FREQUENCY (%)
Sex	Female	60	25.00
	Male	180	75.00
Marital status	Bachelor	12	5.00
	Bride)	210	87.50
	Divorced	4	1.67
	Widower (ve)	14	5.83
Formal education	None	148	61.67
	Primary	40	16.67
	Secondary cycle 1	26	10.83
	Secondary cycle 2	18	7.50
	University	8	3.33
Membership of a group	No	145	60.42
	Yes	95	39.58
QUANTITATIVE VARIABLES		AVERAGE	STANDARD DEVIATION
Age		44.50	10.95
Experience in agriculture (year)		21.15	12.66
Pigeon pea production experience (year)		6.60	7.31
Total available area (ha)		10.26	8.66
Household size (number of individuals)		9.33	7.21
Agricultural assets (number of individuals)		5.37	4.69
Production costs of pigeon peas (FCFA*ha^{-1})		81184.47	65370.87
Pigeon pea yield (kg*ha^{-1})		752.57	600.66
Net profit from pigeon pea production (FCFA*ha^{-1})		297534.6	261045.8

Characterization of pigeon pea cultivation systems

The summary of the results from the Principal Component Analysis and the Ascending Hierarchical Classification are presented in Table 2 and Figure 2. It is observed in the table that the variables integrated in the model provide 83.63% of the information contributing to the classification of cropping systems according to dimensions 1 (53.76%) and 2 (29.87%). Furthermore, the determination of each factorial axis was carried out by analyzing the relative contribution of the modalities of the variables to the inertia explained by the defined factorial axes. The projection of the cropping systems along the factorial axes and the Ascending Hierarchical Classification (Figure 2) make it possible to distinguish three groups (clusters) of pigeon pea cropping systems.

Table 2. Summary of results from the PCA

DIMENSIONS	DIMENSION 1	DIMENSION 2	DIMENSION 3
Variance	1.613	0.896	0.491
% of variance	53.763	29.870	16.367
Cumulative variance (%)	53.763	83.633	100

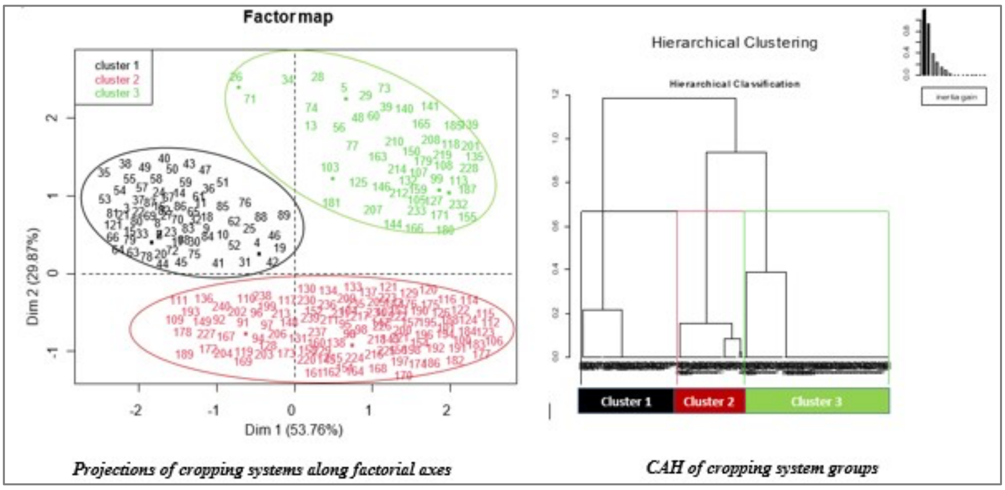

Figure 2. PCA and CAH results

Statistical description and performance of pigeon pea cultivation systems

The frequencies of the different modalities of the variables relating to the different groups are presented in Table 3. The results show varied significance of the relationships between the discriminating variables and the groups of crop systems.

Cropping system 1: Farms practicing type 1 cropping system mainly cultivate pigeon pea on mounds or ridges (93.33%) in pure stand (49.33%) with the use of herbicides (61.33%) and a low frequency of manual weeding (54.67%). In summary, farm group 1 practices a pure cropping system with the use of herbicide and a low frequency of manual weeding.

Cropping system 2: Farms that adopt type 2 cropping system choose to grow pigeon peas on mounds or ridges (72.57%), or in mixed cropping by associating it with corn (37.17%), legumes such as soybeans or peanuts (12.39%), or other crops (cassava, yam, market gardens) (7.08%). Most of these farms do not use herbicides (53.10%), but they practice manual weeding twice (53.98%). It can be noted that this is a mixed cropping system without the use of herbicides, but with an average frequency of manual weeding.

Cropping system 3: The vast majority of farms that opt for type 3 cropping system grow pigeon peas on mounds or ridges (88.46%), favoring mixed cropping (67.31%) by mainly associating it with corn (36.54%). They mainly use herbicide (80.77%) and carry out manual weeding once (50%). This third cropping system can be described as a mixed pigeon pea-corn cropping system with the use of herbicide and a low frequency of manual weeding.

Table 3 also shows the economic performance of each cropping system. The data reveal that although cropping system 1 entails higher production expenses (111,900.33 FCFA/ha), it generates a sufficiently high yield (1,109.10 kg/ha), allowing the farmer to obtain a higher net profit (400,908.67 FCFA/ha). On the other hand, cropping system 3 is less efficient, generating expenses of 42,987.23 FCFA per hectare and producing only 235.71 kilograms of pigeon peas, with a net profit of 90,007.03 FCFA. The average variations in production expenses, yield and net profit between cropping systems are statistically significant at the 1% level (p=0.000).

Table 3. Statistical description and performance of pigeon pea cultivation systems growing systems

VARIABLES	TERMS AND CONDITIONS	SYSTEM 1	SYSTEM 2	SYSTEM 3	TOGETHER	TEST
Type of plowing	No plowing	6.7	27.43	11.54	17.50	Chi2(2) =
	Plowing in ridges or mounds	93.33	72.57	88.46	82.50	15.10***
Type of cultural association	Pure culture	49. 33	43.36	26.92	41.67	Chi2(4) =
	Mixed culture	36	49.56	67.31	49.17	13.64***
	Intercropping	14.67	7.08	5.77	9.17	
Type of associated culture	No association	49.33	43.36	26.92	41.67	Chi2(6) =
	Pigeon Pea-Corn	29.33	37.17	36.54	34.58	11.87*
	Pigeon peas-Legumes (soy or peanut)	18.67	12.39	25	17.08	
	Pigeon peas - Other crops (cassava, yam, market garden)	2.67	7.08	11.54	6.67	
Crop rotation	Yes	53.33	48.67	61.54	52.92	Chi2(2) =
	No	46.67	51.33	38.46	47.08	2.37NS
Use of herbicide	Yes	61.33	46.90	80.77	41.25	Chi2(2) =
	No	38.67	53.10	19.23	58.75	17.15***
Frequency of manual weeding	Low (only once)	54.67	31.86	50	42.92	Chi2(4) =
	Average (twice)	41.33	53.98	34.62	45.83	14.78***
	Strong (more than twice)	4	14.16	15.38	11.25	
Economic performance						
Production costs (FCFA*ha^{-1})		111900.33	78375.33	42987.23	81184.47	F=20.01***
Yield (kg*ha^{-1})		1109.10	753.77	235.71	752.57	F=44.20***
Net profit (FCFA*ha^{-1})		400908.67	324422.89	90007.03	297534.6	F=28.11***

*NOTES: *** significant at 1% ($p \leq 0.01$); ** significant at 5% ($0.01 < p \leq 0.05$); * significant at 10% ($0.05 < p \leq 0.10$); NS= Not significant.*

Distribution of cultivation systems by commune

Figure 3 shows the distribution of cropping systems according to the research municipalities. The analysis of independence carried out with the Chi-square test is statistically significant at the 1% threshold (Pearson Chi2 (4) = 135.8816; p = 0.000), indicating that the spatial distribution of pigeon pea cropping systems depends on the municipality of residence. Indeed, cropping system 2 is more frequently observed in the municipality of Bantè, representing 72.5%. The municipality of Glazoué mainly adopts cropping system 3 (53.75%), while cropping system 1 predominates in the municipality of Ouèssè. Throughout the research area, cropping system 2 is dominant (47.08%), suggesting that pigeon pea is grown mainly in a mixed cropping system without the use of herbicide, but with an average frequency of manual weeding.

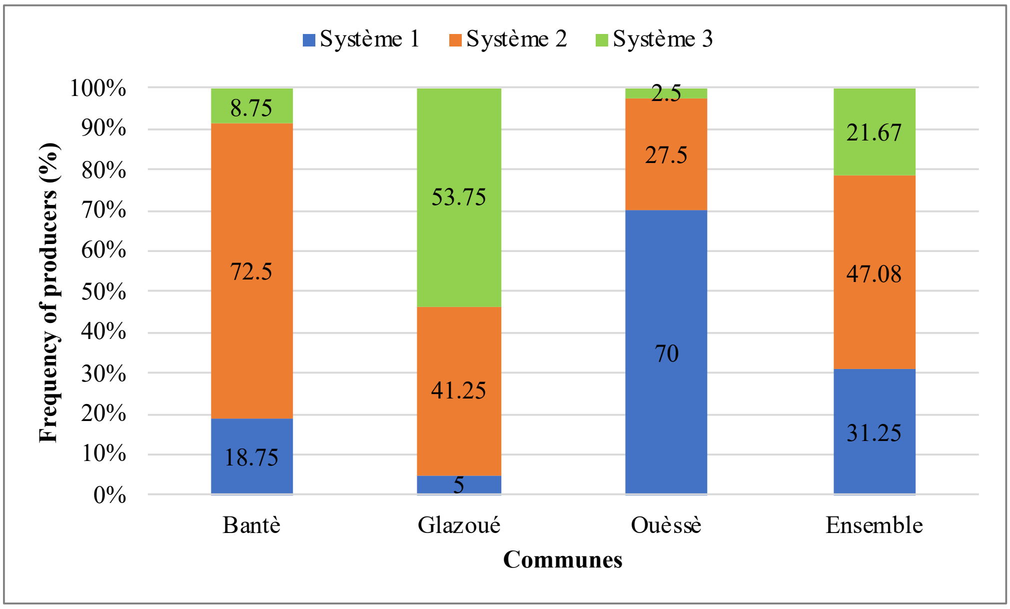

Figure 3. Distribution of pigeon pea cultivation systems by commune

Determinants of belonging to pigeon pea cultivation systems

Due to its predominance as the main cropping system, cropping system 2 was chosen as the reference group in the regression model. The results of the analysis of the determinants of farms' membership in pigeon pea cropping systems are presented in Table 4. The analysis of this table indicates that the likelihood ratio test (LR chi2(12) = 171.11) is significant at the 1% level (Prob > chi2 = 0.0000). This means that the model is globally significant at the 1% level, and therefore, the null hypothesis stating that the sociodemographic characteristics studied have no influence on membership in cropping systems is rejected. In addition, the value of the coefficient of determination R square (Pseudo R^2 = 0.3397) indicates that there is a 33.97% relationship between the explanatory variables and the model predictions. In other words, about 33.97% of the variability in the membership of farms to cropping systems can be explained by all the independent variables introduced in the model. Thus, it is clear that at least one of the explanatory factors makes it possible to discriminate producers according to their choice between cropping system 1 or 3. In light of these results, the estimated model appears interpretable.

The total size of the available agricultural area has a positive and significant impact at the 1% threshold on the choice of cropping system 3. This reflects that farms tend to adopt cropping system 3 rather than system 2 by 10% when the cultivable area increases. Belonging to the Mahi sociolinguistic group positively influences the choice of cropping system 1 at the 1% threshold, but negatively affects the choice of cropping system 3 at the 10% threshold. The marginal effects indicate that a Mahi producer has a 33.6% chance of preferring cropping system 1 over cropping system 2, but a 10.8% probability of not opting for cropping system 3 rather than cropping system 2. The municipality of Glazoué has a negative effect on the adoption of cropping system 1 at a 1% threshold, but positively influences the choice of cropping system 3 at a 1% threshold. Producers in this municipality have a 58.2% propensity not to choose cropping system 1 and a 41.3% propensity to adopt cropping system 3 rather than cropping system 2. On the other hand, the municipality of Ouèssè has a significant positive influence at the 5% threshold on the choice of cropping system 1. Producers in this municipality have a 21.3% probability of preferring cropping system 1 over cropping system 2.

Table 4. Determinants of belonging to pigeon pea cultivation systems growing systems

Variables	System 1		System 3	
	Ef.marg	P>z	Ef.marg	P>z
Experience in the production of pigeon peas	-0.01^{NS}	0.152	0.004^{NS}	0.184
Number of agricultural workers	-0.006^{NS}	0.966	0.001^{NS}	0.734
Available agricultural land area	-0.0007^{NS}	0.867	0.010^{***}	0.001
Sociolinguistic group (Mahi)	0.336^{***}	0.001	-0.108^{*}	0.055
Commune of Glazoue	-0.582^{***}	0.000	0.413^{***}	0.000
Commune of Ouèssè	0.213^{**}	0.036	-0.077^{NS}	0.416
Constant	-0.985^{*}	0.060	$-3,756^{***}$	0.000
Number of observations	= 240			
LR chi2(12)	$= 171.11^{***}$			
Prob > chi2	= 0.0000			
Pseudo R2	= 0.3397			

NOTES: *** significant at 1% ($p \leq 0.01$); ** significant at 5% ($0.01 < p \leq 0.05$); * significant at 10% ($0.05 < p \leq 0.10$); NS= Not significant; Ef.marg = Marginal effects.

Discussion

In the research area, three categories of pigeon pea cropping systems were identified. Analysis of the variables included in the PCA model revealed that crop rotation does not contribute significantly to the distinction between farms (p=0.305). Similarly, although the Chi-square test demonstrated a significant dependence between the type of ploughing and the cropping systems obtained (p=0.001), it is noteworthy that, in all systems, farmers predominantly opt for ridge or ridge ploughing when producing pigeon peas. The major differentiations between cropping systems mainly lie in the type of crop association, the type of associated crop, the use of herbicides and the frequency of manual weeding. These findings are consistent with those of Zongo *et al.* (2016), who found that the frequency of weeding and the type of associated crop play a significant role in the characterization of cropping systems.

The first cropping system concerns 31.25% of the farms surveyed. It is mainly characterized by the cultivation of pigeon peas in pure stands, with the use of herbicides and a reduced frequency of manual weeding (1 time). The second cropping system, predominant at 47.08% of the farms studied, involves the cultivation of pigeon peas in mixed mode, without the use of herbicides but with a moderate frequency of manual weeding (2 times). The third cropping system, less widespread, represents only 21.67% of the farms surveyed. In this system, pigeon peas are grown in mixed culture with corn, with the use of herbicides and a limited frequency of manual weeding (1 time). It seems consistent that the use of herbicides allows farmers to reduce the need for manual weeding on their plots. Herbicides thus play a contributing role in the transition to modern agriculture while limiting mechanization.

These results highlight that the practice of mixed cropping is prevalent in pigeon pea farms in the research area. This observation confirms the findings of Ayenan *et al.* (2017) who pointed out that intercropping is widespread in pigeon pea farms in the central and northern regions of Benin. Intercropping of pigeon pea with cereals and tubers has also been noted in other pigeon pea producing countries such as Nigeria (Egbe and Vange, 2008), Uganda (Manyasa *et al.,* 2009) and Kenya (Mergeai *et al.,* 2001). Indeed, pigeon pea has an initially slow height growth, with a deep root system and late maturity (Emefiene *et al.,* 2014). Its cultivation can be well benefited by associating it with other crops. Mixed cropping practice is often motivated by the failures associated with its pure stand cultivation, including production risks and its generally long cycle (Kermah *et al.,* 2017). This practice can also be adopted with the aim of increasing productivity per unit area (Alla *et al.,* 2015) or to implement species diversification, competition and facilitation practices in cropping systems (Hauggaard-Nielsen and Jensen, 2001).

Further analysis reveals that cropping system 1, which is mainly focused on pure cropping, has higher economic benefits than cropping systems 2 and 3, which are mainly focused on mixed cropping. These results are consistent with the findings of Asiwe and Madimabe (2020) and Issaka *et al.* (2024), who indicate that mixed cropping fails to optimize plant density and ensure efficient use of resources. This practice is suggested to be the cause of the low grain yield of pigeon pea observed in Limpopo Province, South Africa, according to (Gwata and Shimelis, 2013). Comparing systems 2 and 3, system 2 appears more beneficial, a situation that appears to be related to observed variations in cultivation techniques, particularly in the use of herbicides and the frequency of manual weeding.

The geographical distribution of cropping systems reveals a specificity specific to each commune. Indeed, in the commune of Bantè, farmers mainly adopt cropping system 2, characterized by mixed cultivation without the use of herbicides, but with a moderate frequency of manual weeding. The commune of Glazoué is mainly associated with cropping system 3, which involves mixed cultivation with corn, the use of herbicides and a limited frequency of manual weeding. As for the commune of Ouèssè, it is mainly associated with cropping system 1, characterized by pure stand cultivation, the use of herbicides and a reduced frequency of manual weeding. These results are consistent with those of Adjobo *et al.* (2020) who stipulate that the types of farms can vary from one commune to another.

Furthermore, several factors influence the choice of these cropping systems by farms. The increase in the total size of the available agricultural area directs the producer towards the choice of cropping system 3 rather than cropping system 2. The main distinguishing variables between cropping systems 2 and 3 are the use of herbicides and the frequency of manual weeding. The increased availability of cultivable area leads to an expansion of production (Bazie *et al.,* 2020; Rached *et al.,* 2018), which inevitably implies the use of herbicides and a decrease in the frequency of manual weeding.

When the farmer is a Mahi, there is a strong chance that he will opt more for cropping system 1 and not choose cropping system 3. This assumes that the Mahi prefer to cultivate pigeon pea in pure stand, with the use of herbicides and a reduced frequency of manual weeding, or at the limit in mixed mode, without the use of herbicides but with a moderate frequency of manual weeding, rather than in mixed culture with corn, with the use of herbicides and a limited frequency of manual weeding. These choices thus reveal the cultural nature of pigeon pea production. This finding is consistent with the conclusions of Diop *et al.* (2022), who suggest that belonging to certain ethnic groups can influence the choice of agricultural practices. The results obtained by Azonkpin *et al.* (2018) also corroborate this idea, indicating that cropping systems vary according to ethnic groups and municipalities.

Conclusion

Pigeon pea cropping systems in Benin are diverse. Key elements of this diversity include the type of crop association, the type of intercropping, the use of herbicides, and the frequency of manual weeding. Three categories of cropping systems emerge: pure stand cropping, with the use of herbicides and a reduced frequency of manual weeding (system 1), mixed cropping, without the use of herbicides but with a moderate frequency of manual weeding (system 2), and mixed cropping with maize, with the use of herbicides and a limited frequency of manual weeding (system 3). System 2 predominates throughout the study area, although each system appears to be specific to each commune. These cropping systems have different levels of economic performance. Furthermore, factors such as the total size of the available cultivable area, Mahi ethnicity, as well as location in the communes of Glazoué and Ouèssè, significantly influence the choice of these cropping systems. These results highlight the importance of targeted public policies to promote more efficient cropping systems and support pigeon pea production in Benin. The results highlight the potential of stand-based cultivation to improve farm productivity and profitability. They also enable the promotion of improved varieties to boost yields across all cropping systems.

Declarations

Conflict of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

Funding

The authors received no financial support for the research, authorship and/or publication of this article.

Ethics approval

This research was not submitted to an ethics committee for approval, as the University of Parakou, to which the Laboratory for Analysis and Research on Economic and Social Dynamics (LARDES) is attached, does not yet have such a structure for scientific research.

Nevertheless, the data collected for this study fully respects the integrity of the participants. They have been anonymized to guarantee confidentiality. Furthermore, all participants in the surveys and interviews gave their informed consent orally, thus confirming their agreement to answer the questions and contribute to this research.

Data availability

The data used and analyzed during this study can be obtained upon reasonable request from the corresponding author.

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