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Research Article

Farm typology farming practices, diversity and transition to agricultural intensification in Faragouaran Municipality, Southern Mali

Bebe Alfred Dembele*
Pan African University Life and Earth Sciences Institute (Including Health and Agriculture), Ibadan, Oyo State, Nigeria
Mobolaji Omobowale
Department of Agricultural and Environmental Engineering, University of Ibadan Ibadan, Oyo State, Nigeria
Souleymane Sidi Traore
Department of Geography, University of Social Sciences and Management of Bamako, Bamako, Mali

*Corresponding author. E-mail: alfresbooba@gmail.com

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Abstract
Since the 1970s, the Malian Textile Development Company's (CMDT) introduction of cotton has transformed South Mali's agriculture, driving intensification, mechanisation, and farm diversification. While small, poorly equipped farms have declined, some subsistence-focused practices persist. The study aimed to characterise the typology of family farms in the context of anthropogenic pressures and territorial changes. To achieve this, semi-structured surveys were conducted on 180 farms across seven randomly selected villages. Farms were classified into six types (T_1 to T_6) based on cultivated area, crop distribution, livestock, equipment, and agricultural workforce. Multivariate analysis of variance (MANOVA) was used to examine the effect of different farm types on several dependent variables. The results showed a predominance of type T_4 (49%), T_5 (20%), and T_6 (17%) farms, which were mostly medium-scale to large-scale. Wilks' lambda test (0.473) indicated that 52.7% of the variance in dependent variables is attributed to differences between farm types. The F value of 6.478, with a p-value of 0.000, showed that these differences were statistically significant ($p < 0.05$). The Partial Eta Squared of 0.171 reflected a moderate effect size, suggesting that farm types account for 17.1% of the total variance in dependent variables. Significant differences were observed for each variable across the different farm types (T_1 to T_6). Equipment accounted for the highest proportion of explained variance (37.1%), while agricultural labor showed the lowest (12.2%). The typology highlights a marked diversity in farming systems, shaped by socioeconomic and environmental factors, within a context of gradual modernisation and pressure on resources.

Keywords: Diversity, Family Farm, Intensification, Typology, Transition

INTRODUCTION

In Africa, family farms represent a significant portion of the agricultural sector, contributing considerably to food security, rural employment, and economic development (FAO, 2017; Jayne *et al.,* 2014; Wiggins and Keats, 2013). Historically, these family farms have been characterised by their modest size, family management, and reliance on traditional agricultural practices adapted to local conditions. However, over the past few decades, several factors have led to a marked evolution in the typology of these farms (Cousins, 2013; Mellor and Malik, 2017). The evolution of family farm typology in Africa reflects a complex transition marked by gradual modernisation while facing environmental and socioeconomic challenges (Spielman *et al.,* 2021). Understanding this evolution is essential for designing policies and strategies to support family farms' sustainability, resilience, and competitiveness across the continent (Losch and Fréguin-Gresh, 2013; Pingali and Rosegrant, 1995).

In Mali, family farms form the backbone of agriculture, playing a central role in food production, natural resource management, and rural economic development (IFAD, 2019). These farms, typically small to medium-sized and family-managed, have evolved in response to socioeconomic changes, environmental pressures, and agricultural policies (Cotula *et al.,* 2004; IER, 2020). Government policies and development programs have significantly impacted the evolution of family farms in Mali (Kassogué, 2020; Sidibé *et al.,* 2021). Introducing subsidy programs, technical training, and improved access to agricultural inputs has contributed to the modernization of practices. At the same time, the growing demand for agricultural products in national and international markets has led to changes in farm structures and production systems (Koné *et al.,* 2019). Anthropogenic pressure resulting from population growth, urbanization, and intensified agricultural practices places considerable stress on natural resources (Ballo *et al.,* 2016). These changes reflect the socioeconomic transformations, environmental pressures, and agricultural policies that have shaped the rural landscape of this region (Abu Hatab *et al.,* 2019; Schirpke *et al.,* 2023).

Like other regions in Mali, family farms in cotton-growing areas have been characterized by traditional subsistence farming practices, with a strong reliance on local climatic conditions and natural resources (Bataillé, 2015; Traore *et al.,* 2015). Cotton production, introduced and promoted by the CMDT since the 1970s, has had a profound impact on these farms (Dufumier, 2005; Soumaré *et al.,* 2021). This cash crop has intensified agricultural practices, increased specialisation, and restructuring of family production systems (Cesaro, 2020). The development of cotton production corresponds to a deep evolution in agrarian systems and the production systems of family farms. One of the most striking processes is the shift from a traditional slash-and-burn agriculture system (crops rotating with varying lengths of fallow periods) to a permanent cultivation system (Dissa *et al.,* 2024). Over time, farms have invested in increasing their equipment (particularly animal traction equipment) and livestock, significantly reducing the proportion of poorly equipped farms (Belieres *et al.,* 2010). The typology of family farms in Mali has evolved to reflect these changes (Dembele *et al*., 2023; Guirkinger and Platteau, 2015; Rasambatra *et al*., 2020; Soumaré *et al*., 2021). Today, there is increasing diversity in farm types, ranging from more intensified and commercialised farms to more sustainable and subsistence-oriented systems. New classifications highlight variations in farm sizes, cultivation practices, resource management, and resilience levels (Soumaré *et al.,* 2021; Stringer *et al.,* 2020; Van Zonneveld *et al.,* 2020).

In this complex context, the typology of family farms becomes an essential tool for understanding the diversity of agricultural practices and their adaptation to environmental and climatic pressures (Gafsi *et al.,* 2007). This typology allows for the classification of farms based on criteria such as size, structure, resource management practices, and resilience to climate change (Awoke Eshetae *et al.,* 2024). By identifying the different types of farms and their specific characteristics, it is possible to design strategies to promote sustainable agricultural practices and enhance the resilience of family agricultural systems to current challenges. Thus, a thorough typological approach helps to better understand the needs of family farms in Africa, informs policies and interventions to support their sustainability, and fosters a transition towards more resilient and environmentally respectful agricultural systems (Losch and Fréguin-Gresh, 2013). The evolution of family farms in Mali is marked by a transition from traditional agricultural systems to more modern and specialised forms, influenced by economic, environmental, and political factors. However, this transformation does not follow a single, uniform model. It varies by region, production system, and policy context. This raises a key research question: How has the typology of family farms in Mali evolved in response to socio-economic, environmental, and political changes, and what are the implications for the sustainability and resilience of the agricultural sector?

Thus, this study aims to analyse the evolution of family farm typology in Mali in response to socio-economic, environmental, and political changes and to assess its implications for the sustainability and resilience of the agricultural sector.

MATERIALS AND METHODS

Study area

Faragouaran municipality is located in the southern zone of Mali, precisely in the western Bani-Niger agro-ecological zone between 7°58'09" to 7°42'35" Longitude West and 11°12'26" to 11°30'11" Latitude North. The Municipality covers an area of 516.91 km^2 with a total population of 17,943 inhabitants (RGPH, 2023) (Fig. 1). The relief is made up of flat land covered with woody vegetation; some very slightly rocky hills break up the relief. The climate is Sudano-Sahelian and characterised by a very pronounced alteration between a dry season, dominated by dry winds (Harmattan) and a rainy season of three to six months (between May and October), with humid winds coming from the Gulf of Guinea (Monsoon). The annual rainfall varies between 900mm and 1000mm and 20 to 35 °C for the temperature.

No river feeds the area; however, some ditches and permanent seeded ponds favor the rice-growing and watering animals. Agriculture constitutes the main activity of the population. Maize, sorghum, rice, groundnut, cotton and cowpea are the main crops. The flora ranges from open forest to shrub savannah with a varied herbaceous cove and the fodder potential is high. The main ligneous species found in the Municipality are *Khaya senegalensis, Pterocarpus erinaceus, Butyrospermum parkii, Parkia biglobosa, Andansonia digitata and some herbaceous species such as Andropo-*

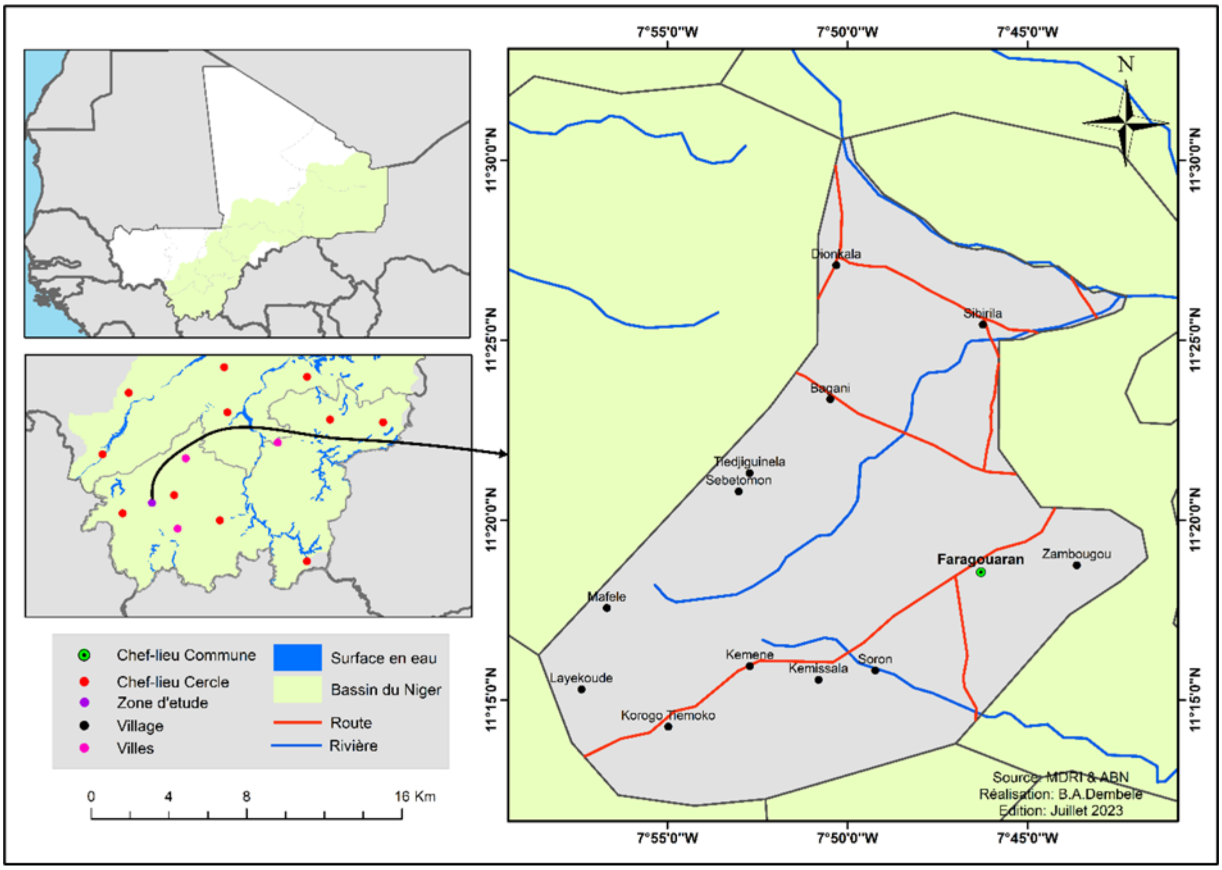

Fig. 1. *Map showing Faragouaran Municipality*

gon gayanus, Andropogon pseudarpricus, Cymbopogon giganteus, Imperata cylindrica, Digitaria horizontalis and *Pennicetum pedicelatum*. The Municipality's fauna was once rich and varied but now consists of a few warthogs, antelopes, rabbits and birds (guinea fowl, partridges, ducks, etc., both nocturnal and diurnal) (Bengaly, 2010).

Data collection

Selection criteria

For this study, random sampling was conducted using the lottery method (small paper or hat method). This type of sampling was chosen because the rural Municipality of Faragouaran consists of 11 villages, which could not be fully studied within the available time and resources (Table 1). Therefore, the survey was focused on 2/3 of the villages in the Municipality. The villages were numbered from 1 to n, and the numbers were drawn to select the villages to be surveyed. Random sampling was done without replacement, meaning that the drawn numbers were not placed back into the hat.

Sample size

Once the target villages were selected, the formula below was used to determine the size of the study population (family farms).

$$n = z^2 \cdot p\,(1 - p) / m^2 \qquad \text{Eq.1}$$

Where:

n = sample size, z = confidence level according to the reduced centred normal distribution (for a confidence level of 95 %, z = 1.96; for a confidence level of 99 %, z = 2.575), p = estimated proportion of the population with the characteristic (if unknown, p = 0.5 is used, which corresponds to the worst case, i.e. the widest distribution) and m = acceptable margin of error (e.g. we want to know the true proportion to within 7%).

The number of family farms to be surveyed per village was determined based on an estimated sample size of 180. With the reduction of the sample size to 180, a margin of error of 7% and a confidence level of 95% were accepted. This adjustment is necessary due to time constraints and financial limitations. It is important to note that the smaller the sample size, the larger the margin of error, which affects the accuracy of the study's results.

Method of selecting family farms

The type of sampling chosen for this study was the systematic method. The rural Municipality of Faragouaran includes 11 villages, which could not be studied in the time and resources available. A sample of 180 family farms was selected for the study. With a total of N (362) family farms and n (180) as the sample size, the sampling step (S) was calculated using the formula:

$$S = N/n. \qquad \text{Eq.2}$$

Table 1. Showing study villages

Villages	Cooperative	Family farms	
		Number	**Sample**
Kemene	Kemene	45	22
Kemissala	Kemissala 1	39	19
	Kemissala 2	29	14
Sebetomon	Sebetomon	36	18
Sibirila	Sibirila	67	33
Soron	Soron	49	24
Tiedjiguinela	Tiedjiguinela	36	18
Zambougou	Zambougou 1	39	19
	Zambougou 2	22	11
Total		**362**	**180**

The sampling interval (S) was approximately 2. Systematic selection was made by selecting the 2nd village in the census (Taherdoost, 2016). After the data cleaning process, 163 family farms were retained out of the initial 180, as they provided complete responses during the field surveys. This selection was based on the need to analyse consistent and reliable information, eliminating family farms with missing or inconsistent data. This filtering is essential to ensure the accuracy and validity of the results, allowing for a more precise analysis of agricultural dynamics. By keeping only the farms that provided exhaustive responses, the study can better reflect on-the-ground realities and variations between the different family farms.

Data analysis

Farm types classification

To characterise family farms typology in the rural Municipality of Faragouaran (Table 2), the methodology was inspired by the experience of the "*Project to Support the Improvement of Governance in the Cotton Sector within its New Institutional Framework, and the Productivity and Sustainability of Farming Systems in Cotton-Growing Areas*" (PHASE II). The proposed method relies on the use of several variables related to the structure and functioning of family farms. After conducting a Principal Component Analysis (PCA) and an Ascending Hierarchical Classification (AHC), the variables selected to establish the typology include the number of agricultural workforces, number of draft oxen (BL), total number of cattle, number of ploughs and carts, total area, total cultivated area, the area dedicated to cotton, and the area allocated to cereals. In the context of this study, the approach follows the same logic while focusing on the main variables already identified (Bélières *et al*., 2017; Diawara *et al*., 2017). The selection of TPO (Total Plough Oxen), TAM (Total Agricultural Materials), TCA (Total Cultivated Area), and TAW (Total Agricultural Workforce) is based on their ability to capture key structural, economic, and labor-related characteristics that define the evolution of family farms in Mali. TPO and TAM reflect the level of mechanization and technological advancement, distinguishing subsistence farms from modernized and commercialized ones. TCA and TAW provide insights into land-use intensity and labor availability, which are critical for assessing farm productivity, diversification, and resilience. These variables collectively enable a robust classification of farm typologies, facilitating a deeper understanding of their sustainability, resource management strategies, and adaptation to socio-economic and environmental changes.

Multivariate Analysis of Variance (MANOVA)

The Multivariate Analysis of Variance (MANOVA) was used to examine the effect of different types of family farms on several dependent variables, including agricultural equipment, total cultivated area, total number of cattle, and agricultural workforces. MANOVA is particularly suitable in this context because it allows for the simultaneous evaluation of differences between groups across multiple dependent measures while controlling for Type I errors associated with multiple univariate tests (Tabachnick *et al.,* 2019). The analyses were conducted using SPSS 20 (Statistical Package for the Social Sciences), which provides robust tools for performing MANOVA and other statistical analyses. Two hypotheses were tested:

Null Hypothesis (H_0): There were no significant differences between the types of family farms regarding the dependent variables.

Alternative Hypothesis (H_1): There were significant differences between the types of family farms concerning at least one of the dependent variables.

The Wilks' Lambda statistic was calculated to determine the proportion of variance in the dependent variables that can be attributed to differences between the groups. A Wilks' Lambda value close to 0 indicates a strong difference between the groups, while a value close to 1 suggests little or no difference (Box, 1954).

An F-test was conducted to assess whether the observed differences were statistically significant. The

Table 2. Indicator/variable framework for determining types of family farms

Types	% Cotton	TPO	TAM	TCA	TAW	Total Cattle	% Cereals	TCA/TAW	TCA/Cattle
T_1	0	0 - 2	0 - 3	1 - 6	2 - 14	0 - 4	80- 100	0.25 - 0.75	0 - 1
T_2	0 - 20	0 - 3	1 - 4	2 - 9	4 - 19	0 - 6	5 - 30	0.30 - 1.00	0 - 0.67
T_3	0 - 25	0 - 4	1 - 10	3 - 11	3 - 20	0 - 15	40 - 80	0.33 - 1.92	0 - 2.86
T_4	20 - 40	1 - 5	3 - 7	4 - 13	4 - 21	1 - 20	30 - 65	0.41 - 1.63	0.11 - 2.50
T_5	40 - 60	3 - 8	3 - 10	8- 21	10 - 22	4 - 31	40 - 60	0.62 - 1.89	0.25 - 3.71
T_6	20 - 43 and over	6 - 20 and over	4 - 13 and over	11 - 31 and over	10 - 50 and over	14 - 80 and over	40 - 70 and over	0.5 - 2.14 and over	1.00 - 5.71 and over

associated p-value was compared to an alpha threshold of 0.05 to decide on the rejection of the null hypothesis.

Effect size was measured using Partial Eta Squared (η²□), which indicates the proportion of variance explained by the types of agricultural operations. Partial Eta Squared values of 0.01, 0.06, and 0.14 are considered weak, moderate, and strong effects, respectively (Cohen, 1988).

Cross-validation was not performed to verify the robustness of the MANOVA results due to the limited dataset (n = 163). The full sample was used to preserve statistical power and ensure the reliability of the analysis within these constraints

Descriptive statistics

Descriptive statistics were used to summarize and describe the main characteristics of the variables studied in our analysis. This process included calculating measures of central tendency, such as the mean and sum, as well as measures of dispersion, such as the standard deviation. These statistics provided an overall view of the data and help to understand the distribution of the variables (Kaliyadan and Kulkarni, 2019).

RESULTS

Sociodemographic characteristics and distribution

Distribution of family farms

The data collected comes from various family farms distributed across several villages (Fig. 2). The total sample was distributed as follows: 17% of the farms were located in each of the villages of Kemissala, Sibirila, and Zambougou, indicating an equal distribution in these three (3) locations. The village of Soro included 14% of the farms, while Kemene and Sebetomon host 12% and 11% of the farms, respectively. Finally, only 9% of the farms were situated in the village of Tiedjiguela.

Distribution of farm types

Fig. 3 illustrates the distribution of different types of farms in the studied villages. Types T_4, T_5, and T_6 are clearly predominant, while types T_1, T_2, and T_3 are less common in the region

Farm type T_1 was the least frequent, found only in the villages of Sibirila and Soron, with a total of eight farms (Table 3). Type T_2 farms were evenly distributed between Kemissala, Sibirila, and Soron, with one farm in each village, totalling three. Type T_3 farms, numbering twelve, were spread across several villages, with a notable presence in Kemissala, Kemene, Sebetomon, Soron, and Tiedjiguinela. Type T_4 farms were the most common, with 80 farms, primarily located in Kemissala, Sibirila, and Zambougou. Type T_5 farms, the second most numerous, were mainly concentrated in Zambougou, while Type T_6 farms, numbering 27, were predominantly situated in Kemene and Kemissala, with a small presence in Zambougou and none in Soron.

Size of agricultural farms

The Fig. 4 presents the family farm distribution in the Rural Municipality of Faragouaran. Medium-scale farms, corresponding to types T_3 and T_4, are the most

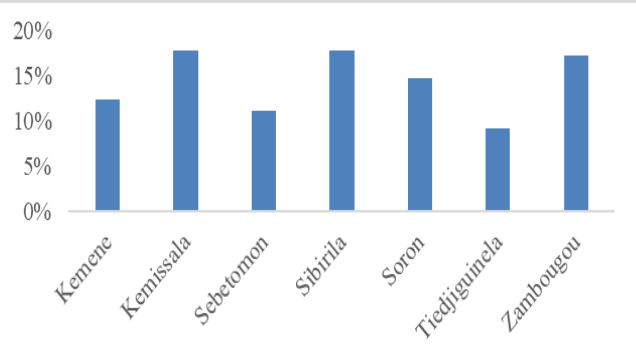

Fig. 2. *Distribution of farms in the rural Municipality of Faragouaran*

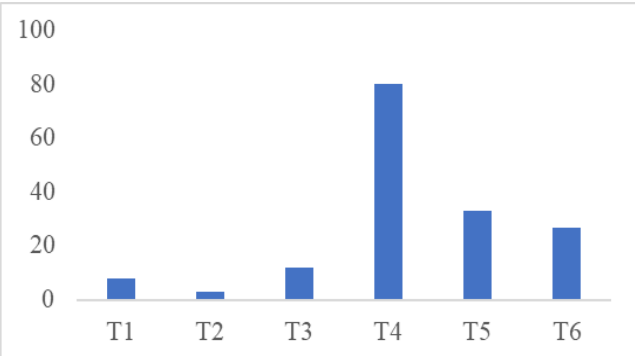

Fig. 3. *Spatial distribution of different types of family farms*

common, representing 56% (92) of the total. Large-scale family farms, including types T_5 and T_6, hold the second position in terms of number and proportion, with 37% (60). Finally, small-scale farms, consisting of types T_1 and T_2, are the least frequent, representing only 7% (11) of the farms in the Municipality.

Analysis of agricultural production factors

The data presented in Table 4 show the means, standard deviations, and sample sizes for four variables measured across different types of farms (T_1 to T_6): total equipment level, total cultivated area (TCA), total number of cattle, and agricultural workforces. The results indicate d a high level of heterogeneity among the types of farms. Type T_6 stands out across all indicators with the highest levels of equipment, cultivated area, cattle, and workforce. In contrast, type T_1 appeared to be the least equipped, with the smallest cultivated area and the lowest agricultural workforce. The other types of farms (T_2 to T_5) fell in an intermediate position, showing moderate variability among them.

Multivariate analysis of variance in agricultural production factors

Table *5* presents the results of the MANOVA test, which examines the influence of farm types on socio-demographic characteristics. The Wilks' lambda value of 0.473 indicated that 52.7% of the variance in the dependent variables is attributable to differences between the farm types. With an F-test value of 6.478, the observed differences are statistically significant, as confirmed by a p-value of 0.000, well below the 0.05 threshold. This allows us to reject the null hypothesis and conclude that farm types significantly affect the dependent variables: agricultural equipment, total cultivated area, total number of cattle, and agricultural workforce. Finally, the Partial Eta Squared value of 0.171 reflects a moderate effect size, suggesting that the farm types explain 17.1% of the variance in the dependent variables.

All dependent variables showed significant differences ($p = 0.001 < 0.05$) based on the different types of farms (T_1 to T_6). However, the percentage of variance explained, measured by the Partial Eta Squared, varied from one variable to another (Table 6). The highest proportion of variance was observed for agricultural equipment, at 37.1%, while the agricultural workforce presented the lowest percentage, at 12.2%.

Analysis of the multiple comparison of socio-demographic characteristics of farms

Multiple comparison of total farm equipment

Table 7 illustrates the results of the multiple comparisons of agricultural equipment levels among different types of farms (T_1 to T_6). T_6 farms significantly stood out from the other types (T_1, T_2, T_3, T_4, and T_5), with p-values below 0.05, indicating a distinctly higher level of agricultural equipment than the other types, particularly concerning T_1. T_1 farms showed a statistically significant difference compared to T6 farms (p = 0.000), but no significant difference was observed with types T_2, T_3, T_4, and T_5 (p-values > 0.05). This suggested that the level of agricultural equipment in T1 farms was lower than that in T6 farms but similar to that in the other types of farms. Other comparisons, such as those between T_2, T_3, T_4, and T_5 farms, did not reveal significant differences (p-values > 0.05), indicating that these farms had similar agricultural equipment levels. These results, with p-values less than 0.05, suggested that T_6 farms stood out in terms of agricultural equipment, while the other types (T_1 to T_5) shared similar organisational characteristics and levels of equipment.

Multiple comparison of total cultivated area (TCA)

Table 8 presents the multiple comparisons among different types of farms (T_1 to T_6) regarding the Total Cultivated Area (STC), analysing the mean differences (I-J), standard errors, significance levels (p-values), and 95% confidence intervals. The main observations were as follows:

T_1 farms show a significant difference in terms of total cultivated area with types T_3, T_5, and T_6 (p-value < 0.05). This indicates that these types of farms cultivate a substantially larger area than T_1. No significant difference is observed with T_2 (p-value > 0.05), suggesting similarity in total cultivated area between T_1 and T_2.

T_2 farms do not show significant differences with the other types of farms. However, there is a slight difference with T_6 (-9.9444, p = 0.150), but it does not reach the significance threshold, implying a degree of proximity in cultivated area with the other types.

T_3 farms show significant differences with T_1 and T_4 (p-values < 0.05), indicating that T_3 farms have a larger total cultivated area than both T_1 and T_4. No significant difference is noted with T_2, T_5, or T_6, suggesting proximity among these types.

T_4 farms differ significantly from types T_3 and T_6 (p-values < 0.05) but not from the other types. This means that T_3 and T_6 farms have a larger total cultivated area than T_4 farms.

T_5 farms show significant differences with T_1 and T_6 (p-values < 0.05), suggesting that T_5 has a larger area than T_1 but a smaller area than T_6. The other comparisons do not show notable differences.

T_6 farms significantly stand out compared to T_1, T_4, and T_5 (p-values < 0.05), confirming that T_6 has the largest total cultivated area among all types of farms.

Multiple comparison of cattle numbers

Table 9 presents the multiple comparisons of mean differences in the number of cattle among different types of farms (T_1 to T_6), analyzing the mean differ-

Table 3. Spatial distribution of farm types in the village

Village	T_1		T_2		T_3		T4		T_5		T_6		Total	
	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Kemene	0	0.0	0	0.0	2	16.7	11	13.8	1	3.0	6	22.2	20	12.3
Kemissala	0	0.0	1	33.3	2	16.7	13	16.3	2	6.1	11	40.7	29	17.8
Sebetomon	0	0.0	0	0.0	2	16.7	9	11.3	4	12.1	3	11.1	18	11.0
Sibirila	5	62.5	1	33.3	1	8.3	15	18.8	4	12.1	3	11.1	29	17.8
Soron	3	37.5	1	33.3	2	16.7	12	15.0	6	18.2	0	0.0	24	14.7
Tiedjiguinela	0	0.0	0	0.0	2	16.7	6	7.5	4	12.1	3	11.1	15	9.2
Zambougou	0	0.0	0	0.0	1	8.3	14	17.5	12	36.4	1	3.7	28	17.2
Total	**8**	**100**	**3**	**100**	**12**	**100**	**80**	**100**	**33**	**100**	**27**	**100**	**163**	**100**

ences (I-J), standard errors, p-values, and 95% confidence intervals. The main results are as follows:

T_1 farms showed no statistically significant differences with the other types (T_2, T_3, T_4, and T_5) in terms of the number of cattle. However, a significant difference was observed with T_6 (-31.14, p = 0.016), suggesting that T_6 farms had significantly more cattle than T_1 farms. T_2, T_3, and T_4 farms did not show statistically significant differences with other types of farms, including T_6 (p = 0.473), indicating that these farms were similar in terms of the number of cattle. However, an exception was noted for T_3 and T_4, which presented significant differences with T_6 and T_5, respectively (p-value < 0.05). This meant that T_5 and T_6 farms had a greater number of cattle compared to T_3 and T_4 farms.

T_6 farms stood out significantly from the other types of farms, particularly T_1, T_3, and T_4, with p-values less than 0.05, indicating that they possessed a markedly higher number of cattle. T_6, however, showed similarities with T_5 in terms of the number of cattle.

Table 4. Characteristics of the main means of production on farms

Type		Mean	Std. Deviation	N
Total Equipment	T_1	2.38	1.302	8
	T_2	3.33	3.215	3
	T_3	5..17	2.368	12
	T_4	4.14	1.329	80
	T_5	4.61	1.870	33
	T_6	8.93	4.714	27
	Total	5.00	3.010	163
Total Cultivated Area (TCA)	T_1	4.81	3.814	8
	T_2	9.67	4.041	3
	T_3	16.14	10.150	12
	T_4	10.20	4.234	80
	T_5	13.85	5.106	33
	T_6	19.61	10.090	27
	Total	12.66	7.314	163
Total Cattle	T_1	9.75	24.406	8
	T_2	10.33	16.197	3
	T_3	11.00	16.492	12
	T_4	4.78	6.455	80
	T_5	25.42	42.376	33
	T_6	40.89	24.532	27
	Total	15.74	26.588	163
Agriculture Workforce	T_1	4.50	3.703	8
	T_2	10.67	8.145	3
	T_3	14.75	15.915	12
	T_4	9.39	5.967	80
	T_5	14.55	9.855	33
	T_6	14.89	8.382	27
	Total	11.52	8.698	163

Multiple comparisons of Agricultural Workforce (AW)

Table 10 presents an analysis of mean differences in the number of active agricultural workers among different farm groups (T_1 to T_6), indicating the mean differences (I-J), standard errors, p-values, and 95% confidence intervals. The main results are summarized as follows:

T_1 farms showed significant differences with T_5 (-10.05, p = 0.037) and T_6 (-10.39, p = 0.033), indicating that T_5 and T6 farms had a greater number of agricultural workers than T1 farms. No significant differences were observed between T_1 and T_2, T_3, and T_4 farms (p-values > 0.05), suggesting that these types had a similar number of agricultural workers.

T_2, T_3, and T_4 farms showed no statistically significant differences with the other types (p-values > 0.05), except for T_4 farms, which demonstrated significant differences with T_5 and T_6 (p-value < 0.05). This indicated that T_5 and T_6 farms had a higher number of agricultural workers compared to T4 farms.

Sociodemographic characteristics of family farms

Family farms varied in size and composition in the villages studied according to their type (Table 11). T_6 farms were the largest, with an average of 34 members, followed by T_3 farms with 31 members, while T_1 farms were the smallest, with an average of 11 members. The number of agricultural workers remained relatively constant, around 15 for most types, except for T_1 and T_4, which had 5 and 9, respectively. The average age of farm managers ranged from 41 years for T_2 to 52 years for T_3, reflecting differences in demographic structure and the distribution of responsibilities within the farm.

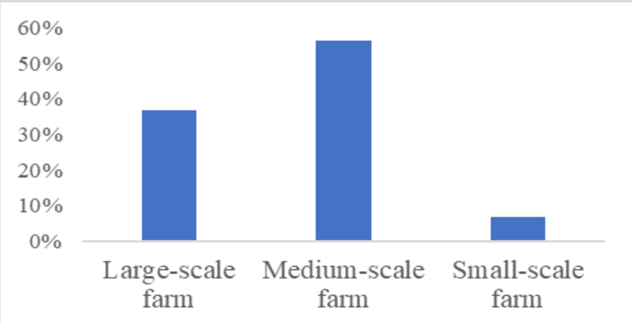

Fig. 4. *Size of family farms in the rural Municipality of Faragouaran*

Agricultural equipment diversity

Table 12 shows the level of equipment in family farms within the study area. Regardless of their type, most farms are primarily equipped with seeders, ploughs, carts, and sprayers, except for T_1 farms, which are the least well-equipped. T_6 farms, on the other hand, are the best equipped, with threshers, combine harvesters, tractors, and tricycles. Conversely, farms of types T_2 to T_5 have moderate equipment levels. This suggests that animal traction remains the predominant method in these farms.

Total cultivated area by crop

Table 13 shows the distribution of cultivated areas by crop type across different family farm types in the studied villages. T_1 farms primarily focused on cereal cultivation, with an average of 2.63 hectares for maize and 1.59 hectares for groundnut, while other crops such as millet, rice, sorghum, cowpea, and soybean each occupied less than one hectare. This type of farm did not cultivate cotton. In contrast, T_2 farms allocated 1.33 hectares to cotton, 4 hectares to maize, 1.33 hectares to rain-fed rice, 2.67 hectares to groundnut, and less than one hectare to millet, with no area dedicated to sorghum, cowpea, or soybean. T_3 farms dedicated an average of 2.56 hectares to cotton, 3.46 hectares to maize, 1.56 hectares to millet, 1.69 hectares to rice, and 4.23 hectares to groundnut, with less than one hectare for other crops. T_4 farms cultivated an average of 3.99 hectares of cotton, 2.96 hectares of maize, and 1.31 hectares of groundnut, with less than one hectare for millet, rain-fed rice, sorghum, cowpea, and soybean. T_5 farms had a larger area, with 6.45 hectares for cotton, 3.98 hectares for maize, and 1.54 hectares for groundnut, while cultivating less than one hectare for other crops. Finally, T_6 farms cultivated an average of 6.09 hectares of cotton, 5.61 hectares of maize, 1.93

Table 5. Wilks' lambda distribution of farm characteristics

Effect	Wilks' lambda	F value	Hypothesis df	Error df	Sig. (p-value)	Partial Eta Squared
Farms types	.473	6.478	20.000	511.710	.000	.171

Table 6. Effects of farm types on agricultural production factors: total cultivated area, total number of farm implements, cattle, and agricultural workforce

Dependent Variable	F value	Sig. (p-value)	Partial Eta Squared
Total Equipment	18.518	0	0.371
Total Cultivated Area (TCA)	12.732	0	0.288
Total Cattle	11.365	0	0.266
Agriculture Workforce	4.358	0.001	0.122

hectares of millet, 2.22 hectares of rice, and 3.04 hectares of groundnut, with less than one hectare for sorghum and cowpea, and no area allocated for soybean.

Use of chemical and organic fertilisers

Table 14 illustrates chemical and organic fertiliser use across different family farms in the studied villages.

The most commonly used chemical fertilisers in the Faragouaran municipality were urea, cereal complexes, and cotton complexes, which all farms used except for T_1 farms, as they did not grow cotton. Generally, all farms used less than one ton of chemical fertilisers, except for T_6 farms, which consumed up to around 1.55 tons of urea and cotton complex. DAP (Diammonium Phosphate) was less commonly used among farms. Organic fertilisers were widely used by all types of farms, with notable production. T_1 and T_2 farms produced less than one ton, while other types produced up to around five tons. The quantity of chemical and organic fertilisers used was proportional to the size of the farm.

Yields and crops commercialisation

Average Crop Yields

Table 15 presents the average yields for various crops according to farm types in the studied areas. T_1, T_3, and T_6 farms exhibited average yields per hectare of 1.08, 1.22, and 1.72 tons for maize, respectively, while other crops such as millet, sorghum, rice, groundnut, cowpeas, and soybeans produced less than one ton per hectare. T_4 farms achieved an average yield of 1.07 tons per hectare for cotton and 1.56 tons for maize but also yielded less than one ton per hectare for other crops. Lastly, T_5 farms produced an average of 1.52 tons of cotton and 1.46 tons of maize per hectare,

Table 7. Multiple comparison of total farm equipment according to family farm type in the rural Municipality of Faragouaran

Group comparison		Mean Difference (I-J)	Std. Error	Sig. (p-value)	95% Confidence Interval	
					Lower Bound	Upper Bound
T_1	T_2	-.96	1.642	1.000	-5.85	3.94
	T_3	-2.79	1.107	.190	-6.09	.51
	T_4	-1.76	.899	.777	-4.44	.92
	T_5	-2.23	.956	.313	-5.08	.62
	T_6	-6.55*	.976	.000	-9.46	-3.64
T_2	T_1	.96	1.642	1.000	-3.94	5.85
	T_3	-1.83	1.565	1.000	-6.50	2.83
	T_4	-.80	1.426	1.000	-5.06	3.45
	T_5	-1.27	1.462	1.000	-5.63	3.09
	T_6	-5.59*	1.476	.003	-9.99	-1.19
T_3	T_1	2.79	1.107	0.190	-0.51	6.09
	T_2	1.83	1.565	1.000	-2.83	6.50
	T_4	1.03	0.751	1.000	-1.21	3.27
	T_5	0.56	0.818	1.000	-1.88	3.00
	T_6	-3.76*	0.841	.000	-6.27	-1.25
T_4	T_1	1.76	0.899	0.777	-0.92	4.44
	T_2	0.80	1.426	1.000	-3.45	5.06
	T_3	-1.03	0.751	1.000	-3.27	1.21
	T_5	-0.47	0.502	1.000	-1.96	1.03
	T_6	-4.79*	0.540	.000	-6.40	-3.18
T_5	T_1	2.23	0.956	0.313	-0.62	5.08
	T_2	1.27	1.462	1.000	-3.09	5.63
	T_3	-.56	0.818	1.000	-3.00	1.88
	T_4	0.47	0.502	1.000	-1.03	1.96
	T_6	-4.32*	0.629	.000	-6.20	-2.44
T_6	T_1	6.55*	0.976	0.000	3.64	9.46
	T_2	5.59*	1.476	0.003	1.19	9.99
	T_3	3.76*	0.841	0.000	1.25	6.27
	T_4	4.79*	0.540	0.000	3.18	6.40
	T_5	4.32*	0.629	.000	2.44	6.20

though, like other types, their yields for other crops remained below one ton per hectare.

Cotton production sales

In Mali, cotton production is fully commercialised immediately after harvest in cotton-growing regions. The processing and sale of this production are managed by the Malian Company for Textile Development (CMDT). At the beginning of the season, CMDT provides on credit to farmers with agricultural inputs, such as pesticides, insecticides, herbicides, fungicides, and chemical fertilisers. This approach allows producers to access the necessary resources to optimise their production, with the commitment to repay these loans upon harvest, once the cotton is sold. This model ensures input access while directly linking production to marketing through CMDT.

Maize sales by farm type

Fig. 5 illustrates the maize share sold by different types of family farms during various marketing periods in the studied villages. T_1 farms sold 40% of their maize at harvest and during the lean season but only 20% at the beginning of the rainy season. Conversely, T_2 farms sold 23% of their maize at harvest and 38% at the beginning of the rainy season and during the lean season. For T_3 and T_4 farms, approximately 48% of the maize was sold at harvest, 28% at the beginning of the rainy season, and nearly 25% during the lean season. T_5 farms sold 31% of their maize at harvest, 28% at the beginning of the rainy season, and 41% during the lean season. Finally, T6 farms sold only 17% of their maize at harvest but increased their sales to 46% during the rainy season and 37% during the lean season.

Millet production sales

Fig. 6 illustrates the millet sales by different types of family farms during various food marketing periods. T_3 farms sold 57% of their millet during the lean season and 43% at the beginning of the rainy season, with no sales at harvest. In contrast, T_5 farms marketed 69% of their millet during the lean season, only 31% at harvest, and none at the beginning of the rainy season. T_6 farms sold the majority of their millet at the beginning of the

Table 8. Multiple comparison of total cultivated area according to family farm type in the rural Municipality of Faragouaran

Group comparison		Mean Difference (I-J)	Std. Error	Sig. (p-value)	95% Confidence Interval	
					Lower Bound	Upper Bound
T_1	T_2	-4.8542	4.24253	1.000	-17.5002	7.7919
	T_3	-11.3250*	2.86031	.002	-19.8510	-2.7990
	T_4	-5.3875	2.32373	.326	-12.3140	1.5390
	T_5	-9.0360*	2.46958	.005	-16.3973	-1.6747
	T_6	-14.7986*	2.52256	.000	-22.3178	-7.2794
T_2	T_1	4.8542	4.24253	1.000	-7.7919	17.5002
	T_3	-6.4708	4.04509	1.000	-18.5284	5.5867
	T_4	-.5333	3.68525	1.000	-11.5183	10.4516
	T_5	-4.1818	3.77892	1.000	-15.4460	7.0823
	T_6	-9.9444	3.81375	.150	-21.3124	1.4235
T_3	T_1	11.3250*	2.86031	.002	2.7990	19.8510
	T_2	6.4708	4.04509	1.000	-5.5867	18.5284
	T_4	5.9375*	1.93996	.039	.1549	11.7201
	T_5	2.2890	2.11248	1.000	-4.0078	8.5859
	T_6	-3.4736	2.17417	1.000	-9.9543	3.0071
T_4	T_1	5.3875	2.32373	.326	-1.5390	12.3140
	T_2	.5333	3.68525	1.000	-10.4516	11.5183
	T_3	-5.9375*	1.93996	.039	-11.7201	-.1549
	T_5	-3.6485	1.29650	.083	-7.5131	.2161
	T_6	-9.4111*	1.39476	.000	-13.5686	-5.2536
T_5	T_1	9.0360*	2.46958	.005	1.6747	16.3973
	T_2	4.1818	3.77892	1.000	-7.0823	15.4460
	T_3	-2.2890	2.11248	1.000	-8.5859	4.0078
	T_4	3.6485	1.29650	.083	-.2161	7.5131
	T_6	-5.7626*	1.62619	.008	-10.6099	-.9153
T_6	T_1	14.7986*	2.52256	.000	7.2794	22.3178
	T_2	9.9444	3.81375	.150	-1.4235	21.3124
	T_3	3.4736	2.17417	1.000	-3.0071	9.9543
	T_4	9.4111*	1.39476	.000	5.2536	13.5686
	T_5	5.7626*	1.62619	.008	.9153	10.6099

Table 9. Multiple comparison of cattle numbers according to family farm type in the rural Municipality of Faragouaran

Group comparison		Mean Difference (I-J)	Std. Error	Sig. (p-value)	95% Confidence Interval	
					Lower Bound	Upper Bound
T_1	T_2	-.58	15.668	1.000	-47.29	46.12
	T_3	-1.25	10.563	1.000	-32.74	30.24
	T_4	4.98	8.582	1.000	-20.61	30.56
	T_5	-15.67	9.120	1.000	-42.86	11.51
	T_6	-31.14*	9.316	.016	-58.91	-3.37
T_2	T_1	.58	15.668	1.000	-46.12	47.29
	T_3	-.67	14.939	1.000	-45.20	43.86
	T_4	5.56	13.610	1.000	-35.01	46.13
	T_5	-15.09	13.956	1.000	-56.69	26.51
	T_6	-30.56	14.084	.473	-72.54	11.43
T_3	T_1	1.25	10.563	1.000	-30.24	32.74
	T_2	.67	14.939	1.000	-43.86	45.20
	T_4	6.23	7.164	1.000	-15.13	27.58
	T_5	-14.42	7.801	.995	-37.68	8.83
	T_6	-29.89*	8.029	.004	-53.82	-5.96
T_4	T_1	-4.98	8.582	1.000	-30.56	20.61
	T_2	-5.56	13.610	1.000	-46.13	35.01
	T_3	-6.23	7.164	1.000	-27.58	15.13
	T_5	-20.65*	4.788	.000	-34.92	-6.38
	T_6	-36.11*	5.151	.000	-51.47	-20.76
T_5	T_1	15.67	9.120	1.000	-11.51	42.86
	T_2	15.09	13.956	1.000	-26.51	56.69
	T_3	14.42	7.801	.995	-8.83	37.68
	T_4	20.65*	4.788	.000	6.38	34.92
	T_6	-15.46	6.006	.164	-33.37	2.44
T_6	T_1	31.14*	9.316	.016	3.37	58.91
	T_2	30.56	14.084	.473	-11.43	72.54
	T_3	29.89*	8.029	.004	5.96	53.82
	T_4	36.11*	5.151	.000	20.76	51.47
	T_5	15.46	6.006	.164	-2.44	33.37

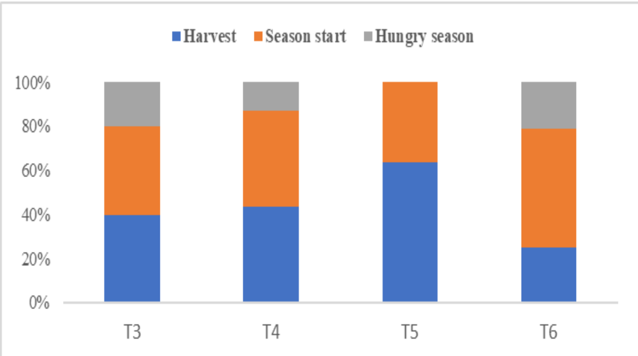

Fig. 7. *Rice sales by farm type*

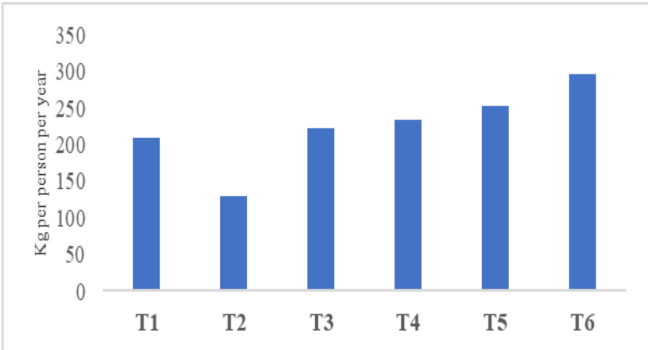

Fig. 8. *Availability of cereals by type of farm*

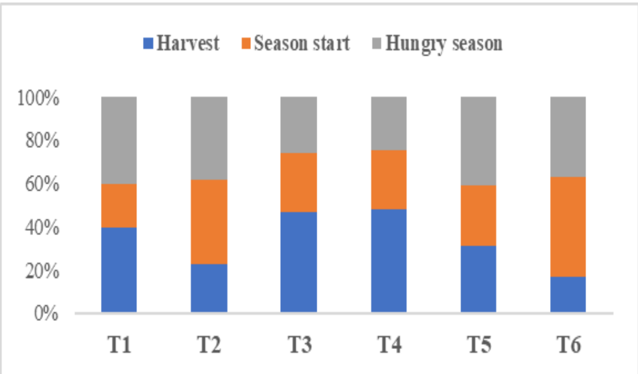

Fig. 5. *Maize sales by farm type*

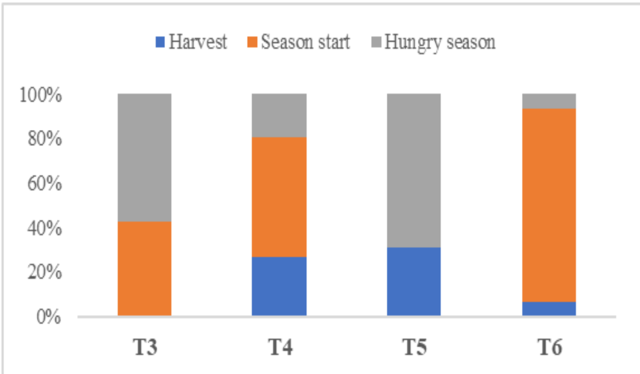

Fig. 6. *Millet sales by farm type*

Table 10. Multiple comparison of agricultural workforce numbers according to family farm type in the rural Municipality of Faragouaran

Group comparison		Mean Difference (I-J)	Std. Error	Sig. (p-value)	95% Confidence Interval	
					Lower Bound	Upper Bound
T_1	T_2	-6.17	5.605	1.000	-22.87	10.54
	T_3	-10.25	3.779	.111	-21.51	1.01
	T_4	-4.89	3.070	1.000	-14.04	4.26
	T_5	-10.05*	3.263	.037	-19.77	-.32
	T_6	-10.39*	3.333	.033	-20.32	-.45
T_2	T_1	6.17	5.605	1.000	-10.54	22.87
	T_3	-4.08	5.344	1.000	-20.01	11.85
	T_4	1.28	4.869	1.000	-13.23	15.79
	T_5	-3.88	4.993	1.000	-18.76	11.00
	T_6	-4.22	5.039	1.000	-19.24	10.80
T_3	T_1	10.25	3.779	.111	-1.01	21.51
	T_2	4.08	5.344	1.000	-11.85	20.01
	T_4	5.36	2.563	.570	-2.28	13.00
	T_5	.20	2.791	1.000	-8.12	8.52
	T_6	-.14	2.873	1.000	-8.70	8.42
T_4	T_1	4.89	3.070	1.000	-4.26	14.04
	T_2	-1.28	4.869	1.000	-15.79	13.23
	T_3	-5.36	2.563	.570	-13.00	2.28
	T_5	-5.16*	1.713	.046	-10.26	-.05
	T_6	-5.50*	1.843	.049	-10.99	-.01
T_5	T_1	10.05*	3.263	.037	.32	19.77
	T_2	3.88	4.993	1.000	-11.00	18.76
	T_3	-.20	2.791	1.000	-8.52	8.12
	T_4	5.16*	1.713	.046	.05	10.26
	T_6	-.34	2.149	1.000	-6.75	6.06
T_6	T_1	10.39*	3.333	.033	.45	20.32
	T_2	4.22	5.039	1.000	-10.80	19.24
	T_3	.14	2.873	1.000	-8.42	8.70
	T_4	5.50*	1.843	.049	.01	10.99
	T_5	.34	2.149	1.000	-6.06	6.75

Table 11. Socio-demographic characteristics of farms

Types	Age	Number			Agricultural workforce		
		People	Men	Women	Total	Men	Women
T_1	44	11	5	7	5	3	2
T_2	41	23	11	12	11	5	6
T_3	52	31	16	15	15	9	6
T_4	49	19	9	10	9	5	4
T_5	49	25	10	15	15	8	7
T_6	45	34	15	18	15	7	8
Total	48	23	11	13	12	6	5

Table 12. Type of agricultural equipment on farms

Types	Seeders	Plows	Carts	Sprayers	Multiculture	Threshers	Harvesters	Tractors	Tricycles
T_1	0.13	0.63	0.50	0.88	0.13	0.00	0.00	0.00	0.00
T_2	0.33	1.67	0.67	0.67	0.00	0.00	0.00	0.00	0.00
T_3	0.83	1.58	1.08	1.00	0.50	0.00	0.08	0.00	0.00
T_4	0.61	1.11	0.98	0.93	0.46	0.03	0.00	0.00	0.01
T_5	0.88	1.21	0.76	1.00	0.64	0.00	0.00	0.03	0.06
T_6	1.30	2.26	1.41	1.67	1.67	0.07	0.04	0.11	0.30
Total	**0.77**	**1.34**	**0.98**	**1.06**	**0.67**	**0.02**	**0.01**	**0.02**	**0.07**

Table 13. Distribution of the total cultivated area per crop

Tyes	Coton (ha)	Cereals (ha)				Legumes (ha)		
		Maize	Millet	Upland rice	Sorghum	Peanut	Cowpea	Soybean
T_1	0.00	2.63	0.25	0.09	0.13	1.59	0.09	0.03
T_2	1.33	4.00	0.33	1.33	0.00	2.67	0.00	0.00
T_3	2.56	3.46	1.56	1.69	0.33	4.23	0.10	0.02
T_4	3.99	2.96	0.83	0.85	0.12	1.31	0.12	0.02
T_5	6.45	3.98	0.73	0.65	0.18	1.54	0.17	0.08
T_6	6.09	5.61	1.93	2.22	0.22	3.04	0.19	0.00
Total	4.49	3.65	1.01	1.07	0.16	1.90	0.13	0.03

rainy season (84%), with only 7% sold at harvest and during the lean season. T_4 farms sold most of their millet at the beginning of the rainy season, 27% at harvest, and 19% during the lean season. Finally, T_1 and T_2 farms did not sell any of their millet, which was entirely used for household consumption.

Rice production sales

Fig. 7 illustrates the sale of rice by different types of family farms during various marketing periods.

T_3 and T_4 farms sold approximately 40% to 43% of their rice at harvest and at the beginning of the rainy season, with only 13% to 20% sold during the lean season. T_5 farms, on the other hand, marketed 64% of their rice at harvest and 36% at the beginning of the rainy season, with no sales during the lean season. For T_6 farms, the majority of rice was sold at the beginning of the rainy season, with only 21% to 25% sold at harvest and during the lean season. Finally, T_1 and T_2 farms did not sell rice, reserving it entirely for domestic consumption.

Food security of family farms

Cereal Availability

Fig. 8 shows the availability of cereals (millet, maize, sorghum, and rice) in different types of family farms within the studied villages. This availability was calculated by dividing the quantity of cereals stored for consumption by the total number of people living in each family farm. T_1 farms had an average cereal availability of 210 kg per person per year, while T_2 farms had only 130 kg per person, which was well below the FAO's recommended standard. In contrast, T_3 and T_4 farms achieved cereal availability that met FAO standards, with 222.52 kg and 233.43 kg per person per year. T_5 and T_6 farms significantly exceeded this threshold, with availability of 254.02 kg and 297.44 kg per person per year, respectively.

The availability of different cereals varied according to farm type. Maize stood out as the most widely available and consumed cereal across the farms in the region. T_5 and T_6 farms had the largest maize reserves, with over 200 kg available per person per year. They were followed by T_1 and T_4 farms, which had around 180 kg per person per year. In contrast, T_2 and T_3 farms had the lowest maize stocks, ranging between 100 and 180 kg per person per year. Besides maize, consumption was supplemented by millet and sorghum, with availability reaching about 80 kg per person per year across all types of family farms.

Average duration of the hunger period

T_1 and T_6 family farms have largely managed to avoid hunger periods in recent years (Fig. 10). In contrast, T_3, T_4, and T_5 farms experienced hunger periods, which were limited to less than a month on average over the past three years. Only T_2 farms were more severely affected, with an average hunger period of 1 to 2 months between 2021 and 2023.

Perception of family farms on food self-sufficiency

The majority of T_1 and T_6 family farms were generally self-sufficient, with only about 25% achieving this status during particularly favourable years (Fig. 11). In contrast, 67% of T_2 farms reached self-sufficiency only if the rainy season was good. Most T_3 farms were self-sufficient except in particularly challenging years, while T_4 and T_5 farms were predominantly always self-sufficient. For the latter, those who were not self-sufficient relied on the quality of the rainy season or never achieved self-sufficiency regardless of conditions.

Spatiotemporal variability in consumption in farms

Table 16 illustrates the spatiotemporal variation in daily cereal consumption across different types of family farms in the villages, categorized by the dry and rainy seasons. Regardless of the farm type, daily consumption remained low during the dry season and increased significantly during the rainy season. For instance, T_3 farms were the highest consumers of cereals, consuming 95 kg of maize per day during the dry season and 113 kg during the rainy season. They also consumed 18.5 kg of millet per day in the dry season, rising to 21.5 kg in the rainy season, 75.4 kg of rice during the dry season compared to 86.7 kg in the rainy season, and consistently 9 kg of sorghum throughout the year. T_1, T_2, T_4, T_5, and T_6 farms consumed up to about 10 kg of various cereals daily throughout the year, with maize consumption reaching up to 21 kg.

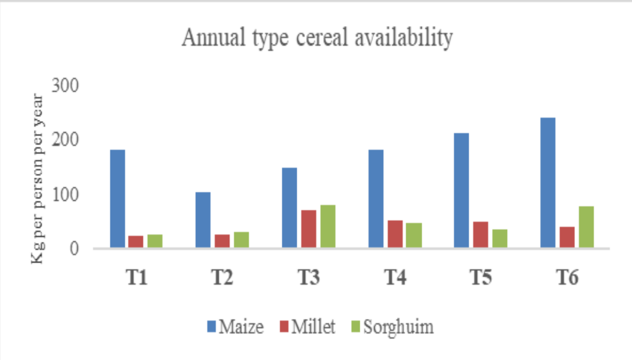

Fig. 9. *Availability of cereals crop by type of farm*

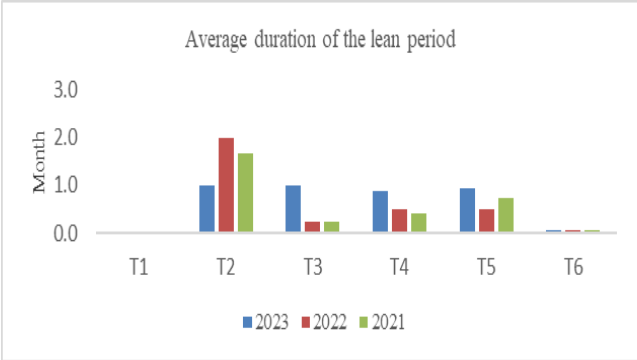

Fig. 10. *Average duration of the lean season on family farms*

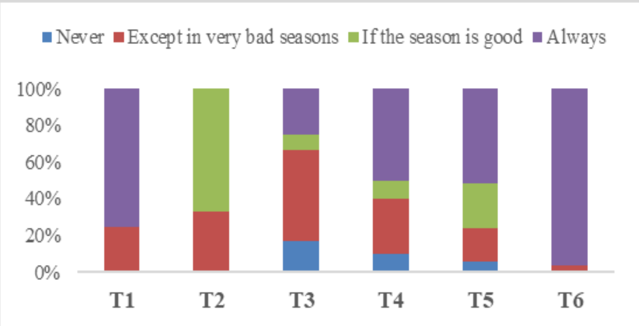

Fig. 11. *Farmers' perception of food self-sufficiency*

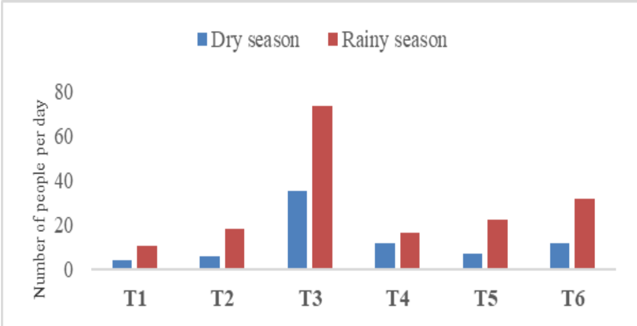

Fig. 12. *Spatiotemporal variability of the number of cereal consumers on family farms*

Table 14. Use of chemical and organic fertilizers

Type	Chemical fertilizer (kg)					Organic fertilizer (kg)
	Urea	DAP fertilizer	Complex cotton	Complex cereal	Total	
T_1	87.50	0.00	0.00	106.63	48.53	300.00
T_2	166.67	0.00	150.00	270.00	146.67	666.67
T_3	351.83	0.00	714.17	181.83	311.96	4316.67
T_4	340.22	0.03	463.59	170.83	243.67	1725.34
T_5	396.42	0.00	486.76	214.61	274.45	2487.88
T_6	1166.67	0.93	1550.89	631.04	837.38	5007.78
Total	473.75	0.17	638.31	255.41	341.91	2524.77

Table 15. Average yields of different crops grown on different types of farms

Types	Coton (tons)	Cereals (tons)				Legumes (tons)		
		Maize	Millet	Sorghum	Rice	Groundnut	Cowpea	Soybean
T_1	0.00	1.08	0.45	0.50	0.93	0.42	0.18	0.00
T_2	0.98	0.83	0.65	0.00	0.25	0.24	0.00	0.00
T_3	0.92	1.22	0.85	0.63	0.82	0.78	0.16	0.00
T_4	1.07	1.56	0.54	0.59	0.68	0.93	0.20	0.24
T_5	1.52	1.46	0.64	0.77	0.83	0.62	0.31	0.00
T_6	0.98	1.72	0.83	0.59	0.88	0.88	0.53	0.00
Total	1.14	1.51	0.63	0.61	0.76	0.81	0.27	0.24

As illustrated in Fig. 12, the number of people within family farms significantly increased during the rainy season, including both family members and temporary workers. T_3 farms needed to feed up to 73 people per day, while T_6 and T_5 accommodated around 31 people. In contrast, T_1, T_2, and T_4 were the smallest consumers regardless of the season. Maize was the primary cereal consumed in the study area, which explained its increase during the rainy season. Millet, rice, and sorghum complemented this consumption. The substantial daily cereal consumption was attributed to hiring daily temporary workers during the rainy season, which coincided with the peak of agricultural activity. The increase in the number of people to be fed during the rainy season due to the addition of temporary workers reflected the intensified agricultural activities. This highlighted the critical role of food resources in supporting increased needs during periods of intensive work. The

Table 16. Spatiotemporal variability of cereal consumption on family farms

Types	Dray season				Rainy season			
	Maize	Millet	Upland rice	Sorghum	Maize	Millet	Upland rice	Sorghum
T_1	4.19	4.00	2.80	5.00	5.00	5.00	3.30	6.00
T_2	7.67	2.00	6.50	4.00	9.00	2.00	10.50	4.00
T_3	95.00	18.50	75.40	9.00	113.00	21.50	86.70	9.00
T_4	20.36	5.13	4.72	3.36	21.13	8.16	5.22	4.00
T_5	9.15	5.09	4.97	6.86	10.39	5.91	5.64	7.57
T_6	14.85	6.72	9.74	8.00	17.24	7.17	10.91	8.00
Total	**21.64**	**6.03**	**10.83**	**5.17**	**24.06**	**8.23**	**12.36**	**5.74**

seasonal dynamics underscored the importance of effective resource management to ensure a sufficient food supply and support agricultural productivity during peak seasons.

DISCUSSION

Farming diversity

The observed predominance of T_4 farms, followed by T_5 and T_6 (Fig. 3), illustrates an uneven distribution of agricultural resources in several regions of Africa (northern Côte d'Ivoire, Burkina Faso, and western Niger). According to Djurfeldt *et al.* (2011), the diversity of agricultural practices is often influenced by access to inputs and local infrastructure. The less frequent T_1 and T_2 farms reflect the situation in less developed areas, where farms are generally smaller, as Jayne *et al*., (2014) reported in Sub-Saharan Africa. The variability in the distribution of T_3 and T_5 farms can be attributed to fluctuating climatic and geographic factors, which alter land use dynamics, especially in rural areas (FAO, 2019). Finally, the diversity of farming systems also addresses rural communities' socioeconomic needs, as Corral *et al*., (2020) demonstrated in their reports on agricultural strategies in Africa. The predominance of medium-scale farms (T_3 and T_4) in Faragouaran municipality accounting for 56% of the family farms (Fig. 4). These farms combine subsistence practices with some commercialisation, particularly in cotton and cereal production, supported by national agricultural policies (Coulibaly and Li, 2020). Large-scale farms (T_5 and T_6), representing 37%, illustrate increased intensification and better access to resources and subsidies, notably due to the CMDT's focus on cotton cultivation (Bélières *et al.,* 2017). In contrast, small-scale farms (T_1 and T_2) are significantly fewer (7%), reflecting the challenges they face in agricultural modernisation and limited access to inputs, which threatens their long-term viability (Liverpool-Tasie, 2012).

Analysis of access to agricultural inputs

The results on agricultural production factors highlight the structural diversity of farms, a crucial aspect in understanding productivity and resilience dynamics in agriculture. The significant heterogeneity observed among farm types, with T_6 farms having high resource levels and T_1 farms being more limited, aligns with general observations on the stratification of farms in developing countries (Table 4). Better-equipped of T_6 farms illustrate a more intensive, market-oriented agricultural production model, which is often associated with greater economic resilience and an increased capacity for investment in mechanization and crop diversification. According to Jayne *et al.* (2014), access to resources, particularly the capital, technology, and skilled labor is a key factor differentiating larger farms from smaller ones. These larger farms tend to be more productive and better able to withstand climate and economic shocks. In contrast, T_1 farms, characterised by limited cultivated area and equipment, typically represent subsistence farms. These farms often face production constraints that limit their capacity to adopt modern techniques or diversify. In a study by Barrett and Carter (2013), small farms are described as more vulnerable to risks and shocks, with an increased dependence on favorable weather conditions and limited market access.

For intermediate farms types (T_2 to T_5), moderate variability reflects the transition between subsistence farms and market-oriented farms. These farms often combine traditional agricultural practices with elements of modernization, showing signs of adapting to new technologies, although their access to resources is more limited than that of T_6 farms. According to a study by Lowder *et al.* (2016), these intermediate farms play a crucial role in the agricultural systems of developing countries, where they contribute to local food security but are also sensitive to agricultural support policies. These observations underscore the importance of tailored strategies for each type of farm, particularly in the context of rural development in Africa. Measures such as providing financing access for small farms, training on mechanization for intermediate farms, and promoting sustainable agricultural practices for large farms are recommended to enhance resilience and overall efficiency in the agricultural sector (Herrero *et al.,* 2017).

Influence of farms on socioeconomic characteristics

The results of the MANOVA analysis reveal a significant influence of farm types on socio-demographic characteristics, which is consistent with recent research on the stratification of agricultural systems and their socioeconomic impacts (Table 6). The Wilks' lambda value (0.473), indicating that 52.7% of the variance is attributable to differences between farm types (Table 5), aligns with studies demonstrating that size, resources, and management practices vary significantly from one farm type to another (Table 5). For instance, Lowder *et al.* (2016) show that the structure and resources of farms directly influence their productivity and resilience, especially in rural areas of developing countries. The statistically significant F value (6.478), confirmed by a p-value < 0.05, allows for rejecting the null hypothesis and indicates marked differences among farm types. This is supported by research from the OECD (2008) and Ross *et al.* (2019), which indicate that larger farms with better equipment and access to resources are often more productive and economically stable, while smaller farms with fewer resources tend to be more vulnerable and less diversified.

The moderate effect size, represented by the Partial Eta Squared (0.171), shows that 17.1% of the variance in dependent variables (agricultural equipment, cultivated area, livestock, and labor) is explained by farm types (Table 6). This finding aligns with the study by Herrero *et al.* (2017), which emphasizes that socioeconomic variables such as labor and agricultural equipment are key indicators of performance and resilience differences among various farm types. These disparities in resources, market access, and investment capacities partially explain the variations in agricultural performance observed across different types of farms. In summary, these results confirm the importance of considering the structural diversity of agricultural operations when implementing agricultural policies. Differentiated approaches that take into account the specificities of each farm type can promote more equitable and sustainable agricultural development. Studies like that of Chamberlin and Jayne, (2013), recommend targeted support programs based on the size and needs of farms to optimize productivity and resilience in the agricultural sector.

The significant differences observed between types of agricultural operations, particularly regarding equipment and labor (Table 7 and Table 10), are supported by recent studies highlighting the importance of resources in enhancing productivity and resilience. Vanlauwe *et al.* (2014) indicate that access to equipment is crucial in improving yields and reducing labor intensity, yet small farms often struggle to obtain these resources. These disparities also influence labor management; Pingali (2012) notes that small farms tend to compensate for the lack of mechanization with increased manual labor, which can limit their growth.

Bazie *et al.* (2020) further explore how small-scale farms, despite their limited material resources, often mobilize significant family labor to maximize production. In contrast, larger farms benefit from greater flexibility in accessing hired labor and mechanizing their processes, which enhances their competitiveness. Ricker-Gilbert and Jayne (2016) emphasize that differential access to resources and equipment contributes to widening inequalities between farms, calling for policies that facilitate resource access for small farms, such as targeted subsidies or credit mechanisms. Regarding support policies, Christiaensen (2017) advocates for a differentiated approach that considers the specific needs of various types of farms. For example, enhanced financing support and access to equipment for small farms can encourage a transition toward more resilient and sustainable agriculture.

Analysis of farming practices

The family farms in the studied villages show considerable diversity in crop distribution and land use (Table 13), consistent with trends observed in other rural areas of Africa (Barrett *et al.,* 2002). Small T_1 farms, focused on cereals and legumes, reflect Norton *et al*.'s (2015) findings, which show that small units prioritise staple crops for subsistence. In contrast, large T_5 and T_6 farms, which allocate a significant portion of their land to cotton, follow commercial crop production strategies, as reported by Hazell and Wood (2008). The relatively even availability of area per agricultural workforce, except for T_2 farms with reduced areas, aligns with (FAO and World Bank, 2009) observations on disparities in access to agricultural resources. Finally, the higher concentration of cattle in T_1, T_5, and T_6 farms is consistent with (Thornton *et al*., 2002) research, highlighting cattle's crucial role in mixed farming systems.

The use of fertilisers in family farms varies significantly by farm type, with distinct preferences for both chemical and organic fertilisers (Table 14). T_6 farms, which use more chemical fertilisers such as urea and cereal complexes, reflect the observations of Heisse and Morimoto, (2024), indicating that large farms specialising in cash crops invest more in fertilisers to maximise yields. In contrast, T_1 to T_5 farms, often constrained by budgetary limitations, use fertilisers less intensively, which is corroborated (Wollni *et al.,* 2024). The production and use of organic fertilisers in large farms demonstrate a sustainable management approach and resource recycling, as highlighted by Fresco *et al.* (2021). This trend is also supported by (Proscovia *et al*., 2024), who show that large farms engaged in cash crops generally apply more fertilisers to enhance productivity.

The variation in crop yields according to farm type indicates significant differences based on cultivated crops

(Table 15). Maize is the most productive crop, particularly in T_6 farms, corroborating the observations of Heisse and Morimoto (2024) regarding high yields achieved through intensive practices and effective input management. T_4 and T_5 farms, despite strong performance with cotton and maize, show yields below one ton per hectare for other crops, highlighting a partial specialisation that limits agricultural diversification, as noted by *Giller et al.* (2021). This situation underscores an opportunity for improving crop diversification and increasing yields, in line with Fresco *et al.* (2021) recommendations for adopting more varied practices. Finally, the results suggest that enhancing yields for underperforming crops could strengthen overall agricultural production, as highlighted by Proscovia *et al.* (2024).

Analysis of farm marketing strategies

The decisions regarding maize sales vary by farm type. T_1 and T_5 farms tend to sell during the lean season to take advantage of higher prices, while T_6 farms increase their sales at the beginning of the rainy season Fig. 5. This diversity in strategies reflects the specific priorities and constraints of the farmers, influenced by economic conditions and agricultural calendars (Bezu and Holden, 2014; Swinnen, 2021). Effective temporal management of resources is crucial for maximising income and meeting food needs, highlighting the importance of strategic planning (Morris *et al.,* 2007).

The sales strategies for millet vary by farm type. T_3 and T_5 farms primarily sell during the lean season to take advantage of higher prices (Fig. 6), as noted by Alemayehu *et al.* (2022). In contrast, T_6 and T_4 farms prefer to sell at the beginning of the rainy season to finance new crops, an approach also observed by Giller *et al.* (2021). T_1 and T_2 farms, which do not sell their millet, focus on family food security, corroborating the findings of Descroix *et al.* (2024) on the resilience of agrosystems in the Sahel and West Africa.

The strategies for groundnut sales vary considerably among different types of family farms. T_5 and T_6 farms maximise their sales at the beginning of the rainy season and at harvest to secure income before the lean period (Fig. 7), as noted by Giller *et al.* (2021). In contrast, T_1 and T_4 farms prefer to sell at the beginning of the farming season to finance new crops, while T3 farms balance their sales between the lean season and the rainy season, and T_2 farms focus mainly on harvest sales, reflecting an approach adapted to local market conditions (Davis *et al.,* 2022; Haggblade *et al.,* 2016).

Food availability and self-sufficiency on farms

Cereal availability varies significantly among farm types in the studied villages. T_2 farms, with cereal availability well below FAO standards, are particularly vulnerable (Fig. 8), posing a significant risk to food security, as noted by Gomez Y Paloma *et al.* (2020) in their study on the role of smallholder farms in food and nutrition security. Conversely, T_3, T_4, T_5, and T_6 farms demonstrate a greater capacity to meet cereal needs, exceeding the FAO's recommended thresholds, in line with Çakmakçı *et al.* (2023) on assessment and principles of environmentally sustainable food and agriculture systems. These results highlight the importance of adapting agricultural practices to improve food security by implementing more effective resource management strategies, as suggested by Mutea *et al.* (2022) in recommendations to strengthen the resilience of vulnerable farms.

The resilience of T_1 and T_6 farms during hunger periods may indicate more effective resource management (Fig. 11) or favourable agricultural conditions, as Chikowo *et al*. (2021). They explained in their study opportunities for building the resilience of African farming systems. On the other hand, although less affected, T_3, T_4, and T_5 farms have still faced food shortages, highlighting potential vulnerabilities, as Musara *et al*. (2021) noted in their research on crop-livestock integration practices in the South Africa region. The situation of T_2 farms is particularly concerning, having experienced the longest hunger periods, revealing an urgent need for targeted interventions to improve food security, a problem also highlighted by Boko *et al.* (2007) in their research on adaptation and vulnerability.

The self-sufficiency capacity of family farms varies significantly by type, with T_1, T_4, T_5, and T_6 farms demonstrating notable resilience even under difficult conditions, as highlighted by Devenish *et al.* (2023) in their study on food self-sufficiency in Sub-Saharan Africa. Conversely, T_2 and T_3 farms, which are more vulnerable, heavily depend on seasonal conditions to achieve self-sufficiency, corroborated by Jiri *et al.* (2017) in their research on climate-smart crops for food and nutritional security. These variations underscore the need to tailor agricultural strategies to strengthen food security, particularly targeting the most vulnerable farms, as recommended by Adebayo (2024) in his guidelines for more resilient agricultural practices in the face of environmental challenges.

Cereal consumption in family farms varies by season, showing a marked increase during the rainy season compared to the dry season (Fig. 12). T_3 farms stand out as the largest consumers of cereals, with significantly higher quantities than other types. In contrast, T_1, T_2, T_4, T_5, and T_6 farms maintain a more moderate consumption pattern, with a notable preference for maize. These observations highlight the impact of seasonal variations on food needs and the storage capacity of different farm categories. This variability underscores the importance of adapting storage and consumption strategies to seasonal changes to ensure food security throughout the year, as indicated by research on seasonal food consumption patterns (Giller *et al*., 2021; Smith and Doris, 2007).

Family farms experience a significant increase in the number of people to feed during the rainy season due to the addition of temporary workers, leading to a higher consumption of cereals, particularly maize. These seasonal dynamics highlight the importance of having sufficient food resources to meet the increased needs during intense work periods. As noted by Aweke *et al.* (2022) in their study on food resource management during agricultural seasons, effective storage and distribution strategies are crucial. Afriyie *et al.* (2023) also support the same observation by emphasising the need for efficient storage and distribution strategies to address seasonal variations in food demand. Proactive management of stocks and food resources is essential to ensure adequate nourishment during these critical periods.

Conclusion

The typology of family farms in the cotton-growing region of Mali revealed a marked diversity, ranging from small, poorly equipped farms to large, intensive, and well-mechanised operations.

The present work yielded several important findings. Farms of types T_4, T_5, and T6 dominated the landscape, representing nearly 86% of the total and exhibiting larger cultivated areas with a more equitable distribution of resources among active members (agricultural workers). The integration of cotton into farming systems had driven significant agricultural intensification, even though animal traction remained the primary production method. Moreover, the analysis revealed marked differences in equipment use, labour distribution, and crop yields across the farm types, with T_6 farms notably possessing higher levels of mechanisation and superior maize yields. Self-sufficiency levels varied considerably, with some farms only achieving this status under favourable climatic conditions while others consistently maintained it. These findings underscored the complex interplay of socio-economic, environmental, and technological factors shaping the evolution and resilience of family farms in the region. Despite this intensification, some farms continue to employ more traditional practices, depending on their resources and size. These findings illustrate the impact of agricultural specialization on the structure of family farms within a context of demographic pressures and territorial changes.

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Conflict of interest

The authors declare that they have no conflict of interest.

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