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Sociodemographic characteristics and drivers of banana productivity in the Mountainous Bushi agrosystem, eastern D.R. Congo

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Abstract

The mountainous Bushi agrosystem, particularly in the Kabare and Walungu territories of eastern Democratic republic of Congo (DRC), constitutes a major banana-producing region where the crop plays a pivotal role in food security and rural household. This study examined the sociodemographic characteristics of farmers and the key drivers influencing banana productivity across different agroecological contets. The study area was stratified into three agroecological zones (AEZ1, AEZ2 and AEZ3) based on biophysical conditions. Data were collected from 425 banana farms distributed across these zones. Results show that bananas cultivation is predominantly practiced under intercropping systems (87.47%), commonly associated with cassava, common beans, and maize. However, monocropping systems exhibited significantly higher yields with an average productivity of 24.672 ± 9.948 t/ha compared to 14.293 ± 8.948 t/ha under intercropping. Several sociodemographic and management factors were found to significantly influence banana productivity ($p < 0.05$), including farmer age, membership in agricultural cooperatives, type of fertilizer used, source of labor, and main occupation. Higher productivity levels were associated with older farmers, cooperative membership, and the use of mineral fertilizers. In addition, farmers employing salaried labor and those whose primary occupation lies in the public sector achieved better yields, likely reflecting greater financial capacity and improved farm management practices. Regression analysis further confirmed the positive and significant effects of these variables on banana productivity (OR > 1, p < 0.05). Despite these opportunities, banana production in the region remains constrained by multiple factors, including biotic pressures (diseases, pests), abiotic stresses (strong winds, decline soil fertility), limited access to credit and improved planting materials, and inadequate agricultural tools and practices.

1 Introduction

Banana (*Musa spp*) is one of the most important staple and cash crops in tropical Africa (Dowiya *et al.*, 2009; Mshani *et al.*, 2010). It plays a crucial role in food security, rural incomes, and the sustainability of smallholder farming systems (Hazarika *et al.*, 2015). In the eastern Democratic Republic of Congo (DRC), bananas are not only a dietary staple but also a key socio-economic asset for smallholder farmers, particularly in South Kivu province (Ocimati *et al.*, 2016; Sivirihauma *et al.*, 2017). The territories of Walungu and Kabare, located in the mountainous Bushi agrosystem, benefit from favorable agroecological conditions, including fertile volcanic soils and abundant rainfall, making agriculture the main livelihood for rural households (Heri-kazi and Bielders, 2021). Within this context, banana cultivation plays a central role in household livelihoods economies. Despite its importance, banana cultivation constitutes a cornerstone of economies.

Despite its importance and the favorable environmental conditions, banana productivity in the region remains low and highly variable (Balimwacha *et al.*, 2021). Farmers operate under multiple constraints, including land scarcity driven by high population pressure (Likange *et al.*, 2023; Masumbuko *et al.*, 2024), unsustainable land-use practices (Karume *et al.*, 2022), limited access to agricultural inputs (Luhiriri and Mubagwa, 2025; Mondo *et al.*, 2021), and persistent socio-political instability (Mukotanyi, 2022). In

addition, banana production is predominantly embedded in mixed subsistence farming systems, where it is intercropped with beans, cassava, and other staple crops (Shamamba *et al.*, 2023). While such systems contribute to livelihood diversification, their implications for productivity remain insufficiently understood.

Beyond biophysical and technical constraints, growing evidence suggests that sociodemographic characteristics of farmers play a critical role in shaping agricultural productivity. Factors such as age, education level, farming experience, household size, access to labor, and participation in farmer organizations can influence condition-making, adoption of innovations, and access to resources. Studies conducted in other regions have demonstrated that farm size, soil conditions, and climate adaptation strategies significantly affect banana yields (Mukul et al., 2013; Abdoussalami et al., 2023; Alemu and Mengistu, 2019). Similarly, sociodemographic factors, including education level, household structure, and input use, have been shown to significantly influence production outcomes (Amen and Desalegn, 2018).

In East Africa, several studies have examined constraints affecting banana production, particularly in Uganda (Ssennoga et al., 2019; Tinzaara et al., 2021), Rwanda (Jagwe et al., 2009; Maniriho, 2013; Okonya et al., 2019), and Tanzania However, in South Kivu, empirical research remains limited and fragmented. Existing studies have primarily focused on agronomic practices such as fertilizer application (Kamira *et al.*, 2016; Ntamwira *et al.*, 2021), pest and disease management (Guy *et al.*, 2020; Kikulwe *et al.*, 2022; Mukeshambala *et al.*, 2024), or broader food security issues (John *et al*.., 2008), with little attention given to the combined influence of sociodemographic factors and farm management practices on banana productivity at the household level.

Furthermore, although banana farming systems in the mountainous Bushi region are often integrated with other crops and livestock (Dowiya *et al.*, 2009; Ntamwira *et al.*, 2021), the extent to which this integration affects productivity, yield stability, and resilience remains poorly documented. In particular, there is a lack of empirical evidence on how different farmer profiles and management strategies interact within diverse agroecological contexts to shape production outcomes.

Against this background, this study aims to analyze the sociodemographic characteristics and key drivers of banana productivity in the mountainous Bushi agrosystem of eastern D.R. Congo. Specifically, it seeks to: (i) characterize banana-based farming systems across agroecological zones; (ii) identify the main sociodemographic, economic, and agrotechnical factors influencing productivity; and (iii) document the major constraints faced by banana producers.

2 Materials and Methods

2.1 Study area

This study was conducted in the mountainous Bushi region, encompassing the Kabare and Walungu in South Kivu province (Fig. 1). Kabare territory is located between 28°45' and 28°55' East longitude and

2°30' and 2°50' South latitude, at altitudes ranging from 1,460 and 3,000 m above sea level, and covers an area of approximately 1,960 km² (Ndeko *et al.*, 2022, 2024). Walungu territory lies between 28°24.6' and 28°45.5' East longitude and 2°41.5' and 3° South latitude, with altitudes varying from 900 to 3,000 m (Balasha *et al.*, 2021). Data was collected across different agroecological zones (AEZs) within these two territories. These zones were delineated based on key soil and climatic characteristics including soil pH, soil organic carbon, texture fraction, cation exchange capacity 'CEC', macronutrients (potassium, phosphorus, and nitrogen), temperature, solar radiation, precipitation and altitude. A Hierarchical ascending Classification (HAC) was performed based on a Principal Component Analysis (PCA) applied to the combined soil and climate dataset. This multivariate approach enabled the identification and delineation of three agroecological zones (AEZs), the characteristics of which are presented in in Table 1).

Table 1
Biophysical and sociodemographical characteristics of the three-agroecological zones considered in the mountainous Bushi region

Characteristics	ZAE 1	ZAE 2	ZAE 3
Elevation (m)	833–1600 (1347)	1800–3298 (2192.4)	1600–1800 (1715.4)
Slope (%)	0–67.4 (16.9)	0–64.2 (17.3)	0–62.3 (16.2)
Average annual temperature (°C)	18.5–24.5 (21.6)	12.4–20.9 (17.2)	17.4–22.5 (19.9)
Precipitation (mm/year)	1067–2001 (1620.9)	1537–2164 (1934.5)	1350–2036 (1745.7)
pH	4.6–7 (5.17)	4.7–5.7 (5.20)	4.6–5.8 (5.24)
Soil organic carbon (%)	1–6 (2.55)	1.6–8.6 (4.84)	1.2–6.6 (2.73)
Total nitrogen (%)	0.11–0.75 (0.39)	0.13–0.82 (0.51)	0.12–0.76 (0.38)
Phosphorus (ppm)	549–3611 (1469.7)	465–2927 (1326.2)	465–3414 (1261.3)
Potassium (ppm)	72–495 (183.55)	115–824 (239.7)	105–539 (230.4)
CEC (cmol/kg)	6–59 (15.78)	11–62 (26.3)	8–43 (21.2)
Dominant land use	Agricultural land, forests, savannas, built-up areas	Forest, savannas	Agricultural land, forests, savannas
Main language	Mashi	Mashi	Mashi
Source of income	Agriculture	Agriculture and livestock farming	Agriculture
Districts/villages	Katana, Miti, Mumosho, Nyangezi, Mulamba, Kamanyola, etc.	Bushwira, Bugobe, Kagabi, Lurhala, Ikoma, etc.	Bugorhe, Bushumba, Mudaka, Izege, Nduba, Walungu Centre, etc.

Source

Soil data were obtained from 86 samples taken from different plots that were representative of the three agroecological zones (AEZs). Samples were taken at depths between 0 and 30 cm using a composite method, combining at least five subsamples per plot.

2.2 Methods

2.2.1 Sampling and data collection

Field surveys were conducted at the farm level to identify and characterize banana farming practices accross different AEZs. This study focused on banana producers in the mountainous Bushi agroecosystem of the Kabare and Walungu territories. Data were collected from 425 randomly selected farmers, distributed across three agroecological zones: AEZ1 (178), AEZ2 (38) and AEZ3 (209). This uneven distribution reflects the spatial concentration of banana farms, which is higher in AEZ1 and AEZ3. Data collection took place between January to April 2024 using a semi-structured interview. The questionnaire was pre-tested to ensure clarity, relevance, and consistency with the study objectives. Once validated, it was digitized using KoboCollect and administered via electronic tablets to facilitate real-time data capture. The questionnaire comprised four main sections: (i) Socioeconomic characteristics of the household (farmer); (ii) farming system attributes (e.g., production system type, fertilizers used, labor, cultivated area, (iii) banana production characteristics (varieties, yields); and (iv) constraints affecting banana production. The full questionnaire is available at (https://ee.kobotoolbox.org/x/XGAXfDaH). The questionnaire was administered directly to banana producers in their fields, with each interview lasting approximately 30 to 45 minutes. Prior to large-scale implementation, a pilot survey was conducted to assess the reliability, clarity, and contextual of the questions, as well as respondents' understanding and consistency of responses. Farmers were randomly selected based on the single inclusion criterion, engagement in banana cultivation, and participated voluntarily after being informed of the study's objectives.

2.2.2 Evaluation of banana productivity and drivers

Banana production at the plantation level was assessed using information on cultivated varieties, number of harvested bunches, and annual harvest frequency. Banana bunches were weighed using a Salter mechanical spring balance manufactured by Yongkang Zhengya Weighing Apparatus Factory (China), with a maximum capacity of 100 kg and a precision of 50 g. Total production was estimated by multiplying the weight by the total number of harvested bunches. Yields were then standardized to extrapolate production over a uniform area of 1 hectare, allowing for better comparison of the different cropping systems.

To identify the factors influencing banana yield under different cropping systems, a multiple linear regression model was applied, following approaches used in previous studies (Ayoola and Dangbegnon, 2011; Dutta *et al.*, 2020; Shah *et al.*, 2020; Firmin *et al.*, 2022). The dependent variable (Y) represents banana yield (continuous variable, expressed in tons per hectare), while the explanatory (independent) variables included a set of socio-economic, agronomic, and structural characteristics. These comprised: territory, respondent's gender, marital status, education level, main activity, age, seniority (in years), access to credit, membership in farmers' organization, land tenure system, farm size (in hectares), age of the banana plantation, plot topography, types of fertilizer used, source of planting material, and type of labor employed. The multiple linear regression model used in this study is specified as follows:

$$Y = \beta 0 + \beta 1X1 + \beta 2X2 + \cdots + \beta nXn$$

Where: Y: banana plantation yield; β0: model constant (ordinate at origin); βi: regression coefficient associated with explanatory variable Xi; Xi: explanatory variables (socioeconomic factors, agronomic factors, etc.)

2.3 Data treatment and analysis

The data was preprocessed in MS Excel 2021 before being downloaded from Kobo Collect to generate the final version of the database. Statistical analyses, data visualization, and graphing were subsequently performed using RStudio and R4.4.1 (R Core Team, 2024). The chi-squared test (χ^2) was used to examine associations between categorical variables (e.g. banana variety, varietal selection criteria, and production constraints) across agroecological zones, with a significant level set at 5%. Analysis of variance was applied to assess differences in quantitative variables (e.g. farming experience, plantation age, and cultivated area, planting density, and yield) among agroecological zones. In addition, linear models were also employed to identify the factors significantly influencing banana productivity across different cropping systems.

3 Results

3.1 Characteristics of banana-based systems in the mountainous Bushi region

Analysis of the socio-demographic characteristics presented in Table 2 indicates a generally consistent pattern across the 2 AEZs for most of the examined variables. The agricultural population is predominantly woman (57.9%) and consists of middle-aged adults (45.8 ± 13.6 years) with long experience in agricultural activity (24.3 ± 10.5 years). This situation reflects both a significant wealth of empirical knowledge and a gradual aging of the workforce. The level of education remains low, with almost half of those surveyed being illiterate (46.1%). This may limit their access to climate information and their willingness to adopt agroecological innovations. Agriculture is the main activity for 77.4% of households, and access to credit remains very limited (3.5%), confirming a structural financial constraint that hinders investment and adaptation capacities However, significant territorial disparities appear with regard to marital status ($x^2 = 11.869, p = 0.018$), membership in farmers' organizations ($x^2 = 8.283, p = 0.016$), and mode of access to land ($x^2 = 14.64, p = 0.023$). AEZ 1 stands out for its relatively higher level of organizational integration (11.2%), a factor recognized as crucial for the dissemination of resilient practices and access to support services. AEZ 3, on the other hand, has a higher proportion of land access through purchase (29.2%), reflecting a trend toward land commodification that is likely to influence long-term investment strategies. Conversely, inheritance is the predominant mode of land acquisition, particularly in AEZ 2 (73.7%).

Table 2
Sociodemographic characteristics of farmers involved in the banana sector

Characteristics	**AEZ 1 (*N = 178*)**	**AEZ 2 (*N = 38*)**	**AEZ 3 (*N = 209*)**	**Average (*N = 425*)**	***Chi ^{2}***	***P-value***
Gender						
Woman	56.2	50.0	60.8	57.9	1.893	*0.388*
Man	43.8	50.0	39.2	42.1		
Marital status						
Single	3.4	0.0	8.1	5.4	11.869	*0.018*
Married	84.3	94.7	75.1	80.7		
Widowed	12.4	5.3	16.7	13.9		
Age (years)	45.5 ± 12.4	46.2 ± 12.4	45.9 ± 14.7	45.8 ± 13.6		*0.942*
Level of education						
Illiterate	51.1	39.5	43.1	46.1	6.676	*0.352*
Primary	33.7	39.5	38.8	36.7		
Secondary	14.0	21.1	14.8	15.1		
University	1.1	0.0	3.3	2.1		
Main activity						
Farmer	70.8	73.7	83.7	77.4	14.135	*0.078*
Trade	12.4	13.2	6.2	9.4		
Breeder	5.1	2.6	2.4	3.5		
Civil servant	5.1	5.3	5.7	5.4		
Small business	6.7	5.3	1.9	4.2		
Experience in agriculture (years)	24.5 ± 10.6	27.1 ± 9.1	23.7 ± 10.7	24.3 ± 10.5		*0.186*
Access to credit						
No	94.9	100.0	97.1	96.5	2.875	*0.238*
Yes	5.1	0.0	2.9	3.5		
Membership in a farmers' organization						

Characteristics	**AEZ 1 (*N = 178*)**	**AEZ 2 (*N = 38*)**	**AEZ 3 (*N = 209*)**	**Average (*N = 425*)**	***Chi*** ^{2}	***P-value***
No	88.8	97.4	95.7	92.9	8.283	*0.016*
Yes	11.2	2.6	4.3	7.1		
Mode of access to land						
Purchase	18.5	26.3	29.2	24.5	14.64	*0.023*
Inheritance	63.5	73.7	57.9	61.6		
Rental	9.0	0.0	8.1	7.8		
Sharecropping	9.0	0.0	4.8	6.1		

Beyond socio-demographic characteristics, understanding the technical aspects of banana production is essential. Table 3 summarizes key information on the banana cultivation system practiced in the study area.

Table 3
Information on the banana cropping systems in three agroecological conditions of the Bushi, eastern D.R. Congo

Parameters	AEZ 1 (N = 178)	AEZ 2 (N = 38)	AEZ 3 (N = 209)	Average (N = 425)	Chi^2	P-value
Cropping system						
Intercropping	83.7	97.4	89.0	87.5	*6.163*	*0.046*
Monoculture	16.3	2.6	11.0	12.5		
Association						
Maize	19.5	18.9	52.7	36.0	44.842	*< 0.001*
Common beans	26.8	5.4	49.5	36.0	35.073	*< 0.001*
Cassava	62.4	73.0	46.2	55.4	13.912	*0.001*
Soybean	0.7	0.0	9.7	5.1	16.057	*< 0.001*
Peanut	0.0	0.0	1.6	0.8	3.024	*0.220*
Sweet potatoes	26.2	35.1	19.4	23.7	5.128	*0.077*
Potatoes	0.7	0.0	1.6	1.1	1.136	*0.567*
Cabbage	2.7	0.0	4.8	3.5	2.626	*0.269*
Amaranth	6.7	2.7	10.8	8.3	3.474	*0.176*
Sorghum	8.7	0.0	2.7	4.8	8.636	*0.013*
Woody plants	4.0	8.1	14.0	9.4	9.694	*0.008*
Cultivated area (ha)	0.80 ± 0.69	0.57 ± 0.35	0.62 ± 0.41	0.69 ± 0.55		*0.001*
Landform						
Shallow	26.4	2.6	7.2	14.8	52.05	*< 0.001*
Hillside	59.0	97.4	43.1	54.6		
Hilltop	14.6	0.0	49.8	30.6		
Fertilizer used						
None	8.4	0.0	27.8	17.2	62.826	*< 0.001*
Compost	6.7	2.6	8.1	7.1		
Organic waste	7.3	15.8	17.7	13.2		

Parameters	AEZ 1 (N = 178)	AEZ 2 (N = 38)	AEZ 3 (N = 209)	Average (N = 425)	Chi^2	P-value
Cropping system						
Manure and Crop residues	36.8	40.7	21.5	29.6		
Mineral	3.9	0.0	3.3	3.3		
Labor						
None	5.6	0.0	7.2	5.9	9.653	*0.047*
Family	85.4	100.0	80.4	84.2		
Paid	9.0	0.0	12.4	9.9		

The results in Table 3 highlight the analysis of production systems marked agroecological differences between the three zones, reflecting contrasting farming practices that are statistically significant for most of the parameters studied. The crop association system is largely dominant (87.5%), but with a significantly higher prevalence in AEZ 2 (97.4%) than in AEZ 1 and AEZ 3 ($x^2 = 6.163, p = 0.046$). The composition of intercropped crops varies greatly from one zone to another: maize and beans are significantly more prevalent in AEZ 3 (52.7% and 49.5% respectively; $p < 0.001$), while cassava predominates in AEZ 2 (73.0%; $x^2 = 13.912$, p = 0.001). The introduction of soybeans, which is virtually non-existent in AEZ1 and AEZ2, is specific to AEZ3 (9.7%). The average cultivated area differs significantly between zones ($p = 0.001$), with AEZ1 having the largest areas (0.8 ± 0.69 ha). The location of the plots reveals a high degree of spatial specialization ($x^2 = 52.05, p < 0.001$): lowlands are mainly exploited in AEZ 1 (26.4%), hillsides in AEZ 2 (97.4%), while AEZ 3 concentrates summit agriculture (49.8%). Fertilization practices also show notable contrasts ($x^2 = 62.826, p < 0.001$): the total absence of fertilizers is particularly marked in AEZ 3 (27.8%), while the use of crop residues dominates in AEZ 1 and AEZ 2, reflecting mainly organic fertility management strategies with low use of mineral inputs (3.3%). Finally, labor remains essentially family-based (84.2%), but the use of paid labor is significantly more frequent in AEZ 3 (12.4%; $x^2 = 9.653, p < 0.05$), reflecting a relative monetization of production systems.

Table 4 below compares banana production systems in three different AEZ. It illustrates the types and varieties of bananas grown, where the planting material comes from, how it is selected and where the produce is sold. Analysis of varietal characteristics and banana production patterns reveals highly significant differences between the three zones, reflecting contrasting production orientations and farming strategies closely linked to local conditions. The distribution between cooking bananas and dessert bananas differs greatly between zones ($x^2 = 31.509, p < 0.001$): AEZ 3 specializes clearly in dessert bananas (73.7%), while AEZ 1 and especially AEZ 2 favor cooking bananas (63.2%), reflecting different dietary and commercial preferences. Among dessert banana varieties, Gros Michel remains dominant (64.0% on average), with a marked preponderance in AEZ2 (85.7%), while Poyo is more

prevalent in AEZ3 (38.3%). About cooking bananas, the predominance of green bananas in AEZ2 (75.0%) and plantains in AEZ3 (67.3%) confirms the existence of production areas with distinct vocations ($x^2 = 46.258, p < 0.001$). The origin of plant material is largely based on suckers from neighboring fields (75.1%), particularly in AEZ2 (100%), while regeneration of plants is mainly observed in AEZ3 (24.4%). The criteria for variety selection are mainly oriented towards yield (76.2%) and short cycle (42.8%), but with marked differences: the search for yield is almost unanimous in AEZ 2 (100%), while organoleptic (32.5%) and nutritional (25.4%) characteristics are considered to a greater extent in AEZ 3 ($p < 0.01$). Consideration of resistance to biotic stress remains limited and highly variable across zones ($x^2 = 27.311$, $p < 0.001$). In terms of production destination, sales on the local market are the main outlet (70.6%), but self-consumption is significantly higher in AEZ 3 (26.8%).

Table 4
Banana cropping practices and criteria according to agro-ecological zones

Parameters	AEZ 1	AEZ 2	AEZ 3	Average	Chi 2	P-value
	(N = 178)	(N = 38)	(N = 209)	(N = 425)		
Types of bananas grown						
Cooking bananas	49.4	63.2	26.3	39.3	31.509	< 0.001
Dessert bananas	50.6	36.8	73.7	60.7		
Cultivated varieties (dessert)						
Cavendish	6.7	0.0	3.9	4.7	40.776	< 0.001
Gros Michel	71.1	85.7	57.8	64.0		
Poyo	22.2	14.3	38.3	31.4		
Cultivated varieties (for cooking)						
Green banana	52.3	75.0	32.7	49.1	46.258	< 0.001
Plantain	47.7	25.0	67.3	50.9		
Origin of planting material						
Donation from organization	9.6	0.0	6.2	7.1	21.776	< 0.001
Foot regeneration	14.0	0.0	24.4	17.9		
Rejects from a neighboring field	76.4	100.0	69.4	75.1		
Variety selection criteria						
High yield potential	88.2	100.0	61.7	76.2	50.213	< 0.001
Short phenological cycle	40.4	63.2	41.1	42.8	7.066	0.029
Organoleptic properties	20.8	2.6	32.5	24.9	18.184	< 0.001
Nutritional value	15.7	5.3	25.4	19.5	11.075	0.004
Resistance to biotic stresses	26.4	34.2	8.6	18.4	27.311	< 0.001
Destination of production						
Own consumption	12.4	15.8	26.8	19.8	20.625	0.002
Exports from urban centers	3.4	0	4.8	3.8		
Wine production	5.6	0.0	7.2	5.9		

Parameters	AEZ 1	AEZ 2	AEZ 3	Average	Chi 2	P-value
	(N = 178)	(N = 38)	(N = 209)	(N = 425)		
Sales on the local market	78.7	84.2	61.2	70.6		

Table 5 summarizes the various constraints identified in banana cultivation. These constraints are classified into four broad categories: biotic, abiotic, socioeconomic and technical, and detail the main factors limiting the productivity and sustainability of plantations. Analysis of the constraints affecting banana-based systems confirms multidimensional vulnerability, which is dominated by biotic, abiotic, socio-economic, agronomic and technical factors. There is significant variability in these factors across AEZs. Overall, almost all farmers report at least one biotic constraint (89.4%). Bacterial diseases are the main health problem (57.4%), followed by viral diseases (49.6%) and insect pest damage (32.7%). These are particularly prevalent in AEZ 1, affecting nearly half of producers. The exclusive occurrence of mite infestations in AEZ 3 (5.3% suggests a local shift in pest and disease pressure, potentially linked to specific microclimatic or management conditions. Abiotic stresses differ significantly between AEZs ($p = 0.009$) and are dominated by strong winds and storm events (72.0%), reported by all producers in AEZ 2. Soil erosion (41.9%) is also a significant stressor, reflecting the sensitivity of steep slopes and poorly protected soils in mountainous environments. High temperatures were mainly reported in AEZ 3 (27.3%), while elevated evapotranspiration was particularly marked in AEZ 2 (36.8%; $p = 0.001$), highlighting differentiated exposure to climatic stresses. Low soil fertility remains a major constraint (40.0%), particularly in AEZ 1, consistent with evidence of nutrient depletion and declining productive capital in banana-based systems on degraded soils. Socioeconomic constraints are strongly discriminatory ($p = 0.001$) and largely relate to access to financial and informational resources. Limited access to finance (33.2%; $p < 0.001$) and formal credit (32.5%; $p < 0.001$) is most frequently reported in AEZ 2 (affecting over 76% of producers), revealing high dependence on monetary resources despite low financial inclusion. Constraints relating to limited access to organic amendments (21.2%; $p < 0.001$) and land (7.1%; $p = 0.024$) reinforce the notion of structural productive insecurity, as well as making it difficult to invest in soil fertility management. At the same time, theft of ripe bunches remains a widespread problem across AEZs (49.9%; $p = 0.236$), posing an additional risk to smallholders. From an agronomic standpoint, the key bottlenecks for farm performance are slow plantation regeneration (52.5%; $p = 0.027$), labor-intensive field maintenance (45.4%; $p < 0.001$) and, above all, low banana yields (61.4%; $p < 0.001$, reaching 100% in AEZ 2). These reflect suboptimal plant densities, sucker management and input use, as documented in similar banana systems. Technical constraints indicate limited control over crop management; over half of producers report inappropriate management practices and limited knowledge of cultivar characteristics, while difficulties in selecting suitable cultivars are particularly acute in AEZ 3, where a mismatch between varieties and local conditions likely exacerbates yield gaps.

Table 5
Main constraints observed by banana producers

Parameters	AEZ 1 (N = 178)	AEZ 2 (N = 38)	AEZ 3 (N = 209)	Average (N = 425)	Chi 2	P-value
Types of constraint						
Biotic constraints	89.3	100.0	87.6	89.4	5.259	*0.072*
Abiotic constraints	83.7	100.0	79.9	83.3	9.369	*0.009*
Socioeconomic constraints	88.2	100.0	78.5	84.5	14.615	*0.001*
Agronomic and technique constraints	92.1	100.0	71.3	82.6	37.839	*< 0.001*
Biotic constraints						
Fungal diseases	6.7	0.0	1.9	3.8	7.817	*0.02*
Bacterial diseases	62.4	63.2	52.2	57.4	4.659	*0.097*
Viral diseases	52.8	36.8	49.3	49.6	3.215	*0.200*
Insect damage	44.9	36.8	21.5	32.7	24.266	*< 0.001*
Mite infestations	0.0	0.0	5.3	2.6	11.67	*0.003*
Abiotic stresses						
Elevated air temperatures	8.4	0	27.3	16.9	32.775	*< 0.001*
Strong winds and storm events	78.7	100.0	61.2	72.0	30.678	*< 0.001*
Elevated evapotranspiration	11.8	36.8	18.2	17.2	14.099	*0.001*
Soil erosion	40.4	63.2	39.2	41.9	7.819	*0.020*
Low soil fertility	55.6	36.8	27.3	40.0	32.355	*< 0.001*
Socioeconomic constraints						
Limited access to organic amendments	28.7	0	18.7	21.2	16.96	*< 0.001*
Limited access to plant protection products	35.4	26.3	31.6	32.7	1.41	*0.494*
Limited access to finance	47.8	81.6	12.0	33.2	99.645	*< 0.001*

Parameters	AEZ 1 (N = 178)	AEZ 2 (N = 38)	AEZ 3 (N = 209)	Average (N = 425)	Chi 2	P-value
Types of constraint						
Limited access to formal credit	50.0	76.3	9.6	32.5	78.249	*< 0.001*
Limited access to technical/market information	50.6	63.2	41.6	47.3	7.292	*0.026*
Theft of ripe fruit	50.6	36.8	51.7	49.9	2.886	*0.236*
Agronomic constraints						
Slow stand regeneration	55.6	68.4	46.9	52.5	7.194	*0.027*
Poor adaptation of cultivars to local conditions	4.5	0.0	8.1	5.9	4.908	*0.086*
Labor-intensive field maintenance	53.9	94.7	29.2	45.4	64.704	*< 0.001*
Difficulties in managing production	21.3	0	26.8	22.1	13.506	*0.001*
Low banana yield	73.0	100.0	44.5	61.4	59.254	*< 0.001*
Technical constraints						
Inappropriate management practices	47.8	63.2	53.1	51.8	3.274	*0.195*
Limited knowledge of cultivar characteristics	47.2	63.2	53.6	51.8	3.745	*0.154*
Inadequate plot layout and spacing	22.5	0.0	23.4	20.9	11.109	*0.004*
Lack of agricultural equipment/tools	49.4	63.2	56.0	53.9	3.101	*0.212*
Long production cycle	42.7	36.8	21.1	31.5	3.274	*< 0.001*

3.2 Banana productivity in the mountunous Bushi, eastern DRC

Figure 2 shows the banana productivity in different agroecological zones (AEZs). It indicates that the yield did not varied according to AEZ but differed from one cropping system to another and from one cultivar to another ($p < 0.05$). The plots presented similar yield in each agroecological zones respectivelent fo 15.83 t/ha (AEZ1), 15.86 t/ha (AEZ3), and 12.30 t/ha (AZE2). However, these differences are not statistically significant (*Kruskal-Wallis chi-squared = 3.96, p > 0.05*). Figure 3 shows the

yield variation in the different cropping systems. The results reveal that the annual number of bunches harvested and the yield vary significantly depending on the type of cropping system (*Kruskal-Wallis chi-squared = 62.66*, p < 0.001) with monoculture meading to 318.75 and 1,600 bunches per hectare on average, with an average of 732 ± 299.7 bunches per hectare, while those using a mixed cropping system harvest between 125.3 and 1,350 bunch per hectare on average, with an average of 411.7 ± 233 bunches per hectare. They also reveal that the yield of farmers practicing monoculture varies from 10.5 to 51.24 tons per hectare, with an average of 24.672 ± 9.948 tons per hectare, while those practicing mixed cropping harvest between 3.275 and 51.0 tons per hectare, with an average of 14.293 ± 8.948 t/ha (*Kruskal-Wallis chi-squared = 57.73, p < 0.001*). .

Figure 4 shows the assessment of banana varieties productivity. These results revealed that higher yields were observed among Gros Michel variety (18.53 ± 10.8t/ha), plantains (15.47 ± 0.14 t/ha) than the Poyo (12,9 ± 8,3 t/ha) and green banana (12,4 ± 6,0 t/ha) (*Kruskal-Wallis chi-squared = 29.49, p < 0.001*).

3.3 Drivers of banana productivity in the mountainous Bushi, eastern DRC

Table 6
Socioeconomic and agronomic driving factors of banana productivity in the mountainous Bushi, eastern DRC.

Parameter	**Coefficient**	**T value**	**OR**	***P value***
(Intercept)	1.522	5.325	4.583	*< 0.001*
Territory: Walungu	-1.945	-1.536	0.143	*0.125*
Gender: Man	-1.106	-1.089	0.331	*0.277*
Marital status: Married	-3.576	-1.429	0.028	*0.154*
Marital status: Widowed	-4.510	-1.434	0.011	*0.152*
Level of education: Primary	-1.704	-1.505	0.182	*0.133*
Level of education: Secondary	-1.570	-1.000	0.208	*0.318*
Level of education: University	1,163	1,350	3.200	*0.178*
Main activity: Trade	1,266	0.743	3,546	*0.458*
Main activity: Livestock farming	1.484	0.562	4.412	*0.574*
Main activity: Civil service	1.083	1.989	2.955	*0.047*
Main activity: Small business	0.573	0.234	1.773	*0.815*
Age	0.141	2.050	1.152	*0.041*
Experience in agriculture	-0.046	-0.702	0.955	*0.483*
Access to credit	0.246	0.075	1.279	*0.940*
Membership in a farmers' organization	-5.298	-2.248	0.005	*0.025*
Method of access to land: Purchase	0.802	0.580	2.230	*0.562*
Mode of access to land: Inheritance	1.497	0.653	4.469	*0.514*
Mode of land access: Rental	1.059	0.355	2.884	*0.723*
Type of land tenure: Sharecropping	1.323	0.624	3.754	*0.533*
Area	0.655	0.737	1.926	*0.462*
Date of establishment of the banana plantation	0.033	1.079	1.034	*0.281*
Topography; Hillside	-1.682	-1.180	0.186	*0.239*
Topography: Hilltop	-2.343	-1.510	0.096	*0.132*
Types of fertilizer: Mineral	-0.846	-0.282	0.429	*0.778*
Types of fertilizer: Organic	-6.908	-5.756	0.001	*< 0.001*

Parameter	Coefficient	T value	OR	*P value*
Origin of waste: neighboring fields	-2.688	-1.354	0.068	*0.176*
Source of discards: Regeneration of plants	-2.112	-0.978	0.121	*0.329*
Type of labor: Family	0.650	1.146	1.916	*0.252*
Type of labor: Paid	1.440	1,472	4.222	*0.014*
R^2	0.171			
R^2 adjusted	0.109			
AIC	3078.313			
BIC	3203.487			
Breusch-Pagan test	33.678	(p = 0.251)		
Durbin-Watson test	0.960	(p < 0,001)		

Table 6 presents the results from multiple linear regression. Older farmers are more likely to achieve higher banana productivity than younger farmers (OR = 1.15; $p < 0.05$). Those whose main activity is in the public sector exhibit higher productivity than those in other categories (OR = 2.95; $p < 0.05$). Additionally, non-membership of farmers' organizations is negatively associated with high yields, as membership significantly reduces the odds of high productivity (OR = 0.005; $p < 0.05$). Using organic fertilizers is strongly and significantly associated with higher banana yields (OR = 0.001; $p < 0.001$), whereas using paid labor rather than family labor increases the odds of higher productivity (OR = 4.22; $p < 0.05$). The intercept suggests that other unobserved factors also positively influence banana yield (OR = 4.58; $p < 0.001$). The low adjusted R^2 suggests that the model does not explicitly capture important factors that explain productivity, such as more refined agronomic practices, soil quality, specific varieties and local climatic conditions.

4 Discussion of results

Characterizing banana-based farming systems in the mountainous Bushi region reveals a relatively homogeneous socio-demographic structure across agroecological zones. However, there are significant institutional, agronomic and environmental differences that influence productivity. The predominance of woman is indicative of the progressive feminization of agriculture that has been widely documented in sub-Saharan Africa, particularly in regions affected by man migration and limited formal employment opportunities (Moyo, 2016; Doss, 2018). Women play a central role in banana production, which constitutes a staple food and an essential source of household income. However, the generally low level of formal education among producers may limit their ability to access agricultural extension services, interpret agronomic recommendations and adopt innovations that enhance productivity (Cafer and Rikoon, 2018; Norton and Alwang, 2020). Studies have shown that education influences farmers'

capacity to integrate improved technologies, optimize resource allocation and adapt to environmental constraints (Masere and Worth, 2022). Similarly, limited access to credit is a significant structural barrier, as financial capital is crucial for acquiring improved planting material, organic amendments and labor, all of which are vital for maintaining banana productivity (Katungi, 2006).Despite overall socio-demographic similarities, significant differences in land tenure, institutional integration and production orientation across AEZ suggest. Membership of farmer organizations is crucial for improving productivity, as it facilitates access to technical knowledge, agricultural inputs and markets (Shiferaw *et al.*, 2016). Such organizations also promote collective learning and enhance adaptive capacity, particularly in smallholder systems where access to formal extension services is limited. The predominance of land acquisition through inheritance reflects the persistence of customary land tenure systems, which often result in land fragmentation and constrain agricultural intensification (Ndjadi *et al.*, 2020).

Agroecological differences between regions have a significant influence on banana production systems, reflecting adaptations to environmental factors such as altitude, slope position, soil fertility and microclimatic variability. Mountain ecosystems are characterized by strong spatial heterogeneity in soil properties, water availability and erosion risk, all of which directly affect crop performance (Chuma *et al.*, 2024). Lowland areas tend to accumulate nutrients and moisture, favoring plant growth. In contrast, hillsides and summit zones are more exposed to soil erosion, nutrient depletion and climatic stress (Mpanda *et al*, 2025). These environmental constraints influence farmers' management practices, including crop associations, fertilization strategies, and cultivar selection. The prevalence of intercropping is a traditional adaptation strategy that optimizes land use, maintains soil fertility, and reduces environmental risk (Ndjadi *et al.*, 2020). Intercropping enhances nutrient cycling, improves soil organic matter content, and reduces erosion by maintaining continuous ground cover (Ndjadi *et al.*, 2022).

The distribution of different varieties of banana across different agroecological zones further illustrates how farmers adapt to local environmental and socio-economic conditions. Banana cultivars exhibit significant genetic variability in terms of their yield potential, nutrient use efficiency, stress tolerance and disease resistance. These characteristics influence their productivity under different agroecological conditions (Wang *et al.*, 2021). Farmers' selection criteria are primarily driven by yield potential, cycle duration, taste and market demand, reflecting subsistence and commercial objectives (Marimo *et al.*, 2020). However, the limited consideration of resistance to biotic and abiotic stresses suggests that varietal selection is not always optimized to maximize productivity under environmental constraints. The widespread use of planting material obtained from neighboring farms may contribute to the accumulation and spread of pathogens, thereby reducing plant vigor and yield potential (Madalla, 2021). Using infected or physiologically aged planting material has been identified as a major factor limiting banana productivity in East Africa (Madalla *et al.*, 2023).

The multidimensional constraints affecting banana production help to explain the variability in productivity observed across different agroecological zones. Biotic stresses, including bacterial wilt and viral diseases, can significantly reduce productivity by impairing physiological processes and reducing

plant vigor (Blomme *et al.*, 2020). These diseases disrupt nutrient transport and reduce photosynthetic efficiency, ultimately decreasing yield. Abiotic stresses, such as soil erosion, strong winds and declining soil fertility, further reduce productivity by limiting nutrient availability and damaging plant structure (Ravi and Vaganan, 2016; Vashisth and Kadyampakeni, 2019). Mountain ecosystems are particularly vulnerable to soil degradation due to steep slopes and intense rainfall, which accelerate nutrient loss and reduce soil productivity. Socio-economic constraints, including limited access to credit (Lucas, 2021), inputs and technical information (Omari *et al.*, 2024), restrict farmers' capacity to improve productivity even further (Muigai *et al.*, 2021; Okech *et al*., 2005). These constraints limit investment in improved planting material, fertilization and plantation management (Meya *et al.*, 2020). Technical constraints, including inadequate plantation management and limited knowledge of cultivar characteristics, also contribute to productivity gaps (Lucas, 2021). These findings highlight the importance of improving access to extension services, technical training, and improved planting material.

The higher productivity observed in monoculture systems is due to reduced competition for essential resources such as nutrients, water and sunlight (Kaur *et al.*, 2024). Banana plants in monoculture systems benefit from optimized spacing, more efficient nutrient uptake and simplified management practices, enabling them to reach their full productive potential (Leonel *et al.*, 2024). Reduced interspecific competition enhances photosynthetic efficiency, root development and biomass accumulation, thereby increasing yield potential. Monoculture systems increase vulnerability to pests and diseases due to genetic uniformity, facilitating pathogen transmission and reducing system resilience (Reina *et al.*, 2024). Furthermore, continuous monoculture accelerates soil nutrient depletion, reduces soil organic matter and increases the risk of soil degradation (Leonel *et al.*, 2024). By contrast, polyculture systems offer significant ecological and economic benefits that contribute to long-term sustainability. Crop diversification enhances soil fertility by recycling organic matter, improves the efficiency with which nutrients are used, and promotes beneficial biological interactions (Sathya *et al.*, 2024). Intercropping reduces the incidence of pests and diseases by disrupting their life cycles and enhancing biological control mechanisms (Altieri *et al.*, 2024). Furthermore, diversified systems mitigate economic risk by providing multiple income streams and enhancing household food security (Ocimati *et al.*, 2021). Therefore, while monoculture systems may offer higher short-term productivity, promoting diversified, banana-based systems is crucial for ensuring long-term sustainability, ecological stability and resilience to environmental stress (Dusi, 2025).

The influence of socio-economic and agronomic factors on banana productivity emphasizes the importance of farmers' capabilities, access to resources, and management practices. More experienced farmers tend to be more productive, as their accumulated knowledge improves their management of plantations, their selection of cultivars, and their ability to adapt to environmental variability (Farah and Visetnoi, 2024). Experience improves farmers' ability to optimize sucker management, maintain appropriate plant density and implement timely agronomic interventions. Similarly, belonging to farmer organizations can facilitate access to extension services, technical information and improved resources, thereby contributing to better agricultural performance (Murigi *et al.*, 2024). Access to financial resources is also critical, as farmers with a stable income are better able to invest in labor and

productivity-enhancing resources. Using hired labor can improve plantation maintenance by ensuring timely weeding, pruning and renewal, all of which are essential for maintaining productivity (Kirimi *et al.*, 2023). Soil fertility management is a critical factor in banana productivity. Organic fertilization improves soil structure, enhances microbial activity and increases nutrient availability, thereby promoting plant growth and yield (Zhang *et al.*, 2019). Organic inputs such as manure and crop residues help maintain soil organic matter, playing a vital role in sustaining soil fertility and improving water retention (Kumar *et al.*, 2025). In smallholder systems where access to mineral fertilizers is limited, organic nutrient management is a vital strategy for maintaining productivity and ensuring long-term sustainability.

This study has several limitations that should be considered when interpreting the results. Firstly, productivity was assessed based on cross-sectional observations and farmer-reported data, which may not fully capture temporal variability in yield. Important agronomic variables, such as soil nutrient status, pest severity and microclimatic conditions, were not measured directly. The regression model also suggests that additional biophysical and management factors influence productivity. Future research should therefore integrate soil analysis, longitudinal monitoring and detailed agronomic assessments to provide a more comprehensive understanding of the determinants of productivity.

5 Conclusion

This study aimed to analyze the determinants of productivity in banana-based agroecosystems in the mountainous Bushi region, eastern DR Congo. Specifically, it sought to: (i) characterize production systems across agroecological zones; (ii) asssess banana productivity under different cropping systems; and (iii) identifying driving factors influencing productivity.

The results indicate relatively homogeneous sociodemographic characteristics across agroecological zones, but significant differences in land tenure systems, institutional integration, varietal distribution, fertilization practices, and farm spatial organization. These variations reflect farmers' adaptation strategies to heterogeneous agroecological conditions. Banana productivity differed markedly across cropping systems, with monoculture systems achieving higher yields, likely due to reduced interspecific competition and more efficient resource use. Nevertheless, intercropping systems remain predominant, given their role in enhancing food security, income diversification, and agroecological resilience. Privity was significantly influenced by several key factors, including farming experience, membership in farmer organizations, fertilization practices, type of labor, and access to financial resources. These findings highlight the combined importance of technical and socio-economic drivers in shaping production outcomes. However, banana production continues to face major constraints, notably biotic stresses (pests and diseases), declining soil fertility, climatic hazards, and limited access to improved planting materials and agricultural support services. Overall, the results demonstrate that banana productivity in the Bushi agroecosystem is governed by a complex interplay of environmental conditions, farm management practices, and institutional factors. Strengthening agricultural extension services, improving access to high-quality, disease-free planting materials, promoting sustainable soil fertility

management, and supporting farmer organizations are critical pathways for enhancing productivity while ensuring the long-term sustainability and resilience of banana-based systems.

Declarations

Ethics approval and consent to participate

The study protocol was approved by the interdisciplinary center for ethics Research (CIRE) of the Université Évangélique en Afrique (UEA), under reference CNES 036/dPSK/322PP/2024 and conducted in accordance with the ethical principles of the declaration of Helsinki, adopted by the 18th World Medical association general assembly, Helsinki, Finland, June 1964. Farmers participating in the study provided oral informed consent after the research team explained the objectives, procedures, and voluntary nature of participation. Written consent was not obtained due to cultural concerns and low literacy levels, and this approach was explicitly approved by the ethics committee of UEA.

Clinical Trial Number: ‘

Clinical trial number: not applicable’

Author Contribution

Safina Bora Francine made comprehensive contributions across all aspects of the research process, including conceptualization, methodology, investigation, data management, analysis, funding acquisition, project administration, supervision, software development, validation, visualization, and manuscript preparation, from original drafting through critical review and editing, demonstrating leadership and full ownership of the study.Mushagalusa Nachigera Gustave , made comprehensive contributions across all aspects of the research process, including conceptualization, methodology, investigation, project administration, supervision, validation, visualization, and manuscript preparation, from original drafting through critical review and editing.Chuma Basimine Geant: made comprehensive contributions across the research process, including , methodology, data management, analysis, software development, validation, visualization, and manuscript preparation, from original drafting through critical review and editing.Bawale Mulungula David: made comprehensive contributions across the research process, including , methodology, data management, analysis, software development, validation, visualization, and manuscript preparation, from original drafting through critical review and editing.Majaliwa Mwanjalolo Jackson, made comprehensive contributions of the research process, including: supervision, validation, visualization, and manuscript preparation, review and editing.Shakanye Ndjadi Serges: made comprehensive contributions of the research process, including: supervision, validation, visualization, and manuscript preparation, review and editing.Bashagaluke Bigabwa Janvier: made comprehensive contributions of the research process, including: supervision , validation, visualization, and manuscript

preparation, review and editing.Walere Muhindo Sahan; made comprehensive contributions across all aspects of the research process, including conceptualization, methodology, investigation,supervision, validation, visualization, and manuscript preparation, from original drafting through critical review and editing

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Data Availability

The climatic parameters of the different ZAEs were obtained from WorldClim version 2 rasters (https://www.worldclim.org/). The variables considered included average annual temperature and precipitation. Topographic data (elevation and slope) were obtained from a digital terrain model downloaded from ALOS PALSAR (https://search.asf.alaska.edu/).

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Figures

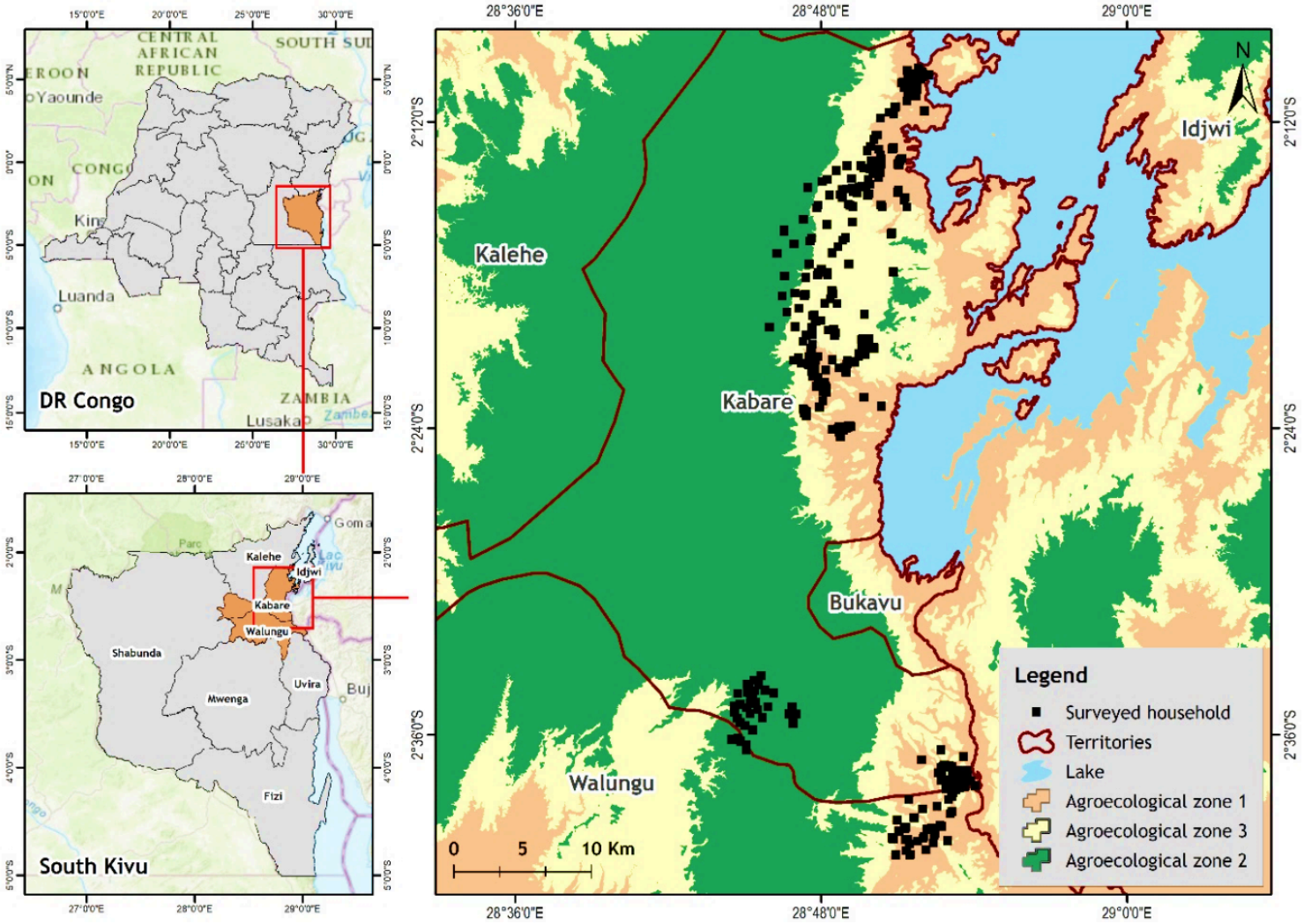


Figure 1

Study area (different agroecological zones in the mountainous Bushi region, eastern DR Congo: data source from the RGC: https://www.rgc.cd)

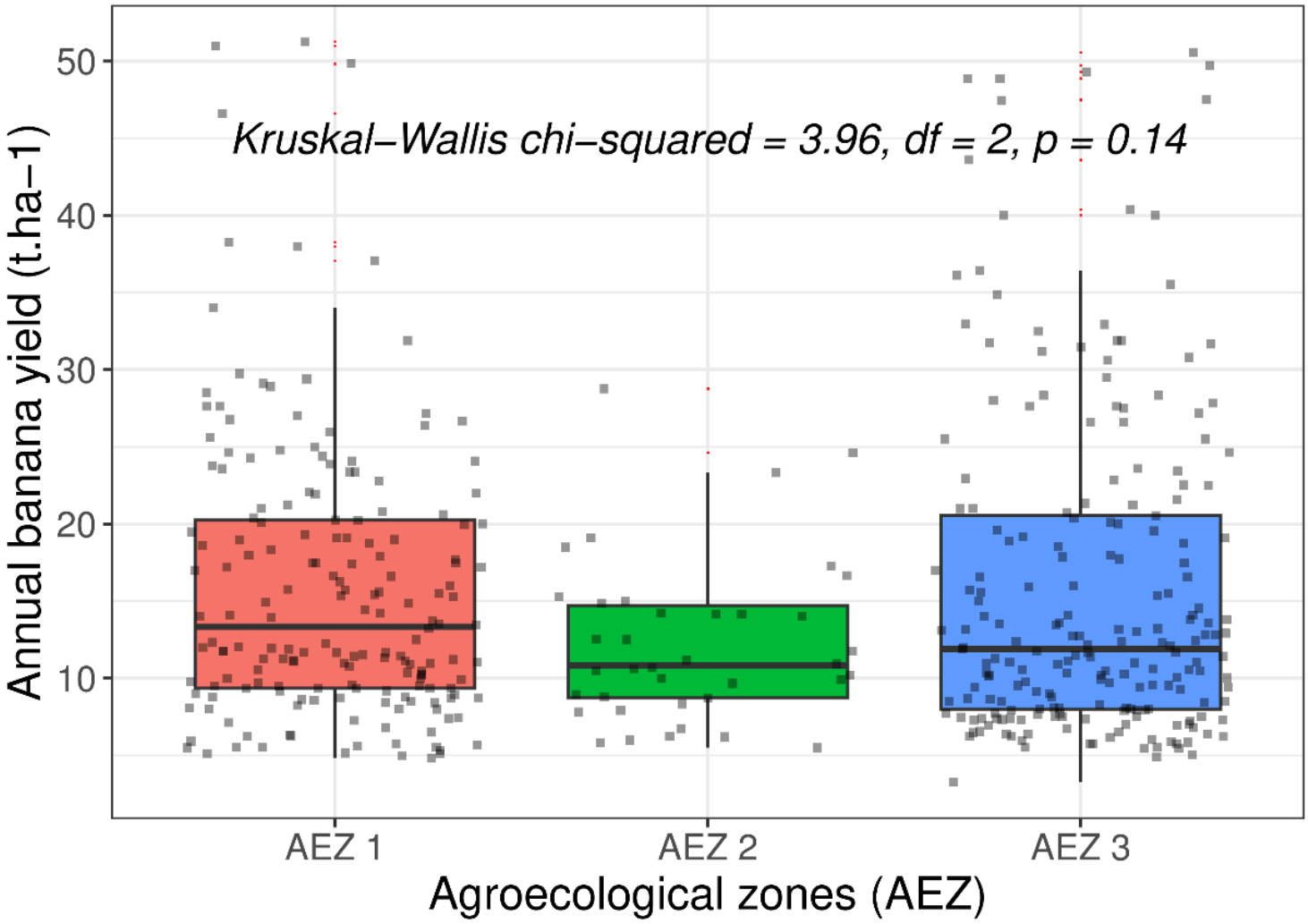


Figure 2

Banana yield patterns across agroecological zones in mountainous Bushi

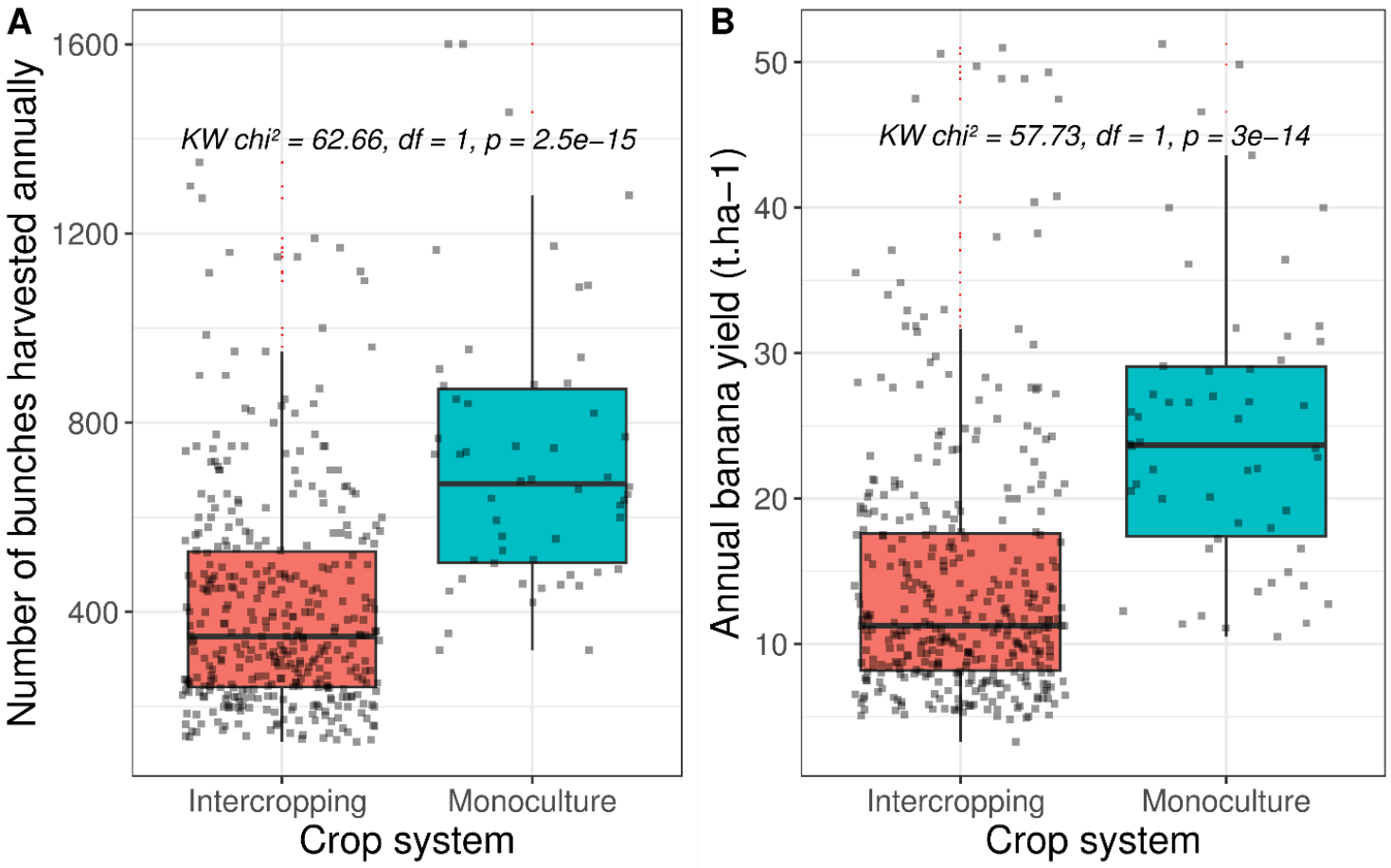


Figure 3

Number of brunches harvested and annual yield per year of Banana in the Moutainous Bushi, eastern DRC

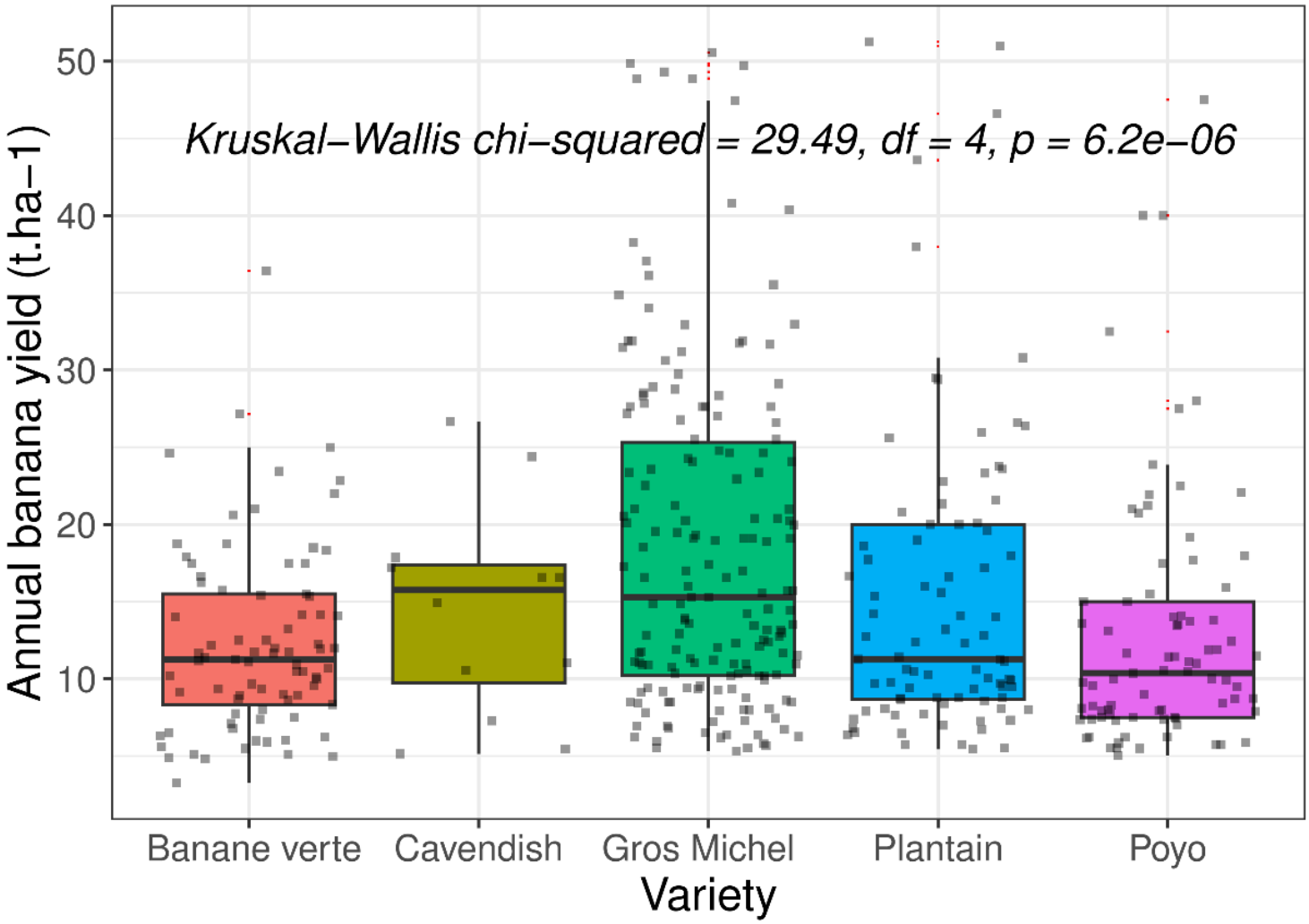


Figure 4

Banana productivity of banana varieties