

Determinants of Crop-Livestock Diversification among Smallholder Farmers in Mbeere North Sub-County, Embu County, Kenya

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ABSTRACT

Smallholder farming systems face increasing risks from climate variability, market fluctuations, soil degradation, and socioeconomic inequalities. Crop-livestock diversification can improve resource-use efficiency, spread production risks, and strengthen resilience. However, evidence on its socioeconomic and institutional determinants remains limited in Kenya's semi-arid regions. This study examined these determinants among smallholder farmers in Mbeere North Sub-County, Embu County. A cross-sectional survey of 394 randomly selected households used stratified sampling. Diversification was measured using the Simpson Diversity Index, and fractional regression identified associated factors. Overall, household size ($\beta = 0.065$, $p < 0.01$), age ($\beta = 0.005$, $p < 0.10$), market distance ($\beta = 0.086$, $p < 0.01$), land tenure security ($\beta = 0.171$, $p < 0.05$), climate information access ($\beta = 0.287$, $p < 0.01$), and credit access ($\beta = -0.172$, $p < 0.01$) were significant determinants. Gender-disaggregated results revealed distinct patterns. Among female-headed households, household size, land tenure security, and market distance significantly influenced diversification. Among male-headed households, household size, farmer-group membership, climate information access, and market distance had significant positive effects, whereas credit access had a significant negative effect. These findings highlight the importance of secure land rights, accessible climate information, effective farmer organizations, and gender-responsive agricultural support. Policies addressing these factors could strengthen crop-livestock diversification and improve smallholder resilience in semi-arid farming systems.

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1. INTRODUCTION

Smallholder farming systems face growing risks from climate variability, market fluctuations, soil degradation, and socioeconomic inequalities, threatening agricultural productivity and livelihood stability (Daba et al., 2025). These challenges are acute in areas where farmers depend on rain-fed agriculture and have limited access to productive resources, markets, and agricultural services (Gitonga, 2025). These conditions have intensified global efforts to develop more resilient and sustainable farming systems that can improve productivity while reducing farmers' exposure to production and economic risks (Zeressa et al., 2023).

Crop-livestock diversification has emerged as a key strategy for enhancing resilience and livelihood stability of smallholder farming systems (Chennalwad et al., 2025). The practice diversifies multiple crop and livestock enterprises to improve agricultural productivity, stabilize income, and reduce production risks (Cruz Colazo et al., 2022). It also enhances resource use efficiency, strengthens resilience to climatic and market shocks, and reduces household vulnerability (Mohamed & Nusrathali, 2023; Vernoooy, 2022). The diversification of crop-livestock enterprises also facilitates resource complementarity, where crop residues are used for animal feed, while livestock

manure is returned to crop fields to improve soil fertility and structure (Kim et al., 2022; Ofosu et al., 2023). These complements promote efficient resource recycling, reduce dependence on external inputs, and support both agricultural productivity and environmental sustainability (Nazir et al., 2025).

The decision to diversify crop-livestock systems among smallholder farmers is influenced by socioeconomic, farm-level, and institutional factors that determine farmers' capacity and incentives to diversify (Kihoro et al., 2026). Farm size, land tenure, and household size affect farmers' capacity to maintain multiple enterprises, while education and farming experience influence access to and use of agricultural information (Shabbir et al., 2026). Access to credit, extension services, market access, farmer groups, and climate information can also facilitate crop-livestock diversification by reducing financial and market constraints (Micheni et al., 2024). A recent study from Kenya shows that farm size, membership in farmer groups, age, gender, and other household characteristics significantly influence crop-livestock diversification decisions among smallholder farmers (Midamba et al., 2025).

Despite the importance of crop-livestock diversification for managing agricultural risks, there is limited evidence on its determinants in arid and semi-arid farming systems. In Mbeere North Sub-County, where farming is predominantly rain-fed and exposed to climatic and livelihood risks, the factors shaping farmers' diversification decisions are poorly documented. Therefore, this study examined the socioeconomic, farm-level, and institutional determinants of crop-livestock diversification among smallholder farmers in Mbeere North Sub-County, Embu County, Kenya.

2. RESEARCH METHODOLOGY

2.1 Description of the Study Area

The study was conducted in Mbeere North Sub-County, Embu County, from April to June 2026. Mbeere North Sub-County is one of the four sub-counties in Embu County. It covers 783.6 km², has a population density of 138.9/km², has a population of 108,881, and comprises three wards: Evurore, Nthawa, and Muminji. It lies within latitudes 0°25' and 0°35' South and longitudes 37°32' and 37°50' East. It falls within the lower midlands (LM4–LM5) and arid-to-semi-arid agroecological zones (ASALs) of Embu County (KNBS, 2019). Altitude ranges from 500 m to 1,200 m above sea level, with annual rainfall ranging from 640 mm to 1,495 mm. Temperatures range from 15 °C to 30 °C (Jaetzold et al., 2007). Farming is mainly rain-fed, with farmers growing drought-tolerant crops such as millet, sorghum, pigeon peas, cowpeas, maize, beans, and green grams, alongside crop-livestock diversification, including goats, cattle, and poultry. These conditions made Mbeere North suitable for assessing crop-livestock diversification among smallholder farmers under resource and climatic constraints (Ngayu & Olale, 2025).

2.2 Research Design, Sample Size, and Sampling Procedure

This study used a cross-sectional survey design, which allowed data collection at a single point in time and was used to examine the relationships between socioeconomic, farm-level, and institutional factors and crop-livestock diversification (Garbole et al., 2025; Salifu & Salifu, 2023). The targeted population comprised 25,000 smallholder farming households in Evurore, Nthawa, and Muminji wards of Mbeere North Sub-County, Embu County (KNBS, 2019). Using Yamane's (1967) formula, a sample of 394 households was determined. A proportionate stratified random sampling was used, with each ward serving as a stratum (Table 1). Households were then randomly selected from the sampling frame obtained from the Sub-County Agricultural Office.

Table 1. Sample Size of Smallholder Farming Households in the Study Area

Name of the ward	Frequency	Percentage (%)
Evurore	121	30.7%
Muminji	116	29.4%
Nthawa	157	39.9%
Total	394	100

2.3 Data Collection

Primary data was collected from 394 smallholder farming households in Mbeere North Sub-County using a structured questionnaire and key informant interviews administered face-to-face. The questionnaire captured socioeconomic, farm-level, and institutional characteristics hypothesized to influence crop-livestock diversification, including household head's age, gender, education level, household size, access to extension services, market access and distance to market, credit access, farmer group membership, land tenure, irrigation, and access to climate information. The questionnaire was pre-tested on 39 households (10% of the sample size) in Tharaka South Sub-County, Tharaka Nithi County, and its reliability was assessed using Cronbach's alpha, with coefficients ranging from 0.700 to 0.833.

The data was analyzed using Stata version 17, and descriptive statistics were used to summarize the explanatory variables, while a fractional regression model was employed to estimate determinants of crop-livestock diversification. Statistical significance was assessed at the 1%, 5%, and 10% levels.

2.4 Data Analysis: Fractional Regression Model

The study employed a fractional regression model to identify socioeconomic, farm-level, and institutional factors associated with crop-livestock diversification. This model was appropriate because crop-livestock diversification (CLD) was measured using the Simpson Diversity Index (SDI), which is a continuous variable bounded between 0 and 1. Fractional regression ensured that all predicted values remained within the 0 to 1 interval and provided consistent estimates without requiring the dependent variable to be normally distributed (Papke & Wooldridge, 1996). The model was specified as:

$$E(SDI | X_i) = G(X_i\beta) \quad (1)$$

where SDI_i = Simpson Diversity Index for household i , representing the level of crop-livestock diversification; $X_i = (X_{1i}, X_{2i}, \dots, X_{Ki})$ is the vector of explanatory variables (socioeconomic, farm-level, and institutional factors); $\beta = (\beta_1, \beta_2, \dots, \beta_K)$ is the vector of coefficients to be estimated; and $G(\cdot)$ is the logistic or probit cumulative distribution function that ensures the predicted SDI values remain between 0 and 1. The fractional regression model estimates the expected value of SDI conditional on the explanatory variables, with the coefficients (β s) indicating the direction and magnitude of each factor's influence on crop-livestock diversification. Marginal effects were computed to interpret the quantitative effect of unit changes in explanatory variables on the SDI. The explanatory variables, their measurement, and their expected signs are summarized in Table 2.

Table 2. Summary of the Explanatory Variables Used in the Fractional Regression Model

Variable	Description	Data	Measurement	Expected sign
Age of HHH	Years of HHH	Continuous	Years	+
Gender of HHH	Sex identity	Dummy	1 = Male, 0 = Female	+/-
Educational level	Years of schooling	Continuous	Years	+
Household size	Number of members in the household	Continuous	Number	+
Farm size	Total land owned or cultivated	Continuous	Hectares (ha)	+
Farming experience	Years of farming experience	Continuous	Years	+
Access to extension services	Access to agricultural training or advice	Dummy	1 = Yes, 0 = No	+/-
Access to credit	Access to financial credit for farming	Dummy	1 = Yes, 0 = No	+/-
Access to market	Ease of selling farm produce	Dummy	1 = Yes, 0 = No	+/-
Membership in farmer groups	Member of a farmer organization	Dummy	1 = Yes, 0 = No	+/-
Land tenure	Ownership of land	Dummy	1 = Owned, 0 = Rented	+/-
Climate information	Access to climate information	Dummy	1 = Yes, 0 = No	+/-

Note: HHH = household head.

3. RESULTS AND DISCUSSION

3.1 Household Demographic Characteristics

The findings show that the average age of household heads was 43.24 years ($SD \approx 13$), ranging from 20 to 95 years (Table 3). This indicates that most respondents were within the economically active age groups. This suggests that the majority of household heads had the physical capacity and farming experience required to engage in crop-livestock farming. This finding is consistent with Micheni et al. (2024), who reported that most smallholder household heads were of economically active age. The findings show that 205 (52.0%) of households were female-headed, while 189 (48.0%) were male-headed, indicating a slight predominance of female-headed households (Table 3). This may be attributable to male out-migration in search of employment, which leaves women to manage household and farming activities. These findings align with the findings of Vimefall and Levin (2023), who observed an increasing proportion of female-headed farming households in rural areas.

Table 3. Descriptive Statistics of Household Demographic Characteristics

Variable	Category	Freq.	Percent	Min	Max	Mean	SD
Age of HHH	Years			20	95	43.24	12.55
Gender of HHH	Female	205	52.0%				
	Male	189	48.0%				
HHH education	No formal	29	7.4%				
	Primary	196	49.8%				
	Secondary	129	32.7%				
	Tertiary	40	10.1%				
HH size	Family size			1	13	4.80	1.70
Farming members	Active			1	8	2.32	1.04
HHH's main occupation	Farming	231	58.6%				
	Business	118	30.0%				
	Employment	44	11.2%				
	Other	1	0.2%				
Marital status	Divorced	6	1.5%				
	Married	331	84.0%				
	Single	31	7.9%				
	Widowed	26	6.6%				

Note: HH = household; HHH = household head; SD = standard deviation.

During the study, it was observed that 196 (49.8%) of the household heads had attained primary education, 129 (32.7%) secondary, 40 (10.1%) tertiary, and 29 (7.4%) had no formal education (Table 3). This suggests that the majority of household heads possess basic literacy skills, which likely enhances their ability to access agricultural information and adopt crop-livestock diversification farming practices. These findings agree with Kantoğlu et al. (2025), who found that most smallholder farmers had attained primary education. However, Tarekegn et al. (2024) reported a higher proportion of household heads with no formal education and a lower proportion with secondary education. The observed differences may be attributed to variations in educational opportunities and socioeconomic conditions across the study area.

The findings of this study showed that the average household size was 5 persons ($SD \approx 2$), with household sizes ranging from 1 to 13 members. The mean number of active farming members was 2 ($SD \approx 1$), ranging from 1 to 8 members (Table 3). This indicates that although households were large, only about half of the household members were actively engaged in farming activities. This suggests that limited household labor may constrain agricultural production and effective management of diversified crop-livestock enterprises. These findings are in line with Awoke et al. (2025), who reported that households with fewer active farming members often face labor constraints in managing diversified enterprises.

During the study, it was also observed that farming was the main occupation of the majority of household heads of 231 (58.6%), followed by business 118 (30.0%), formal employment 44 (11.2%), and other occupations 1 (0.2%; Table 3). This indicates that agriculture was the primary livelihood activity in the study area, although a considerable proportion of households also depended on non-farm income-generating activities. This livelihood diversification may reduce dependence on agriculture and improve household income stability. This finding aligns with those of Saba et al. (2022), who observed that engagement in non-farm income-generating activities reduces dependence on agriculture and contributes to household income stability.

The findings reveal that 331 (84.0%) of the household heads were married, followed by 31 (7.9%) single, 26 (6.6%) widowed, and 6 (1.5%) divorced (Table 3). This may indicate that a high proportion of married household heads had access to family labor and shared decision-making, which may facilitate farm management and the adoption of crop-livestock diversification practices. Conversely, the few single, widowed, and divorced household heads were more likely to face labor and resource constraints that could limit agricultural productivity and household welfare. This

finding is consistent with that of Yariied and Bullo (2025), who observed that livelihood diversification differs across marital groups due to variations in household labor and resource availability.

3.2 Household Farm Characteristics

The findings show that the average farm size was 3 ha ($SD \approx 1.45$), ranging from 1 to 14 acres, indicating that households in the study area are smallholder farmers. The average land allocated to crop production was 2 ha ($SD \approx 1$), and 0.83 ha ($SD \approx 1.0$) was allocated to livestock activities (Table 4). This suggests that crop production occupies a larger portion of the available land use compared to livestock production, which reflects the importance of crop farming as the dominant agricultural enterprise in the study area. Similar findings were reported by Otieno (2024), who found that smallholder farmers allocate a larger share of their land to crop production than to livestock activities.

Table 4. Descriptive Statistics of Household Farm Characteristics

Variable	Category	Freq.	Percent	Min	Max	Mean	SD
Farm size	Hectares (ha)			1	14	2.96	1.45
Land for crops	Hectares (ha)			0	6.9	2.13	1.10
Land for livestock	Hectares (ha)			0	12	0.83	1.24
Farming experience	Years			1	70	16.79	13.37
Soil fertility	Good	18	4.6%				
	Moderate	346	88.0%				
	Poor	30	7.6%				
Land tenure type	Communal	14	3.6%				
	Owned	327	83.0%				
	Rented	53	13.4%				
Secure land tenure	No	100	25.4%				
	Yes	294	74.6%				
Irrigation access	No	269	68.3%				
	Yes	125	31.7%				
Irrigation frequency	Seasonal	70	56.0%				
	Occasional	55	44.0%				

Note: SD = standard deviation.

Based on the findings, it was observed that the average farming experience was 17 years ($SD \approx 13$), ranging from 1 to 70 years, indicating that most households had considerable farming experience (Table 4). This suggests that farmers had accumulated knowledge and skills that may enhance farm management, resource allocation, and decision-making related to crop-livestock diversification. These findings are consistent with those of Makumi (2025), who observed that farming experience positively influences farm management decisions and technology adoption. About 346 households (88.0%) reported moderate soil fertility, 30 (7.6%) reported poor, and 18 (4.6%) reported good (Table 4). This indicates that most farmers operate under moderate soil productivity conditions, which may support agricultural production but still require appropriate soil fertility management practices to sustain productivity.

The findings of this study also showed that 327 (83.0%) of the households owned their land, 53 (13.4%) cultivated rented land, and 14 (3.6%) used communal land. Additionally, 294 households (74.6%) had secure land tenure, while 100 (25.4%) did not (Table 4). This indicates that most farmers had secure ownership rights, which may encourage long-term investment in crop-livestock enterprises. This may suggest that secure land tenure promotes the adoption of improved farming practices and sustainable land management. These findings align with those of Duker et al. (2025), who found that land tenure security positively influences farmers' investment decisions. During the study, it was observed that 269 (68.3%) of households had no access to irrigation, while 125 (31.7%) had access, indicating that most households relied on rain-fed agriculture.

Among households with access to irrigation, 70 (56.0%) used irrigation seasonally, and 55 (44.0%) practiced irrigation occasionally (Table 4). This may suggest that irrigation was primarily used to supplement agricultural production during periods of water shortage, highlighting the need to improve irrigation access to support crop-livestock diversification and enhance household resilience. These findings accord with those of Karimba et al. (2022),

who found that smallholder irrigation is largely supplementary and constrained by limited water resources, infrastructure, and institutional arrangements. However, limited irrigation may constrain the diversification of crop-livestock enterprises by reducing year-round fodder and crop production.

3.3 Household Institutional and Market Characteristics

The findings of this study show that 372 (94.4%) of households had access to agricultural extension services, while 22 (5.6%) had no access (Table 5). This indicates strong institutional support for agricultural information dissemination and advisory services. This suggests that most farmers had opportunities to acquire knowledge on improved agricultural practices, which may enhance crop-livestock diversification and farm production. This concurs with the findings of Amghani et al. (2025), who reported that access to extension services enhances farmers' knowledge of improved agricultural practices and supports agricultural productivity.

Table 5. Descriptive Statistics of Institutional and Market Characteristics

Variable	Category	Freq.	Percent	Min	Max	Mean	SD
Access to extension	No	22	5.6%				
	Yes	372	94.4%				
Access to credit	No	151	38.3%				
	Yes	243	61.7%				
Distance to market	km			1	23	5.80	4.46
Market access	No	25	6.3%				
	Yes	369	93.7%				
Farmer group membership	No	141	35.8%				
	Yes	253	64.2%				
Access to climate information	No	54	13.7%				
	Yes	340	86.3%				

Note: SD = standard deviation.

Access to credit was reported by 243 (61.7%) of households, while 151 (38.3%) had no access (Table 5). This suggests that the majority of farmers were able to obtain financial resources to invest in farm inputs, technologies, and other productive activities, which may enhance agricultural productivity and household livelihoods. Similar findings were reported by Mohammad et al. (2025), who found that agricultural credit improves farm productivity by increasing farmers' investment capacity. The analysis demonstrates that 369 (93.7%) of the households reported access to markets, while 25 (6.3%) did not (Table 5). The average distance to market was 5.8 km (SD $\approx$ 4.46), ranging from 1 to 23 km. This indicates that most households were located within reasonable proximity to market centers, which may reduce transaction costs and improve market participation. This suggests that improved market access is likely to encourage farmers to diversify crop and livestock enterprises to increase household income. These findings agree with Mutea et al. (2025), who found that improved market access promotes agricultural commercialization and enhances household income.

The findings of this study show that 253 (64.2%) of the households were members of farmer organizations, while 141 (35.8%) were not. This indicates that most households had access to farmer groups or cooperatives, which facilitated access to agricultural information, extension services, inputs, credit, and markets, improving agricultural productivity and household livelihoods. These findings support those of Magasha et al. (2025), who noted that farmer organizations improve access to agricultural information, extension services, farm inputs, credit, and markets.

The findings further demonstrate that 340 (86.3%) of the households reported having access to climate information, while 54 (13.7%) did not (Table 5). This suggests that the majority of farmers were able to obtain weather and climate-related information to guide agricultural planning and adaptation strategies. Access to timely climate information may enable farmers to make informed decisions regarding planting dates, crop selection, and risk management, thereby enhancing resilience to climate variability and improving livelihood outcomes. These findings are consistent with those of Dayo et al. (2025), who reported that access to climate information enhances farmers' understanding of climate variability, promotes the adoption of appropriate adaptation strategies, and contributes to improved household food security.

3.4 Empirical Analysis of Determinants of Crop-Livestock Diversification

The findings of this study show that the fractional regression model was statistically significant for both the pooled sample and the ward-level analyses ($p < 0.001$), indicating that the selected socioeconomic and institutional factors significantly influenced the extent of crop-livestock diversification among smallholder farmers (Table 6). In the pooled sample, household size had a positive and significant effect ($\beta = 0.065$, $p < 0.01$), indicating that households with more members were more likely to diversify their crop and livestock enterprises, due to greater labor availability (Table 6). This supports the findings of Sen et al. (2026), who reported that larger households were more likely to diversify their livelihoods because of increased household labor. Age had a positive influence on crop-livestock diversification ($\beta = 0.005$, $p < 0.10$), suggesting that older farmers, who possess more farming experience, were more likely to adopt diversified farming systems (Table 6). These findings are consistent with those of Adane et al. (2025), who reported that older farmers were more likely to diversify agricultural production because of their greater farming experience and better production decision-making. However, the finding contrasts with Asante et al. (2024), who observed that younger farmers were more likely to diversify because they were willing to adopt innovative farming practices and new technology.

Table 6. Socioeconomic and Institutional Factors and Crop-Livestock Diversification

Dependent variable: CLD	Pooled (1)	Evurore (2)	Muminji (3)	Nthawa (4)
Education	-0.007 (0.041)	0.152** (0.075)	-0.111* (0.064)	-0.076 (0.065)
Age	0.005* (0.003)	0.008** (0.004)	0.006 (0.004)	0.001 (0.004)
Gender	0.023 (0.049)	0.018 (0.102)	0.020 (0.051)	0.071 (0.072)
Household size	0.065*** (0.016)	0.043 (0.025)	0.095** (0.046)	0.050* (0.027)
Farm size	0.003 (0.017)	0.056* (0.027)	0.092*** (0.036)	-0.004 (0.035)
Farming experience	0.001 (0.012)	0.003 (0.002)	-0.005** (0.002)	0.002 (0.0017)
Extension services	0.040 (0.132)	0.197 (0.204)	-0.071 (0.121)	-0.128 (0.206)
Credit access	-0.172*** (0.065)	-0.283** (0.137)	-0.031 (0.064)	0.403*** (0.128)
Market distance	0.086*** (0.008)	0.062 (0.050)	-0.074* (0.044)	0.039*** (0.010)
Membership	0.075 (0.060)	0.100 (0.140)	0.109 (0.074)	-0.020 (0.101)
Land tenure	0.171** (0.068)	-0.081 (0.183)	0.181*** (0.058)	-0.024 (0.427)
Climate information	0.287*** (0.099)	-0.088 (0.143)	0.216** (0.109)	0.463*** (0.171)
Constant	-2.040*** (0.347)	-1.841*** (0.665)	-0.592 (0.523)	-1.578 (1.117)
Log LR	-246.554	-64.213	-76.487	-98.518
Wald χ^2	250.45	31.68	142.60	196.21
Prob > χ^2	0.000	0.000	0.000	0.000
Pseudo R ²	0.075	0.026	0.047	0.089
Observations (N)	394	121	116	157

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$. Robust standard errors are in parentheses. CLD = crop-livestock diversification.

Market distance positively affected crop-livestock diversification ($\beta = 0.086$, $p < 0.01$; Table 6). This implies that farmers farther from markets tended to diversify their enterprises to reduce market-related risks, spread production risks, and enhance livelihood resilience, compared with households closer to markets, which tended to specialize in profitable enterprises. Similarly, Rashid et al. (2026) found that household socioeconomic characteristics and institutional support play a significant role in shaping farmers' diversification decisions and the intensity of enterprise diversification. The findings showed that land tenure had a positive and significant effect ($\beta = 0.171$, $p < 0.05$), indicating that secure land ownership encourages farmers to invest in multiple agricultural enterprises (Table 6). These findings are consistent with Danso-Abbeam et al. (2025), who reported that secure land tenure increases

farmers' willingness to make long-term investments, including enterprise diversification and improved land management practices.

Access to climate information also significantly increased crop-livestock diversification ($\beta = 0.287, p < 0.01$), suggesting that informed farmers are better able to adopt diverse enterprises as an adaptation strategy to climatic uncertainties (Table 6). These findings align with Sanfo and Amikuzuno (2026), who noted that timely climate information enables farmers to make informed production decisions and adopt diversified farming systems as a climate adaptation strategy. Credit access negatively influenced crop-livestock diversification in the pooled model ($\beta = -0.172, p < 0.01$; Table 6). These findings suggest that households with access to credit may specialize in fewer but more profitable enterprises rather than diversify across multiple crop and livestock activities. Similarly, Trinh (2025) observed that access to credit supported agricultural investment and production but did not lead to crop-livestock diversification, as farmers often use loans to strengthen existing enterprises rather than to diversify, due to higher returns.

This study's ward-level finding showed that there was heterogeneity in factors influencing crop-livestock diversification. In Evurore, education ($\beta = 0.152, p < 0.05$), age ($\beta = 0.008, p < 0.05$), and farm size ($\beta = 0.056, p < 0.10$) positively influenced crop-livestock diversification, while credit access had a negative effect ($\beta = -0.283, p < 0.05$; Table 6). In Muminji, household size ($\beta = 0.095, p < 0.05$), farm size ($\beta = 0.092, p < 0.001$), land tenure ($\beta = 0.181, p < 0.01$), farming experiences ($\beta = -0.005, p < 0.05$) and climate information ($\beta = 0.216, p < 0.05$) promoted crop-livestock diversification, whereas education ($\beta = -0.111, p < 0.10$) and market distance ($\beta = -0.074, p < 0.10$) reduced it (Table 6). In Nthawa, household size ($\beta = 0.050, p < 0.10$), credit access ($\beta = 0.403, p < 0.01$), market distance ($\beta = 0.039, p < 0.01$), and climate information ($\beta = 0.463, p < 0.01$) positively and significantly influenced crop-livestock diversification, with access to climate information exhibiting the strongest positive effect (Table 6). These variations demonstrate that the influence of socioeconomic and institutional factors differs across locations due to differences in resource endowment, market conditions, and institutional support. Bashiru and Oseni (2025) found that regional differences in socioeconomic conditions, institutional support, and agroecological characteristics shape farmers' decisions to adopt crop-livestock diversification, highlighting the need for location-specific interventions.

The qualitative findings corroborated the quantitative results, showing that socioeconomic and institutional factors influenced crop-livestock diversification. The Sub-County Agricultural Officer reported that government programs, including the Upper Tana Catchment National Resource Management Project, Emergency Locust Response Project, and National Agricultural Value Chain Development Project, promoted diversification through farmer training, extension services, input support, value addition, and climate information. These programs encouraged enterprises such as dairy farming, apiculture, and coffee production, as well as improved fodder technologies, including Juncao Napier grass. Extension and livestock officers further noted that secure land tenure, demand-driven extension, timely climate information, improved breeds, and fodder technologies supported diversification. However, high input costs, limited land and capital, labor shortages, climate variability, weak market linkages, and inadequate institutional support constrained diversified farming. Therefore, these findings reinforce the quantitative results and explain differences in diversification across wards.

3.5 Gender-Disaggregated Analysis of Factors of Crop-Livestock Diversification

The findings of this study show that socioeconomic and institutional factors influenced crop-livestock diversification differently between female- and male-led households. Among female-led households, household size ($\beta = 0.037, p < 0.10$), market distance ($\beta = 0.092, p < 0.01$), and land tenure ($\beta = 0.297, p < 0.01$) positively and significantly influenced crop-livestock diversification. Among male-led households, household size ($\beta = 0.077, p < 0.01$), market distance ($\beta = 0.081, p < 0.01$), access to climate information ($\beta = 0.468, p < 0.01$), and farmer group membership ($\beta = 0.205, p < 0.05$) positively influenced crop-livestock diversification, whereas access to credit ($\beta = -0.288, p < 0.01$) had a negative effect (Figure 1).

Based on these findings, household size positively influenced crop-livestock diversification ($\beta = 0.037, p < 0.10$), indicating that households with more members were more likely to diversify their crop-livestock enterprises due to greater family labor availability (Figure 1). Land tenure had the strongest positive effect ($\beta = 0.297, p < 0.01$; Figure 1). This suggests that women with secure land rights were more likely to invest in diversified farming enterprises, which provided them with confidence to undertake long-term investment in both crop and livestock production. These findings are consistent with Goli et al. (2025), who reported that secure land rights and improved access to productive resources enhance women's participation in diversified agricultural production and strengthen household livelihoods.

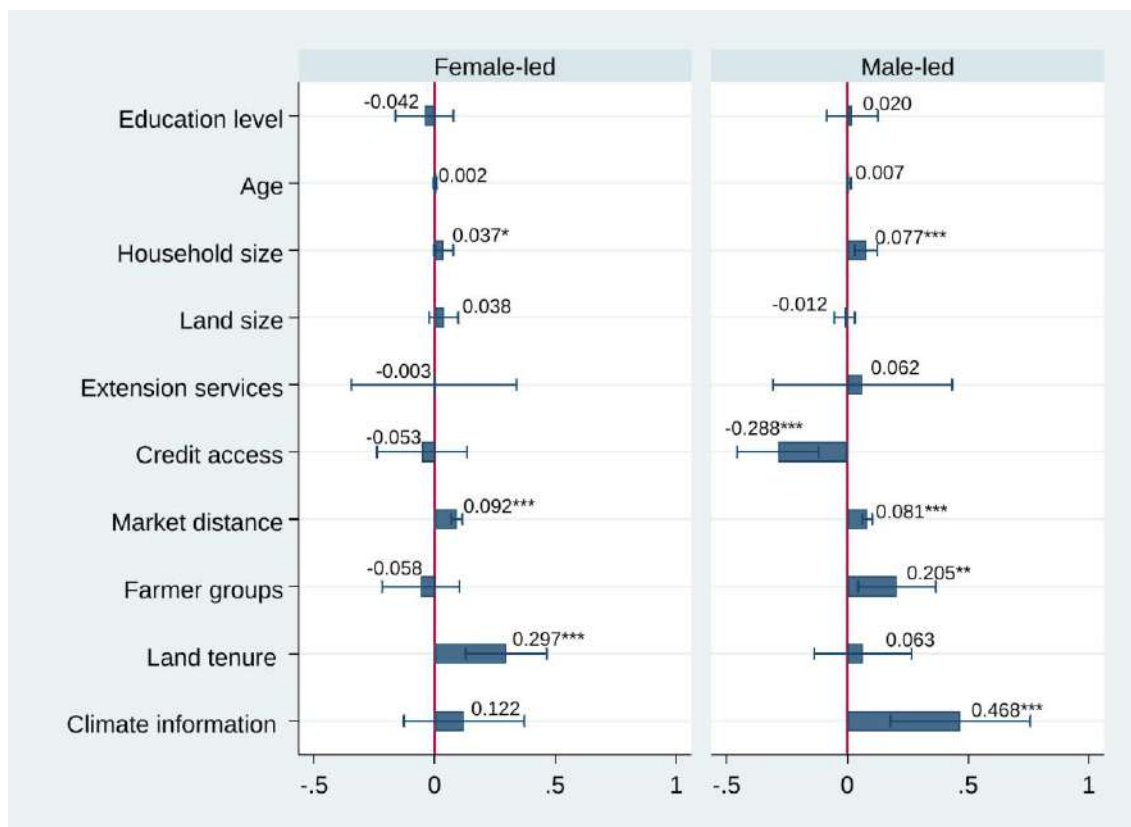


Figure 1. Gender-Disaggregated Factors of Crop-Livestock Diversification

Note: * $p < 0.1$; ** $p < 0.05$; *** $p < 0.01$.

Market distance ($\beta = 0.092$, $p < 0.01$) had a positive influence, indicating that women in more remote areas may diversify their crop and livestock enterprises to reduce market-related risks and improve household food and income security (Figure 1). This finding agrees with Rashid et al. (2026), who reported that market conditions significantly influence farmers' diversification in crop and livestock decisions. These findings contrast with those of Ayalew and Merin (2026), who found that greater distance to markets reduced diversified farming systems among smallholder farmers due to high transaction and transportation costs, limited access to agricultural inputs, and profitable output markets.

Among male-led households, household size ($\beta = 0.077$, $p < 0.01$) and market distance ($\beta = 0.081$, $p < 0.01$) significantly enhanced crop-livestock diversification. Similarly, access to climate information ($\beta = 0.468$, $p < 0.01$) had a great positive effect, implying that male led households use climate-related knowledge to diversify enterprises and manage production risks (Figure 1). These findings align with Sanfo and Amikuzuno (2026), who reported that access to reliable climate information enhances farmers' adaptive capacity and encourages enterprise diversification. Membership in farmer groups ($\beta = 0.205$, $p < 0.05$; Figure 1) promoted crop-livestock diversification, likely through improved access to information, technologies, and social networks, supporting the findings of Gemechu et al. (2024), who found that farmer organizations improve access to agricultural information, technologies, extension services, and social networks that encourage livelihood diversification.

In contrast, access to credit ($\beta = -0.288$, $p < 0.01$) significantly reduced crop-livestock diversification, suggesting that male-led households with access to credit tended to specialize in fewer but more profitable enterprises rather than diversify. This finding supports the report of Rituay et al. (2026), who found that agricultural credit is commonly used to increase investment and farm productivity in existing farm enterprises rather than to promote enterprise diversification. However, it contrasts with Bodhgire (2025), who found that improved access to financial resources encouraged livelihood diversification by easing capital constraints. The differences may be attributed to variations in farmers' investment priorities, enterprise profitability, and local economic conditions.

During the study, it was observed that crop-livestock diversification among female-led households was mainly influenced by land tenure security and market access factors, while among male-headed households it was driven by access to climate information, farmer group membership, and access to credit. These observations underscore the need for gender-responsive interventions that address the distinct socioeconomic and institutional factors influencing crop-livestock diversification among male- and female-headed households. However, the Agribusiness Officer further showed that women faced greater constraints in accessing land and capital, limiting their diversification in

crop and livestock opportunities, while men benefited more from farmer groups and agricultural training. These insights explain the observed gender differences in crop-livestock diversification.

4. CONCLUSION AND RECOMMENDATIONS

The study concludes that crop-livestock diversification is an important livelihood strategy among smallholder farmers in Mbeere North and is influenced by a combination of socioeconomic and institutional factors. Household size, age of the household head, land tenure security, market distance, and access to climate information were significantly associated with diversification, while access to credit was associated with lower diversification. Gender differences were also evident, with female-headed and male-headed households responding differently to the factors influencing diversification. These findings imply that policies promoting crop-livestock diversification should strengthen land tenure security, improve rural market infrastructure, and enhance access to timely and reliable climate information. Agricultural credit programs should be designed to support diversified production rather than encourage specialization, while extension and farmer-group interventions should adopt gender-responsive approaches that address the different needs and constraints of female- and male-headed households.

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Declarations

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