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Exploring the determinants of crop-livestock diversification and its effect on farm income: Evidence from smallholder farmers in Homa Bay County, Kenya

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ABSTRACT

The integration of crops and livestock has been reported to have several benefits for farmers. It reduces farm risks, leading to increased output from crops and livestock. It also enhances household food production, resulting in improved household food security. Therefore, farmers are advised to incorporate as many crop types and livestock species as possible into their farms. However, the majority of farmers in Kenya tend to produce common crops such as maize and beans, alongside common livestock like cattle. This results in low crop-livestock diversification, which subjects many farmers to poor living standards. Consequently, it is imperative to assess the predictors and effects of crop-livestock diversification on farm income. This study evaluated the covariates influencing crop-livestock diversification and its effects on farm income in Homabay County, Kenya. Primary data were collected from 402 farmers using multistage sampling. The analysis employed propensity score matching and gross margin methods. The findings indicated that farm size, group membership, marital status, age, and gender significantly influence farmers' crop-livestock diversification. The results also demonstrated that crop-livestock diversification increases farm income by KES 40,800 per acre (Nearest neighbor matching), KES 41,488 per acre (Kernel matching), and KES 36,132 per acre (Radius Matching). These findings underscore the importance of encouraging farmers to incorporate multiple crops and livestock into their farms through public sensitization. Extension agents should target young farmers and female-headed households when providing extension services. Finally, there is a need for public awareness campaigns among farmers regarding the benefits of crop-livestock diversification.

Contribution/Originality: The study contributes to the existing literature by assessing the determinants of crop-livestock diversification and its effect on farm income. It also provides policy insights that can be used to increase the production of various crop types and livestock species, thereby improving the living standards of farmers and food security in Homa Bay County, Kenya.

1. INTRODUCTION

The majority of rural farmers closely depend on their crops and livestock as a major source of their livelihoods (Muyambiri, 2024). Thus, agriculture plays a significant role in household food security and farmers' livelihoods through the production and sale of crops and livestock products (Walaga & Hauser, 2005). At the same time, many households in Sub-Saharan Africa have recorded high rates of poverty and household food insecurity despite participating in agricultural activities such as crop and livestock production (World Bank Group, 2020). Around 2.3

billion people are reported to suffer from moderate food insecurity globally (FAO, 2025). Reportedly, a higher proportion of poor people are rural smallholder farmers, whose main source of livelihood relies on agriculture. These farmers are not only poor but also characterized by household food insecurity (Gafa & Chachu, 2023).

Since food security is closely related to agricultural productivity (FAO, 2016), poverty and food insecurity could be a result of the poor performance of agricultural enterprises, especially among farmers who concentrate on single crops. Over-concentration on mono-cropping has resulted in low farm output due to challenges associated with farming. These include incidents of crop pests such as the fall armyworm, diseases (Murray, Jepson, & Huesing, 2019), and climate variability (Weldemichael & Teferi, 2019), characterized by frequent and prolonged droughts, floods, and high temperatures, among others. Farmers who depend solely on agriculture as their only source of livelihood tend to be heavily affected, as they lack alternative livelihood sources.

Integration of crops and livestock on a given farm is a viable solution to the challenges and risks associated with agriculture (Mekuria & Mekonnen, 2018). As such, farmers need to incorporate food crops for household food security and cash crops for farm income. Moreover, drought-resistant crops can thrive well under extreme temperatures and resist attacks by pests and diseases. In addition, crops like maize, beans, cassava, sweet potatoes, sorghum, and millet are multipurpose crops that provide household food as well as farm income. Reportedly, cash crops such as cotton, vegetables, and tomatoes also provide farmers with high income required to meet household economic needs. On the other hand, livestock such as cattle, poultry, sheep, and donkeys play key roles on the farm. These include food production, income generation, production of organic manure, and provision of farm labor, among others. As such, there are numerous benefits of incorporating various crop types and livestock species into the farm. Thus, incorporating many crop types and livestock species not only boosts household income (Khanam, Bhaduri, & Nayak, 2018; Mzyece & Ng'ombe, 2021) but also offers food to farmers, thereby reducing household food insecurity (Ahmadzai & Morrissey, 2023).

Despite the numerous benefits derived from integrating crops and livestock, many farmers in Western Kenya are characterized by a high concentration of crops, especially common crops like maize (Kariuki, 2020). With the current trend in climate variability and unpredictable weather patterns, there is a need to embrace crop-livestock diversification to reduce farm risks, boost farm income, and enhance food security. However, increasing the rate of crop-livestock diversification requires farm-based policies set and implemented by policymakers. This necessitates empirical studies on the predictors of crop-livestock diversification and its effects on farm income among farmers. Many studies on farm diversification have concentrated on crop diversification, with little work on crop-livestock diversification. Many authors have neglected livestock and focused on studying the determinants of crop diversification and its contribution to household food security (Adjimoti & Kwadzo, 2018; Appiah-Twumasi & Asale, 2024; Bhat & Salam, 2016; Burchfield & de la Poterie, 2018; Dube, 2016; Gebiso, Ketema, Shumetie, & Leggesse, 2023). In addition, the majority of the studies have mainly focused on the determinants of crop diversification, with little work on whether crop-livestock diversification increases household food security or not. For example, Mekuria and Mekonnen (2018) assessed the determinants of crop-livestock diversification, with no attempt to establish the effect of crop-livestock diversification on farm income. Similarly, Dube (2016); Dube, Numbwa, and Guveya (2016); Inoni, Gani, and Sabo (2021); Ojo, Ojo, Odine, and Ogaji (2014) and Thayaparan (2022) studies on diversification mainly focused on the factors affecting crop diversification. They did not assess the effects of crop diversification on farm income. As such, the effect of crop-livestock diversification on farm income is an area that has not been well researched, as many studies on diversification have focused on crop diversification. It is therefore not known whether crop-livestock diversification increases farm income or not, and by what magnitude. Thus, it is imperative to study the factors affecting crop-livestock diversification and its effects on farm income, and to recommend policies that can be implemented to improve farmers' living standards. The main novelty and contribution of this work is that, unlike past studies that failed to consider the livestock sector as well as the effects of crop-livestock diversification on farm income, this study took into account the entire farm, which includes crops and livestock, and its effects on farm income in Homa Bay County, Kenya. The findings from this work are important in many ways. First, it recommends policies that can be implemented by the government to increase the rate of production of many crop types and livestock species. Second, the study adds to the global debate on the determinants and effects of crop-livestock diversification on farm income. Lastly, the results from this work can be used by other researchers as contributions to their studies.

1.1. Research Objectives

a. To assess the determinants of crop-livestock diversification among farmers in Homa Bay County, Kenya.
b. To determine the effect of crop-livestock diversification on farm income among farmers in Homa Bay County, Kenya.

1.2. Literature Review

Farm diversification is an important topic that has attracted numerous authors globally. This is due to the fact that through crop-livestock diversification, farmers can maximize their farm returns and achieve household food security. However, most studies on farm diversification have omitted the livestock sector, despite the roles of livestock in achieving food security, boosting farm labor, and increasing farm income, which makes farmers highly economically resilient. For example, Dube et al. (2016) assessed the factors influencing crop diversification in Zambia using the Tobit model. Their study found that socio-economic factors such as farm size, market distance, farm investment, and area cultivated significantly influenced crop diversification. However, their study mainly concentrated on crop diversification, with no focus on livestock. Additionally, their work did not assess the association between crop diversification and farm income. Furthermore, Mekuria and Mekonnen (2018) applied the Margalef index and Tobit model to assess the extent and determinants of crop-livestock diversification in the Central Highlands of Ethiopia. They reported that the intensity of diversification was positively influenced by land size, livestock holdings, and farm location. Conversely, non-farm income and seed rates negatively predicted the intensity of diversification. Despite incorporating both crops and livestock in their analysis, their study did not evaluate the effects of crop-livestock diversification on farm income. Similarly, Asante, Villano, Patrick, and Battese (2018) conducted a study in Ghana to assess the state of farm diversification among farmers using the Herfindahl index and Tobit model. Their econometric results indicated that farm diversification is predicted by socio-economic covariates such as gender, credit, use of tillage equipment, stable income, market information, and agricultural extension. However, their work did not examine the effects of crop-livestock diversification on farm income. This study bridges these research gaps by incorporating both crops and livestock, assessing the factors influencing crop-livestock diversification, and analyzing how crop-livestock diversification is associated with farm income among farmers in Homa Bay County, Kenya. This provides policy insights to increase the production of crops and livestock among farmers in Homa Bay County, Kenya.

1.3. Conceptual Model

Crop-livestock diversification is hypothesized to be influenced by socio-economic and institutional predictors, as depicted in Figure 1. The socio-economic factors that may significantly influence farmers' decisions to embrace crop-livestock diversification on their farms include land size (Danso-Abbeam et al., 2021), market distance (Dessie, Abate, Mekie, & Liyew, 2019), farming system, age (Inoni et al., 2021), gender (Ge, Fan, Li, Guo, & Niu, 2023), marital status (Baba & Abdulai, 2021), family size (Gebiso et al., 2023), education of the farmers (Thayaparan, 2022) and non-farm income (Mekuria & Mekonnen, 2018). Additionally, group membership (Dube, 2016), extension (Asante et al., 2018), and credit availability to the smallholders (Asante et al., 2018) can dictate whether they practice crop-livestock diversification or not. It is also hypothesized that farmers' income increases with an increase in the level of crop-livestock diversification. Thus, crop-livestock diversification may have a positive and significant effect on farm income (Basantaray, Acharya, & Patra, 2024). This may be a result of the high volumes of sales of the crops produced. The rest of the paper is organized into methodology, results and discussion, and finally, conclusion and recommendations.

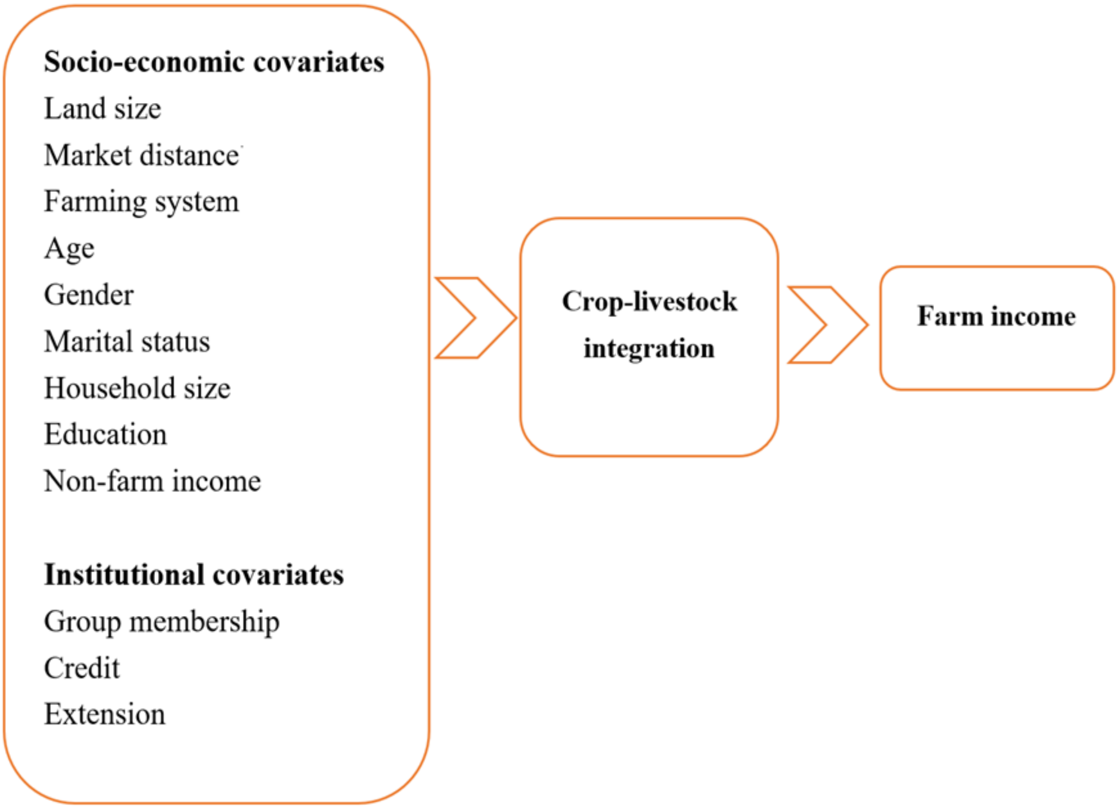

Figure 1. Conceptual model.

1.4. Theoretical Perspectives

Farmers engage in farming, knowing that the crops and livestock they produce have economic benefits. This can be in terms of food for the household members and farm income used for additional household needs. Thus, the integration of crops and livestock in a given farm is underpinned by the utility maximization theory (UMT). UMT argues that the primary economic agents (farmers) decide to produce a given crop and livestock as a result of their perception of those crops and livestock under consideration (Aleskerov, Bouyssou, & Monjardet, 2007). They perceive that the production of a given crop and livestock has higher economic benefits in terms of food security and farm income. Thus, they would produce crop k if the benefits of its production are higher than its production costs. The same applies to livestock. This results in higher economic utility U_1, for instance $U_1 > U_o$. This implies that the utility obtained from its production U_1 is higher than utility obtained when it is not produced U_o. It is also important to note that the production of crop k can be influenced by several socio-economic predictors X_k as shown in Equation 1. However, if expected utility U_1 is not met due to other socio-economic factors X_k, most of them divert to other crops and livestock that can guarantee them the highest utility (U_k).

$$U_k = \beta X_k + \varepsilon_k \quad (1)$$

2. METHODOLOGY

2.1. Description of the Study Area

This study was conducted in Homabay County, in Western Kenya (Figure 2). Homabay has a total land area of 3,155 km². It comprises 8 sub-counties, with 262,036 households and a population of 1.1 million people, mainly farmers according to the 2019 census (Kenya National Bureau of Statistics (KNBS), 2019). Homa Bay records a poverty rate of 48% with household food insecurity affecting more than 50% of the population (Ambale, 2018; GoK, 2023). As a result of the high poverty and food insecurity rates in Homa Bay, many interventions, including supporting farmers to embrace crop-livestock diversification, have been recommended. The County government of Homa Bay has heavily invested in smallholder agriculture by supporting farmers through agricultural extension services and farm inputs as a way of encouraging them to adopt farm diversification (GoK, 2023). In terms of climate, the county experiences adequate rainfall that supports agriculture. It is also endowed with black cotton soil that supports the production of crops. The widely grown crops in this county include maize, beans, sweet potatoes, cassava, cotton, sugarcane, tomatoes, among others. The weather can also support the rearing of livestock such as cattle, sheep, goats, poultry, and donkeys. Apart from farming, fishing is widely practiced in Lake Victoria in Homa Bay County.

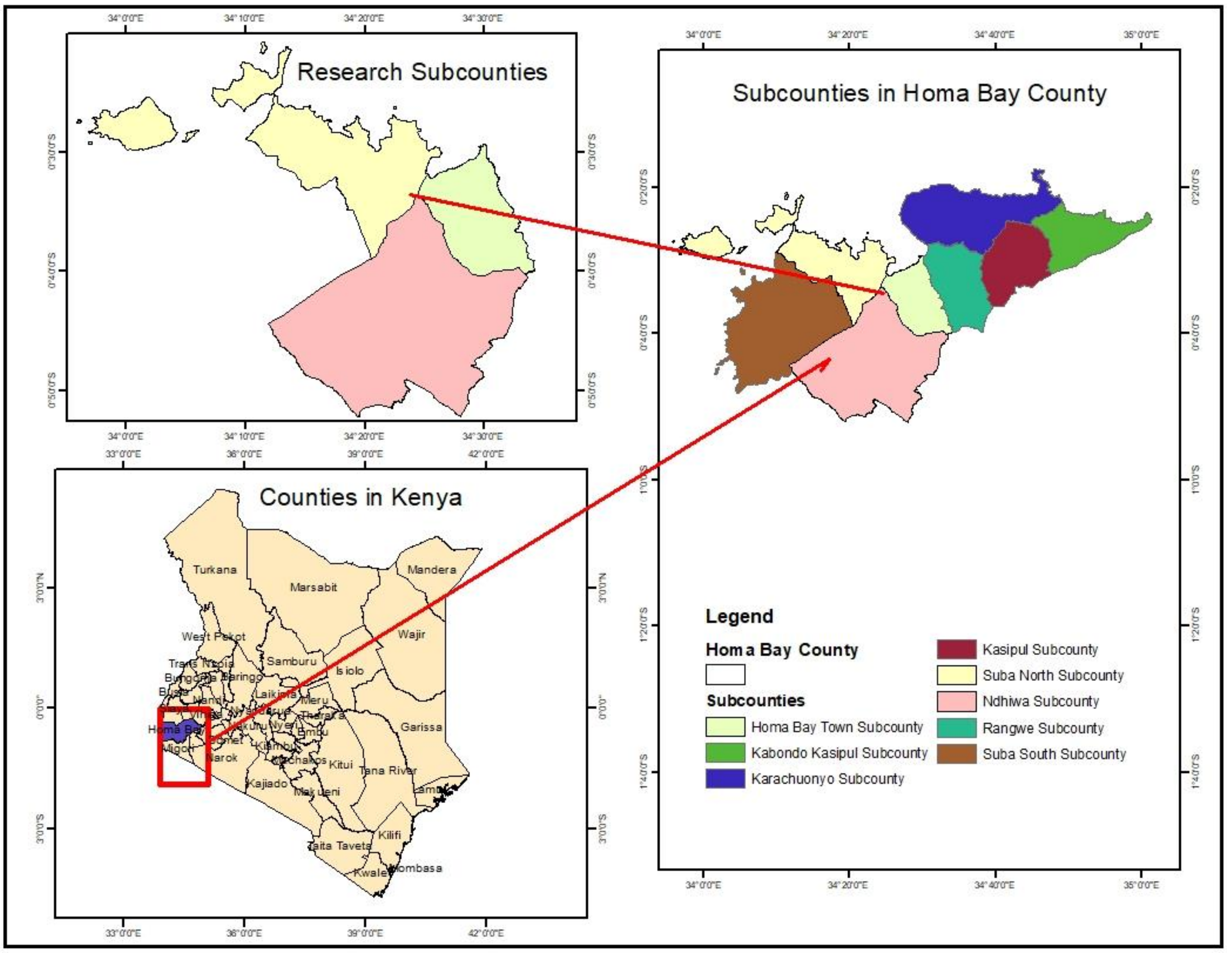

Figure 2. Study area.

2.2. Sampling

The study adopted multistage sampling to collect data from the farmers. First, we sampled Homabay County due to the high prevalence of poverty as well as food insecurity in the area (Ambale, 2018). Second, three sub-counties were purposively sampled from Homabay County. These include Suba North, Ndhiwa, and Homabay Town sub-counties. These were purposively selected due to the high number of farmers. In the final stage, three villages were purposively selected for data collection based on the large number of farmers. The study then randomly selected farmers from the selected villages. Random selection helped in avoiding study participation bias. The sample size was determined following Yamane (1967) sample size formula, thus a total of 402 farmers were sampled for the study. The formula is further illustrated below.

$$n = \frac{N}{[1+N(e^2)]} \qquad (1)$$

$$n = \frac{460513}{1 + 460513(0.05^2)}$$

$$n = \frac{460513}{1152.2825}$$

$$n = 399.6528$$

$$n = 400\ farmers$$

Where is the sample size, N is the population size of farmers in Ndhiwa (218,136), Suba North (117,439), and Homabay Sub-Counties (124,938), which totals 460,513 farmers. e is the level of precision (0.05).

2.3. Data Sources

Data collection tool was developed after a thorough literature review to ensure that the tool captured all variables. The tool incorporated open-ended and closed questions. In terms of nature, most of the questions were quantitative, capturing key study variables such as farmers' demographics, crop and livestock production, farm inputs and outputs, and food security questions, based on the study objectives. The tool was reviewed by experts to ensure that it provided valid and reliable results. Moreover, pretesting was conducted on 30 farmers in Rangwe sub-county to ensure that the tool provided reliable data. Pretesting also helped to revise the tool, including adding and editing some questions. Enumerators from Homabay County, who spoke Dholuo fluently, were then hired and thoroughly trained for three days on data collection, including ethical considerations such as consent seeking, privacy, and confidentiality, among others. Primary data was then collected using face-to-face interviews between the enumerators and the farmers. They asked questions and recorded farmers' responses accordingly. Farmers who could not speak Kiswahili and English had the questions asked in the local language to avoid communication bias. Data collection lasted for three weeks. Cleaning of the data was then performed and later subjected to formal analysis.

2.4. Econometric Analysis

2.4.1. Estimating the Extent of Crop-Livestock Diversification

Several indices have been used to assess farm diversification. These include the Ogive index, Margalef index, Simpson index, and Herfindahl index. Margalef and Ogive indices are preferred when measuring crop diversification (Adjimoti & Kwadzo, 2018). However, for crop-livestock diversification, the Herfindahl Index is the best method to use since it considers the share of each crop and livestock in a given farm (Asante et al., 2018). As such, the study adopted the Herfindahl Index to assess the level of crop-livestock diversification since it can incorporate livestock, unlike other indices that are designed for crop diversification. The Herfindahl index is illustrated below.

The share from individual crop is given as (Equation 2).

$$SC_k = \frac{RC_k}{\sum_{k=1}^{n} RC_k} \qquad (2)$$

Where SC_k represents the share from individual crop, RC_k is the value of the crop while $\sum_{k=1}^{n} RC_k$ is the summation of the value of all crops.

The share from individual livestock is given as (Equation 3).

$$SL_k = \frac{RL_k}{\sum_{k=1}^{n} RL_k} \qquad (3)$$

Where SL_k represents the share from individual, RL_k is the value of the crop while $\sum_{k=1}^{n} RL_k$ is the summation of the value of all livestock.

The share from individual crop or livestock enterprise is given as (Equation 4).

$$SCL_k = \frac{RCL_k}{\sum_{k=1}^{n} RCL_k} \qquad (4)$$

Where SCL_k represents the share from an individual crop or livestock enterprise, RCL_k is the value of the crop or livestock enterprise while $\sum_{k=1}^{n} RCL_k$ is the summation of the value of all livestock and crop enterprises.

Herfindahl index (HI) is then calculated in Equation 5, while crop-livestock diversity is calculated in Equation 6.

$$HI = \sum_{k=1}^{n} SCL_k^2 \qquad (5)$$

$$CropLivestock\ diversification = 1 - HI \qquad (6)$$

Where, HI represents the Herfindahl Index $\sum_{k=1}^{n} SCL_k^2$ represents the summation of all the crop and livestock shares. The crop-livestock diversity ranges from 0 to 1. Those who score more than 0.5 are considered high diversifiers, while those who score up to 0.5 are considered low diversifiers.

2.4.2. Estimating The Effect of Crop-Livestock Diversification on Farm Income

Farmers were divided into two groups based on their crop-livestock diversification index. Low diversifiers scored up to 0.5, while high diversifiers scored above 0.5. This classification enabled the creation of treatment and control groups by assigning 0 to low diversifiers (control group) and 1 to high diversifiers (treatment group). Consequently, propensity score matching (PSM) was employed to analyze the effect of crop-livestock diversification on farm income. The crop-livestock diversification treatment model was estimated using Probit model. Probit model is represented in Equation 7.

$$P(X_a) = \Pr(D = 1 |\, X_a) \qquad (7)$$

Where, $P(X_a)$ is the probability of diversifying to crop-livestock, $D = 1$ for the treatment groups with HI greater than 0.5 while $D = 0$ for the control group with HI less than 0.5. X_i are the predictor variables. The PSM determined how crop-livestock diversification affects farm income using nearest neighbor, kernel, and radius matching algorithms, as shown in Equation 8.

$$ATT = E[E\{Y_1|D = 1, p(X)\} - E\{Y_0|D = 0, p(X)\}|D = 1] \qquad (8)$$

Where Y_1 represents the outcome variable (farm income) for the treatment groups (farmers who score more than 0.5 crop livestock diversification index), Y_0 represents the outcome (farm income) in the control group (farmers who score less than 0.5 CLD), $D = 1$ represents the treatment group (farmers who score more than 0.5 CLD) while $D = 0$ on the other hand, represents the control group (farmers who score less than 0.5 CLD), X represents the covariates that can potentially predict farmers' income. They are summarized in Table 1. Farm income was calculated by subtracting the total variable costs from the total revenues for each crop as shown in Equation 9.

$$Farm\ Income = Total\ revenue - Total\ Variable\ Costs \qquad (9)$$

Table 1. Explanatory variables for the PSM analysis.

Predictors	Measurement	Hypothesized sign.
Credit access	1-Yes, 0-Otherwise	+
Extension access	1-Yes, 0-Otherwise	+
Group membership	1-Yes, 0-Otherwise	+
Land size	Acres	+
Non-farm income	1-Yes, 0-Otherwise	±
Market distance	Kilometers	-
Household size	Number of family members	±
Farming system	1-Commercial, 0-Otherwise	±
Education	Years	+
Age	Years	±
Gender	1-Male, 0-Otherwise	+
Marital status	1-Married, 0-Otherwise	+

3. RESULTS AND DISCUSSIONS

3.1. The Socio-Demographic Comparison of High and Low Crop-Livestock Diversifiers

The results of the socio-demographic characteristics of the farmers are presented in Table 2. The high diversifiers were 6.23 years significantly (P>0.01) older than the low diversifiers. The average number of years spent in school by the farmers was 11.20 years. There was no significant difference in the years of education between the high and low diversifiers. The findings further showed a significant (P<0.01) difference in household size among the two groups of farmers. The high diversifiers had a mean household size of 6 household members, unlike the low diversifiers whose mean household size was 5 household members per household. A similar result was also reported in Ethiopia by Derso, Tolossa, and Seyoum (2022), whose results showed that the number of family members among the diversifiers was higher than among the non-diversifiers. The higher number of family members among the high diversifiers indicates the availability of family labor among them.

The high diversifiers had significantly (P<0.01) higher land size than the low diversifiers. The high diversifiers had 2.6 acres, while the low diversifiers' land size was a mean of 1.67 acres, depicting a 0.89-acre difference. This justifies the many crops produced by the high diversifiers due to the availability of large portions of land. The results comparing the two groups showed that the high diversifiers were 3.98 km away from the market, while the low diversifiers were 3.50 km from the markets. Similar to farmers' age, there was a significant (P<0.01) difference in farming experience between the high and low diversifiers. The findings showed that the high diversifiers had a mean of 19.04 years of farming, while the low diversifiers' farming experience was 14.90 years. On average, the high diversifiers' non-farm income was Kenyan Shillings 15,530, compared to Kenyan Shillings 16,292 for the low diversifiers. In both categories, male-headed households constituted 57 percent of the samples. The findings further showed that 47% of the high diversifiers had access to extension services, while only 40% of the low diversifiers reported having access to extension, with no significant difference between the two groups.

Table 2. The socio-demographic comparison of high and low diversifiers.

Variables	Measurement	High diversifiers N=298	Low diversifiers N=104	Mean difference (Absolute)	t-statistics
Age	Years	47.124	40.894	6.229***	-4.141
Education	Years	11.184	11.269	0.084	0.235
Household size	Number	5.657	5.144	0.513***	-2.178
Land size	Acres	2.565	1.675	0.889***	-4.048
Market distance	Kilometers	3.979	3.504	0.474	-1.261
Farming experience	Years	19.040	14.903	4.136***	-2.671
Distance to the farm	Kilometers	0.720	0.574	0.145	-1.414
Non-farm Income	Kenyan shillings	15,530.20	16,292.31	762.106	0.327
Gender	1-Male, 0-Otherwise	0.573	0.576	0.003	0.054
Extension	1-Yes, 0-Otherwise	0.473	0.403	0.069	-1.221

Note: ***=1% significant.

3.2. Crops and Livestock Production

The types of crops and livestock produced by the farmers are presented in Table 3. These crops and livestock play key roles in household food security and farmers' income. Most of the farmers (92%) produced maize (Table 3). This is attributed to the benefits of maize, such as being a source of farm income and food security crop. Beans were also produced by a number of farmers (42%). The high number of bean farmers is a result of the incorporation of maize and beans in the same field. Other crops that attracted many farmers include vegetables (37%) and sorghum (30%). However, only 2% of the farmers were engaged in millet production, despite it being a multipurpose crop. Cowpeas also attracted very few farmers. Livestock such as cows were fairly (56%) produced by the farmers. Most of the sampled farmers (81%) reared chickens. Ducks and donkeys were produced by 12% and 13% of the farmers, respectively.

Table 3. Crops and livestock production.

Crops	Frequency (N)	Percentage (%)
Maize	369	92
Beans	181	42
Millet	7	2
Cow peas	53	13
Sorghum	122	30
Cassava	89	22
Sweet potatoes	54	13
Cotton	40	10
Vegetables	150	37
Tomatoes	33	8
Livestock	Frequency (N)	Percentage (N)
Cows	225	56
Goats	184	46
Sheep	104	26
Chicken	327	81
Ducks	47	12
Donkeys	52	13

3.3. Factors Influencing Crop-Livestock Diversification Among Farmers in Homabay County, Kenya

Understanding the factors affecting crop-livestock diversification among farmers is highly important in many ways. It provides insights to policymakers on areas that require adjustments to boost the incorporation of crops and livestock among farmers. This study found that credit access significantly predicted crop-livestock diversification. Farmers who have access to credit have an 8.1% higher likelihood of integrating crops and livestock in their farms than those who are credit-constrained. This is a result of the role of credit in agriculture. According to Chandio, Jiang, Wei, and Guangshun (2018), credit plays several roles in agriculture. These include the payment of farm workers, adoption of modern technology, purchase of farm inputs, and access to input and output markets, among others. Farmers who have access to credit can easily purchase agricultural inputs on time, prepare land, and plan more effectively than those who are credit-constrained. They can also purchase livestock feed, drugs, and access veterinary services to boost their livestock productivity. This is supported by the findings of Danso-Abbeam et al. (2021), whose results from OLS showed that credit increases the intensity of crop-livestock diversification in Ghana.

Membership in farmer groups and associations positively influences the diversification of crops and livestock among farmers. As shown in Table 4, farmers who are affiliated with groups have a 4.6% higher likelihood of crop-livestock diversification on their farms compared to non-members. Many farmers recognize the benefits of forming groups, which include bulk input purchases at lower prices due to economies of scale, lending and saving activities among members, bargaining for output prices, and accessing information on the best-performing crops to incorporate into their farms. Consequently, group members tend to diversify their crop types and livestock species more extensively. In addition, group members often collaborate on activities such as weeding, land preparation, planting, and harvesting. They can also borrow from the group to purchase seeds, fertilizers, and other farm inputs. This collective approach results in higher levels of crop-livestock diversification among group members compared to non-members. These findings align with the results of Vatana, Keo, and Yoeun (2024), which indicated a positive influence of farmer associations on farm diversification.

Similar to the results reported by Inoni et al. (2021) in Nigeria, Derso et al. (2022) in Ethiopia, and Asante et al. (2018) in Ghana, farm size has a positive influence on crop-livestock diversification. Farmers with larger parcels of land have a 13.2% higher likelihood of integrating crops and livestock into their farms than those with smaller parcels. Land is the primary factor of production; many farming activities require large parcels of land. Additionally, some crops, such as sweet potatoes and tomatoes, cannot be integrated within the same field. Therefore, farmers with larger landholdings can cultivate a greater variety of crops. Sufficient land also provides grazing fields for livestock, allowing them to graze freely on land not used for crop production.

As reported by Kemboi, Muendo, and Kiprotich (2020) in Kenya and Dessie et al. (2019) in Ethiopia, the results showed that older farmers had a 2.1% higher probability of crop-livestock diversification than young farmers. The positive influence of age on crop-livestock diversification can be attributed to the wealth of expertise and skills gathered by older farmers. Such farmers have a wealth of skills in farm production, including the best crops and livestock to integrate into their farms. It has also been reported that older farmers have developed social capital, joined many farmer groups, and adopted agricultural technologies that contribute to crop-livestock diversification. However, older farmers can also be weak, resulting in low adoption of crop-livestock diversification since producing many crops and livestock is labor-intensive. This justifies the negative effect of age on farm diversification as reported by Danso-Abbeam et al. (2021) in Ghana.

The results further indicated that gender was positively associated with crop-livestock diversification among farmers. Male-headed households had a 20% significantly higher likelihood of crop-livestock diversification than those headed by females. According to Midamba and Ouko (2024), male-headed households have greater access to resources such as land, credit, and extension services. Similarly, Midamba et al. (2022) argued that male-headed households have better access to farm inputs than their female counterparts. This results in a higher likelihood of crop-livestock diversification among the male-headed households than those headed by females. Similar results are evident in a study done by Asante, Koomson, Villano, and Wiredu (2021) in Ghana.

It is evident from the presented results that marital status has a positive effect on crop-livestock diversification. Married farmers have a 40% higher likelihood of engaging in crop-livestock diversification compared to their unmarried counterparts.

Most married farmers are characterized by having many family members, which creates a need to produce more food through integrating various crops and livestock. Additionally, married farmers can more easily share investment plans, including investments in different crop and livestock species, to enhance their economic growth. This aligns with the findings of Baba and Abdulai (2021), which demonstrated that marital status positively influences farm diversification in Northern Ghana.

Table 4. The predictors of crop-livestock diversification among farmers in Homabay.

Predictors	Coefficients	Standard errors	p>|t|	Marginal effects
Access to credit	0.096**	0.176	0.045	0.081**
Access to agricultural extension services	-0.232	0.185	0.211	-0.229
Group membership	0.579***	0.177	0.001	0.459***
Farm size	0.136***	0.050	0.007	0.132***
Non-farm income	-0.013	0.166	0.934	-0.001
Market distance	-0.012	0.113	0.915	-0.015
Household size	0.039	0.042	0.342	0.040
Farming system	0.137	0.178	0.442	0.132
Education	0.008	0.026	0.756	0.010
Age	0.017***	0.006	0.013	0.021***
Gender	0.270*	0.169	0.100	0.200*
Marital status	0.396*	0.236	0.093	0.400*
Model summary				
Prob>Chi²	0.000			
Observations	402			
Pseudo R²	0.0942			
Log likelihood	-208.171			

Note: *,**,***=Significant at 10%, 5%, and 1%, respectively..

3.4. Farm Production Costs and Income

3.4.1. Crop Variable Costs

The costs associated with the production of the crops are presented in Table 5. It provides the means and total variable costs (TVC) per acre. The total variable costs include the cost of seeds, fertilizer, chemicals, and farm labor. From the results, the variable cost of cotton was at Kenyan shillings 12,393 per acre. Cotton production is labor-intensive, especially during harvesting. Farmers also spent a considerable amount of money on fertilizers and chemicals in cotton. Like cotton, tomatoes require fertilizers and chemicals to prevent diseases like blight. Thus, the total variable cost of tomato production was at Kenyan shillings 19,400 per acre. The total variable cost of maize was at Kenyan shillings 6,238 per acre. Interestingly, the cost of millet was the lowest at Kenyan shillings 1,852 per acre. This was a result of the low acreage and the cheap cost of millet seeds.

Vegetables and beans' total variable costs were Kenyan shillings 15,708 and 4,866 per acre, respectively. Vegetables also incurred the costs of chemicals and fertilizers to reduce pests and increase soil productivity, respectively. From these variable costs, it is depicted that crops such as maize, beans, millet, sorghum, sweet potatoes, and cassava did not have chemical costs, lowering their production costs. In addition, farmers did not incur any cost of fertilizers for crops such as millet, sorghum, cassava, sweet potatoes, and cowpeas. Normally, farmers tend to produce these crops without applying fertilizers.

Table 5. Crops Variable Costs.

Crops	Acreage (Acres)	Seeds cost (Ksh)	Fertilizer cost (Ksh)	Chemical cost (Ksh)	Labour cost (Ksh)	Total variable cost (Ksh)	TVC/acre (Ksh)
Maize	1.24	1,764.21	3,501.86	0.00	2,468.56	7,734.63	6,237.60
Beans	0.98	670.00	2,134.30	0.00	1,964.64	4,768.94	4,866.30
Millet	1.01	441.42	0.00	0.00	1,428.57	1,870.00	1,851.50
Sorghum	0.78	350.91	0.00	0.00	1,502.45	1,853.36	2,376.10
Tomatoes	0.43	1,690.62	2,772.91	2,101.20	1,777.27	8,342.00	19,400.00
Sweet potato	0.43	650.00	0.00	0.00	947.22	1,597.22	3,715.00
Vegetables	0.33	578.38	1,961.81	1,822.07	821.45	5,183.71	15,708.21
Cowpeas	0.34	245.42	0.00	0.00	461.13	709.55	2,087.00
Cotton	0.94	2,811.39	3,067.27	2,537.03	3,234.15	11,650.00	12,393.62
Cassava	0.61	1,082.43	0.00	0.00	1,182.02	2,264.45	3,712.20

3.4.2. Crops Gross Margins

Gross margin was used as a proxy for farm income from the crop enterprises, presented in Table 6. From the list, cotton was the most profitable enterprise with a gross margin of Kenyan shillings 29,106.45. This was followed by millet with a gross margin of Kenyan shillings 16,770. Beans were the third-best crop in terms of gross margin. The farmers earned a mean of Kenyan shillings 12,858.81 from beans production. The crop with the lowest gross margin was cowpeas at only Kenyan shillings 1,313.30. Moreover, the mean gross margin from vegetables and sorghum was Kenyan shillings 4,478.15 and 6,833.58, respectively. These two were among the crops with the least gross margins.

Table 6. Crops gross margin for the year 2025.

Crops	Units of measure	Units harvested	Unit price (Ksh)	Total revenue (Ksh)	Total revenue/ Acre (Ksh)	Total variable Costs (Ksh)	TVC/ Acre	Gross margin (Ksh)	GM/ Acre
Maize	2kg tin	189.401	103.059	19,517.67	15,740.05	7,734.63	6,237.60	11,783.04	9,503.00
Beans	2kg tin	50.365	350.00	17,627.75	17,987.50	4,768.94	4,866.30	12,858.81	13,121.23
Millet	2kg tin	133.142	140.00	18,640.00	18,455.44	1,870.00	1,851.50	16,770.00	16,604.00
Sorghum	2kg tin	93.408	93.00	8,686.94	11,137.10	1,853.36	2,376.10	6,833.58	8,761.00
Tomatoes	Crate	9.781	2,120.31	20,738.78	48,300.00	8,342.00	19,400.00	12,396.78	28,830.00
Sweet potato	Lump sum	Lump sum	11,400.00	11,400.00	26,511.63	1,597.22	3,715.00	9,802.78	22,797.20
Vegetables	Lump sum	Lump sum	10,261.86	10,261.86	61,400.00	5,183.71	15,708.21	4,478.15	13,570.15
Cow peas	2kg tin	7.06	286.52	2,022.83	5,950.00	709.55	2,087.00	1,313.30	3,862.65
Cotton	90-kg Sack	15.42	2,643.09	40,756.45	43,357.93	11,650.00	12,393.62	29,106.45	30,964.30
Cassava	Lump sum	Lump sum	12,038.57	12,038.57	19,735.36	2,264.45	3,712.20	9,774.12	16,023.15

3.5. Farm Income and Crop-Livestock Diversity Range

Figure 3 presents the results of farm income and crop-livestock diversity range. The table compares the crop-livestock diversity range and farm income earned by the farmers. The findings indicate that farmers who scored up to 0.2 in crop-livestock diversity had a mean farm income of 10,823.33 Kenyan shillings. It is also evident that those who scored between 0.21 and 0.40 in crop-livestock diversity earned 18,722.02 Kenyan shillings as farm income. Additionally, farmers who operated within the 0.41 to 0.60 crop-livestock diversity range earned 24,375.55 Kenyan shillings. A similar pattern is observed up to the highest level of the crop-livestock diversity index. From these findings, farm income increases as the level of crop-livestock diversification index increases. Farmers with higher crop-livestock diversity scores had higher incomes, while those with lower diversification levels had correspondingly lower farm incomes, as further illustrated in Figure 3. This suggests that crop-livestock diversification may contribute to higher income among farmers.

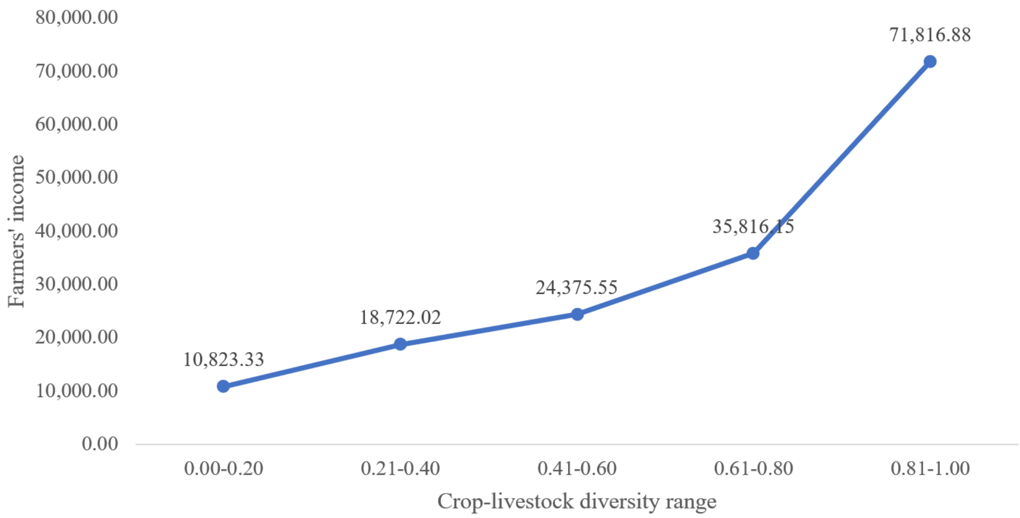

Figure 3. Crop-livestock diversity and farm income.

3.6. Matching Quality Analysis: T-Test

Table 7 presents the matching quality analysis. From the results, it can be seen that the matching process was highly effective and appropriate. This is attributable to the insignificant covariates, implying that all the covariates were statistically insignificant after matching, meeting the requirements for quality matching (Ahmed & Mesfin, 2017; Emmanuel, Owusu-Sekyere, Owusu, & Jordaan, 2016). Moreover, the percentage bias was less than 20, which is also an indication of the appropriateness of the matching process (Kiyingi et al., 2024). Thus, there was an adequate balance between the high diversifiers and the low diversifiers.

Table 7. Matching quality analysis: t-test.

Variables	Mean			t-test	
	Treated	Control	Percentage Bias	t	p>|t|
Credit access	0.473	0.434	8.0	0.97	0.332
Extension access	0.349	0.383	-7.2	-0.87	0.385
Group membership	0.520	0.508	2.4	0.29	0.775
Land size	2.565	2.649	-4.6	-0.45	0.649
Non-farm income	0.624	0.649	-5.2	-0.63	0.530
Market distance	1.336	1.286	6.5	0.77	0.443
Household size	5.658	5.669	-0.6	-0.07	0.944
Farming system	0.305	0.274	6.9	0.84	0.399
Education	11.185	11.188	-0.1	-0.01	0.990
Age	47.124	46.424	5.4	0.62	0.533
Gender	0.574	0.521	10.6	1.28	0.200
Marital status	0.819	0.826	-2.0	-0.23	0.822

3.7. Matching Quality Test Using Propensity Graph

The quality of matching was further tested using the propensity score graph shown in Figure 4. Figure 4 depicts a considerable overlap of the propensity scores between the high diversifiers (treated) and low diversifiers (control). The overlap is mainly evident between 0.4 and around 0.95. This implies that there was a good and balanced match.

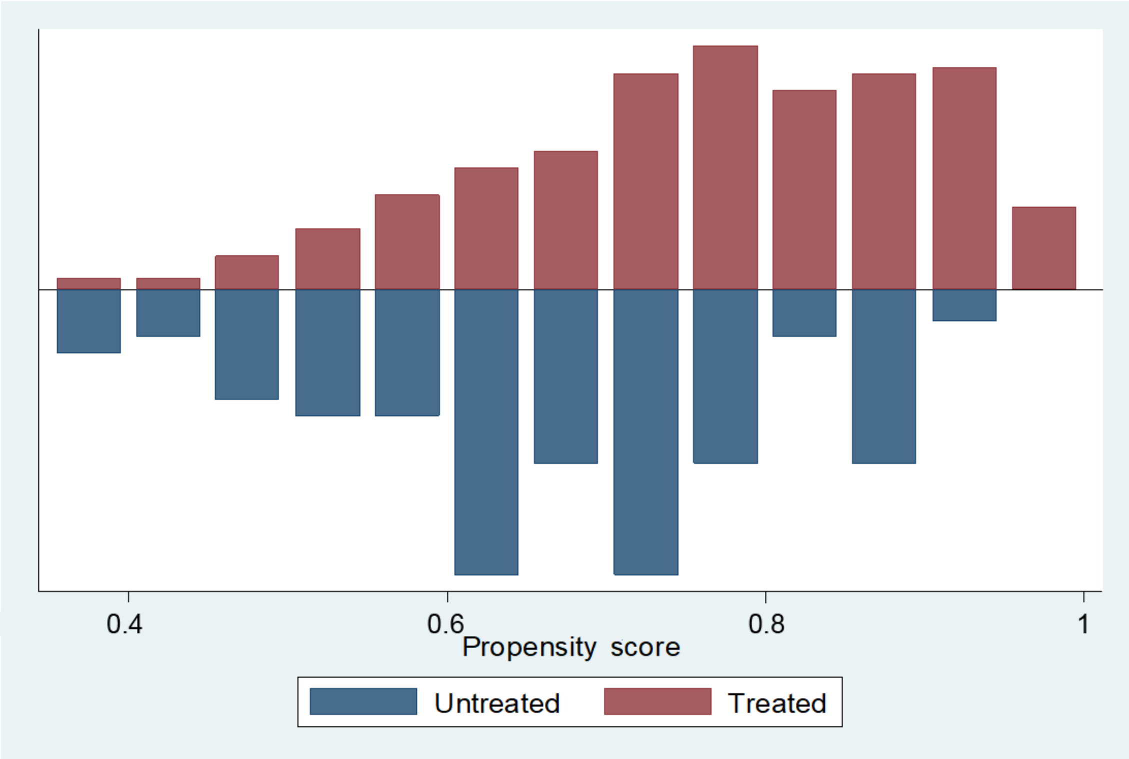

Figure 4. Propensity score graph for CLD and farm income.

3.8. Effects of Crop-Livestock Diversification on Farm Income

The propensity score matching results on the effects of crop-livestock diversification on farm income are presented in Table 8. Three matching algorithms (Kernel, Radius, and Nearest neighbor matching) were used for the analysis to ensure that the reported results are valid. The results from the nearest neighbor matching indicated that crop-livestock diversification has a positive effect on farm income. The findings revealed that high diversifiers had a mean farm income of Kenyan shillings 73,937.2 per acre, while low diversifiers' mean income was Kenyan shillings 33,137.0 per acre. The results further showed that crop-livestock diversification significantly (t-statistic=3.91) increases farm income by Kenyan shillings 40,800 per acre based on the nearest neighbor matching algorithm.

The findings from Kernel matching also indicated a positive effect of crop-livestock diversification on farm income. From Kernel matching, it is evident that high diversifiers had a mean farm income of Kenyan shillings 73,937.2 per acre, while the low diversifiers' mean income was Kenyan shillings 32,450 per acre. This implies that crop-livestock diversification significantly (t-statistics = 4.15) increases farm income by Kenyan shillings 41,487.7 per acre, as shown in the value of the ATT below. The results from radius matching also showed positive effects of crop-livestock diversification on household farm income. It is evident that crop-livestock diversification significantly increases household farm income by Kenyan shillings 36,131.66 per acre. This increase is attributable to the additional and higher volumes of crop sales. Farmers who focus on a single crop, such as maize, are more likely to report lower income than those who produce multiple crops. This is supported by the findings of Mzyece and Ng'ombe (2021), who reported that farm diversification increases efficiency and reduces income variability among farmers in Ghana. Additionally, the findings of Basantaray et al. (2024) also revealed that farm diversification increases farm income.

Table 8. Effects of crop-livestock diversification on farm income.

Matching algorithm	Outcome variables	High diversifiers	Low diversifiers	ATT	Standard errors	t-statistics
Nearest neighbor	Farm income	73,937.16	33,136.97	40,800.20***	13,179.18	3.10
Kernel	Farm income	73,937.16	32,450.00	41,487.66***	10,545.52	3.93
Radius	Farm income	73,937.16	37,805.50	36,131.66***	6,849.48	8.33

Note: ***=1% significant

4. CONCLUSION

The challenges in agriculture, such as climate variability and climate change, resulting in adverse temperatures, floods, humidity, and outbreaks of pests and diseases, can adversely affect the productivity of crops in Sub-Saharan Africa. Thus, the integration of many crops and livestock species on a farm can help reduce uncertainties and risks in farming. Farmers can produce various crop types, especially those that are hardy and capable of surviving in adverse temperatures, alongside livestock. However, it is imperative to assess the types of crops produced by farmers, the covariates influencing crop-livestock diversification, and how it affects farmers' income. This study aimed to meet two objectives.

First, it assessed the socio-economic predictors responsible for crop-livestock diversification. Additionally, it determined the effect of crop-livestock diversification on farm income. From the first objective, the study concluded that crop-livestock diversification is positively predicted by credit, group membership, farm size, age, gender, and marital status. These socio-economic predictors significantly increase the likelihood of crop-livestock diversification among farmers. From the second objective, it is concluded that crop-livestock diversification increases farm income. All three matching algorithms (kernel, radius, and nearest neighbor) affirmed that crop-livestock diversification increases farmers' income.

5. RECOMMENDATION

Based on the findings, the study recommends that the County government of Homabay should conduct public sensitization on the roles of crop-livestock diversification in farmers' income. This will encourage many farmers to embrace crop-livestock diversification. In addition, extension agents should support farmers in forming associations where they can share and learn from each other. This will result in increased diversification. Financial institutions should offer loans at reduced interest rates to farmers. This will ensure that the majority of farmers can purchase farm inputs on time.

Linking farmers to reliable and trusted agricultural loans is highly recommended, as it will increase timely access to and purchase of farm inputs. Moreover, female-headed households should be targeted by extension officers for training on crop-livestock diversification. Extension agents should prioritize young farmers during farm diversification training. This will ensure that they incorporate as many crops and livestock species as possible into their farms.

5.1. Study Limitations and Areas for Further Research

The study relied on cross-sectional data collected among 402 farmers, which may not represent other regions. Therefore, it is imperative to conduct the same study in other counties with larger sample sizes. The study did not consider other significant crops in Kenya, such as sugarcane, tea, nuts, and coffee. Future work should include these crops as well.

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