frontiers | Frontiers in Sustainable Food Systems

TYPE Original Research
PUBLISHED 13 March 2025
DOI 10.3389/fsufs.2025.1518276

OPEN ACCESS

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RECEIVED 28 October 2024
ACCEPTED 25 February 2025
PUBLISHED 13 March 2025

CITATION
Lumumba BO, Otieno DJ and Nyikal RA (2025) Analysis of factors influencing farmers' adoption of desert locust control methods in Kenya.
Front. Sustain. Food Syst. 9:1518276.
doi: 10.3389/fsufs.2025.1518276

Analysis of factors influencing farmers' adoption of desert locust control methods in Kenya

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Transboundary pests present a significant threat to agricultural production and household incomes, with desert locust invasions being among the most disruptive. Despite ongoing control efforts, such as surveillance and chemical interventions, the rapid spread of locusts into non-traditional breeding areas and limited preparedness underscore the need for integrated desert locust management. This study aimed to identify indigenous locust control practices and examine the factors influencing their adoption to support informed policy for integrated pest management. Using a multivariate probit model (MVP) corrected for selection bias, we assessed factors affecting the adoption of these control methods. Data from a random sample of 473 farmers in Isiolo and Meru counties, Kenya, revealed that desert locust control methods are complementary, meaning that they are more effective when used together rather than in isolation. Key factors influencing adoption included access to information, experience with previous pest shocks, and social networks. These findings emphasize the importance of establishing effective early warning systems and enhancing farmer training on locust management through social groups as strategic entry points for intervention.

KEYWORDS

complementarity, indigenous control, integrated desert locust management, *Schistocerca gregaria*, multivariate probit

1 Introduction

Transboundary pests (migratory pests invading and affecting large geographical areas), including desert locusts and fall armyworms (FAW), negatively impact agro-pastoral resources and livelihoods across the globe, accounting for losses estimated at US$65.58 billion annually in terms of production losses and control costs (Eschen et al., 2021). Desert locusts (*Schistocerca gregaria*) are one of the most destructive transboundary pests; a swarm covering one square kilometer can consist of up to 80 million adults capable of eating the same amount of food consumed by 35,000 people in one day (FAO, 2020a).

Recent trends show that Africa, south of the Sahara and South Asia have the highest global hunger index (GHI) score of 27. This is high compared to having the second highest GHI score compared to West Asia and North Africa (11.9), Latin America and Caribbean (8.6), East and South East Asia (8.3), and a score of 6.1 in Europe and Central Asia (von Grebmer et al., 2023). Key drivers of rising food insecurity include climate variability, conflicts, and economic downturns (IFPRI, 2023). In this context, climate variability is associated with the unpredictable and devastating effects of desert locust invasions (Herbillon et al., 2024). It is therefore imperative to effectively manage the disastrous consequences of desert locust invasions on farms and livelihoods.

The most recent invasion over the period 2019–2020 resulted from heavy rainfalls in the breeding areas of the Arabian Peninsula, moving across Yemen, Eritrea, and Somalia. Strong winds and heavy rainfalls favored increased breeding and pushed adult locusts into Ethiopia and Kenya in late 2019 and further into Uganda, Tanzania, and South Sudan (FAO, 2020b; Kimathi et al., 2020). These invasions affected millions of livelihoods in South Asia and Eastern Africa. For instance, in Pakistan, agricultural losses were estimated at US$1.2 billion (FAO, 2020c).

The desert locust invasion in Ethiopia caused an estimated loss of 197,163 hectares of cropland, 1,350,000 hectares of pasture, and an estimated cereal loss of 356,286 metric tons, affecting approximately 806,400 farming households (FAO, 2020d). In Kenya, an estimated 30,213 hectares of cropland and 579,786 hectares of pasture were affected by the desert locust invasion (FAO, 2020e). Furthermore, the United States Agency for International Development (USAID, 2020) valued the East African region's economic losses due to the desert locust invasion at US$8.5 billion.

Desert locust mitigation efforts employed a multi-faceted strategy led by the FAO in collaboration with other multilateral partners. This strategy focused on establishing early warning systems, monitoring locust populations, and implementing control measures (FAO, 2020b; Pandey et al., 2021; Showler et al., 2022). Key technological advancements—including the eLocust3 application, drone technology, and machine learning—significantly enhanced surveillance capabilities (Mamo and Bedane, 2021; Enns et al., 2022; Klein et al., 2023). The control approach primarily involved chemical spraying of locust swarms, conducted through aerial, handheld, and vehicle-mounted methods. However, the heavy reliance on chemical treatments has raised concerns about potential adverse effects on the environment and human health (Praneetvatakul et al., 2024).

Another alternative control method involves the use of biopesticides, such as *metarhizium*. Although biopesticides are less harmful, they have a slow reaction time and a small range of hosts and are thus expensive to develop (Githae and Kuria, 2021). At the farm and community level, households implemented various indigenous control methods to some degree of success (FAO, 2020d). These indigenous control methods included hitting objects (hitting metallic objects to produce noise expected to scare the locusts), lighting fires (burning dry material such as leaves and branches), burying, trampling, plowing infested fields, avoiding invaded areas, and on-farm spraying of insecticides like cypermethrin (FAO, 2020d; Pandey et al., 2021).

Despite calls for the implementation of integrated pest management (IPM) in controlling migratory pests (Cheke and El Hady Sidatt, 2019; Shuang et al., 2022), and in this case, integrated desert locust management (IDLM) (Githae and Kuria, 2021; Showler et al., 2022), there is limited information on how household and institutional characteristics influence the adoption of desert locust control measures, yet understanding these factors is critical in the formulation of effective management strategies.

IDLM is an effective strategy that combines robust early warning and surveillance systems that form the basis for rational use of chemical spraying, biological control, and the inclusion of indigenous control methods. Previous research has focused on assessing the impacts of desert locust invasion (Kassegn and Endris, 2021; Le and Nguyen, 2022; Conte et al., 2023) and improving control through technologies (Anjita and Indu, 2023; Landmann et al., 2023). At the farm level, research has also focused on farmers' use of indigenous control methods (Pandey et al., 2021; Showler et al., 2022), though little attention has been paid to understanding the drivers influencing their adoption. Moreover, the study goes further by assessing the control of a transboundary pest, unlike other studies that mainly focused on pests that have established habitats, for example, the FAW and tsetse flies.

While there is recent literature on the drivers of the adoption of pest or disease management methods (Musungu et al., 2021; Nzuma and Mzera, 2023; Bryant et al., 2024; Tambo et al., 2024), it is unclear whether factors such as shocks, informal sources of information, and perceptions influence pest management. Here, we address this literature gap. This study, therefore, addresses the mentioned research gaps by empirically assessing the factors influencing the adoption of desert locust management methods. Essentially, the findings of this study are instrumental in developing policies toward IDLM that lead to improved food security and household incomes.

2 Materials and methods

2.1 Study area

The desert locust invasion between 2019 and 2020 affected some counties in Kenya, classified into three clusters (FAO, 2020d). Cluster 1 consisted of Baringo, Elgeyo Marakwet, Isiolo, Laikipia, Samburu, and Turkana. Cluster 2 consisted of Mandera, Wajir, and Marsabit, while Cluster 3 included Embu, Garissa, Kitui, Machakos, Meru, Tana River, and Tharaka Nithi (FAO, 2020d).

2.2 Research design and sampling procedure

A quasi-experimental quantitative research design was used in this study. To get the sample for the study, a three-stage sampling procedure was applied. In the first stage, Isiolo and Meru counties were purposely selected because they experienced multiple desert locust invasions between 2019 and 2020. In addition, both areas have medium- to high-population settlements, which limits chemical application (GCRF African Swift, 2020). Isiolo County is characterized by semi-arid and arid zones where pastoralism and agro-pastoralism are practiced (County government of Isiolo, 2023). Meru County is a high agricultural potential area characterized by various levels ranging from the upper highlands to the lower midlands, where mixed farming, rain-fed cropping, and marginal mixed farming are practiced (County Government of Meru, 2023). In the second stage, Imenti North (Meru County) and Garbatulla sub-county (Isiolo County) and selected. Lastly, with the help of sub-county agricultural officers, one administrative ward was selected from each sub-county: Nyaki East ward (Miriga Mieru east) in Imenti North (Figure 1) and Kinna ward in Garbatulla sub-county (Figure 2). Simple random sampling method was applied to select the respondents.

2.3 Data collection and analysis

Insights from key informant interviews (county directors of agriculture and officers involved in the desert locust control program), focus group discussions conducted with farmers and key informants, and information from previous desert locust studies (Emana, 2002; Showler, 2019; Pandey et al., 2021) were used to refine and validate the

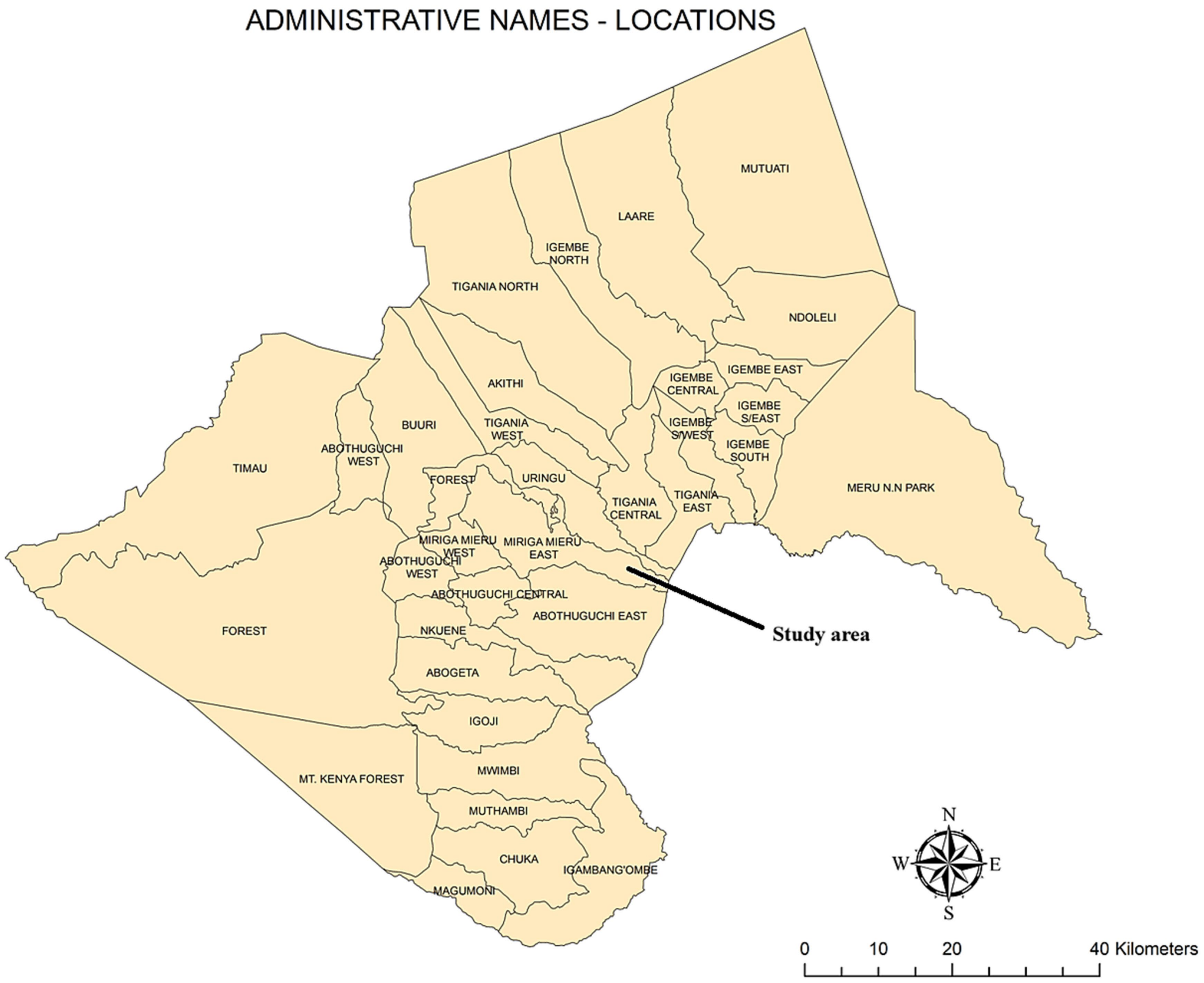

FIGURE 1
Map of Meru County. Source: Adapted from County Government of Meru (2024).

questionnaire tool. The final questionnaire covered various sections that included household characteristics, effects of desert locust invasion, control methods used, and 15 statements assessing perceptions of desert locust management. Five statements were related to the formal control measures; four statements were related to desert locust information; three statements were related to IDLM; and three statements were related to indigenous control methods. The statements are described in Equation 1.

The sampling formula of Cochran (Bartlett and Kotrlik, 2001) was used to calculate the sample size as described below:

$$n = \frac{Z^2 pq}{e^2} \quad (1)$$

where n is the sample size, Z is the desired confidence level, p is the estimated proportion with the attribute being studied, q is 1-p, and e is the margin of error. This study used a confidence level of 95% and a 5% margin of error. The p was assumed to take a value of 0.5 since the exact number of farmers in both study sites was unknown. The formula gave a sample size of 385. To account for non-response, the sample size was adjusted upwards by 25% following the 10–25% range suggested by Lindner et al. (2001), resulting in a total of 480 respondents, 240 for each study site. The sample size was close to other studies focusing on pest management, for instance, Tambo et al. (2020) and Weyori (2021), who used a sample size of 465 and 482 households, respectively. Due to incomplete data in some questionnaires, 7 households were dropped, leaving a valid sample size of 473 households for the analysis. The data were analyzed using Stata version 15.

2.4 Empirical framework

Farmers can either adopt single or multiple technologies; thus, there is a need to account for this situation. The multivariate probit model (MVP) accounts for the simultaneous adoption of different technologies by considering the correlation of disturbance terms that may arise from the relationship between different agricultural technologies. The model has been applied in assessing factors influencing the adoption of agricultural technologies (Musungu et al., 2021; Bwiza et al., 2024; Geda et al., 2024; Tambo et al., 2024). In this case, unobserved factors simultaneously influence the adoption of each desert locust control method, and the MVP model would be appropriate (Tham et al., 2023).

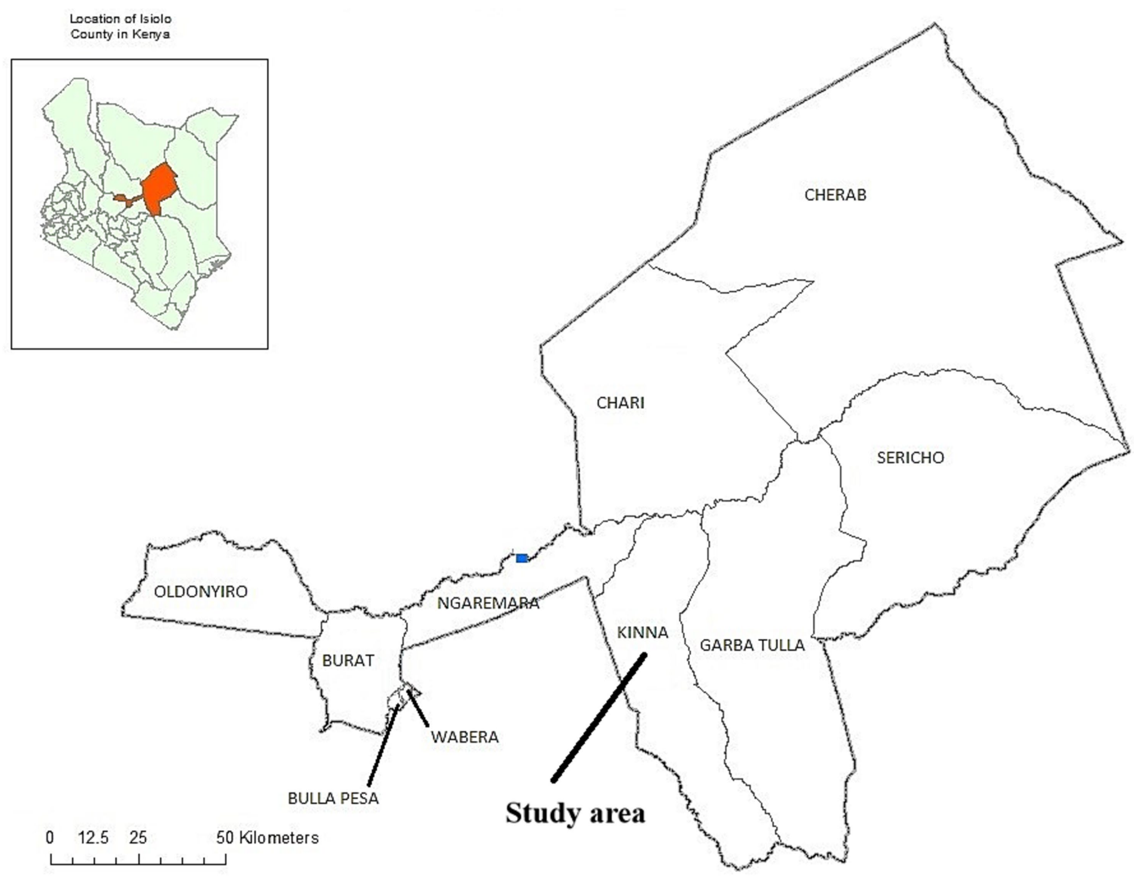

FIGURE 2
Map of Isiolo County. Source: Adapted from Maarifa Centre (2022).

In a multivariate model, different control methods, in this case, hitting objects (HO), lighting fire (UF), burying with soil (BT), avoiding invaded areas (AI), and on-farm spraying (OS), which are binary variables, can be modeled as:

$$Z_{jk}^{*} = \beta_{k}^{\prime} X_{jk} + \varepsilon_{jk}, \left(k = HO, UF, BT, AI, OS\right) \tag{2}$$

where Z_{jk}^{*} are the unobservable latent variables in the choice of desert locust control methods selected by a farmer. X is a vector of explanatory variables that influence the choice of desert locust control method, β represents a vector of parameters to be estimated, and ε_{jk} is a set of multivariate error terms that are normally distributed with a zero conditional mean and variance normalized to unity $(U_{HO}, U_{UF}, U_{BT}, U_{AI}, U_{OS})$ and a covariance matrix (Ω). This can be expressed as Equation 3:

$$\Omega = \begin{pmatrix} 1 & \rho_{HO,UF} & \rho_{HO,BT} & \rho_{HO,AI} & \rho_{HO,OS} \\ \rho_{UF,HO} & 1 & \rho_{UF,BT} & \rho_{UF,AI} & \rho_{UF,OS} \\ \rho_{BT,HO} & \rho_{BT,UF} & 1 & \rho_{BT,AI} & \rho_{BT,OS} \\ \rho_{AI,HO} & \rho_{AI,UF} & \rho_{AI,BT} & 1 & \rho_{AI,OS} \\ \rho_{OS,HO} & \rho_{OS,UF} & \rho_{OS,BT} & \rho_{OS,AI} & 1 \end{pmatrix} \tag{3}$$

where ρ (rho) is the pairwise correlation coefficient of error terms matching any two desert locust control methods. A significant ρ (rho) value indicates interdependence between the error terms (non-zero) result, and then Equation 2 becomes an MVP model.

Farmer awareness of desert locust control and adoption of control methods follow a two-step process. In the first stage, the farmer is aware or not, while in the second stage, a farmer adopts a control method. The second stage of adoption is a sub-sample of the first (awareness of desert locust control). Therefore, there is an increased likelihood that the sub-sample used in the second stage is non-random and different from the first stage (which included farmers who were not aware), which creates sample-selection bias (Rezaee et al., 2022). The Heckman two-stage procedure was used to correct for potential selection bias in the adoption decision (Heckman, 1979). In the first stage, an assessment of the factors influencing awareness of desert locust control methods was done. In the second stage, an MVP model corrected for selection bias was fitted. Both stages were fitted simultaneously using the CMP (conditional mixed processes) command in Stata to correct for self-selection bias following Bwiza et al. (2024). In the first stage, the following equation (Equation 4) was fitted as follows:

$$\begin{aligned} Awareness_{jk} = \varphi_0 + \varphi_1 Gender + \varphi_2 Farmingexp + \\ \varphi_3 Droughtshock + \varphi_4 Pestordiseaseshock + \\ \varphi_5 Groupmembership + \varphi_6 Formalsources + \\ \varphi_7 Informalsources + \varepsilon_{jk} \end{aligned} \tag{4}$$

TABLE 1 Description of variables and their expected signs.

Explanatory factors	Description	Expected sign
Gender	Gender of household head (1 = male)	+
Age	Age of the household (1 = Below 35 years)	–
Farming experience	Farming experience in years.	+
Formal education	Years of formal education	+
TLU	Total number of livestock owned (units)	+
Location	Location of the household (1 = Meru)	±
Drought shock	Experienced drought over the past 5 years (1 = Yes)	+
Pest/disease shock	Experienced pest/disease shock over the past 5 years (1 = Yes)	+
Group membership	Membership to a farmer group (1 = Yes)	±
Sale of crop/livestock	Sale of crops or livestock products (1 = Yes)	+
Access to desert locust information	Information on desert locusts from extension/ county agents (1 = Formal)	+
Access to desert locust information	Information on desert locusts from neighbors/community members (1 = Informal)	+
Perception Rank	Household's perception of desert locust management (1 = Positive)	+

Source: Authors' compilation (2022).

where $Awareness_{jk}$ represents the jth farmer's awareness about the kth desert locust control method, $Awareness_{jk} = 1$ if the farmer was aware and 0 otherwise, φ_k are unknown parameters to be estimated, and ε_{jk} is the error term assumed to be normally distributed. In the second stage, the following MVP (Equation 5) was fitted:

$$\begin{aligned} Z_{jk} = {} & \beta_0 + \beta_1 Age + \beta_2 Farmingexp + \beta_3 Educationyears + \\ & \beta_4 TLU + \beta_5 Location + \beta_6 Droughtshock + \\ & \beta_7 Pestordiseaseshock + \beta_8 Groupmembership + \\ & \beta_9 Saleofcroporlivestock + \beta_{10} Formalsources + \\ & \beta_{11} Informalsources + \beta_{12} Perceptionindex + \delta_{jk} \end{aligned} \quad (5)$$

where Z_{jk} represents the jth farmer's decision to adopt the kth desert locust control method, 1 = hitting objects; 2 = lighting fire; 3 = burying with soil; 4 = Avoiding invaded areas; 5 = on-farm spraying.

2.5 Definition of variables and expected signs

Table 1 describes the explanatory variables used in MVP analysis and their expected signs. The choice of explanatory variables was informed by previous studies. Gender has been positively associated with the adoption of pest or disease control technologies (Nzuma and Mzera, 2023). Age is positively associated with the adoption of pest or disease control technologies; studies have found adoption to increase with age (Anang et al., 2021; Ateka et al., 2021). Households with more farming experience are more likely to adopt pest or disease control technologies (Miyittah et al., 2022). Households with more years of education have been found to likely adopt pest or disease control technologies (Owusu and Skevas, 2024). Households with large herd sizes, expressed in terms of tropical livestock units (TLUs), are more likely to adopt pest or disease control technologies (Musungu et al., 2021; Weyori, 2021). Household location reflects the geographical context in terms of pest management. Considering that desert locusts affect different locations; it was hypothesized that location would either positively or negatively influence the adoption of desert locust control methods.

Tambo et al. (2020) reported that previous experience with pest and disease shocks improved adoption of FAW management practices. It was therefore expected to be positively related to the adoption of desert locust control methods. Groups as key social networks provide an avenue for learning and increase the likelihood of uptake of control technologies (Ma et al., 2023; Mwenda et al., 2023; Tham et al., 2023).

Pests and diseases pose a major threat to livelihood incomes, and households engaged in commercial crop or livestock production are more likely to adopt alternatives to chemical control (Chelanga et al., 2023). It was hypothesized that households engaged in commercial agricultural production would adopt desert locust control methods.

Access to information from formal sources such as extension services has been positively linked with the adoption of pest control technologies (Ipara et al., 2021; Tambo et al., 2023; Adjei et al., 2024). Tham et al. (2023) highlighted the importance of including modern and indigenous communication channels in increasing the adoption of pest control technologies. It was therefore expected that informal sources of information (information sharing among community members) would positively influence the adoption of desert locust control methods.

Both structural equation modeling (SEM) and principal component analysis (PCA) are techniques for dimensionality reduction, but they serve distinct purposes. The PCA is primarily a descriptive method that simplifies data by identifying principal components, linear combinations of variables that capture the maximum variance within a dataset (Jolliffe and Cadima, 2016). In contrast, SEM goes beyond data reduction by simultaneously modeling relationships between observed and latent variables and examining causal pathways (Mishra et al., 2024). While PCA focuses on summarizing data patterns, SEM incorporates theoretical frameworks to test both direct and indirect relationships between variables, making it a more complex and theory-driven approach.

The SEM is widely used in studies examining behavioral patterns and the adoption of new technologies, often guided by frameworks

TABLE 2 Summary statistics of desert locust control methods adopters and non-adopters.

Variables	Adopters	Non-adopters	Pooled
	n = 411	*n* = 62	*n* = 473
Household characteristics			
Gender (1 = Male)	84% (36.76)	82% (38.51)	84% (36.96)
Age Category (1 = Below 35 years)	27% (44.7)	27% (44.97)	27% (44.69)
Farming experience (Years)	13.02 (8.21)	12.06 (6.70)	12.89 (8.02)
Formal education (Years)	8.50 (4.60)	8.89 (4.12)	8.55 (4.54)
TLU (Units)	12.30 (24.62)	5.40 (10.80)	11.40*** (23.39)
Location (1 = Meru)	47% (49.98)	61% (49.11)	49%** (50.04)
Shocks experienced			
Drought shock (1 = Yes)	81% (39.26)	74% (44.11)	80% (39.95)
Pest/disease shock (1 = Yes)	67% (47.20)	79% (41.04)	68%** (46.58)
Institutional characteristics			
Group membership (1 = Yes)	53% (49.95)	50% (50.41)	53% (49.97)
Sale of crop/livestock (1 = Yes)	83% (37.85)	73% (44.97)	81%* (38.96)
Access to DL Information (1 = Formal sources)	28% (44.95)	39% (49.11)	29%* (45.60)
Access to DL Information (1 = Informal sources)	32% (46.56)	27% (44.97)	31% (46.33)
Perception attribute			
Perception Rank (1 = Positive)	39% (48.87)	26% (44.11)	37%*** (48.44)

TLU – Tropical Livestock Units computed as: cattle = 1, camels = 1, donkeys = 0.8, goats and sheep = 0.2 and poultry = 0.04 (WISP, 2010). DL – Desert locust information. Asterisks indicate statistically significant variables at: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Standard deviations are in parentheses. Source: Authors' own computation based on field data (2022).

like the technology acceptance model (TAM) (Ejigu and Yeshitela, 2024; Forouzani et al., 2024). While SEM and path analysis are advanced techniques for assessing factors influencing farmer behavior, they require data on sequential constructs such as awareness, interest, desire and action (AIDA) that predict human behavior over time; such data were not available in our case. In contrast, the current study examined how perception, as a single construct (Filmer and Pritchett, 2001; Olana et al., 2023), affects the adoption of integrated desert locust management methods. To do this, PCA is used to create a perception index, which is then applied in subsequent analyses as a simplified representation of perception. Following Okello et al. (2021), the PCA method was used to reduce the 15 statements (Supplementary Table 1) to derive a perception index. This was specified as Equation 6:

$$P_m = \sum_{m=1}^{n} c_n \left(d_{mn} - d_n\right) / s_n \tag{6}$$

where P_m is the perception index for the mth farmer, c_n is the weight or factor loading of the nth perception statement, d_{mn} is the response of the mth farmer for the nth perception statement, d_n, and s_n are the mean and standard deviation of the nth perception statement, respectively. The derived perception index was categorized as a binary variable, where a household either has positive perceptions or otherwise. It has been shown that households with favorable or positive perceptions toward pest or disease control methods are more likely to adopt them (Misango et al., 2022; Bryant et al., 2024). It was therefore expected that positive perceptions toward desert locust management would increase the adoption of control methods.

Prior to fitting the empirical models, multicollinearity was tested using the variance inflation factor (VIF) approach. The results revealed no multicollinearity, as all values were below 10 (Gujarati and Porter, 2009). The "hetprobit" command was used to test for heteroskedasticity. The null hypothesis of homoskedasticity was not rejected [chi2(6) = 0.17, $p = 0.99$], implying that the error terms had constant variance. Potential selection bias was controlled using awareness as a dependent variable in the selection Equation 4 and incorporated into Equation 5 using the CMP command in Stata version 15.

3 Results

3.1 Summary statistics

3.1.1 Descriptive results

Table 2 presents the summary statistics of the variables that were considered. The majority of households in the sample were male headed, with an average head age of 44 years and approximately 13 years of farming experience. Households reported an average of 9 years of formal education. Households that adopted desert locust control methods owned more livestock units on average (12) than non-adopters (5). Adoption rates were slightly higher in Isiolo (53%) compared to Meru (47%), indicating regional differences in control method uptake.

Over 60% of households that had been affected by pests or diseases in previous agricultural production cycles adopted desert locust control methods. Slightly over 80% of households engaged in the sale of crop produce, livestock, and related products adopted desert locust control methods. Nearly 50% of the households were in farmer groups. Access to desert locust information from both formal and informal sources was low, at 29 and 31%, respectively (Table 2). Over 30% of the households had positive perceptions of desert locust management; the percentage of adopters (39%) was higher compared to non-adopters (26%).

3.1.2 Control methods applied by households

Figure 3 depicts the control methods applied by the sampled households. Among the 473 households surveyed, 87% adopted at least one desert locust control method, while 13% did not use any. The most common method, employed by 86% of households, involved making noise by hitting objects to scare away the locusts. Additionally, over half of the households used fire by burning grass, dried leaves, or branches as a control strategy. Slightly more than 30% managed the locusts by burying hopper bands (immature, wingless locusts) with soil. Avoiding locust-infested areas, especially for livestock grazing, was practiced by 21% of households. Furthermore, only 12% used pesticides originally intended for other farm pests as a control measure against desert locust invasions.

3.2 Interrelationships among the desert locust control methods

Table 3 presents the results on the substitutability and complementarities of desert locust control methods. The correlation coefficients between desert locust control methods were positive and significant, except for the correlation between avoiding invaded areas and lighting fire, leading to the conclusion that the control methods used by farmers are complementary and not substitutes.

3.3 Awareness and adoption of desert locust control methods

Table 4 presents the probit regression results of the selection equation (awareness) and the MVP regression (outcome equation) results of the factors influencing the adoption of desert locust control methods. The Wald Chi-square (χ^2 = 219.25, ρ= 0.000) for the goodness of fit model is significant at the 1% level, justifying the use of a multivariate probit model for analysis (Table 4). The values of the "*atanhrhos*" (test of correlation among residuals) were significant (Supplementary Table 2), implying the presence of selection bias in the adoption of desert locust control methods. This necessitated the need for corrective measures by applying a corrected MVP model to account for selection bias (Bwiza et al., 2024).

3.3.1 Factors influencing awareness of desert locust control methods

The results from the selection equation showed that farming experience, group membership, and access to information from informal sources positively influenced awareness of desert locust management. Experienced farmers were more likely to be aware of desert locust control methods. Group membership was associated with increased awareness, while access to informal sources of information increased awareness of desert locust control methods.

3.3.2 Factors influencing the adoption of desert locust control methods

An analysis of the MVP model (outcome equation) showed that household characteristics had mixed effects on the adoption of desert locust control methods. Male household members were less likely to adopt hitting objects as a control method. Years of formal schooling had a positive and significant effect on lighting fires and on-farm spraying as a control method (Table 4). Households with larger herd sizes (TLUs) were more likely to use burying with soil or avoid invaded areas as desert locust control measures.

The location of a household had mixed effects on the use of desert locust control methods. Households located in Meru were more likely to light fire and bury desert locusts with soil as control measures and less likely to avoid invaded areas.

The various shocks experienced by households positively influenced the adoption of desert locust control methods. Having

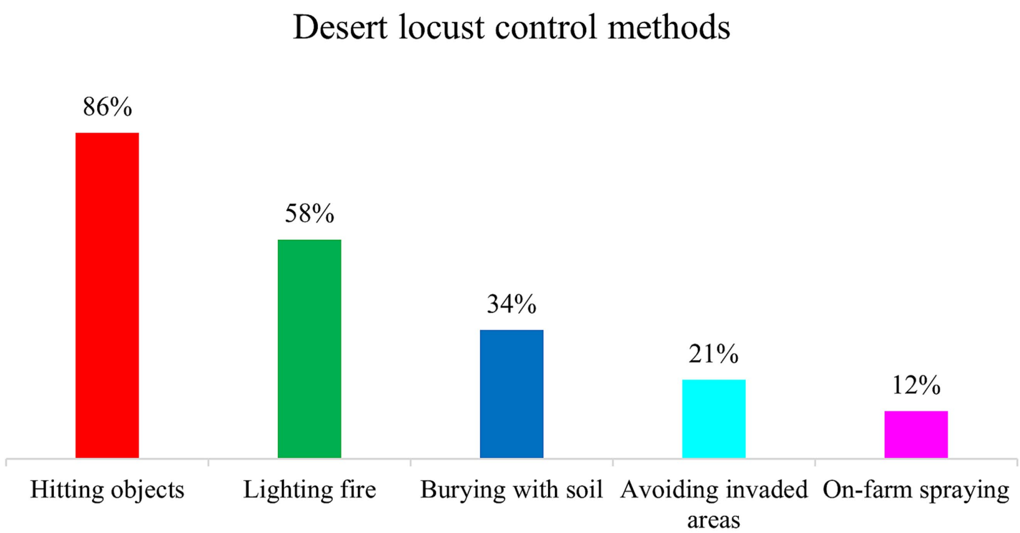

FIGURE 3
Control methods implemented by households. Source: Authors' own computation based on field data (2022).

TABLE 3 Correlation coefficients of desert locust control methods.

Control methods	Hitting objects	Lighting fire	Burying with soil	Avoiding invaded areas	On-farm spraying
Hitting objects	1				
Lighting fire	0.44*** (0.00)	1			
Burying with soil	0.29*** (0.00)	0.47*** (0.00)	1		
Avoiding invaded areas	0.19*** (0.00)	−0.04 (−0.41)	0.19*** (0.00)	1	
On-farm spraying	0.12** (0.01)	0.21*** (0.00)	0.37*** (0.00)	0.34*** (0.00)	1

Asterisks indicate statistically significant variables at: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. p-values are in parentheses. Source: Authors' own computation based on field data (2022).

TABLE 4 MVP regression results on factors influencing the adoption of interrelated desert locust control methods.

Desert locust control methods						Selection equation
	Hitting objects	Lighting fire	Burying with soil	Avoiding invaded areas	On-farm spraying	Awareness
Variables	Coeff	Coeff	Coeff	Coeff	Coeff	Coeff
Household characteristics						
Gender (1 = male)	−0.07**(0.03)	0.13(0.16)	0.02(0.15)	−0.18(0.19)	0.18(0.21)	0.19(0.21)
Age of household (1 = Below 35)	0.01(0.03)	0.06(0.15)	0.20(0.14)	0.09(0.16)	0.28(0.19)	
Farming experience (years)	−0.00(0.00)	0.01(0.01)	0.00(0.01)	−0.01(0.01)	0.01(0.01)	0.02***(0.01)
Formal education (years)	−0.00(0.00)	0.03**(0.01)	0.01(0.01)	0.01(0.02)	0.08***(0.02)	
Tropical livestock units	0.00(0.00)	−0.00(0.00)	0.01**(0.00)	0.01**(0.00)	0.00(0.00)	
Location (1 = Meru)	−0.05(0.04)	0.74***(0.20)	0.79***(0.21)	−0.91***(0.21)	−0.01(0.20)	
Shocks experienced						
Drought shock (1 = Yes)	−0.01(0.04)	1.04***(0.20)	0.42**(0.18)	−0.16(0.19)	0.56**(0.24)	0.26(0.20)
Pest/disease shock (1 = Yes)	−0.04(0.03)	−0.17(0.14)	0.17(0.15)	0.40**(0.18)	0.55**(0.21)	−0.16(0.18)
Institutional characteristics						
Group membership (1 = Yes)	0.01(0.03)	0.32**(0.15)	0.18(0.14)	0.37**(0.16)	0.41**(0.17)	0.36**(0.17)
Sale of crop/livestock (1 = Yes)	0.10**(0.04)	0.30*(0.16)	0.24(0.16)	0.52**(0.22)	0.17(0.21)	
Access to desert locust Information (1 = Formal sources)	−0.01(0.03)	0.12(0.16)	−0.03(0.16)	0.19(0.17)	−0.13(0.19)	−0.04(0.19)
Access to desert locust Information (1 = Informal sources)	−0.01(0.03)	0.60***(0.16)	0.40***(0.15)	0.16(0.16)	−0.00(0.19)	0.54**(0.21)
Perception attribute						
Perception rank (1 = Positive)	0.02(0.03)	−0.12(0.12)	0.29**(0.13)	0.38***(0.14)	0.30**(0.15)	

Number of observations = 473; Log likelihood = −953.77; (72) = 219.25***. Asterisks indicate statistically significant variables at: *$p < 0.1$, **$p < 0.05$, ***$p < 0.01$. Robust standard errors are in parentheses. Source: Authors' own computation based on field data (2022).

experienced a drought shock was positively associated with adoption of lighting fire, burying with soil, and on-farm spraying as control methods. Furthermore, being affected by a previous pest or disease shock positively increased the adoption of burying and on-farm spraying as control methods (Table 4).

Institutional characteristics such as social networking and information sources influenced the adoption of desert locust control methods. Membership in a farmer group had a positive effect on the adoption of lighting fire, avoiding invaded areas, and on-farm spraying as control methods. Households that participated in the sale of crops or livestock produce were more likely to adopt desert locust control methods.

It had been hypothesized that access to information positively influences the adoption of desert locust control methods; however, results showed that access to formal sources of information (for instance, extension agents) had an insignificant effect. Conversely, access to desert locust information from informal sources, such as community members, positively influenced the adoption of lighting fire and burying desert locusts as control methods.

In conformity with expectations, positive perceptions of desert locust management had a significant positive influence on the use of burying, avoiding invaded areas, and on-farm spraying as control methods (Table 4).

4 Discussion

4.1 Summary statistics

The socio-economic characteristics of households significantly influence their adoption of desert locust control methods. Households with larger livestock holdings, for instance, were more inclined to adopt control strategies. Desert locust invasions severely impact pasture lands, diminishing feed availability for livestock and making control measures critical to reducing these losses (Landmann et al., 2023). Notably, a slightly higher percentage of households in Isiolo adopted control methods compared to those in Meru, likely due to Isiolo County experiencing more severe locust invasions (FAO, 2020e). Over 60% of households previously exposed to various pests and diseases were more likely to implement control measures, a rate surpassing the 45% adoption reported by Tambo et al. (2020). The low dissemination of desert locust information through both formal and informal channels likely reflects the inadequate locust management framework in place at the onset of the invasion (FAO, 2023). The most common desert locust control method was making noise by hitting objects, a finding that aligns with observations reported by FAO (2020e).

4.2 Awareness and adoption of desert locust control methods

4.2.1 Factors influencing awareness of desert locust control methods

Our findings indicate that farming experience, group membership, and access to information from informal sources positively influence awareness of desert locust control methods (Table 4). Experienced farmers were more likely to be aware of these methods, likely because prolonged exposure to agricultural cycles impacted by pests and diseases increases their motivation to adopt control measures to reduce losses (Kumar et al., 2023; Ngoya et al., 2023). Additionally, households involved in social groups and those with access to informal information channels were more likely to be aware of desert locust control methods, underscoring the role of farmer-based networks in spreading knowledge about pest management (Tham et al., 2023; Odong et al., 2024). While previous studies, such as Tambo et al. (2023) and Bryant et al. (2024), have emphasized the role of formal extension agencies in promoting pest control adoption, our findings suggest that informal sources are also valuable for disseminating information.

4.2.2 Factors influencing adoption of desert locust control methods

The results indicated that socio-economic and institutional factors had varied effects on the adoption of desert locust control methods. For instance, male farmers were less likely to use object-hitting as a control method. This finding contrasts with those of Okonya et al. (2021) and Mwadzingeni et al. (2022), who observed that men are generally more inclined to adopt pest control measures. The positive influence of years of formal schooling on the adoption of control methods like lighting fires and spraying aligns with findings by Owusu and Skevas (2024).

Our findings established a positive correlation between livestock ownership and the adoption of control methods such as burying hopper bands with soil and avoiding invaded areas. A plausible explanation for this is that desert locust invasions devastated grazing lands, leading to forage loss. Consequently, households sought alternative grazing areas and either trampled or buried hopper bands (immature wingless locusts) as a control strategy. This finding reinforces the results of Musungu et al. (2021), who identified a positive relationship between herd size (measured in Tropical Livestock Units) and the practice of avoiding invaded areas as a control measure against tsetse fly invasions.

Based on location, cropping farmers in Meru County were less likely to avoid invaded areas as control method compared to pastoralists in Isiolo County. Desert locust invasions affected pasture availability, causing livestock farmers to seek alternative grazing land (FSNWG, 2021). This finding concurs with Durocher et al. (2023) and Keyser et al. (2024) who emphasized the consideration of social and ecological conditions as important aspects of effective pest management.

Previous exposure to shocks, such as droughts or pest-related incidents, has been shown to enhance the adoption of desert locust control methods such as chemical spraying. A plausible explanation for this finding is that, over time, increased exposure to these shocks compels farmers to invest in or seek out resilience-building interventions (Freudenreich and Kebede, 2022; Ahvo et al., 2023). In this context, they may adopt various strategies to mitigate the damage caused by desert locusts. However, this finding contrasts with Tambo et al. (2020), who reported a negative relationship between climate shocks and the adoption of spraying as a pest control method.

The positive effect of group membership on the adoption of desert locust control measures underscores the significance of social networks as channels for learning and the dissemination of technologies or ideas (Maina et al., 2024). Similarly, findings by Ma et al. (2023) and Mwenda et al. (2023) emphasize the role of group participation in promoting collaborative pest and disease control efforts. Agriculture serves as a vital source of income for many households, particularly those engaged in commercial farming. These households are more likely to adopt desert locust control methods, which is crucial for reducing losses and enhancing market output (Stetkiewicz et al., 2022; Chelanga et al., 2023).

A surprising finding was the insignificant effect of access to formal sources of information on the adoption of desert locust control methods. One possible explanation is that, during the invasion period, relevant agencies at both the national and county levels lacked sufficient resources and capacity to address the rapid spread of desert locusts and establish effective early response mechanisms for disseminating information (FAO, 2022; MoALF, FAO, and World Bank, 2022; Anjita and Indu, 2023). This result stands in contrast to findings by Nzuma and Mzera (2023), Tambo et al. (2023), and Adjei et al. (2024), who emphasized the critical role of extension services in promoting the adoption of pest and disease management methods.

Conversely, access to information from informal sources had a positive effect on the adoption of desert locust control methods. This finding can be attributed to two main factors. First, during the initial stages of the desert locust invasions, community members relied on one another to share knowledge about indigenous control methods, especially given the limited contact with extension services (FAO, 2020e). Second, as the invasion progressed, trained community members actively disseminated information about both formal and indigenous control measures. These findings underscore the significance of informal networks in facilitating the adoption of pest management technologies (Kabirigi et al., 2022). This aligns with Tham et al. (2023), who also emphasized the crucial role of informal networks in improving the management of fall armyworm (FAW).

We identified a link between positive perceptions and the adoption of interrelated desert locust control methods. Farmers' psychological constructs significantly influence their perceptions of specific technologies or policy-related issues (Sok et al., 2021; Lumumba et al., 2024). This finding aligns with the research of Bryant et al. (2024), and Xu and Kong (2024), which emphasized the importance of considering perceptions in the development and adoption of Integrated Pest Management (IPM) strategies.

5 Conclusion and recommendations

Desert locust invasions cause devastating effects on both agricultural production and livelihood incomes, necessitating the need for control. Though formal control, mainly through spraying, is effective, it negatively affects human health and the environment. There have been increased calls for IDLM, an approach that combines surveillance, formal control through rational use of chemicals and biological control, and the inclusion of indigenous control methods. To date, at the farm level, there is limited information on the drivers of the adoption of desert locust control methods.

Understanding these driving factors is important for targeted responses to effective IDLM. This study aimed to fill this gap in knowledge by including additional factors such as shocks and perceptions. An MVP model corrected for sample selection was fitted.

This study found that the indigenous control methods used by farmers are complementary, suggesting that farmers combine methods rather than substituting one for another. This complementarity implies that the effectiveness of any single control method can be enhanced by the concurrent adoption of others. Therefore, future interventions for desert locust control should integrate both formal and indigenous methods to mitigate agricultural income losses and improve food security. Achieving this integration will require addressing key socio-economic and institutional factors that influence the adoption of these diverse control strategies.

For instance, the significant influence of education, access to information, and social networks underscores the importance of designing policy interventions that recognize farmers as essential stakeholders. Educating farmers on the identification and effective management of desert locust invasions at the farm level is crucial. Additionally, the study highlighted the critical role of informal social networks in disseminating information about desert locust management and the application of various control methods. This finding suggests that farmer and community groups should be actively involved in integrated desert locust management. Leveraging these groups as entry points for training on locust management offers a practical approach, as large-scale locust invasions affect farms and households collectively.

Moreover, the adoption of complementary indigenous desert locust control methods is likely influenced by farmers' prior experiences with climate-related and pest or disease shocks. This points to the need for enhanced early warning systems that utilize technology to monitor and control desert locust populations before they invade farms or grazing lands. Such proactive measures could strengthen resilience, ultimately reducing agricultural losses and food insecurity. Additionally, given the critical role of farmers' perceptions in adopting locust control methods, it is essential to integrate their perspectives into the formulation of integrated management plans. This can be achieved by conducting consultative workshops or discussion sessions, ensuring that farmers' insights inform policy and intervention strategies.

Although our study offers valuable insights, it was conducted in a few desert locust breeding locations, which may limit the generalizability of the findings. Additionally, a further limitation of the study lies in its focus on both chemical and indigenous control methods, which may not fully represent the broader spectrum of control strategies employed in different regions or contexts.

Future research could build upon these findings and expand the understanding of desert locust control in ways that were beyond the scope of this study. First, future studies could improve the sampling design by including households located in many diverse desert locust breeding areas. Second, they could assess the effectiveness of biological control methods. Finally, future studies could examine the impact of adopting desert locust control methods on mitigating losses related to household incomes and food security.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving humans were approved by the National Commission for Science, Technology and Innovation. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

BL: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Validation, Writing – original draft, Writing – review & editing. DO: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – review & editing. RN: Conceptualization, Investigation, Methodology, Supervision, Validation, Writing – review & editing.

Funding

The author(s) declare that financial support was received for the research and/or publication of this article. This research was partially funded by the African Economic Research Consortium (AERC) and the German Academic Exchange Service (DAAD) through their Ph.D. Scholarship Award to the first author (Grant Award Number 1430: DAAD Reference No: 91789300).

Acknowledgments

The authors would like to thank enumerators who participated in data collection as well as farmers for providing valuable information.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The author(s) declare that no Gen AI was used in the creation of this manuscript.

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Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2025.1518276/full#supplementary-material

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