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Integration of Tsetse Fly and Trypanosomiasis Control Methods From Livestock Farmers' Perspective: A Multivariate Probit Approach

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Abstract

Integration of tsetse fly and trypanosomiasis control methods is identified as most feasible and effective approach to eradication of African Animal Trypanosomiasis (AAT) and Human African Trypanosomiasis (HAT). However, little focus is directed towards understanding the drivers of integration of the control methods by farmers. We used cross-sectional data collected from 536 livestock keeping households in Lamu County of Kenya to identify factors influencing multiple use of insecticide treated livestock (ITL), insecticide treated targets (ITT), and treatment with trypanocidal drugs (TTD). Multivariate probit model was applied in estimation of covariates of multiple use of the control methods. Descriptive results indicated that nearly 61% of the livestock keeping households used at least one of the tsetse fly and trypanosomiasis control methods, with about 9%, 7%, and 13% of the households using ITL, ITT, and TTD, respectively. The results also indicated that nearly 32% of the households integrated the control methods. Furthermore, multivariate probit results showed that sex of household head, age of farmer, positive perceptions of technology availability and effectiveness, and off-farm income increased the likelihood of integration. In contrast, household size, having agriculture as the main occupation, and cost of the technology significantly reduced the likelihood of multiple use of the control methods. The results suggest heterogeneity in farmers' decisions to integrate tsetse fly and trypanosomiasis control methods. Therefore, farmer outreach programs should consider key household characteristics, as well as technological attributes which may stimulate adoption of appropriate tsetse fly and trypanosomiasis control technologies.

Keywords: control method, farmers, tsetse fly

1. Introduction

Tsetse fly is an important insect in Africa, with negative implication on livestock and human health and welfare. There are 23 species and sub species of tsetse fly out of which two namely *Glossina pallidipes* Austen, 1903 and *Glossina austeni* Newstead, 1912 (Diptera: Glossinidae) are found in the Coastal region of Kenya. The blood-sucking insect transmits trypanosomes that cause sleeping sickness, also known as Human African Trypanosomiasis (HAT), in humans. Trypanosomes also cause *nagana*, known as African Animal Trypanosomiasis (AAT) in livestock (Saarman et al., 2018). The most affected livestock are cattle, goats, sheep, and donkey. Thirty-seven countries in Africa are affected by the fly, with the problem being endemic in thirty-six of them (MacMillan, 2020). Besides its negative effect on human health, the fly is also a major livestock production constraint. Recent estimates indicate that AAT results in annual livestock production losses of five billion dollars (Vreysen et al., 2013; Shaw et al., 2014). The losses occur directly through death of animals and their products and indirectly though reduction in productivity and values of animals and animal products (Morrison et al., 2016; Olaide et al., 2019). Tsetse fly also affect where people settle, interfering with intensity and diversity of crop and livestock enterprises (Ilemobade, 2009). The net effect of the losses is the stagnated contribution of livestock production to reduction of food insecurity and poverty.

In efforts to combat the tsetse fly, the African Union established the Pan African Tsetse and Trypanosomiasis Eradication Campaign (PATTEC) program to lead multinational interventions aimed at controlling AAT and HAT (Schofield & Kabaye, 2008). For over two decades, PATTEC has worked in partnership with national governments towards creation of a tsetse free region. The campaign was also a consensus to overcome tsetse fly burden in a more feasible way (Peck & Bouyer, 2012). With grants from African Development Bank, the program has been launched in several countries in Africa over the last one-and-half decades. Kenya is one of the beneficiary countries in East Africa.

In Kenya, tsetse fly is spread across 38 out of 47 counties, covering an estimated land area of 138 thousand square kilometres (Mureithi, 2020). The tsetse fly is prevalent in the Coastal, Lake Victoria, Central and South Rift, and North-Eastern regions. According to the most recent statistics, tsetse fly and AAT are responsible for about 2-million-dollar livestock production losses in the country (Mureithi, 2020). Besides, the risk of HAT is still high in most tsetse fly infested counties. To underline the seriousness of the fly in Kenya, the Kenya Tsetse and Trypanosomiasis Eradication Council (KENTTEC) was established as a public body responsible for the control and eradication of the fly in the country. This is an indication of the importance of the fly to livestock and human health in the country.

1.1 Tsetse Fly and Trypanosomiasis Control Methods

There are several tsetse fly control methods. Traditional tsetse fly control methods include bush burning, smoke, and livestock enclosures (Torr et al., 20011). Among integrated tsetse and trypanosomiasis control methods promoted by PATTEC include stationary baits (insecticide treated targets (ITT)), mobile targets (insecticide treated livestock (ITL)), aerial spraying and Sequential Aerosol Technique (SIT), and trypanocidal drugs (Shaw et al., 2013). ITL are sometimes baited with attractants. Besides controlling tsetse fly, ITL also eradicate ticks and other vectors. On the other hand, trypanocidal drugs are administered in doses for control of AAT. The integrated methods complement each other for effective control of insects (Bouyer et al., 2011). Additionally, they are meant to replace the unsustainable traditional control methods.

The promotion of integrated methods of tsetse fly and trypanosomiasis control was piloted in the coastal tsetse fly belt of Kenya, which is one of the regions with endemic burden of the insect (Mureithi, 2020). Specifically, PATTEC and KENTTEC collaborated to implement the tsetse fly eradication project in 2010 in Lamu County, with a focus on upscaling uptake of ITT, ITL and TTD in the larger coastal counties. Despite the efforts, tsetse fly problem still persists. This notwithstanding, there is limited understanding of the factors that led to differentiated patterns in uptake of the control methods.

Technology adoption studies identify several factors that underline farmers' decision to use a given practice. Guided by random utility theory, studies have demonstrated that household and farm characteristics, profitability, institutional environment, labour supply, and risk and uncertainty perceptions are important drivers of technology adoption (Gedikoglu & McCann, 2012). The random utility model postulates that farmers are profit-oriented and will choose technology that yields maximum returns. Nevertheless, most livestock technology adoption studies ignore that farmers are guided by multiple goals that sometimes may conflict (Gedikoglu & McCann, 2012). Consequently, they may adopt multiple tsetse fly and trypanosomiasis control methods to meet a broader set of goals. To this end, limited information is available about drivers of integration of tsetse fly and trypanosomiasis control methods in Lamu County.

Given above-mentioned background, the objective of this study is to determine factors that influence multiple uptake of tsetse fly and trypanosomiasis control methods in Lamu County. Results from this study will guide livestock policy by identifying needed policy interventions with a high potential of encouraging large-scale integration of the tsetse fly and trypanosomiasis control methods. Since farmers in Lamu County use several traditional tsetse fly control methods, the study focused on integration of ITT, ITL, and TTD.

2. Methodology

2.1 Study Area

The study was conducted in Lamu County. Lamu County is one of the six counties in the coastal region of Kenya. The study area is along the 800 kilometre coastal border with the Indian Ocean that is heavily infested with *G. pallidipes* and *G. austeni* species of tsetse fly. Lamu was purposively selected because it hosted the PATTEC and KENTTEC integrated tsetse fly and trypanosomiasis eradication project that commenced in Pate Island in 2010. Livestock production is one of the main economic activities in the county alongside the much lucrative tourism and fishing industries. Rainfall is bimodal, with long rainy and short rainy seasons being experienced between

April and June and November and December, respectively. Cattle, goats, sheep, and donkey are dominant types of livestock in Lamu County.

2.2 Research Design

The study employed quantitative research design. Particularly, a quasi-experimental research design was used where cross-sectional data was collected from users and non-users of tsetse fly and trypanosomiasis control methods. Cross-sectional data were collected and analysed quantitatively to uncover statistical causal relationships between variables. The study used quantitative research design because it was an exploration of status of integration of tsetse fly and trypanosomiasis control methods.

2.3 Sampling Design and Sample Size Determination

The target population were livestock keeping households in Lamu East and Lamu West Sub-Counties. The Sub-Counties were purposively selected. Lamu East was purposively selected because it was a pilot site (Pate Island) for the implementation of the integrated tsetse fly and trypanosomiasis control project. On the other hand, Lamu West was selected because its socioeconomic and institutional characteristics are comparable to those in Lamu East.

Multi-stage sampling procedure was applied. First, Lamu County was stratified into Lamu East and Lamu West. Lamu East had eight administrative locations, namely Kwatini, Kwatongani, Pate, Siyu, Shanga, Tchundwa, Kizingitini, and Myabogi. Lamu West had Hindi, Bargoni, Mokowe, Kilimani, Matondoni, Kipungani, and Manda as administrative units. The number of livestock keeping households varied by administrative units. Therefore, a systematic proportional random sampling method was used to select households from each administrative unit. The village roads were used as transects along which proportional samples were systematically drawn. The first household along each transect was randomly selected. Systematic random sampling was then applied, which involved selection of household after every fifth household. A total of 536 households were sampled and interviewed; 254 in Lamu East and 282 in Lamu West.

2.4 Data Collection

The data were collected using a pre-tested semi-structured questionnaire. The data collected were farm level information, including farm size, livestock inventory, input use, and application of tsetse fly and trypanosomiasis control methods. Household socioeconomic characteristics and institutional factors were also captured.

2.5 Analytical Framework

The data were analysed using both descriptive and regression analyses. Averages and proportions were used to analyse continuous and categorical variables, respectively. The analysis of variance (ANOVA) and the Pearson Chi-square test of proportions were used to test statistical differences of variables of interest. The multivariate probit (MVP) regression model was applied to analyse the determinants of multiple use of tsetse fly and trypanosomiasis control methods.

Household decision to use tsetse fly control methods is a qualitative variable because the livestock farmer has a choice of either using or not using. This observation implies that qualitative regression model would be appropriate in testing the effects of socioeconomic characteristics, institutional and farm factors, and farmers' perceptions on choices of the practices. Therefore, the dependent variable is coded one (1) if the farmer chooses to use the practice and zero (0) when the farmer chooses not to use the practices. The coding suggests that the dependent variable is dichotomous because of equal chances of either using or not using. Although both probit and logit models are appropriate when estimating dichotomous dependent variables, the former was used because it yields consistent parameter estimates and standard errors than the latter (Wooldridge, 2006).

Nonetheless, the choice of probit model is not sufficient in answering the research question. Since the focus of the study was to obtain coefficient estimates for each of the three tsetse fly and trypanosomiasis control methods, several probits are supposed to be run. However, Greene (2003) indicated that running univariate probit for each individual household would produce results that suffer from endogeneity problem due to correlation of the error terms. The MVP overcomes the endogeneity problem that may arise due to farmers' decisions of using more than one control method. In other words, MVP allows interdependencies in the probability of farmers' using more than one practice. Following Assa et al. (2014) and Mullahy (2016), the general MVP equation is written as:

$$y_{im}* = \beta'_m X_{im} + \varepsilon_{im}\ ,\ m = 1,\ \ldots\ 4 \tag{1}$$

$$y_{im} = 1 \text{ if } y_{im}* > 0,\ 0 \text{ otherwise} \tag{2}$$

where, $y_{im}*$ are unobservable latent variable choices of tsetse fly and trypanosomiasis disease control methods by a farmer, X is a vector of explanatory variables that influence choice of the control methods, β is a vector of parameters to be estimated, and $\varepsilon_{im}, m = 1, \ldots 3$ are multivariate error terms that are normally distributed.

The MVP is fitted using simulated maximum likelihood estimation. The implicit functional form of the model was specified as follows:

$$\begin{aligned} ControlMethods_{1,2,3} &= \beta_0 + \beta_1 GenderHHH + \beta_2 SizeHH + \beta_3 Age + \beta_4 Education \\ &+ \beta_5 OccupationHHH + \beta_6 TLU + \beta_7 Landacreage + \beta_8 AccessCredit + \beta_9 DistMarket \\ &+ \beta_{10} Extension + \beta_{11} GroupMembership + \beta_{12} TechAvail + \beta_{13} TechUse + \beta_{14} TechCost \\ &+ \beta_{15} TechEffectiveness + \beta_{16} OffFarincome + \beta_{17} Location + \varepsilon \end{aligned} \quad (3)$$

where, $ControlMethods_{1,2,3}$ is a set of tsetse and trypanosomiasis control methods to choose. The possible choices in the set include insecticide treated livestock (ITL), which entails use of insecticide to spray, dip or apply pour-on to livestock. The second control method is insecticide treated targets (ITT), which involves using insecticide treated clothes fitted with metal frames attracting and killing tsetse flies on contact. The last control method in the set is treatment with trypanocidal drugs (TTD). *GenderHHH* is the gender of the household head, *SizeHH* is the size of the household, *Age* is age of the household head in years, *Education* is number of years of schooling of the household head, *OccupationHHH* is farming as the main occupation of the household head, *TLU* is the tropical livestock units including total number of cattle, sheep, goats and donkeys, *Landacreage* is the total land in acres owned by a household, *AccessCredit* is household access to credit facilities, *DistMarket* is the distance of the household to nearest market, *Extension* is availability of extension services, *GroupMembership* is household membership to a group, *TechAvail* is the availability of technology to the household, *TechUse* is ease of use of the technology, *TechCost* is cost of the technology, *TechEffectiveness* is the perception of the household about effectiveness of the technology, *OffFarincome* is off-farm income of the household, *Location* is the sub-county where the household is located, $\beta_i \ldots \beta_{17}$ are the parameters to be estimated and ε is the error term.

3. Results and Discussion

The results in Table 1 show that nearly 39% of the households were non-users of the integrated tsetse fly and trypanosomiasis control methods, with 29% and 48% of them being located in Lamu East and Lamu West, respectively. However, non-use of the integrated control methods does not imply that the households did not control the insects. Instead, the use of traditional methods is common in both counties. Of the 61% users, about 9% of them used ITL to control tsetse fly. The highest proportion of ITL users were in Lamu West Sub-County. The ITT was the least used control method (7%), with nearly about 15% of livestock farmers using it in Lamu East Sub-County and none in Lamu West Sub-county. This is attributed to the fact that the promotion of the practice by PATTEC mainly concentrated in Pate Island in Lamu East. Additionally, even though ITT is available in Lamu East, livestock keeping households have to walk longer distances to access the grazing fields and thickets where the technology was deployed. In contrast, TTD is the most widely used single practice. Pooled results indicate 13% of the livestock keepers used TTD, with all of them located in Lamu West (nearly one-quarter of the sampled households in the Sub-County). Test statistics presented in Table 1 show that except for ITL, the proportions of households that used TTD and ITT differed significantly by location.

Table 1. Status of use of tsetse fly and trypanosomiasis control methods

Control Methods	Overall (N = 536)		Location		χ^2
			Lamu East (n = 254)	Lamu West (n = 282)	
	n	*Proportion (%)*	*Proportion (%)*	*Proportion (%)*	
Non-users	208	38.81	29.13	47.52	19.019***
ITL	46	8.58	5.12	11.70	0.895
ITT	37	6.90	14.57	0.00	52.612***
TTD	71	13.25	0.00	25.18	34.378***
ITL & TTD	44	8.21	0.00	15.60	22.162***
ITL, ITT & TTD	130	24.25	51.18	0.00	138.762***

Note. *** denotes significance at 1%.

Furthermore, about 32% of users integrated the control methods. About 8% (16% of the livestock farmers in Lamu West) integrated ITL and TTD. On the other hand, nearly one-quarter (24%) of the households (51% of the livestock keeping households in Lamu East) integrated the three methods. These finding suggests that farmers integrate the practices possibly to increase their effectiveness, for economic reasons, ease of use or their availability. This analogy is cross-validated by the results presented in Table 2.

3.1 Farmer Perceptions of Tsetse Fly Control Methods

As earlier stated, farmer perceptions of technologies influence their probability of using technology either singly or as combinations. Table 2 shows farmer perceptions of the attributes of the three promoted tsetse fly and trypanosomiasis control methods disaggregated by location. Pooled results indicate that higher proportion (76%) of farmers across the two Sub-Counties reported that ITL techniques were easy to use compared to about 44% and 71% for ITT and TTD, respectively. This could be because ITL is the most available (72%) control method for tsetse fly, ticks and other insect on-farm vectors than ITT (47%) and TTD (64%). Thus, farmers were possibly more experienced in using ITL than the other control methods, thereby, influencing their perception of ease of use. The low availability of ITT was due to the fact that it was being implemented mainly in Lamu East, while TTD and ITL were used across the two Sub-Counties. Nonetheless, ITL and TTD were considered as costly by farmers relative to ITT. Despite farmers considering ITL and TTD as costly, they affirmed that the practices are effective in the control of tsetse fly and trypanosomiasis, respectively. Sub-County comparison of the findings indicated significant differences in farmers' perceptions of the availability, ease of use, cost, and effectiveness of the control methods. Although causation cannot be called at this point, the significant differences in farmer perceptions suggest that they play an integral role in influencing uptake and integration of the practices.

Table 2. Perceptions of households on Tsetse and Trypanosomiasis control methods

Control Methods		Overall	Location		χ^2
			Lamu East (n = 254)	Lamu West (n = 282)	
		Proportion (%)	*Proportion (%)*	*Proportion (%)*	
Insecticide Treated Livestock (ITL)	Availability (High)	71.64	81.50	62.77	23.076***
	Ease of use (Easy)	75.75	84.25	68.09	19.012***
	Cost of Technology (High)	76.12	73.62	78.37	1.656
	Effectiveness (Yes)	80.78	91.73	70.92	37.280***
Insecticide Treated Targets (ITT)	Availability (High)	47.20	95.28	3.90	447.707***
	Ease of use (Easy)	44.78	94.49	0	482.501***
	Cost of Technology (High)	26.49	55.91	0	214.473***
	Effectiveness (Yes)	43.28	91.34	0	454.145***
Trypanocidal Drugs (TTD)	Availability (High)	64.56	47.24	80.14	63.205***
	Ease of use (Easy)	70.65	55.51	84.34	53.479***
	Cost of Technology (High)	77.80	66.93	87.59	33.022***
	Effectiveness (Yes)	76.49	62.29	82.98	13.923***

Note. *** denotes significance at 1% level.

3.2 Household Socio-economic Characteristics

Technology adoption studies explain that besides technology characteristics or attributes, socioeconomic characteristics also play a crucial role in not only determining uptake, but also level of uptake (Theriault et al., 2013; Borges & Lansink, 2015; Karanja-Lumumba et al., 2015; Mwaseba & Kigoda, 2017). Table 3 presents the socioeconomic characteristics of users and non-users of tsetse fly and trypanosomiasis control methods. The findings show users were older (38 years on average) than non-users (30 years). The level of integration of the technologies significantly differed with the age of the household head, with heads of users of ITL and combinations of the practices being older than users of TTD and ITT. The average household size was 6 persons, with non-using households and users of TTD and ITT having averagely 7 persons. The household size of users of ITL and combinations of the three practices was on average 6 persons, which was significantly lower than those of non-users and users of TTD and ITT.

Furthermore, results in Table 3 show that educational level of household heads significantly differed depending on the use status and level of integration. While users who integrated ITL and TTD had the highest level of education, ITL users had the lowest level of education (4.35 years) than even non-users (5.55 years). The difference in landholding by livestock keeping households differed significantly by use status. While ITT users owned on an average 11 acres of land, users who integrated ITL and TTD and all practices owned 3 acres of land.

This result was expected because ITT was promoted in Lamu East because of relative availability of grazing land. Surprisingly, non-users had higher annual household incomes ($3000) than users ($2396). However, the difference was marginally significant. On average, non-users owned 9.57 tropical livestock units, while users owned 6.81 units. Nonetheless, those households that combined ITL and TTD owned about 11 tropical livestock units, while TTD (5.53) and ITT (5.30) users had the least livestock ownership.

The description of categorical variables in Table 3 indicate that most (60%) of the livestock keeping households in Lamu were male-headed, with about 70% and 55% of non-users and users of tsetse fly and trypanosomiasis being male-headed. The results reveal that less than half of the households that integrated the practices were male-headed. Households that used TTD and ITL tended to be dominantly male-headed, while only 41% of the male-headed households used ITT. Over 60% of the households had agriculture as the main occupation. However, only 41% of the households that used ITT and those that integrated the three practices had agriculture as their main occupation. Furthermore, there were non-significant differences in access to credit between users and non-users, as well as among the different categories of users. Access to extension services significantly differed by use status, with over 71% of users of ITT, ITL and TTD, and all the practices reporting that they had access, respectively. In contrast, 65%, 55%, and 61% of non-users, TTD, and ITL had access to extension services, respectively. Nearly 55% of the households belonged to groups. Most households (58%) that adopted all practices lived less than 5 kilometres from the market centres. In comparison, only 41%, 46%, 52%, and 50% of TTD, ITT, ITL, and ITL and TTD homesteads were located within a radius of 5 kilometres from marketplace, respectively.

Table 3. Description of household characteristics

Variable	Mean/percentage							F/χ^2
	Pooled	Non-users	TTD	ITT	ITL	ITLTTD	All	
Continuous variables								
Age of HH head	38.32	30.83	39.00	42.59	44.15	44.61	44.52	41.85***
	(11.68)	(11.06)	(8.98)	(11.35)	(8.08)	(9.49)	(8.77)	
Household size	6.32	6.66	6.93	6.68	5.61	5.73	5.79	2.29**
	(3.40)	(3.92)	(3.44)	(3.63)	(2.59)	(2.50)	(2.77)	
Education HH head (years)	5.39	5.55	4.41	5.00	4.35	7.43	5.45	3.33***
	(4.38)	(4.31)	(4.14)	(4.80)	(3.85)	(4.16)	(4.10)	
Land size (acres)	4.35	4.29	4.39	11.03	4.76	2.59	2.99	2.13*
	(2.90)	(3.63)	(3.63)	(9.34)	(3.04)	(2.57)	(2.26)	
Household income ($)	2,632	3,005	2,153	2,399	1,912	2,062	2,812	2.18*
	(2581)	(2822)	(2042)	(1872)	(1888)	(1822)	(2599)	
Tropical livestock units	7.88	9.57	5.53	5.30	6.00	11.02	6.82	5.12***
	(8.94)	(9.85)	(5.08)	(4.11)	(6.14)	(14.31)	(7.75)	
Categorical variables								
Sex of Household Head (Male)	60.45	69.71	83.1	40.54	76.09	45.45	38.46	63.96***
Primary Occupation (Farming)	62.13	68.27	76.06	40.54	82.61	70.45	40.77	51.22***
Access to Credit (Yes)	23.32	25.96	18.31	8.11	17.39	27.27	26.92	8.83
Extension Services (yes)	68.28	64.9	54.93	89.19	60.87	72.73	76.15	19.70***
Group Membership (Yes)	55.24	53.85	50.7	56.76	41.3	61.36	63.08	8.30
Distance to Market (< 5 km)	55.04	61.54	40.85	45.95	52.17	50.00	57.69	11.54**

Note. Standard deviation in parenthesis; ***, ** and * denotes significance at 1%, 5% and 10% levels respectively.

3.3 Econometric Result

The MVP estimates of determinants of uptake of tsetse and trypanosomiasis control methods are presented in Table 4. The model performed multiple exclusion test of null hypothesis that all household socio-economic, farm, and institutional characteristics, as well as farmer perceptions of the technologies have no joint effect on choice of the technologies. The test statistic was statistically significant (χ^2 = 517.23; p = 0.000), implying that independent variables included in the MVP model jointly affect farmers' choices of using either single technologies or integrating them. Second, the likelihood ratio test was performed to test the independence of the error terms. The test results revealed that the error terms were interdependent (χ^2 = 136.294; p = 0.000). This results indicate that the probability of using one of the three tsetse fly and trypanosomiasis control methods is dependent on the use of another practice. Therefore, MVP was an appropriate estimator of the relationship between the decision to use the practices and the covariates included in the model. Furthermore, the estimates of the correlation between the regression error terms of TTD and ITL and between TTD and ITT are positive and significant, suggesting complementarities between TTD and the other control methods.

Age of the household head had a positive effect on the choice of all the three tsetse fly and trypanosomiasis control methods. These results indicate that older household heads would probably want to use more than one method of control as compared to young household heads. Probably, it could be argued that farmers gained knowledge through experiential learning of livestock farming and, therefore, had an understanding of the several available technologies. It is likely that the technologies are used singularly at different times or combined for effective results. These results are in line with those found by Karanja-Lumumba et al. (2015) that showed that older farmers were likely to adopt east coast fever vaccine compared to younger farmers. The results are, however, contrary to those by Mwaseba and Kigoda (2017) who found that more middle aged farmers accepted recommended tsetse control methods compared to older farmers. Although acceptance could be synonymous to uptake of control methods, the level of uptake, as well as combination of several methods, could be different. This argument validates the results of this study. The results show that off-farm income had a positive effect on choice of the three methods. As expected, off-farm activities are crucial sources of resources that finance investment in farm technologies. In the case of this study, tsetse fly and trypanosomiasis control technologies are cost intensive, particularly if a farmer has to purchase treatment drugs, insecticides or use of specialized gadgets for example insecticide treated targets and spray pumps. Therefore, it is likely that farmers who earn income from other activities can use part of it to obtain these technologies and equipment. These results corroborate those found by Theriault et al. (2013) that an increase in off-farm income has a positive influence on uptake of new technologies. Similarly, the results are in line with those found by Karanja-Lumumba et al. (2015) which indicated that off-farm income increased probability of up-taking east coast fever vaccine.

Table 4. Factors affecting choice and combination of Tsetse and Trypanosomiasis control methods

Control method	Insecticide treated livestock		Insecticide treated targets		Trypanocidal drugs	
	Coefficient	Std. Error	Coefficient	Std. Error	Coefficient	Std. Error
Sex of HH Head	0.372***	0.141	0.372**	0.174	0.186	0.135
Size of Household	-0.059***	0.019	-0.050*	0.028	-0.005	0.018
Age of HH Head	0.055***	0.006	0.048***	0.007	0.039***	0.006
Education of HHH	0.001	0.014	-0.013	0.022	-0.020	0.014
Occupation HHH	-0.020	0.142	-0.442***	0.166	-0.262*	0.148
TLU	0.012	0.008	-0.004	0.010	0.005	0.008
Land Acreage	-0.006	0.005	0.005	0.003	-0.013	0.010
Off-farm income	0.338***	0.088	0.622***	0.136	0.886***	0.100
Access to Credit	0.202	0.157	0.304	0.197	-0.023	0.158
Distance to Market	-0.006	0.128	0.153	0.173	0.206	0.127
Extension Services	-0.081	0.140	0.045	0.178	-0.054	0.133
Group Membership	0.059	0.130	0.048	0.165	0.159	0.127
Tech. Availability	-0.056	0.162	1.108***	0.349	0.120	0.169
Ease of use	-0.192	0.177	0.495	0.374	-0.112	0.167
Technology Cost	0.214	0.148	-0.202	0.181	-0.300**	0.149
Tech Effectiveness	-0.221	0.189	1.034***	0.326	0.578	0.148
Location	0.588***	0.154			-0.241	0.160

Note. Log pseudo likelihood = -602.981: Wald χ^2 = 517.23; p = 0.000;

LR test of rho21 = rho31 = rho32 = 0: χ^2 = 136.294; p = 0.000;

***, ** and * denotes significance at 1%, 5% and 10% level respectively.

Sex of household head had a significant effect on choice of ITL and ITT. A household whose head was a male was likely to use ITL or ITT to control tsetse flies and trypanosomiasis disease. This finding corroborates results reported by Mwaseda and Kigoda (2017) who established that more male respondents agreed to use recommended tsetse fly control methods as compared to female among communities neighbouring Serengeti

National Park in Tanzania. Similarly, Mose et al. (2013) found that sex affected farmer preferences for alternative trypanosomiasis control technologies. ITL entails singular methods including dipping, spraying and application of pour-on insecticides on the animals. These methods are not only labour intensive but also require that animals be restrained in a crush pen. This is perhaps the reason why such methods are mostly done by men, justifying the positive effect on their choice.

The number of household members was negatively associated with use of ITL and TTD. The negative effect of household size on choice of ITL and ITT was unexpected. The two technologies are labour intensive and thus it would be argued that larger households are likely to provide labour required when applying them. On the contrary, larger households demand more in terms of consumption expenditure thus reducing the amount that can be used to acquire the control technologies. Perhaps, this could explain the negative effect observed by this study.

The results further show that livestock owners whose major occupation was farming were unlikely to use ITT, as well as TTD. An explanation for this could be that, first, ITT was designated in geographical zones that were possibly unreachable by most households due to long distances. On the other hand, individuals who solely depended on farming are likely to diversify their farm enterprises and thus unlikely to graze in areas further away from their farm. This allows them to attend to other farm enterprises. Secondly, TTD is a costly technology and therefore individuals who solely depend on farming may lack finances to purchase the required drugs.

Furthermore, results in Table 4 indicate that farmers who perceived technologies to be readily available, as well as those who considered effectiveness, were more likely to use ITT. In Lamu East, this method was introduced as part of the interventions to control tsetse fly and trypanosomiasis. Such intervention may have improved the availability of ITT hence the observed response. Generally, availability and effectiveness of a technology positively influences its uptake. The probability that farmers will adopt a given technology is usually higher if they are sure that the technology is effective. Perhaps, farmers in the study area considered ITT an effective method compared to ITL and TTD. These findings support those found earlier by Howley et al. (2012). The authors reported that the success of technologies is likely to affect the probability of farmers choosing them.

The cost of technology had a negative influence on choice of TTD. This result is similar to those found by Aenishaenslin et al. (2015) who explained that cost of any technology affects its acceptability and uptake. In their study, they argued that acceptability and uptake of tick control interventions depended on the cost of interventions. TTD is a costly method that require drugs for treatment and thus, it is unlikely that farmers will choose it particularly those who consider cost of a technology before making the choice. A similar argument was put forward by Saini et al. (2017) that uptake of tsetse flies control technology depended on cost effectiveness of the technology in question.

The location of the farmers was found to be significant and positively influencing choice of ITL. This means that farmers in Lamu East were more likely to use ITL compared to their counterparts in Lamu West. Probably, there were spatial differences in the use of ITL as compared to other methods of controlling tsetse fly and trypanosomiasis. Differences could exist in access to private and public support service, as well as their acquisition and application. From the descriptive statistics discussed earlier, a larger proportion of farmers in Lamu East perceived ITL as being readily available, effective and easy to use in terms of its application. These perceptions explain the likelihood of choice of ITL by farmers in Lamu East sub-county.

Nevertheless, it is crucial to make predictions of joint use probabilities by livestock farmers using the practices even if they are not currently using. The predicted probabilities of joint use and marginal success are shown in Table 5. The results show that the probability of farmers fully integrating the three methods of controlling tsetse flies and trypanosomiasis was 19 per cent. This indicates that joint uptake of all the three methods or any two of them was possible. However, the results further show marginal success of single method uptake. ITT had the highest probability (42.7%) of being applied singly as compared to others ITL (19.4%) and TTD (25.9%). This could be explained by farmers' perception that it is inexpensive compared to ITT and TTD.

Table 5. Predicted probabilities of joint use and marginal success

Probabilities	Control Methods	Success (%)	Failure (%)
Marginal Success	ITL	0.194	
	ITT	0.427	
	TTD	0.259	
Predicted Probability	Joint Use	0.190	0.389

4. Conclusion

The promotion of adoption of integrated tsetse fly and trypanosomiasis control methods is identified as crucial to creating tsetse fly free Kenya. It is anticipated that eradication of the insect would result in elimination of HAT and AAT. Livestock keepers in Lamu County were among beneficiaries of the PATTEC sponsored technology integration project. Nevertheless, one decade later, there was limited understanding of drivers of differentiated uptake of ITL, ITT, and TTD, which limits approaches to large scale rollout of control methods in neighbouring counties. This study addressed this gap by focusing on determinants of multiple uptake of ITT, ITL, and TTD.

Result indicated that thirty-nine percent of the livestock keeping households in Lamu did not adopt tsetse fly and trypanosomiasis control methods. Nearly twenty-eight per cent of the users used them singly, while the rest integrated the practices. Male-headed households were more likely to adopt ITL and ITT than female-headed households. Large-sized households were less likely to use ITT and ITL. Results also indicated that older farmers were more likely to integrate the three control methods. Off-farm income increased the propensity of households using ITT, ITL, and TTD. Positive perceptions of technology availability and effectiveness increased the odds of the control method being adopted. The cost of the practice significantly reduced farmers' probability of using TTD.

The study recommends that national institutions and devolved units of government should design farmer outreach programs that consider key household characteristics, as well as technological attributes which may stimulate adoption of appropriate tsetse fly and trypanosomiasis control technologies. The periodic review of agricultural policy, national livestock policy and development of strategies in the livestock sector should recognize the demographic, farm-specific, social, and personal characteristics like gender, household size, occupation of household head, availability and effectiveness of technology that may encourage or limit adoption of tsetse fly and trypanosomiasis control methods.

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