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Are the current animal trypanosomiasis management methods in Kenya complementary or substitutes? Evidence from Kwale County

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Abstract

African animal trypanosomiasis (AAT) and its vectors, mainly tsetse, are a major constraint to livestock production in sub-Saharan Africa (SSA). Control efforts have been ongoing for decades, but finding a sustainable solution remains a major concern. This paper assessed the complementarity and substitutability of existing AAT management methods to inform policies toward an integrated approach. A multivariate probit (MVP) analytical technique was used to model interrelationships in the control methods from 308 randomly selected livestock keepers. The results show that the current AAT control methods are complementary and not substitutes. Furthermore, the number of years of formal education, household size, household income and land size had mixed effects on the households' decisions to adopt multiple AAT control methods. The key institutional factors that influenced the adoption behaviour were access to credit, group membership, access to veterinary services and drugs, and agricultural training. The results instil confidence in integrated AAT management if livestock farmers' socio-economic and institutional constraints are addressed sufficiently.

Key words: animal trypanosomiasis; integrated management; livestock; Kenya

1. Introduction

The livestock sector is a significant contributor to the global economy and has a considerable socio-economic influence, especially on food supply and job creation. According to the Food and Agriculture Organization of the United Nations (FAO 2018), approximately 600 million poor people in the developing world derive their livelihoods directly from livestock. In Kenya, the sector accounts for half of the agricultural labour force and it is the primary source of livelihood for the rural population, especially those in the arid and semi-arid areas that occupy 80% of the land mass. Consequently, this sector appeals to policymakers as a pathway for sustainable rural development and poverty alleviation (Amare *et al*. 2012; Smith *et al*. 2013).

Livestock production, however, is still constrained in most parts of sub-Saharan Africa (SSA), despite the revolution in the livestock industry projected by Delgado *et al*. (2001). Livestock diseases and climate change are considered the leading natural constraints to cattle production in the region. Diseases have contributed significantly to low production and low productivity among pastoralists, thus inhibiting the full commercial and food security potential. Notably, the African animal trypanosomiasis (AAT) and its vector have severely affected livestock production in the region (Geerts *et al*. 2009). The epidemiology of AAT and its related effects on cattle production depend on the prevalence and spatial spread of the disease and its vectors in the affected geographical region (Shimelis *et al*. 2011). It is estimated that approximately 30% of livestock in SSA are kept in AAT-endemic areas, where three million livestock deaths are recorded annually. This translates into an economic loss of USD 1.2 billion per year (FAO 2011). Smallholder cattle producers are particularly affected because of the inaccessibility of adequate veterinary services, and thus resort to the indiscriminate use of trypanocides – a practice that has been directly linked to increased risks of drug resistance (Specht 2008; Geerts *et al*. 2009). The implications are low milk and meat productivity, reduced draft power, low stock birth rates and increased stock mortality rates, with a long-term effect of reduced herd size and disruptions in herd composition (Swallow 2000). Furthermore, institutional failures, particularly the neglect of smallholder producers in public policy and inadequate investment in the sector, have led to their exclusion from the benefits of growth in the livestock sector in SSA (World Bank 2009; Fitzpatrick 2013).

While there have been ongoing efforts, including technological advances, to manage AAT (Cayla *et al*. 2019), statistics show that both its prevalence and drug-resistance risks are on the rise in SSA (Talakai *et al*. 2014; Tsegaye *et al*. 2015; Tchamdja *et al*. 2016; Adungo *et al*. 2020). The high prevalence is attributed to inefficient and ineffective control measures, while the increasing resistance rates are a result of indiscriminate over-reliance on and excessive use of trypanocides. The challenges with the use of trypanocides imply that the method cannot stand alone in the control of AAT. This prompts farmers to use multiple control methods and practices, in line with the concept of integrated livestock disease management, which is widely considered to be a better solution for the sustainable management of AAT in SSA (Clausen *et al*. 2010; Liebenehm *et al*. 2016). However, information on the complementarity and substitutability of these multiple AAT management methods used by livestock farmers is currently not available. Previous studies analysed the adoption of individual, isolated methods, thus ignoring the ideal household decision-making scenario when faced with alternatives that are complementary or substitutes. There furthermore is a dearth of empirical insights into the factors that facilitate or constrain the simultaneous adoption of multiple AAT management methods. These are the key research gaps that the present study addresses. It does so by assessing whether farmers are using multiple, interrelated AAT management methods, and analysing how households' socio-economic characteristics and institutional factors influence their decisions to adopt and use the interrelated AAT management methods.

The rest of the paper is organised as follows. The next section outlines the materials and methods, while Section 3 presents the results and discussion. Finally, Section 4 offers key conclusions from the results and makes relevant policy recommendations to improve AAT control for sustainable livestock production.

2. Materials and methods

2.1 Sampling and data collection

This study was conducted as part of a project of the International Centre for Insect Physiology and Ecology (ICIPE), called "Up-scaling integrated control of tsetse and trypanosomiasis among agro-pastoralists in Kenya". A multistage sampling method was applied to identify the respondents. In the first stage, Kubo South Ward in Kwale County was purposively selected, as it is the region targeted by the ICIPE project. Kwale County also is one of the areas in Kenya affected most severely by tsetse and AAT (McCord *et al*. 2012). In the second stage, six blocks were randomly selected from a total of 12 blocks in Kubo South Ward. This selection was based on the presence of more livestock farming households, a high tsetse population, and exposure to AAT. The six selected blocks met these criteria. Lastly, the probability proportional to size method was used to sample 316 livestock-farming households from a list of livestock-farming households in the six blocks. The proportion-to-size sampling method was applied following the baseline survey that was carried out before the start of the project in 2017. Therefore, this method was most appropriate for selecting a representative sample from each block.

This study utilised both qualitative and quantitative data obtained from Kwale County, Kenya, one of the hotspot areas of AAT (Saini *et al*. 2017). The qualitative data was obtained through focus group discussions (FGDs). A total of five FGDs, each comprising 10 farmers, one extension officer, one government veterinary officer and one private veterinary officer, were conducted in May 2019. The FGDs provided general information on livestock production, prevalence of AAT in the area and the trends in existing AAT management methods and their challenges. Quantitative data was then obtained through a household survey conducted in August and September 2019. During the survey, the respondents, who were mainly key decision makers in livestock production in the households (household heads or their spouses), were randomly selected in each block and interviewed using a face-to-face approach with a structured, pretested electronic questionnaire programmed in REDCAP software. The pre-tested questionnaire was administered by adequately trained local enumerators who had a vast knowledge of the farming practices in the study area.

The questionnaire had different sections that captured detailed information on household socioeconomic characteristics, land tenure, crop and livestock production, AAT prevalence and severity, tsetse and AAT control methods, knowledge and perceptions of the existing control methods, challenges of the current control methods, state of infrastructure, and institutional factors such as agricultural and non-agricultural group membership and networks. A total of 308 households were included in the final data analysis after the removal of eight incomplete questionnaires during data cleaning.

2.2 Theoretical framework and empirical data analysis

This study follows the theory of production decision-making under risk (Debertin 2012). Given disease threats such as AAT and potential losses in livestock productive capacity and household welfare outcomes, farmers are faced with constrained optimisation decisions in their choice of different livestock disease-management technologies, such as vaccines, trypanocides, repellent collars, tsetse traps and baits. As such, their perceptions of, preferences for and adoption behaviour of different technologies and inputs used in the livestock production process will vary depending on risk exposure, and socio-economic and institutional characteristics (Akhtar *et al*. 2018; Komarek *et al*. 2020). In their quest to optimise returns from livestock production, farmers have to choose to either adopt new/innovative complementary disease-management strategies or those that are better substitutes for existing options (Lipińska 2016). These ultimately inform their decisions on investment and resource allocation (Asfaw *et al*. 2011). Thus, by cushioning livestock production against constraints such as AAT, the adoption of interrelated management methods and strategies is critical in improving the resilience of farmers and reducing economic losses.

Empirically, we follow insights from Abdulai and Huffman (2014) and Kassie *et al*. (2015) to model the adoption decision behaviour of livestock farmers in an expected utility framework. In this framework, rational agents are expected to maximise their utility function (in this case, livestock farmers are considered to be pursuing the minimisation of losses from AAT), subject to different resource constraints. Given a set of AAT management alternatives, livestock-keeping households face various constraints in their adoption decision process. Nevertheless, persistent losses caused by AAT and increasing cases of drug resistance have prompted farmers to simultaneously combine different methods so that they can minimise the losses as much as possible. Against this background, we assume that the farmers adopt a management method set, m, at time t, to maximise utility – max $U_{it} = f(x_{it})$, subject to the various adoption constraints, where x is the vector of explanatory variables affecting the adoption decision of the farmer.

A livestock-producing household considers adopting a set of AAT management methods if the expected utility of adoption, $E(U_{itA})$, is higher than the expected utility of non-adoption $E(U_{itN})$. Households are therefore assumed to choose the combination of management methods that yield maximum expected utility, where the expected utility as a result of adoption is greater than the expected utility of non-adoption ($Y^* = E(U_{itA}) - E(U_{itN}) > 0$). Since the utilities gained are unobservable, it can be expressed as the following latent variable model:

$$Y_{itm}^* = \beta X_{itm} + \mu_i \; where \; Y_{itm} = \begin{cases} 1 \; if Y_{ij}^* > 0 \\ 0 \; otherwise \end{cases} \quad m = 1,2 \ldots M \tag{1}$$

Our assumption that livestock-keeping households are using a combination of AAT management methods to minimise losses has been evident in the existing literature. A limitation of previous studies on AAT control methods is that they fail to consider interdependence in different control methods. Such studies overlook the real decision-making scenario in households when they have various alternatives at their disposal. The complementarity and substitutability of all the options available to the household when making adoption decisions is often unclear.

The aforementioned shortcoming, which is always the case with univariate modelling, excludes essential economic information when making interdependent and simultaneous choice decisions. Therefore, building on this argument, the univariate logit and probit models are not appropriate because they assume the independence of the error terms of the different control methods. The use of univariate models would result in biased and inefficient estimates (Kassie *et al*. 2013). To prevent this, using a multivariate probit (MVP) model, which accounts for the interrelationships among the various control methods by allowing the error terms to be freely correlated, was the most appropriate approach (Belderbos *et al*. 2004).

Following Cappellari and Jenkins (2003), and consistent with the utility function in Equation (1), a multivariate model with five dependent variables, $y_1, \ldots, y_5$ can be specified such that:

$$Y_{ij}^* = x_{ij}' \beta_j + \varepsilon_{ij}, \; j = 1, \ldots, m \tag{2}$$

and

$$Y_{ij} = \begin{cases} 1 \; if Y_{ij}^* > 0 \\ 0 \; otherwise \end{cases}, \tag{3}$$

where Y_{ij} (j = 1,…, m) represent the available control methods (in our case, m = 5) faced by the i[th] household/farmer (i = 1,…, n), x'_{ij} is a 1 × k vector of explanatory variables that affect a farmer's choice of the control methods (household socio-economic characteristics and institutional factors), β_j is a k × 1 vector of unknown simulated maximum likelihood (SML) parameters to be estimated, and ε_{ij} is the unobserved error term.

Equation (2) implies that the dependent variable (control method) is binary, taking the value 1 if the farmer uses the control method, and 0 if not.

If the control strategies adopted by a farmer are independent (i.e. adoption and use of one does not affect the decision to choose and use another control method), then the specifications in equations (1) and (2) would assume a univariate probit model, implying that the household's decision to adopt one AAT control strategy does not in any way affect the probability of choosing any another among the available alternatives. But, since it is hypothesised that farmers are using a combination of interdependent AAT control methods and strategies, an ideal model specification is that which assumes that the error terms are not distributed normally (as in univariate probit), but follow a multivariate normal (MVN) distribution with zero mean and a variance-covariance matrix V, with values of 1 in the leading diagonals given as:

$$\begin{bmatrix} 1 & \rho_{12}\rho_{13}\cdots\rho_{1m} \\ \rho_{12} & 1 \quad \rho_{23}\cdots\rho_{2m} \\ \rho_{13}\rho_{23} & 1 \quad \cdots\rho_{3m} \\ \vdots \quad \vdots & \vdots \quad 1 \quad \vdots \\ \rho_{1m}\rho_{2m}\rho_{3m} & \cdots 1 \end{bmatrix} \tag{4}$$

The above considerations therefore give Equation (2) an MVP model that treats decisions to adopt various control methods jointly. This specification allows for the estimation of several equations whose dependent variables (in this case, AAT control methods) are correlated (Greene 2003). The non-zero off-diagonal elements in Equation (4) provide for this correlation, thus allowing the joint estimation of multiple equations.

The empirical model for this case is thus specified as:

$$\begin{Bmatrix} y_1 \\ y_2 \\ y_3 \\ y_4 \\ y_5 \end{Bmatrix} = \beta_0 + \beta_1 X_1 + \cdots, + \beta_n X_n + + \varepsilon_{1\ldots5}, \tag{5}$$

where $y_1, \ldots y_5$ are the AAT management methods, $X_1, \ldots X_n$ are the household socioeconomic characteristics and institutional factors, while $\varepsilon_{1\ldots5}$ are the error terms for each of the five equations.

The parameter estimates of the MVP model provide only the direction of the effects of the explanatory variables on the response variable, but do not provide any information on actual magnitudes of change. In order to address this shortcoming, we follow the suggestion of Greene (2008) and compute marginal effects that measure the expected change in the probability of adopting and using a particular AAT control method with respect to a unit change from the mean for in the case of the continuous explanatory variable, or changing from 0 to 1 if the explanatory variable is a binary value.

Following Mullahy (2017), we specify and compute marginal effects as:

$$\frac{\partial Prob(y_{ij}|x)}{\partial x}, j = 1, \ldots, m, \quad (6)$$

where y_{ij} is the m-variate binary outcome vector, x are conditioning covariates, and Prob(…) is a joint probability from a multivariate normal distribution.

2.3 Description of variables in the model

The dependent and explanatory variables included in the analysis are presented in Table 1. Consistent with previous literature on technology adoption (for instance De Groote & Coulibaly 1998; Bandiera & Rasul 2006; Marenya & Barret 2007; Pender & Gebremedhin 2007; Kaufman *et al*. 2009), the adoption of multiple AAT management methods is modelled as a function of household socio-economic characteristics and institutional factors. Consistent with the characterisation by Valeeva *et al*. (2011), the specific household socio-economic variables included in the model were age of household head, household size, years of formal schooling of the household decision makers, household on-farm and off-farm income, household assets – mainly livestock size (number of cattle, sheep, goats and chickens owned by the household) – and land-related variables such as land size, land tenure and household's grazing patterns.

Table 1: Description of variables

Variables	**Description of variables**
Dependent	
Trypanocides	Household uses drugs/trypanocides and sprays to treat AAT (1 = Yes; 0 = No)
Repellent collars	Household uses repellent collars (1 = Yes; 0 = No)
Selective bush clearing	Household applies selective bush clearing to eliminate/reduce tsetse population (1 = Yes; 0 = No)
Traditional herbs (ethnoveterinary)	Household uses medicine made from traditional herbs to treat AAT and smoke from burnt dry plant material to kill tsetse (1 = Yes; 0 = No)
Avoiding areas with a high tsetse infestation	Household carefully selects grazing areas to avoid those with a high tsetse infestation (1 = Yes; 0 = No)
Explanatory	
Age	Age of the household head in years
Household size	Number of members of the household, including children
Education	Years of formal education attained by the household head
Income	Total monthly household income in Kenyan shilling (Kshs)
Livestock income	Proportion of the household monthly income from livestock
Tropical livestock units (TLUs)	Standardised expression of total number of livestock (cattle, goats and sheep) owned by the household
Land size	Total land owned by the household in acres
Credit access	Household received credit in the last 12 months (1 = Yes; 0 = No)
Veterinary services	Number of times household received veterinary services in the last 12 months
Training	Household received agricultural training in the last 12 months (1 = Yes; 0 = No)
Group membership	Member of the household belongs to an agricultural group (1 = Yes; 0 = No)
Access to trypanocides	The household can easily access trypanocides (1 = Yes; 0 = No)

The importance of considering observable household characteristics in informing household decision-making is reaffirmed by Tornimbene *et al*. (2014). For instance, a household in which the main decision maker has a higher education level may have better access to relevant information and have higher off-farm incomes, thus being able to adopt relatively more effective AAT management methods and strategies. Similarly, household assets such as bigger land size mean having enough grazing space for their cattle, thus reducing tsetse bites and AAT. It could also mean having more agricultural land for production, hence higher productivity and household incomes, which would be invested in more AAT control methods. However, larger fallow or unmaintained land may create tsetse habitats closer to households, resulting in increased tsetse-animal contact, which would eventually lead to a higher number of animal trypanosomiasis cases. The age of the household head is also likely to have mixed effects on adoption decisions. While in some cases age would mean being more experienced and knowledgeable about specific control methods, it might also suggest being risk-averse, and slow or unwilling to adopt new technologies such as disease control methods. Therefore, the actual effect of age on the adoption of AAT control methods was assumed to be indeterminate.

Concerning institutional factors, access to trypanocides – which can be explained by distance to market, access to veterinary services (number of veterinary visits), access to agricultural training, group membership and access to credit were hypothesised to influence a household's adoption and use of various AAT control methods. As Weyori *et al*. (2017) note, social networks such as membership of agricultural groups facilitate access to crucial information necessary for making essential adoption decisions. Similarly, such groups could facilitate access to drugs and other technologies for managing AAT. This is consistent with the existing literature, which argues that informal institutions, access to inputs and extension services play an essential role in economic development (Bandiera & Rasul 2006; Kaufman *et al*. 2009). Most importantly, according to recent new institutional economics studies, social networks are believed to reduce transaction costs and increase bargaining power, thus increasing returns to farmers (Pender & Gebremedhin 2007). Access to agricultural training and group membership were hypothesised to positively influence the adoption of multiple AAT control methods. Also, access to credit and trypanocides was hypothesised to positively influence the use of trypanocides and other control methods.

3. Results and discussion

3.1 Descriptive statistics

Table 2 shows the socio-economic profiles of the sample households. About 89% of the households were headed by men, who were 54 years old on average. These results are consistent with recent findings in the study area by Wamwenje *et al*. (2019). Markakis (2004) also observed that men are the decision makers in livestock-keeping households, as they have more access and rights to economic resources compared to women. Furthermore, the average household size was five, which is in line with the latest population and housing census results from Kwale County (KNBS 2019).

The majority of the household heads had primary education as their highest level of formal education; the average years of formal schooling was seven. According to the KNBS and SID (2013), not more than 16% of Kenya's population over 50 years had attained secondary school education. Similarly, Kwale County is one of the semi-arid parts of Kenya, where there is low human development, including low literacy levels (Njoka *et al*. 2016).

Land size and ownership, and distance to a game reserve, play a major role in determining livestock grazing patterns. Consistent with the findings from the FGDs, the household survey results showed that the average household land size was 8.5 acres. On average, the distance in walking time to the Shimba Hills game reserve was 1.5 hours. The relatively larger land sizes and longer walking distances to the game reserve could partly explain the observed variations in grazing patterns. Grazing in household-owned land was common in slightly more than half (52.3%) of the surveyed households. Similarly, 52.6% of the households reported that they grazed their livestock on communally owned land.

Table 2: Socioeconomic characteristics of sample households

Variable	Mean (n = 308)	Std dev.	Minimum	Maximum
Age	54.27	13.50	22.00	90.00
Education	7.21	4.00	0.00	16.00
Household size	5.16	2.01	1.00	11.00
Land size	8.46	13.84	1.00	56.48
TLUs[1]	7.08	6.62	1.00	74.00
Household Income[2]	18 141.92	26 938.57	5,000.00	297,000.00
Distance to livestock market	39.04	28.41	0.00	100.00
Distance to game reserve	271.73	377.13	18.00	600.00
Distance to credit source	80.88	76.06	5.00	300.00
Proportion of income from livestock	104.40	83.21	5.00	400.00
Gender (1 = male)	0.89	0.31		
Access to credit (1 = yes)	0.21	0.41		
Access to extension services (1 = yes)	0.27	0.44		
Access to veterinary services (1 = yes)	0.33	0.47		
Access to livestock training (1 = yes)	0.36	0.48		
Group membership (1 = yes)	0.21	0.41		

Less than one third of the respondents had received extension services in the preceding 12 months, while only one-third of the households received veterinary services in the same period. However, about 33% had received veterinary services, while 37% of the respondents had received training on livestock production, disease control and general management aspects. The main sources of training were government and non-governmental organisations (NGOs) such as ICIPE. Regarding social rural networks, about 21% of the respondents had been members of a rural agricultural development group for approximately five years. One-third of those who belonged to an agricultural development group had a leadership position in the group. This implies that they were responsible for making key decisions in their respective groups. The existing literature suggests that social networks such as membership of rural development groups and personal relationships inform rural households' decision-making on technology adoption and risk-mitigation strategies (Bandiera & Rasul 2006; Matuschke & Qaim 2008; Nyangena 2011). In rural settings that are usually characterised by inadequate information, imperfect markets and high transaction costs, social networks through development groups facilitate the timely flow of relevant information and access to vital inputs, minimise credit access constraints, reduce transaction costs and improve farmers' bargaining power, thus enabling the adoption of technologies and risk-mitigation strategies (Pender & Gebremedhin 2007; Wollni *et al*. 2010; Nyangena 2011).

As shown in Figure 1, the four main types of livestock owned by the surveyed households were cattle, sheep, goats and chickens.

[1] Following the World Initiative for Sustainable Pastoralism ([WISP] 2010), the TLU equivalents for various livestock were considered as cattle = 1, camels = 1, donkeys = 0.8, goats and sheep = 0.2 and poultry = 0.04.
[2] 1USD was equivalent to 103 Kenyan shillings (Kshs) at the time of the survey (September 2019).

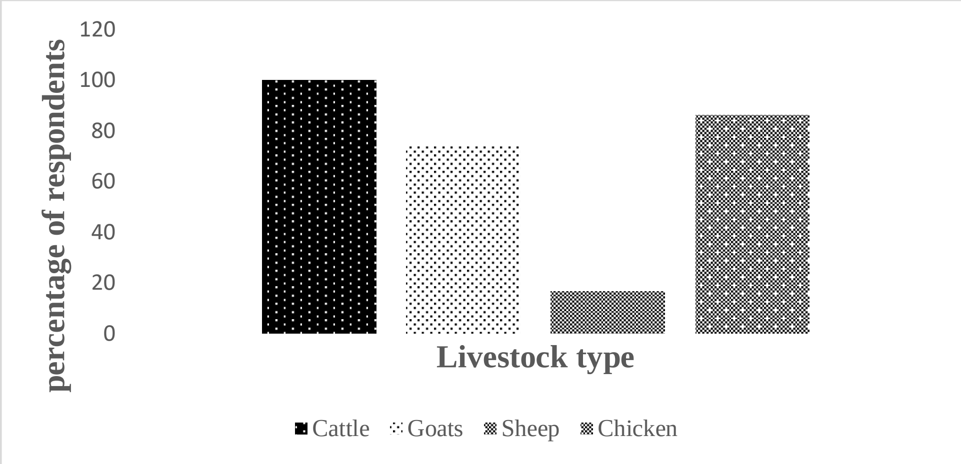

Figure 1: Composition of household livestock

The average TLUs per household was seven. Almost all households owned cattle, while sheep, goats and chicken ownership was recorded in about 17%, 74% and 86% of the households respectively.

Figure 2 shows how livestock contribute to household livelihoods. About 83% of the households mainly kept livestock, especially cattle, for draft power (own use), while approximately one third of the households were hiring out the draft power to other households. These findings are in accordance with initial revelations from the FGDs that cattle, especially oxen, are used for traction when tilling land for crop production. Milk production and the sale of live animals were also important contributions of livestock to the livelihoods of 79% and 71% of the households respectively. Previous studies have reported that livestock and livestock products are a major source of household income and food in pastoral communities (Herrero *et al*. 2012; Tembo *et al*. 2014; Nyberg *et al*. 2015). However, in our case, it was noted that the mean share of livestock to on-farm income was only 40%. This can be attributed to the region's exposure to tsetse and AAT risks, which limits the full potential of livestock contribution to household incomes and food security; and this provides a suitable rationale to urgently address AAT management in the area to safeguard livelihoods.

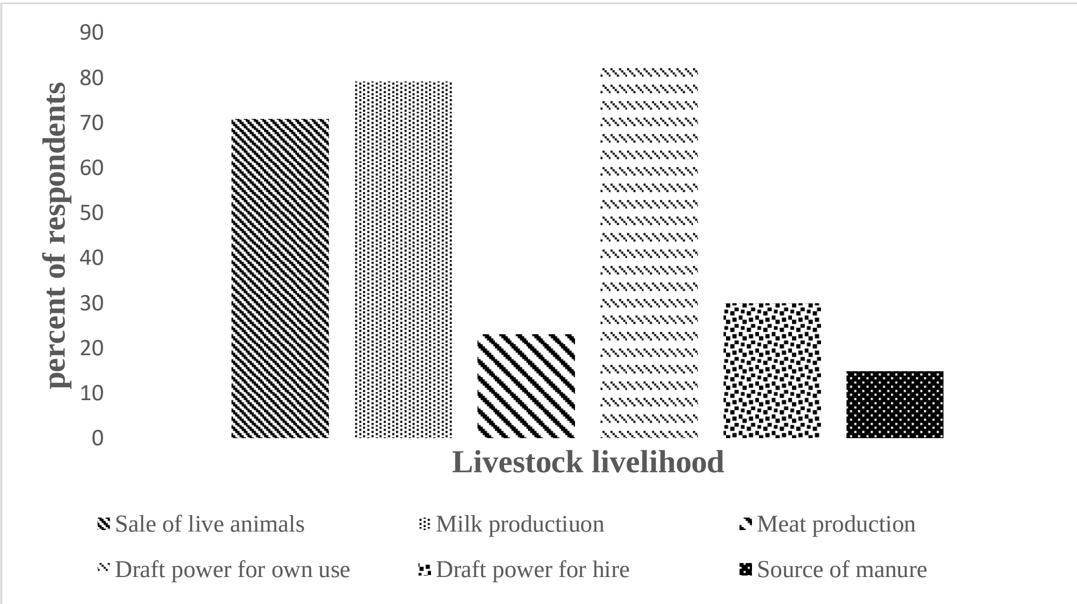

Figure 2: Contribution of livestock to the livelihood of the household

3.2 Methods for the management of animal trypanosomiasis

The AAT management methods used by farmers were trypanocides (drugs), repellent collars, selective bush clearing, traditional herbs and the avoidance of areas believed to be highly infested with tsetse. As shown in Table 3, repellent collars were used by 40% of the households. The presence of this AAT management technology can be attributed to the efforts by the ICIPE in Kwale County, as it seeks to promote the use of modern approaches to control the disease and its vectors. Repellent collars are believed to be affordable, and up to 94% effective in reducing tsetse bites in livestock (Bett *et al*. 2015). Saini *et al*. (2017) also found that they reduced the prevalence of AAT by over 80%, and drug (trypanocide) use by 60%. The use of drugs (trypanocides) was found to be the main control method applied by about 93% of the farmers. The high use of drugs can be attributed to what farmers perceive as high benefits, and the renewed interest by the government, private sector and NGOs in researching and investing in drug discovery and novel control methods (Scoones 2014; Meyer *et al*. 2016). Selective bush clearing was a common AAT management method among 60% of the farmers. Most livestock keepers in the study area are probably aware of the role of the biophysical environment in managing tsetse and AAT. In most tsetse-infested areas, selective bush clearing is used mainly to make more land available for crop production, while at the same time eliminating tsetse habitats.
Livestock-keeping households were also incorporating their indigenous knowledge into AAT control efforts. This is reflected in the 51% and 49% of the households that used traditional herbs (ethnoveterinary) and the avoidance of areas perceived to be highly infested with tsetse respectively. From the preliminary FGDs, it was found that the use of traditional herbs is one of the main indigenous methods used by farmers. As reported in the FGDs, wild plants were mainly used to make traditional medicine for treating livestock. In addition, smoke from burning dry coconut husks was also used to keep tsetse away from human settlements. These findings corroborate those of Dharani *et al*. (2015) that pastoralists and agro-pastoralists in East Africa have a long tradition of ethnoveterinary practices involving the use of many plants to prevent and treat different diseases and health conditions. Similarly, a review of past control methods by Headrick (2014) showed that pastoralists and agro-pastoralists in East Africa intentionally avoid tsetse-infested areas to minimise the contact between both humans and livestock in order to reduce the risk of contracting AAT.

Table 3: Methods to manage animal trypanosomiasis

AAT management methods	Percentage of respondents (n = 308)
Using sprays and trypanocides (1 = yes)	92.51
Repellent collars and tsetse traps (1 = yes)	40.39
Selective bush clearing (1 = yes)	59.93
Traditional herbs (1 = yes)	51.14
Avoiding tsetse-infested areas (1 = yes)	48.53

3.3 Interrelationships among the animal trypanosomiasis management methods

In this section, we present the MVP regression results. We first show the complementarity and/or substitutability in the current AAT management methods (Table 4), followed by the determinants of adoption of these AAT management methods.

Table 4: Correlation coefficients showing interrelationships among AAT management methods

	Trypanocides (ρ_1)	Repellent collars (ρ_2)	Selective bush clearing (ρ_3)	Traditional herbs (ρ_4)
Repellent collars (ρ_2)	0.461 (0.129) ***			
Selective bush clearing (ρ_3)	0.346 (0.120) ***	0.259 (0.116) **		
Traditional herbs (ρ_4)	0.349 (0.117) ***	0.449 (0.097) ***	0.443 (0.107) ***	
Avoiding infested areas(ρ_5)	0.375 (0.121) ***	0.273 (0.111) ***	0.380 (0.102) ***	0.480 (0.889) ***
Likelihood ratio test of rho21 = rho31 = rho41 = rho51 = rho32 = rho42 = rho52 = rho43 = rho53 = rho54 = 0: X^2 (10) = 76.26 Prob > chi^2 = 0.000 ***				

Note: ** and *** denote statistical significance at the level of 5% and 1% respectively. Standard errors are in parentheses.

The likelihood ratio test, X^2 (10) = 76.26 (Table 4), is statistically significant at the 1% level, thus supporting the rejection of the null hypothesis that the various AAT control methods used by farmers are independent and further justifying the use of the MVP model. This implies that estimating each equation separately (applying univariate regressions) would have yielded biased and unreliable results. Most importantly, all the correlation coefficients between multiple AAT control methods, as shown in Table 4, are positive and significant, leading to the conclusion that the AAT management methods used by livestock farmers are complementary and not substitutes.

Table 5 presents the MVP regression results on determinants of adoption of interrelated AAT management methods. The Wald test, X^2 (126) = 221.98 (Table 5), for the goodness of model fit is significant at the 1% level.

The results show that the age of the household head had a positive and significant effect on the use of selective bush clearing. Specifically, an increase in the age of the household head by one year increased the probability of using selective bush clearing by 22.8%, all other factors held constant. This is probably because selective bush clearing was the most dominant method in early efforts to combat the disease in SSA (Muriuki *et al*. 2005). Similarly, as observed from the FGDs, older farmers were well versed in selective bush clearing and were therefore more likely to integrate the method into the management of tsetse and AAT.

A unit increase in household size increased the probability of using selective bush clearing by 16.2%, but decreased the chances of using traditional herbs by 13.5%. Household size is a proxy for labour availability, especially in cases where the majority of household members are adults. The implication is that larger households are likely to invest in labour-intensive AAT management methods, such as selective bush clearing. Previous studies on multiple on-farm technology adoption and resource management have shown that larger households have higher chances of adopting labour-intensive technologies (Marenya & Barret 2007; Kassie *et al*. 2009, 2013). Similarly, the available labour, if allocated appropriately, can translate into higher on-farm incomes, which likely would reduce households' chances of relying on traditional herbs as a control method but enable them to invest in new technologies, such as repellent collars and trypanocides.

Years of formal education had positive, significant effects on the use of repellent collars and selective bush clearing. A one-year increase in the household head's formal education increased the probabilities of adopting and using repellent collars and selective bush clearing by 12.5% and 20% respectively. This is probably because more educated livestock keepers are aware of the importance of managing the surrounding biophysical environment better to control the tsetse population and also are conversant with new technologies such as repellent collars. These findings are also consistent with those of Mignouna *et al*. (2011), who revealed that formal level of education improves a farmers ability to access and process information relevant to making technology-adoption decisions. As a result, farmers with higher levels of formal education can rationally compare benefits among the available strategies and shift to cost-effective technologies with perceived higher benefits (Waller *et al*. 1998). Intuitively, households with educated decision makers (household heads) are aware that bushes create tsetse habitats around their residents; thus, selective clearing reduces the tsetse population and subsequently minimises tsetse-animal contact. In addition, a study by Saini *et al*. (2017) in the same study area revealed that repellent collars were affordable by most farmers and were effective in reducing tsetse bites in livestock by 94%.

A unit increase in TLUs increases the probabilities of using trypanocides and repellent collars by 5.5% and 8.6% respectively. Households with large numbers of livestock are more likely to be faced with stock management and grazing challenges and therefore are at higher risk of AAT. As a result, they are more likely to adopt AAT management technologies such as trypanocides and the use of repellent collars.

Table 5: Results of multivariate probit regression on determinants of adoption of interrelated AAT management methods

	Sprays and trypanocides		Repellent collars		Selective bush clearing		Traditional herbs		Avoiding tsetse-infested areas	
Explanatory variables	**Coefficient**	**δy/δx**	**Coefficient**	**δy/δx**	**Coefficient**	**δy/δx**	**Coefficient**	**δy/δx**	**Coefficient**	**δy/δx**
Age	-0.174 (0.424)	-0.033	-0.417 (0.366)	-0.133	0.694** (0.359)	0.228**	-0.497 (0.355)	-0.169	-0.485 (0.349)	-0.172
Household size	0.059 (0.282)	0.011	-0.069 (0.232)	-0.022	0.494** (0.243)	0.162**	-0.396* (0.233)	-0.135*	0.099 (0.220)	0.035
Education	0.429 (0.274)	0.082	0.392* (0.228)	0.125*	0.610*** (0.229)	0.200***	0.207 (0.218)	0.071	0.060 (0.210)	0.021
Total income	-0.056 (0.125)	-0.011	-0.213** (0.100)	-0.068**	-0.029 (0.097)	-0.009	-0.435*** (0.098)	-0.148***	-0.122 (0.097)	-0.043
Access to drugs	0.728*** (0.264)	0.138***	0.030 (0.193)	0.010	-0.274 (0.191)	-0.090	-0.515*** (0.189)	-0.175***	-0.185 (0.186)	-0.066
Income from livestock (proportion)	0.015*** (0.005)	0.003***	0.004 (0.003)	0.001	0.001 (0.003)	0.000	-0.001 (0.003)	0.000	-0.001*** (0.003)	0.000
Total livestock	0.290* (0.159)	0.055*	0.268* (0.141)	0.086*	0.111 (0.136)	0.037	0.216 (0.134)	0.074	0.279 (0.134)	0.099
Land size	-0.011 (0.130)	-0.002	0.380*** (0.107)	0.122***	0.266*** (0.103)	0.087***	0.276 *** (0.101)	0.094***	0.337*** (0.100)	0.120***
Credit access	-0.200 (0.309)	-0.038	-0.202 (0.246)	-0.065	0.412* (0.242)	0.135*	0.042 (0.240)	0.014	0.588*** (0.240)	0.208***
Group membership	0.132 (0.227)	0.025	0.295** (0.147)	0.094**	0.142 (0.161)	0.047	0.228 (0.152)	0.078	0.000 (0.145)	0.000
Veterinary visits	0.261* (0.139)	0.050*	0.031 (0.067)	0.010	-0.186*** (0.069)	-0.061***	0.021 (0.065)	0.007	0.033 (0.062)	0.012
Agricultural training	0.582** (0.277)	0.111**	0.809*** (0.201)	0.259***	0.533*** (0.210)	0.175***	0.575*** (0.204)	0.196***	0.262 (0.192)	0.093

Number of observations = 308; Log likelihood = -545.911; Wald $X^2(60)$ = 144.06 ***; Levels of statistical significance:* = 10%, ** = 5% and *** = 1%; Standard errors in parentheses; δy/δx = marginal effects

Higher household monthly incomes reduce the use of repellent collars and traditional herbs. An increase in household monthly incomes by Kshs 1 reduced the probabilities of using repellent collars and traditional herbs by 6.8% and 14.8% respectively. The negative effect on the use of traditional herbs can obviously be explained by the rationale that higher incomes enable farmers to invest in new control technologies. However, the negative effect of household monthly income on the use of repellent collars can be interpreted in two ways. Firstly, the correlation results in Table 4 show that the repellent collars and traditional herbs are not substitutes, but complementary methods. Economic theory provides that, if two goods are complementary, then the quantity demanded of such goods moves in the same direction with respect to changes in their prices and people's incomes. Therefore, the effect of increasing monthly incomes on both control methods is expected to be the same (reduces the probability of using both methods). Secondly, following the observation by Saini *et al*. (2017), that repellent collars were generally affordable among most livestock farmers from Kwale County, it would therefore be rational for farmers to invest in more-effective technologies when their incomes increase. This view is corroborated by the positive significant effect of the proportion of monthly income from livestock production on the use of trypanocides. The results show that a one percent increase in the proportion of monthly income from livestock production increased the probability of using trypanocides by 0.3%, all other factors held constant.

As land size increases, the households' chances of using repellent collars, selective bush clearing and traditional herbs and of avoiding areas with high tsetse infestations increase. As such, a one-acre increase in the size of the household land increased the probabilities of using repellent collars, selective bush clearing and traditional herbs and avoiding areas with high tsetse infestations by 12.2%, 8.7%, 9.4% and 12% respectively. Large land sizes are likely to push tsetse habitats closer to people if not well managed and conserved. As a result, farmers will find it necessary to adopt multiple complementary control methods to effectively mitigate against AAT threats.

Access to institutional support services like credit, drugs, veterinary services and agricultural training had positive, significant effects on multiple AAT control methods. For instance, access to credit increased the use of selective bush clearing and avoiding high tsetse-infested areas by 13.5% and 20.8% respectively. Further, a unit increase in veterinary visits increased the probability of using trypanocides by 5% and reduced the probability of using selective bush clearing by 6%. The explanation for this could be that farmers who receive credit and visit veterinarians are likely to invest in environmental conservation to eradicate tsetse habitats around their homesteads and can readily invest in effective AAT preventive and treatment technologies. Predictably, access to drugs increased the probability of using trypanocides by 13.8%, but decreased the probability of using traditional herbs by 17.5%. Access to agricultural training, on the other hand, increased the households' chances of adopting and using all the AAT management methods, except for the avoidance of tsetse-infested regions. Specifically, the results showed that receiving agricultural training increased the probabilities of using trypanocides, repellent collars, selective bush clearing and traditional herbs by 11%, 26%, 17.5% and 19.6% respectively. This can be attributed to the role agricultural training plays in educating farmers about how to integrate new technologies into AAT management efforts and the benefits of using multiple AAT control methods.

Membership of an agricultural development group had a positive effect on the use of repellent collars. Specifically, being a member of a rural agricultural group increased the probability of using repellent collars by 9.4%. This can be attributed to the valuable social capital associated with these groups, as they facilitate the sharing of information on the latest disease-control technologies. Rural agricultural groups also enhance collective decision-making (Nyangena 2007; Kassie *et al*. 2009). Apparently, when using repellent collars as a method to manage tsetse and AAT, it is not required that every animal in the herd should have a collar, as only a few of the animals need them. Therefore, farmers who belong to an agricultural group can collectively agree to buy a few repellent collars and decide to graze their herds together if there is adequate space to prevent crowding and the depletion of natural resources.

4. Conclusions and policy implications

The African animal trypanosomiasis (AAT) is a significant constraint to livestock production in most parts of SSA. Therefore, finding a sustainable solution to this problem is of particular interest to policymakers. An integrated approach could be the most reliable course of action. However, unlike in crop production, where the concept of integrated disease management has picked up pace, it is still new in pest and disease management for livestock. This paper provides useful insights for drawing up relevant policies on an integrated approach to managing livestock diseases, particularly AAT. As a necessary requirement towards an integrated approach, the paper reveals that the current AAT management methods are complementary. A key policy implication of this complementarity is that livestock-keeping households do not have to forego one AAT control method in favour of another. Instead, the effectiveness and efficiency of one control method is enhanced by the adoption of other methods. This calls upon the relevant authorities to promote simultaneous adoption of multiple AAT management methods. For this to work, it is important to effectively manage various socio-economic and institutional factors that underpin multiple control strategies.

For instance, the significant effects of education, and access to veterinary services and agricultural training suggest the need to formulate policy interventions and programmes that seek to educate and sensitise livestock farmers on the use of more efficient and cost-effective methods and strategies.

The study has also highlighted the role of social networks as a more reliable option in the presence of government inefficiencies in the allocation of resources, for instance inefficient veterinary and extension services. This implies that rural agricultural groups should be encouraged and supported through training on group management and leadership. However, rural institutions and networks cannot stand alone in addressing cases of market failure and missing markets. Therefore, the necessary inputs and services such as drugs, repellent collars, tsetse traps, veterinary and extension services should be brought closer to the farming communities. This includes developing infrastructure such as cattle dips and local roads to reduce the time taken to access essential services.

Finally, it is more likely that the simultaneous adoption of interrelated AAT management strategies and practices could be influenced by the costs of individual management methods and other factors, such as prevalence rates, vulnerability to climate shocks, household food security status, household wealth indices, ownership of and access to communication devices like mobile phones and participation in agricultural markets. In order to provide a comprehensive understanding of the complex institutional environment within which multiple AAT control methods have to be designed and implemented, future studies should assess the cost implications and effects of these factors on the adoption of the interrelated control methods.

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