Micro-economic Impact of Tsetse and Trypanosomiasis Control Interventions on Farmers' Livelihoods in Kwale County, Kenya

by Muriithi B.W., Menale K., Diiro G., Nyanganga M.O., and Masiga D.

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1. Introduction

Agriculture contributes a substantial share of the Gross Domestic Product (GDP) of most countries in sub-Saharan Africa (SSA), including in Kenya. The sector particularity plays a vital role in food production and poverty alleviation among rural smallholder farmers. The livestock sub-sector is estimated to contribute about 30% of all agricultural GDP in the developing world and 40% of the global agricultural GDP (World Bank, 2009). According to Food and Agriculture Organization (FAO) 2018), global livestock asset is valued at $1.4 trillion and employs over 1.3 billion people. Directly the sub-sector supports about 600 million smallholders in developing countries. Livestock are valued for their contribution to food and nutrition, income generation through the sale of livestock and their products, draft power and manure for crop production, and a source of heritage and culture (Powell et al., 2004). Livestock are also critical for resilience, especially under harsh weather conditions where crops cannot endure. In Kenya, the livestock sub-sector plays an important economic and socio-cultural role among many rural communities. The sub-sector contributes about 15% of the country's GDP and 14% of the agricultural labor force (GoK, 2019). The SSA, including Kenya, lags in milk and meat production. In Kenya for instance, the pastoral cattle do not meet the 350Kg minimum market weight (GoK, 2015). The livestock potential is however constrained by various infectious diseases such as trypanosomiasis and tick-borne diseases, besides vulnerability to persistent droughts, that significantly affect their productivity.

Tsetse flies, the vectors of nagana (African Animal Trypanosomiasis - AAT), and sleeping sickness (African Human Trypanosomiasis - HAT) are unique to Africa and occur in 37 sub-Saharan African (SSA) countries occupying an area of 8.5 million square kilometers. In Kenya, 138,000 square kilometers of land is infested with different species of tsetse flies. About 13% of the country's cattle population resides in this area and therefore these animals are at risk of contracting trypanosomiasis. AAT is estimated to be responsible for 3 million cattle deaths annually and over 46 million others at risk of contracting the disease (Mattioli et al., 2004). Directly, the disease is associated with USD 1.2 billion losses each year, while indirect losses include the inability to use land and draft power to full capacity (Machila et al., 2007). Although great effort has been made towards controlling the tsetse flies and AAT, SSA continues to endure the heavy economic burden of the disease(McCord et al., 2012).

While integrated effort would be more efficacious, most investment has targeted the disease, using trypanocidal drugs y (Machila et al., 2007). However, drug resistance and associated health and environmental risks related to drug toxicity and improper disposal of drug leftovers have weakened these previous efforts (Anene et al., 2001; Moti et al., 2012). The development and use of vaccines against trypanosomiasis have also been futile. Subsequently, researchers continue to search for environmentally friendly vector control targeting approaches such as repellent collars (Saini et al., 2017); insecticide-impregnated targets (Leak et al., 1996); tsetse fly traps, and pour-on technologies (Magona et al., 1998). Area-wide control approaches such as targets and traps have not been successful due to limited community participation (Catley & Leyland, 2001; Echessah et al., 1997). The International Centre of Insect Physiology and Ecology (*icipe)* and partners have in the past over 15 years researched and developed an integrated tsetse fly control approach, implemented both at community (area-wide strategies) and household (herd) level, for sustainable control of trypanosomiasis (Saini et al., 2017). The herd-level intervention is the tsetse repellent technology that enhances fly suppression and significantly reduces disease incidence (protection & control).

The tsetse repellent technology involves controlled release of potent repellents from a prototype dispenser (specifically designed to facilitate the release of the repellents at a constant rate) that individual cattle wear encircling their necks like a collar, thus synonymously referred to as Tsetse Repellant Collar technology (TRCT) (Saini et al., 2017). The technology has been validated in large-scale field trials; whose results demonstrate substantial benefits as perceived by farmers (Saini et al., 2017). These benefits include reduced disease prevalence, cattle mortality, and cost of animal production, increased animal body weights resulting in higher selling prices, among other benefits. While the promotional activities show clear indications of the success of the technology, significantly reducing tsetse bites, AAT prevalence, and use of trypanocidal drugs (Saini et al., 2017), rigorous evaluation studies that measure the impact of the technology on the livelihoods of the cattle keepers in the trial sites are non-existent. Subsequently, this study utilizes advanced empirical methodologies to assess the immediate farm-level impacts of the TRCT among farmers residing in the technology trial sites.

2. Data and summary statistics

2.1. Study area and sample description

The data utilized in this study was collected among livestock keepers from Kwale County in the coastal region of Kenya. A multi-stage sampling technique was utilized. First, a purposive sampling method was used to select the county, sub-county, wards, and villages for the survey, which are the benchmark sites for the ongoing *icipe*'s field promotional campaign of the tsetse and AAT management. Kwale County is one of the hotbeds of tsetse and AAT infestation in Kenya with a prevalence rate of over 56% (Mbahin et al., 2013; McCord et al., 2012). The county occupies an area of 8,267Km^2 with an estimated population of 866,820 people (GoK, 2019). Crop farming and livestock keeping are the main economic activities in the county contributing over 80% both directly and indirectly to the livelihoods of the community. Cattle, shoats (sheep and goats), and chicken are the main types of livestock kept by farmers in this area. Most households own a few local cattle breeds that provide traction for ploughing land, transporting goods (including water) and a source of meat and milk, and income through the sale of animals. Crop farming in the area includes fruit farming with coconut, mangoes, passion fruits, cashew nuts, and citrus as the most dominant, and food crop farming such as maize, cassava, sweet potatoes, peas, and green grams

Matuga Sub-county was purposively selected; from which three wards, Kubo South Ward, Mkongani, and Tsimba Golini wards were similarly purposively selected. Twelve (12) villages were then selected from the three wards; eight from Kubo South, two from Mkongani, and 1 from Tsimba Golini (Figure 1). The selected villages border the Shimba Hills Game Reserve (SHGR), which hosts a variety of wild animals, which provides a conducive breeding environment for tsetse flies, hence perpetuating the high burden and prevalence of tsetse.

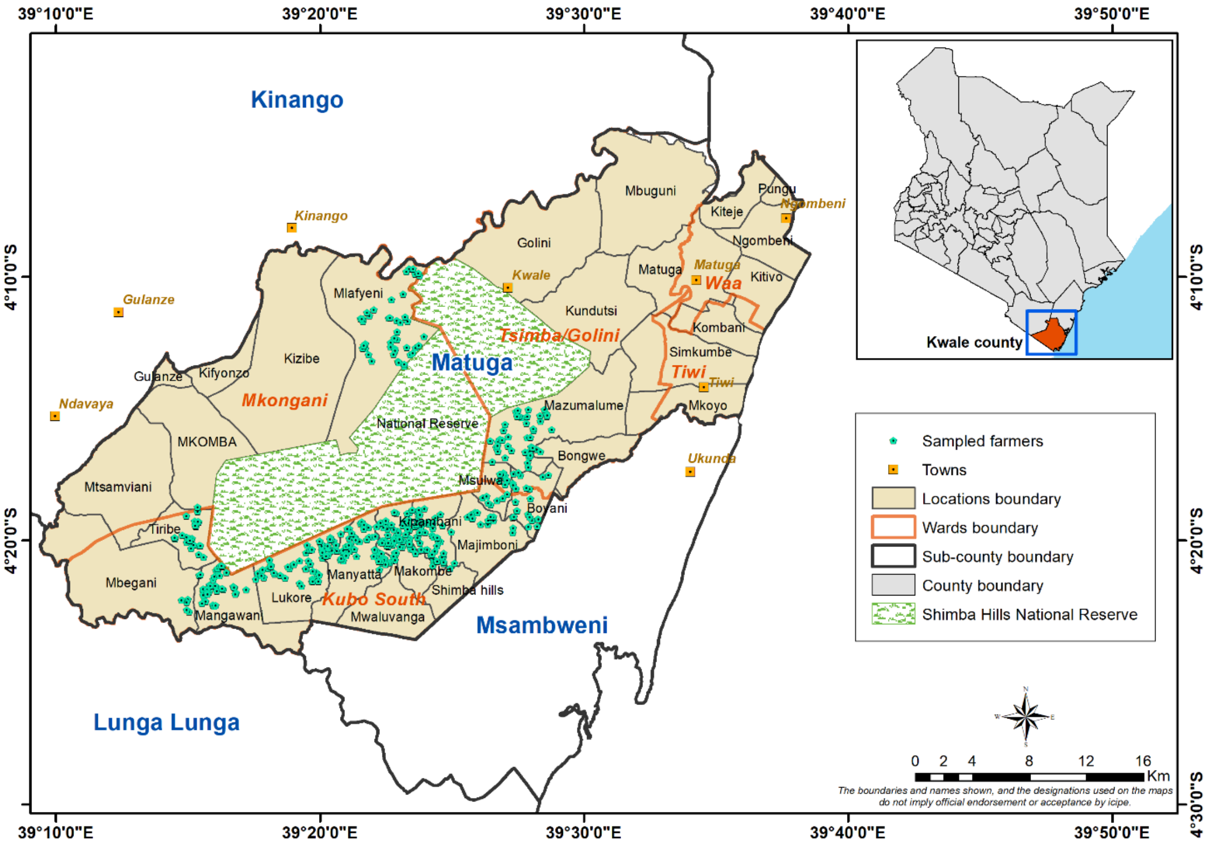

Figure 1: Map of the study area

A census of cattle-keeping households from the 12 villages was developed with the support of the front-line extension officers from the area, from which a sample of households was selected for interviews. Since the size of cattle keepers among the selected wards and villages vary, and to ensure that every household in the target population had an equal probability of being selected for the interview, we used probability proportional to size (PPS) approach to determine the number of farmers to interview from each village. A total of 632 households were randomly selected for the interviews. Of these sampled households, about 30% were using *icipe* TCRT. The number of sampled households and the TCRT use status by ward and location are reported in Table 1.

Table 1: Number of sampled livestock keeping households and their TRCT use status by ward and location

Ward	Village	Total sample	TRCT use status Users	Non-users
Kubo South	Kipambani	53	28	25
	Kindongo	52	27	25
	Katangini	64	25	39
	Mangawani	89	31	58
	Kinango Ndogo	22	15	7
	Mkanda	33	23	10
	Msulwa Tangini	27	15	12

	Msulwa Viriko	43	14	29
	Mawia	74	34	40
Mkongani	Zunguruka	47	2	45
	Mlafyeni	78	2	76
Tsimba Golini	Msulwa	50	22	28
Total		632	238	394

Before conducting the household level survey, a community level study through focus group discussions (FDGs) was conducted in six of the 12 villages. The purpose of the FDGs was to provide preliminary information on the farmers' knowledge and perceptions of the tsetse management technologies promoted by *icipe*, as an input in designing the later in-depth household-level survey for comprehensive empirical impact analysis. The FDGs were conducted in June 2017. Information on the perceived benefits of the technologies was also captured as well as their willingness to purchase them once made commercially available. These findings are presented to a different paper that is currently under peer review. The household-level survey was conducted in September and October 2018.

The survey covered detailed household, farm, and contextual information. Using a semi-structured questionnaire, trained enumerators collected information on socioeconomic and demographic characteristics of the respondents and their households, livestock production and marketing, knowledge, perception, and management of tsetse and trypanosomiasis including *icipe* developed and promoted technologies, availability, and access to agricultural support services (extension services), social capital and networks, and other contextual data. Recall information on perceived benefits of the TRCT and other *icipe* efforts in the management of tsetse and AAT was also collected, up to seven years ago before the introduction of the technologies. To ensure the data collected as accurately as possible, the survey was administered to the head of the household, and in their absence, the spouse. The survey tool and data collection protocol were reviewed and approved by the *icipe* science committee before the commencement of the survey. Data were collected using a pre-tested digital questionnaire programmed in CSPro 7.0 data collection software. The enumerators begin the survey by requesting the respondent's consent to ensure voluntary and ethical participation by the farmers in the survey. The qualitative data obtained earlier through FDGs complemented the household survey data and further augmented the analysis of the impact of TRCT.

2.2. Descriptive statistics

2.2.1 Perceived benefits of the tsetse repellent collar technology

As highlighted in the previous section data on perceived benefits of the TRCT was captured for two periods: - recall period seven years ago (before introduction) and currently. The perceived benefits include the change in herd size, market value of different animal types, AAT prevalence, and related animal mortality, among other economic indicators as outlined below. In this study

Table 2 shows ownership of major livestock from the survey respondents comparing currently and 7 years ago before the TRCT was introduced. About 85% (535 households) of the respondents owned an average of 3.17 indigenous cows, while only 15 households had an exotic or a crossbreed cow. Out of the sample, only 58% (368 households) owned indigenous cows before icipe TRCT was introduced, although the average ownership was higher than the currently owned (4.04 cows). Generally, ownership of all categories of animals increased after the introduction of TRCT across the survey respondents, but the size of the herd remained within the same range or decreased. It is important to note here that although most of the sampled households were not using TRCT, a significant number (89%) were aware of the technology, and a few stated that they also benefited (spillovers) from those who were using it. On average livestock contribute about 27% of the total annual household income, while collectively, farming contributes about 54%.

Table 2: Livestock ownership currently and before the introduction of TRCT

	Livestock ownership	Total sample (n=632)			TRCT Users (n=238)			TRCT Non-users (n=394)			
		Household (count)	Mean	SD	Household (count)	Mean [A]	SD	Household (count)	Mean [B]	SD	Difference [A-B]
Indigenous cows	Currently	535	3.17	3.19	212	3.12	2.98	323	3.20	3.33	-0.08
	Before TRCT	368	4.04	3.61	160	4.29	4.06	208	3.86	3.21	0.43
Exotic/ crossbreed	Currently	15	1.80	1.90	12	1.75	2.01	3	2.00	1.73	-0.25
	Before TRCT	3	2.67	1.53	3	2.67	1.53	0	0.00		2.67***
Oxen	Currently	498	2.80	1.24	195	2.60	1.06	303	2.93	1.33	-0.33***
	Before TRCT	367	3.34	2.08	149	3.19	1.86	218	3.45	2.21	-0.26
Bulls	Currently	193	2.15	1.49	72	2.36	1.54	121	2.02	1.45	0.34
	Before TRCT	119	2.61	1.66	56	2.59	1.65	63	2.62	1.68	-0.03
Heifers	Currently	252	2.29	1.84	102	2.33	1.89	150	2.26	1.81	0.07
	Before TRCT	115	3.40	2.51	50	2.86	2.03	65	3.82	2.77	-0.96**
Calves	Currently	361	2.23	1.61	150	2.33	1.67	211	2.16	1.56	0.18
	Before TRCT	188	3.17	2.32	86	2.93	2.08	102	3.37	2.51	-0.44

Significant at *10%, **5%, ***1%; *Source*: Household baseline survey

Table 3 presents the perceived values of the different animal types, currently and 7 years ago. The current perceived values are significantly different from values 7 years ago across all animal types. For instance, on average, oxen would be sold at KES 32,334 now compared to KES 26,803 before the introduction of icipe collars. The significant change in animal values agrees with the qualitative study carried out earlier in the study area through focus group discussions.

Table 3: Perceived value (Kenya shillings, KES) of different animal types currently and 7 years ago

Animal type	Total sample			TRCT users	TRCT Non- users	
	Currently [a]	Value 7 years ago [b]	Difference [a-b]	Currently [c]	Currently [d]	Difference [c-d]
Indigenous cows	24,354 (7,364.20	19,346 (6,734.11)	5008.19***	24,825.44 (519.49)	24035.6 412.93	789.84
Exotic or cross breed	70,133 (42,605.95)	33,000 (21,213.20)	37133.33	68,916.67) (11,306.65)	75,000.00 (37,527.77)	6083.33
Oxen	31,797 (9,825.63)	26,570 (9,031.33)	5226.59***	611.37 (623.12)	31,937.71 (31,578.13)	-359.59
Bulls	28,206 (10,510.83)	23,717 (8,176.85)	4489.02***	29,401.41 (1,198.83)	27,474.14 (996.34)	1927.27
Heifers	16,333 (5,402.69)	13,001 (6,430.99)	3331.58***	16,613.86 (576.52)	16,135.42 (426.83)	478.45
Calves	10,599 (3,739.28)	8,719 (3,434.24)	1880.51***	11,231.29 (306.69)	10,136.82 (260.67)	1094.48**

Significant at *10%, **5%, ***1%; *Source*: Household baseline survey
Note: Exchange rate during the period of the survey was KES 100 for 1US$.

Table 4 shows the perceived severity of prevalence and mortality rates related to trypanosomiases before and after the introduction of the TRCT as reported by the survey respondents. Out of the 88% that responded positively to this question, only 18% of them rated the prevalence of the disease high currently. This is significantly lower compared to 93% who rated the disease high before the introduction of the TRCT. Similarly, most of the respondents rated the mortality rate low (63%) currently, compared to 7 years ago (85%).

Table 4: Tsetse fly/ trypanosomiasis infestation and severity

	Currently (%)				7 years ago (%)			
Variable	Pooled [a]	TRCT users [b]	TRCT non-users [c]	Difference [b-c]	Pooled [d]	TRCT users [e]	TRCT on-users [f]	Difference [e-f]
Tsetse infestation	88.13	85.71	89.60	3.88	85.62	90.60	82.60	0.80**
Prevalence				Pearson χ2				Pearson χ2
High	16.14	14.6	22.40	25.08***	79.68	79.68	77.60	14.06***
Medium	34.81	33.53	40.00		4.11	3.16	8.00	
Low	37.18	40.04	25.60		1.74	2.17	0.00	
No tsetse incidence	11.87	11.83	12.00		14.87	14.99	14.40	
Mortality								
High	8.39	8.09	9.60	17.36***	70.57	70.81	69.60	12.05***
Medium	24.21	23.08	28.80		8.86	8.68	9.60	
Low	55.54	57.00	49.60		3.64	2.96	6.40	
No trypanosomiasis incidence	11.87	11.83	12.00		16.93	17.55	14.40	

Significant at *10%, **5%, ***1%; *Source*: Household baseline survey

Table 5 shows the perceived change in other economic benefits of using icipe TRCT in addition to reduced prevalence of trypanosomiasis and mortality rate related to the disease. Over half (52%) of the survey respondents agreed that abortion rates had decreased. About 42% felt that the calving interval had decreased, while 35% said there no change. Agreeing with our earlier qualitative study, most of the respondents reported that milk production (liters/animal/day) increased (45%), frequency of treating animals and subsequently the expenditure on livestock decreased, grazing period increased, and market value for oxen increased significantly. More respondents however felt that there was no change in traction power, the number of oxen owned, and the size of land cultivation.

Table 5: Perceived change in livestock parameters since the introduction of tsetse repellant collars technology

Parameters (n=632)	Currently		7 years ago		Difference	Currently by TRCT				Difference
						TRCT users		**TRCT non-users**		
	Mean [a]	SD	Mean [b]	SD	**[a-b]**	Mean [c]	SD	Mean [d]	SD	**[c-d]**
Abortion rate (% in every 10 in calves)	6.69	9.31	28.85	26.66	-22.16***	7.10	10.10	6.41	8.74	0.68
Calving interval (months between two calving)	11.66	4.43	16.15	5.40	-4.49***	11.56	4.33	11.73	4.51	-0.17
Lactation period (months)	7.70	2.75	6.60	3.11	1.10***	7.64	2.61	7.75	2.84	-0.11
Milk production (liters/animal/day)	1.76	1.17	1.27	1.17	0.48***	1.71	0.94	1.79	1.31	-0.09
Livestock treatment frequency (number of times in 6 months)	3.73	3.34	6.99	5.33	-3.25***	3.32	3.09	3.99	3.46	-0.67**
Livestock treatment expenditure (KES/animal/year)	2,512.26	3,583.36	3,895.76	5,165.55	-1383.50***	2,089.60	4,024.49	2,790.66	3,236.69	-701.06**
Traction/draft power(days/acre)	2.48	3.19	3.20	2.55	-0.72***	2.19	2.50	2.68	3.57	-0.49*
Grazing period (hours/day)	6.95	2.04	5.09	1.45	1.86***	6.89	1.52	6.99	2.30	-0.09
Number of oxen owned	2.34	1.53	2.63	2.46	-0.29*	2.25	1.35	2.39	1.63	-0.14
Land Cultivated (acres)	3.62	3.87	3.10	3.45	0.83***	3.72	3.37	4.06	4.16	-0 .34
Oxen market price/value (KES/oxen)	31,027.09	11,529.03	24,057.85	10,028.17	6969.24***	31,666.35	11,846.47	30,615.85	11,319.29	1050.497

Significant at *10%, **5%, ***1%; *Source*: Household baseline survey; *Note:* Exchange rate during the period of the survey was KES 100 for 1US$.

2.2.2. Description of regression variables

Table 6 presents the definitions of variables used in the regression models, as well as summary statistics and statistical significance tests on equality of means for continuous variables and equality of proportions for binary variables for the TRCT users *versus* non-user households.

Independent variables

We control farm and farmer characteristics including livestock management characteristics, social capital and networks, demographic and resources indicators, access to information, and institutional and market services. The selection of the variables is based on agricultural technology adoption literature (e.g., Blake et al., 2007; G. Feder et al., 1985; Kassie et al., 2011; Marenya & Barrett, 2007; Teklewold et al., 2013).

Among the livestock keeping and management characteristics, we considered the size of the herd, ownership of oxen, and use of animal vaccination and commercial animal feeds. On average, the sampled farmers owned about 5.8 TLU of livestock, and the difference was not statistically different between TRCT users and non-users. The size of the animal herd is expected to be positively associated with the outcome variables. About 79% of the respondents owned oxen, which are kept mainly for draft power as also observed by Mbahin et al. (2013) and Ohaga et al. (2007). Seventy (70%) and 49% percent of the TRCT users and non-users used animal vaccination, and the difference was significant. Farmers adopting modern technologies such as vaccination are expected to be more likely to adopt other innovations such as TRCT and subsequently higher impact on household welfare.

On average, a higher proportion (24%) of TRCT users are members of the rural institutions (e.g., producer and marketing organizations and networks) than TRCT non-users (6%). In rural areas where information access is limited and markets imperfect, social capital and networks are important in facilitating the exchange of information, enabling farmers to access inputs and overcome marketing and credit constraints (Barrett, 2005; Shiferaw et al., 2015). Participation in social networks is therefore expected to impact positively on household welfare.

There are significant differences in gender, age, and household size: TRCT users are older but have more years of education than their TRCT non-users counterparts. While the age of a farmer is often associated with short-planning horizons and risk-averseness (Kassie et al., 2013), experience increases with age, suggesting better knowledge and assessment of benefits of adoption of an innovation such as TRCT (Angella et al., 2014). There are more male-headed households among the TRCT non-users than TRCT users. Female-headed households are more constrained in access to productive resources such as land, labor, and market information, in comparison with men (Quisumbing & Pandolfelli, 2010), thus may be intrigued to use TRCT to increase their returns from livestock keeping. Education, on the other hand, used as a proxy for human capital and technical skills, is associated with more awareness of the benefits of technology and a greater ability to interpret new information to address production constraints (Pender & Alemu, 2007).

With respect to access to information and market services, more TRCT users had on average accessed livestock training within the last 12 months before the survey compared to. Credit constrained variable defined in this study as a 1 if a household needed credit but unable to get and zero otherwise following (Gershon Feder et al., 1990), is significantly different between TRCT users and non-users. More TRCT users (53%) were credit constrained than the TRCT non-users (41%). This is plausible as TRCT users are expected to seek capital to invest in their farm enterprises such as TRCT to increase their farm returns. Distance to the main farm produce was also significantly different across the two groups of farmers, with TRCT users reporting on average more walking minutes (241 min) in comparison to the TRCT non-users (200 min). Access to the output market may provide easy disposal of the produce to buyers, information, support institutions such as credit facilities, and the opportunity cost of labour, which might all influence technology adoption and livelihood impact (Pender & Alemu, 2007).

Table 6: Descriptive statistics and description of variables for treatment and control households

	Description of variables	TRCT users Mean [A]	TRCT users St. Dev.	TRCT non-users Mean [B]	TRCT non-users St. Dev.	Difference [A-B]
Outcome variables						
Livestock income	Net annual livestock income (Ksh/household)	23,559.45	35,943.55	28,260.14	94,832.39	-4,700.68
Headcount ratio	Headcount ratio (1=if household per capita income is below the poverty line; 0 =otherwise)	0.83	0.02	0.85	0.02	-0.02
Land Cultivated (hectares)	Size of farm cultivated by the household in hectares	1.89	1.30	1.90	1.88	-0.02
Household food insecurity coping strategy index (CSI)	Household food insecurity coping strategy index (CSI)	22.83	41.11	31.76	50.30	-8.93**
Household hunger scale (HHS)	Household hunger scale (HHS)	3.98	3.15	4.55	3.60	-0.57*
Individual Dietary diversity score	Individual (women) dietary diversity score (DDS)	4.96	1.57	4.67	1.82	0.29*
Independent variables						
Livestock keeping characteristics and management						
Size of the livestock (TLU)	Owned livestock in tropical livestock units (TLU)	5.90	4.01	5.67	3.93	0.23
Use animal vaccination	Used animal vaccination last 12 months (0=No, 1=Yes)	0.70	0.46	0.49	0.50	0.21***
Use commercial feed or minerals	Use commercial livestock feed last 12 months (0=No, 1=Yes)	0.27	0.44	0.26	0.44	0.01
Own oxen	Own an ox for home use or hiring out (0=No, 1=Yes)	0.82	0.39	0.77	0.42	0.05
Social capital and networks						
Rural institutions	Participate in rural institutions e.g. Producers Organization (0=No;1=Yes)	0.24	0.43	0.06	0.23	0.18***
Household characteristics and resources						
Gender	Sex of the household head (0=female;1=male)	0.81	0.40	0.86	0.35	-0.05*
Age	Age of household head (years)	55.26	14.26	51.46	13.82	3.81***
Education level	Education of the household head (years)	7.77	3.97	7.11	4.07	0.66*
Household size	Adult equivalents in the house (adult equivalent)	2.83	0.98	2.94	1.02	-0.11
Off-farm income	Access to off-farm income (0=No; 1=Yes)	0.65	0.48	0.68	0.47	-0.02
Access to information and institutional and market services						
Livestock training	Access to livestock management training within 12 months prior to the survey (0=No; 1=Yes)	0.33	0.47	0.13	0.34	0.20***
Extension proximity	Distance to the nearest government veterinary extension office from residence (walking minutes)	114.30	88.04	109.06	80.62	5.24
Credit	Credit constrained (0=No; 1=Yes)	0.53	0.50	0.41	0.49	0.12**
Market distance	Distance to the main farm produce (livestock and crops) market from residence (walking minutes)	240.92	136.70	199.71	119.78	41.21***
Means of communication	Household owns a means of communication (TV/RADIO/PHONE) (1=Yes, 0=No)	0.97	0.16	0.95	0.22	0.03*
Means of transport	Household owns a means of transport (car/van/motorbike/bicycle) (1=Yes, 0=No)	0.40	0.49	0.39	0.49	0.01

Significant at *10%, **5%, ***1%

Dependent variables

Regarding the direct welfare impact of using the TRCT, a comparison of livestock income between the users and non-users shows that non-users reap higher income, but the difference is not statistically significant (Table 6). Similar results are also shown regarding cultivated land between TRCT users and non-users. We further compare poverty and food security measures between the two groups of farmers. We measure poverty using the headcount ratio, which is a dummy defined as 1 if the household per capita income is below the poverty line and zero otherwise following Kassie et al. (2011). In the study area, poverty is extremely high, with the County's absolute poverty estimated to be about 74.9% (County Government of Kwale, 2013), while the overall poverty headcount rate for individuals in the County estimated at 47.4% (national level is 36.1%) (County Government of Kwale, 2018). The headcount ratio from our study was on average 84% for both TRCT users and non-users and the difference was not significant.

We compare, between TRCT users and non-users, three measures of food security; Household food insecurity coping strategy index (CSI) (Maxwell & Caldwell, 2008), Household hunger scale (HHS) (Ballard et al., 2011), and Individual dietary diversity score (DDS). The CSI measures households' behaviour, that is, the things that people do when they cannot access enough food or coping strategies (Maxwell & Caldwell, 2008). Consequently, the higher the CSI, the more food insecure a household is. The CSI has been previously used for early warning and food monitoring and assessment in Sub-Saharan Africa, the Middle East, and Asia ((Maxwell & Caldwell, 2008). HHS is a household food deprivation scale constructed based on the premise that when a household experiences food deprivation, the reactions can be captured through a survey and summarized on a scale (Ballard et al., 2011). A high HHS indicated severe hunger in the household. Individual DDS, on the other hand, reflects nutrient adequacy. Previous studies have shown that an increase in dietary diversity is correlated with household socioeconomic status and food security (household energy availability) (Hoddinott & Yohannes, 2002). On average TRCT users had a lower CSI (22.8) compared to the TRCT non-users (31.8) and the difference was significant, suggesting that the TRCT non-users are more food insecure than the users. The results corroborate with the HHS which is also higher for the TRCT non-users and significantly different from that of the TRCT users. The two food security indicators also correlate with the Individual (women) DDS, which was higher among the TRCT users and significantly different from that of the TRCT non-users. In this study, we considered women's DDS due to data availability and better representation in all the sampled households, compared for instance to children DDS.

3. Econometric approach

Assessing the impact of technology adoption using observational studies is empirically challenging in identifying a suitable counterfactual against which the impact can be measured. This is, we cannot observe the outcome variables for adopters, in case they did not adopt (or the reverse). These challenges result in self-selection bias and unobserved heterogeneity concerns. These problems however can be addressed using experimental research designs such as the randomized control trial (RCT) by randomly assigning adoption to treatment and control status (Angelucci and Di Maro 2010; Gertler *et al*., 2016). However, as applies to our current study, budgetary or ethical reasons may limit the use of experimental designs. Thus, to appropriately estimate the effect of TRCT with a non-experimental or quasi-experimental evaluation design, we use control groups that are not affected by the technology either directly or indirectly.

The standard approaches for dealing with the problem of self-selection in a quasi-experimental evaluation are the instrumental variable (IV), two-step Heckman, matching methods (Baker, 2000; Kassie et al., 2011). Each of these methods, however, has some limitations. For example, both IV and two-step Heckman methods tend to impose a functional form assumption by presuming that adoption of TRCT has only an intercept shift and not a slope shift in the outcome variables (Alene & Manyong, 2007). The PSM on the other hand addresses this problem by avoiding functional form assumption and assuming the selection is based on observable variables. It however ignores the unobservable characteristics, such as innate abilities, skills, and motivation that might affect the adoption process, and thus challenged in some empirical analysis (e.g.Asfaw et al., 2012; Di Falco et al., 2011; Shiferaw et al., 2014; Teklewold et al., 2013). To address these issues, we adopt the endogenous switching regression (ESR) to estimate the impact of TRCT using the extensive household-level survey data from Kwale County, Kenya.

3.1 Endogenous switching regression

We use endogenous switching treatment effect regression in a counterfactual framework to estimate the causal effects of TRCT on the selected impact outcomes, measured by the average treatment effect on the treated (AAT). The AAT calculates the average difference in impact outcomes of the treated with and without the technology. ESR is increasingly being used in evaluating the impact of farmer's decisions on household well-being or farm performance (e.g. Khonje et al., 2015; Tambo & Wünscher, 2017). To model the effect of using TRCT of the selected household outcomes using the ESR framework, separate outcome equations are specified for each regime, conditional on a selection equation. In our study, we estimate separate household impact outcomes for TRCT users and non-users, conditional on the TRCT use decision:

$$P_i = Z_i\alpha + \varepsilon_i \quad (1)$$

$$\text{Regime 1: } y_{1i} = X_{1i}\boldsymbol{\beta}_1 + \mu_{1i} \text{ if } P=1 \quad (2)$$

$$\text{Regime 2: } y_{2i} = X_{2i}\boldsymbol{\beta}_2 + \mu_{2i} \text{ if } P=0 \quad (3)$$

where P is a binary variable 1 or 0 for the use of TRCT; P=1 if the household uses TRCT and P=0 otherwise;Z is a vector of household and farm characteristics that might influence TRCT use; α is a vector of parameters of the selected characteristics to be estimated, and ε is the random error term. y_1 and y_2 represent a vector of welfare variables, described in the previous section, for TRCT users and non-users respectively, and $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_2$ are there corresponding parameters to be estimated, and random disturbance terms μ_1 and μ_2. The estimation of $\boldsymbol{\beta}_1$ and $\boldsymbol{\beta}_2$ using OLS may lead to biased estimates if the error term of the selection equation (ε) is correlated with the disturbance terms of the outcome equations (μ_1 and μ_2) (Shiferaw et al., 2014).The error terms ε, μ_1 and μ_2 are assumed to have a joint-normal distribution with mean vectir zero and a covariance matrix (Fuglie & Bosch, 1995).

$$\Omega = cov(\varepsilon, \mu_1, \mu_2) = \begin{bmatrix} \sigma_\varepsilon^2 & \sigma_{\varepsilon\mu_1} & \sigma_{\varepsilon\mu_2} \\ \sigma_{\varepsilon\mu_1} & \sigma_{\mu_1}^2 & \sigma_{\mu_1\mu_2} \\ \sigma_{\varepsilon\mu_2} & \sigma_{\mu_1\mu_2} & \sigma_{\mu_2}^2 \end{bmatrix} \quad (4)$$

where

$\sigma_\varepsilon^2 = \text{var}(\varepsilon), \sigma_{\mu_1}^2 = \text{var}(\mu_1), \sigma_{\mu_2}^2 = \text{var}(\mu_2), \sigma_{\varepsilon\mu_1} = cov(\varepsilon, \mu_1)$, and $\sigma_{\varepsilon\mu_2} = cov(\varepsilon, \mu_2)$. The σ_ε^2 is assumed to be equal to 1 since α is only estimable only to a scalar factor, and since y_1 and y_2 are never observed simultaneously, the covariance between μ_1 and μ_2 (i.e. $\sigma_{\mu_1\mu_2}$) is not defined (Maddala, 1983). Since the error term of the selection equation (ε), is correlated with the error terms of the outcome variables (μ_1 and μ_2), the expected values of μ_1 and μ_2 conditional on the sample selection are non-zero (Asfaw et al., 2012).

$$E(\mu_1|P=1) = \sigma_{\varepsilon\mu_1}\frac{\phi(Z_i\alpha)}{\Phi(Z_i\alpha)} \equiv \sigma_{\varepsilon\mu_1}\lambda_1 \quad (5)$$

$$E(\mu_1|P=0) = \sigma_{\varepsilon\mu_2}\frac{\phi(Z_i\alpha)}{1-\Phi(Z_i\alpha)} \equiv \sigma_{\varepsilon\mu_2}\lambda_2 \quad (6)$$

where ϕ is the standard normal probability density function, Φ the standard normal cumulative density function and λ_1 and λ_2 are inverse mills ration (IMR) calculated from the selection Eqn. (1). The IMR is included in Eqns. (2) and (3) to correct for selection bias in a two-step estimation procedure, thus the endogenous switching treatment regression model, specified as (Maddala, 1983);

$$y_{1i} = X_{1i}\boldsymbol{\beta_1} + \sigma_{\varepsilon\mu_1}\lambda_1 + \xi_1 \text{ if } P=1 \quad (7)$$

$$y_{2i} = X_{2i}\boldsymbol{\beta_2} + \sigma_{\varepsilon\mu_2}\lambda_2 + \xi_2 \text{ if } P=0 \quad (8)$$

The above can be estimated using the full information maximum likelihood (FIML) approach which estimates the selection and outcome equations simultaneously (Lokshin & Sajaia, 2004). While the FIML ESR approach is identified through non-linearities of the IMR (λ_1 and λ_2), a better identification requires exclusion restriction (Shiferaw et al., 2014). That is *Z* variables in the selection Eq. (1) contain at least one selection instrument that affects TRCT use in our case but does not directly affect any of the impact outcome variables. Following previous studies on the adoption of agricultural innovations (e.g. Asfaw et al., 2012; Khonje et al., 2015; Tambo & Wünscher, 2017), we used membership in a rural institution/group (yes=1) as our selection instrument. Following Di Falco et al. (2011) the validity of the selection instruments was established by performing a falsification test; if a variable is an appropriate instrument, it will affect TRCT use decision but it will not affect the impact outcome variable. We found the selection instrument satisfies these conditions.

The above ESR framework can be used to estimate the average treatment effect of the treated, (ATT), and the untreated (ATU), by comparing the expected values of the impact outcome variables of the TRCT users and non-users in both actual and counterfactual scenarios. While the ATT compares the outcomes of TRCT users with and without TRCT, the ATU compares the outcomes of the TRCT non-users with and without the TRCT technology. Following Di Falco et al. (2011), Shiferaw et al., 2014), and Khonje et al. (2015), we calculate ATT and ATU as follows:

For the households using TRCT technology (observed in the sample)

$$E(y_{1i}|P = 1; X) = X_{1i}\boldsymbol{\beta_1} + \sigma_{\varepsilon\mu_1}\lambda_{1i} \quad (9)$$

TRCT non-users (observed in the sample)

$$E(y_{2i}|P = 0; X) = X_{2i}\boldsymbol{\beta_2} + \sigma_{\varepsilon\mu_2}\lambda_{2i} \quad (10)$$

TRCT had they decided not to use the technology (counterfactual)

$$E(y_{2i}|P=1;X) = X_{1i}\boldsymbol{\beta_2} + \sigma_{\varepsilon\mu_2}\lambda_{1i} \quad (11)$$

TRCT non-users had they decided to adopt (counterfactual)

$$E(y_{1i}|P=0;X) = X_{2i}\boldsymbol{\beta_1} + \sigma_{\varepsilon\mu_1}\lambda_{2i} \quad (12)$$

The average treatment effect on the treated (ATT) is calculated as the difference between Eqns. (9) and (11);

$$ATT = (y_{1i}|P=1;X) - (y_{2i}|P=1;X) \quad (13)$$
$$= X_{1i}(\beta_1 - \beta_2) + \lambda_{1i}(\sigma_{\varepsilon\mu_1} - \sigma_{\varepsilon\mu_2})$$

The average treatment effect on the untreated (ATU) is calculated as the difference between Eqns. (12) and (10);

$$ATU = (y_{1i}|P=0;X) - (y_{2i}|P=0;X) \quad (14)$$
$$= X_{2i}(\beta_1 - \beta_2) + \lambda_{2i}(\sigma_{\varepsilon\mu_1} - \sigma_{\varepsilon\mu_2})$$

The first term on the right side of Eqn. (13) show the expected change in TRCT users' mean outcome, if the users' had similar characteristics to TRCT non-users. The second term (λ) is the selection term that captures all potential effects of the difference in unobserved characteristics. Similarly, the first term on the right side of Eqns. (14) show the expected change in the TRCT non-users' mean outcome of non-users had similar characteristics to TRCT users. The second term adjusts the ATU for the effect of unobservable factors.

4. Empirical results and discussion

The descriptive analysis in the previous section revealed significant differences in some of the outcome variables between the TRCT users and non-users. Similarly, the qualitative survey revealed positive perceived benefits of TRCT. However, to properly analyze the impact of TRCT, we use an econometric model, the FIML ESR. The model involves a selection equation and separate outcome equations for the TRCT adoptions and non-adopters, which are estimated simultaneously. The first equation reveals the determinants of the use of TRCT, and the results are shown in Table 7. This model exclusion restriction variables: membership in a rural institution (yes=1), are statistically significant in all the models, hence satisfying the instrument relevance condition. Besides, the positive coefficient of the instrument confirms that households who are members of groups are likely to adopt the TRCT.

Table 7: First stage results of the FIML ESR models

	Livestock income	Headcount ration	Land Cultivated (hectares)	Household food insecurity coping strategy index (CSI	Household hunger scale (HHS)	Individual (Women) Dietary diversity score (WDDS)
Size of the livestock (TLU)	0.000 (0.015)	0.002 (0.015)	0.003 (0.015)	0.003 (0.015)	0.002 (0.015)	0.01 (0.015)
Use animal vaccination	0.433 (0.113)***	0.38 (0.117)***	0.384 (0.115)***	0.38 (0.115)***	0.385 (0.115)***	0.418 (0.107)***
Gender of household head	-0.406 (0.154)***	-0.428 (0.155)***	-0.415 (0.155)***	-0.42 (0.155)***	-0.404 (0.155)***	-0.397 (0.145)***
Age of household head	0.018 (0.004)***	0.019 (0.004)***	0.019 (0.004)***	0.019 (0.004)***	0.019 (0.004)***	0.016 (0.004)***
Education level of household head	0.036 (0.015)**	0.037 (0.015)**	0.037 (0.015)**	0.037 (0.015)**	0.037 (0.015)**	0.035 (0.014)**
Household size	-0.029 (0.057)	-0.016 (0.057)	-0.018 (0.057)	-0.016 (0.057)	-0.023 (0.057)	-0.073 (0.056)
Off-farm income	-0.166 (0.120)	-0.168 (0.121)	-0.169 (0.121)	-0.173 (0.121)	-0.16 (0.121)	-0.158 (0.113)
Extension proximity	0.000 (0.001)	0.000 (0.001)	0.000 (0.001)	0.000 (0.001)	0.000 (0.001)	0.000 (0.001)
Credit constrained	0.199 (0.111)*	0.234 (0.112)**	0.229 (0.112)**	0.231 (0.112)**	0.222 (0.112)**	0.276 (0.104)***
Market distance	0.001 (0.000)***	0.001 (0.000)**	0.001 (0.000)**	0.001 (0.000)**	0.001 (0.000)**	0.001 (0.000)***
Means of communication	0.262 (0.291)	0.295 (0.302)	0.295 (0.298)	0.292 (0.297)	0.293 (0.297)	0.273 (0.266)
Mean of transport	-0.117 (0.116)	-0.103 (0.117)	-0.105 (0.117)	-0.103 (0.117)	-0.116 (0.117)	-0.004 (0.111)
Use commercial feed or minerals	-0.132 (0.126)	-0.121 (0.127)	-0.11 (0.127)	-0.115 (0.127)	-0.122 (0.127)	-0.166 (0.118)
Own oxen	0.202 (0.140)	0.179 (0.145)	0.174 (0.142)	0.175 (0.141)	0.181 (0.141)	0.112 (0.131)
Livestock training	0.445 (0.139)***	0.47 (0.142)***	0.456 (0.139)***	0.46 (0.139)***	0.388 (0.139)***	0.164 (0.095)*
Rural institutions	1.069 (0.167)***	0.889 (0.183)***	0.851 (0.176)***	0.855 (0.175)***	0.892 (0.172)***	0.529 (0.131)***
Constant	-2.148 (0.476)***	-2.25 (0.491)***	-2.24 (0.485)***	-2.243 (0.484)***	-2.228 (0.481)***	-1.909 (0.440)***

Significant at *10%, **5%, ***1%. Standard errors in parentheses.

4.1. The welfare impacts of TRCT use

The second stage estimates of the FIML ESR models for the different impact outcomes are presented in Table 8. The results show the effect of each explanatory variable on the outcome variables. The correlation coefficients between the error terms of the selection and outcome equations (ρ1, ρ2), reported at the bottom of Table 8, indicate the status of selection bias. A statistical significance of either of them suggests self-selection would be a problem if not accounted for. The correlation coefficients for the livestock income, headcount ratio, household hunger scale (HHS), and individual dietary diversity score are significant but only for the TRCT in the former models. The latter model is significant for both TRCT users and non-users. For the livestock income model, for instance, the significant correlation implies that households with lower-than-average livestock income are more likely to use TRCT, non-TRCT non-users are not better or worse-ff than a random household. The log-likelihood ratio tests for independence of equations are significant implying that there is joint dependence between the selection equations and outcome equations for TRCT users and TRCT non-users.

Table 8 shows the effects of the independent variables on the outcome variables. For instance, a large herd of livestock contributes positively to livestock income, size of land cultivated, and WDDS, but negatively to headcount ratio, and food security coping strategy index among the TRCT non-users. Similarly having an ox positively influences livestock income, and land cultivated among the TRCT users. This is expected as animals are the main source of draft power in this region. As expected, and consistent with related literature, there are notable differences across different outcome variables regarding the household characteristics, resources, information access, and market access variables as demonstrated in Table 8.

Table 8: Endogenous switching regression estimates for selected household welfare outcomes

	Livestock income		Headcount ratio		Land Cultivated (hectares)		Household food insecurity coping strategy index (CSI)		Household hunger scale (HHS)		Individual (Women) dietary diversity score (WDDS)	
	TRCT users	TRCT non-users	TRCT users	TRCT non-users	TRCT users	TRCT non-users	TRCT users	TRCT non-users	TRCT users	TRCT non-users	TRCT users	TRCT non-users
Size of the livestock	791.062	4974.392	-0.008	-0.011	0.002	0.050	-0.468	-1.107	0.013	-0.014	0.017	0.048
(TLU)	(597.298)	(1,236.742)***	(0.006)	(0.005)**	(0.021)	(0.025)**	(0.658)	(0.648)*	(0.052)	(0.046)	(0.030)	(0.027)*
Use commercial feed	5007.147	17407.879	0.010	0.007	0.332	-0.264	-8.397	-3.300	-1.480	0.302	0.247	0.188
or minerals	(5,270.335)	(10,748.052)	(0.054)	(0.041)	(0.182)*	(0.213)	(5.816)	(5.631)	(0.454)***	(0.400)	(0.259)	(0.230)
Use animal	-13378.522	8776.765	0.062	-0.058	0.061	0.244	1.640	4.859	1.005	0.573	-0.075	0.641
vaccination	(5,294.798)**	(9,933.008)	(0.054)	(0.059)	(0.196)	(0.200)	(5.947)	(5.397)	(0.513)*	(0.421)	(0.251)	(0.208)***
Own oxen	13279.147	-1355.256	-0.064	0.045	0.394	0.273	-14.495	-1.295	-0.310	0.141	0.122	-0.036
	(6,187.375)**	(11,781.546)	(0.064)	(0.046)	(0.216)*	(0.235)	(6.866)**	(6.185)	(0.538)	(0.442)	(0.299)	(0.253)
Gender of household	-2144.843	3732.406	-0.018	-0.058	0.273	-0.161	9.621	2.862	-0.355	0.112	0.112	-0.603
head	(6,194.345)	(14,512.522)	(0.064)	(0.065)	(0.216)	(0.288)	(6.838)	(7.669)	(0.549)	(0.559)	(0.314)	(0.299)**
Age of household	111.747	-220.767	0.003	0.002	0.020	0.020	-0.537	-0.072	-0.010	-0.012	-0.009	0.015
head	(185.246)	(391.825)	(0.002)	(0.002)	(0.007)***	(0.008)**	(0.207)***	(0.213)	(0.018)	(0.017)	(0.009)	(0.008)*
Education level of	1329.789	-37.983	0.001	-0.004	0.018	0.015	-1.887	-1.511	-0.051	-0.085	-0.013	0.111
household head	(675.477)**	(1,288.501)	(0.007)	(0.006)	(0.024)	(0.026)	(0.760)**	(0.682)**	(0.062)	(0.050)*	(0.033)	(0.028)***
Household size	1246.268	6199.623	0.063	0.040	0.210	0.007	1.251	-0.044	0.256	-0.121	0.147	0.014
	(2,445.211)	(4,951.917)	(0.025)**	(0.019)**	(0.085)**	(0.098)	(2.707)	(2.594)	(0.211)	(0.185)	(0.122)	(0.107)
Off-farm income	2777.856	13367.939	-0.071	-0.035	0.089	0.074	1.988	-3.240	-1.012	-0.556	0.115	0.035
	(5,209.223)	(10,189.801)	(0.054)	(0.040)	(0.183)	(0.202)	(5.765)	(5.351)	(0.463)**	(0.382)	(0.255)	(0.218)
Livestock training	-34.684	-22.650	0.001	0.000	-0.001	-0.001	0.018	0.031	0.005	0.005	-0.001	0.000
	(27.495)	(60.761)	(0.000)**	0.000	(0.001)	(0.001)	(0.030)	(0.032)	(0.002)**	(0.002)**	(0.001)	(0.001)
Credit constrained	-3324.016	18216.741	0.096	-0.002	-0.163	-0.098	11.881	19.668	0.395	0.944	-0.111	0.235
	(4,803.120)	(9,697.375)*	(0.049)*	(0.045)	(0.171)	(0.193)	(5.344)**	(5.146)***	(0.436)	(0.380)**	(0.237)	(0.204)
Market distance	6.263	43.846	0.000	0.000	0.000	0.000	0.013	-0.004	0.002	-0.002	-0.002	0.004
	(17.714)	(41.971)	0.000	0.000	(0.001)	(0.001)	(0.020)	(0.023)	(0.002)	(0.002)	(0.001)*	(0.001)***
Means of	-11558.072	-6955.854	-0.150	0.163	0.476	-1.140	-1.497	-20.585	1.908	0.241	-1.922	-0.566
communication	(14,802.703)	(21,141.770)	(0.153)	(0.086)*	(0.520)	(0.420)***	(16.507)	(11.134)*	(1.281)	(0.799)	(0.682)***	(0.470)
Mean of transport	-12203.079	8631.756	0.070	-0.033	0.391	0.398	-11.290	-13.706	-0.956	-1.940	-0.017	0.536
	(4,889.783)**	(9,989.222)	(0.050)	(0.039)	(0.169)**	(0.199)**	(5.394)**	(5.244)***	(0.420)**	(0.375)***	(0.243)	(0.214)**
Constant	31092.655	-35977.862	0.448	0.617	-1.115	1.474	70.583	67.920	0.927	6.408	8.802	3.419
	(25,271.136)	(36,920.506)	(0.260)*	(0.156)***	(1.000)	(0.737)**	(29.007)**	(19.494)***	(2.733)	(1.413)***	(1.220)***	(0.805)***
lnσ1, lnσ2	10.5	11.419	-1.002	-1.066	0.188	0.591	3.654	3.865	1.148	1.223	0.726	0.775
	(0.064)***	(0.036)***	(0.058)***	(0.040)***	(0.048)***	(0.036)***	(0.050)***	(0.036)***	(0.099)***	(0.044)***	(0.080)***	(0.051)***

ρ1, ρ2	-0.514	0.026	0.385	0.071	-0.097	0.086	-0.177	0.086	0.576	0.187	-1.395	1.415
	(0.155)***	-0.134	(0.157)**	-0.59	-0.243	-0.151	-0.18	-0.186	(0.325)*	-0.297	(0.219)***	(0.176)***
N	632		632		631		632		632		632	
Wald chi2(14)	27.03**		30.81***		38.54***		35.45***		40.95***		16.89	
Log-likelihood	-8238		-584.3275		-1528.98		-3644.48		-1985.42		-1548.63	

Significant at *10%, **5%, ***1%

Table 9 shows the treatment effects of the TRCT on the selected welfare outcomes. The results show that the use of TRCT reduces livestock income, poverty levels, cultivated land, food insecurity (CSI and HHS), and women's dietary diversity. The unexpected effect of TRCT use on livestock income can be attributed to the fact that smallholder farmers with less income to buy drugs for management of the tsetse are the ones who are more willing to adopt the TRCT as an alternative pest management practice. These observations were made during the qualitative survey and confirmed by the key area informants. The use of TRCT reduces the probability of poverty by 5 percentage points for TCRT users. For the TRCT non-users, the ATU estimates show that the probability of poverty would have been 23 percentage points lower had they adopted the technology. The food security outcomes- household food insecurity coping strategy index and household hunger scale- show that using TRCT decreases food security, an important welfare indicator for agricultural innovations. The ESR results show that using TRCT decreased the CSI and HHS by 15 and 1.5 points respectively among the adopters. The ATU results for the two outcomes indicate that the TRCT non-users would benefit more had they used the technology and the food insecurity outcomes would reduce by about 3 points each[1].

Table 9: ESR-based average treatment effects on adoption

		Decision stage			
Outcome variable	**Treatment effects**	**TRCT user**	**TRCT non-user**	**Average treatment effects**	**Treatment effect (%)**
Livestock income	ATT	23,466.53	36,266.26	-12799.74****	-35.3
	ATU	48,767.1	28,260.25	20506.85****	72.6
Headcount ratio	ATT	0.832	0.881	-0.049****	-5.6
	ATU	0.615	0.850	-0.235***	-27.6
Land Cultivated (hectares)	ATT	1.886	2.240	-0.354***	-15.8
	ATU	1.958	1.903	0.055**	2.9
Household food insecurity coping strategy index (CSI)	ATT	22.829	38.319	-15.490**	-40.4
	ATU	34.738	31.764	2.975***	9.4
Household hunger scale (HHS)	ATT	3.979	5.484	-1.505***	-27.4
	ATU	1.415	4.550	-3.136***	-68.9
Individual (Women) Dietary diversity score (WDDS)	ATT	4.962	7.860	-2.898***	-36.9
	ATU	7.742	4.669	3.073***	65.8

Significant at *10%, **5%, ***1%

5. Conclusion and Policy Implications

This paper attempted to analyze the determinants and impact of a recently developed and disseminated technology (TRCT) for the management of trypanosomiasis transmitting tsetse

[1] We also estimated the treatment effects using the matching method (propensity score matching). The direction of effect was similar to that of the ESR, but the size of the effect varied although by a small margin.

flies using data obtained from over 600 cattle-keeping households in Kwale County, in Kenya. The first stage estimates of the determinants of TRCT use showed that the technology use is significantly associated with the use of cattle vaccination, gender, age, and education level of the household head, livestock training, participation in rural groups, credit constraint, and distance to the market. From these findings, the use of TRCT can be improved by providing access to improved animal management technologies such as vaccination, participation in rural institutions, providing livestock training, and targeting households whose farms are located away from the markets. Institutional innovations such as farmer groups play an important role in providing access to information and collective input purchases and marketing that reduce transaction costs. Livestock training on the other hand provides knowledge and awareness of available technologies to address certain constraints such as the management of tsetse flies. Farmers located away from markets often have fewer livelihood opportunities other than farming, and therefore might be more willing to adopt technologies for enhancing their farming returns.

To assess the impact of TRCT, the study used endogenous switching regression and verified the results using the propensity score matching model. We evaluated the impact of the technology on livestock income, crop income, poverty levels (headcount ratio), and food security (household food insecurity coping strategy index (CSI), household hunger scale (HHS), and women dietary diversity score (WDDS). The ESR estimation shows that the use of TRCT reduced poverty levels and that non-users would have gained significantly had they used the technology. Therefore, the adoption of the tsetse management technology, similarly to other agricultural technologies, may improve household welfare, thus the need for policies that focus on enhancing the use of TRCT including strengthening rural institutions and capacity building of livestock keepers.

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