Controlling Human And Animal African Trypanosomiasis Using Insecticide Treated Cattle: What Are The Costs And Benefits?

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Abstract

Background The tsetse-transmitted African trypanosomiases affect humans and animals. Trypanosoma. brucei rhodesiense sleeping sickness, or human African trypanosomiasis is a zoonosis, for which cattle are the main reservoir of infection in south-eastern Uganda. Transmission of human and animal infective trypanosomes can be reduced by the application of deltamethrin insecticide to the belly and legs of cattle, thus reducing tsetse fly populations. Alongside an epidemiological study in southeastern Uganda, a farm level assessment was done to calculate the average and incremental benefit-cost ratios of spraying different proportions of the village cattle population using this restricted application protocol.

Method A study comprising 2,400 semi-structured interviews was undertaken over a period of 18 months. Financial data on household income and expenditure on cattle provided the basis for the marginal analyses. The benefit of RAP to farmers was assessed using gross margin analysis whereas the costs were obtained from expenses incurred by farmers in participating in the RAP intervention. Subsequently, the RAP intervention villages were compared with a control village to determine the average and incremental benefit-cost ratio across all households.

Results The benefit-cost analysis of spraying 25%, 50% and 75% of the cattle population yielded benefit-cost ratios of 6.22, 5.56 and 4.46. The incremental benefit-cost ratios from spraying each additional 25% of the population cattle were 14.32, 3.97 and 0.79 respectively, showing a very high return on investment in spraying 25% of the population, with returns reducing thereafter.

Conclusion Comparing the gross margins per bovine of applying RAP to different proportions of the cattle population to a pre-intervention situation and a control, the study found that increasing the proportion of cattle sprayed yielded increasing benefits to farmers, but that these benefits were subject to diminishing returns. Given the high proportion of draft males in the cattle population (37%) their important contribution to livestock output and farmers' preference for treating these animals, from a practical viewpoint this study recommends spraying only draft cattle to control trypanosomiasis in this area, although in areas or households with a lower proportion of draft males, farmers could be advised to also include cows.

Background

African animal trypanosomiasis (AAT) and human African trypanosomiasis (HAT) are controlled by targeting the tsetse fly or by using chemotherapeutic/chemoprophylactic trypanocidal drugs [1], [2]. Approaches are often combined in order to improve the effectiveness of control measures [3]. In the past, ground spraying of tsetse breeding and resting sites with residual insecticides and aerial spraying have both been deployed against tsetse flies in Uganda [3], [4]. The drawbacks to large scale spraying of tsetse habitats include environmental degradation, the high costs incurred, the unsuitability of some methods for hilly terrain and the re-invasion of cleared areas [5]. Environmental issues associated with large scale spraying led to the development of bait technologies that can be implemented by the community and these involved the use of odour-baited traps and insecticide-impregnated targets or traps (stationary baits) and insecticide-treated cattle (mobile baits) [6]. Traps have been successfully deployed in Uganda to control human African trypanosomiasis (HAT) during large scale epidemics [7]. The restricted application protocol (RAP) is a form of bait technology that involves spraying of insecticide at dip concentration only to the tsetse predilection feeding sites on cattle (the legs and belly), rather than applying insecticide to the entire animal (as in dipping) or when a concentrated formula is applied along the back of the animal in the case of pour-on formulations [8]. RAP is environmentally friendly and cheaper as it uses less insecticide compared to other methods, while conserving the enzootic stability of tick-borne diseases (TBDs) [9].

Aside from vector control, trypanocidal drugs are used prophylactically and therapeutically to control AAT. It has been estimated that 35 million doses of trypanocides are administered annually in Africa [10]. Control of TBDs and AAT is often considered to be a private good with the farmers frequently expected to pay for the service [11]. To ensure farmers' participation and decrease overall disease impacts, it is vital to have an affordable and effective farmer-led integrated control of both tsetse and tick-borne diseases [12].

Assessments of the economic impacts, the costs and benefits from controlling tsetse and trypanosomiasis [13], [14], [15], are critical for deciding on interventions. Uganda was the subject of one of the earliest studies on the economics of AAT control [16], and more recently the costs of different techniques for tsetse control were estimated for Uganda [17] and an analysis of historic and current tsetse control costs done [18]. The few recent studies that looked at the impact of trypanosomiasis in Uganda include [19], [20], the latter emphasizing the importance of draft power, also later analyzed in more detail [21].

The largest scale study on the impact of AAT was undertaken by the African Trypanotolerant Livestock Network (ATLN) [22]. Similar protocols were implemented in study sites in eight countries, combining the monitoring of cattle, sheep and goats for trypanosomiasis alongside the collection of livestock productivity data, including milk yields [22]. Productivity data from various studies has been used to model the economic impact of AAT and its control in different contexts [23], [24], [25]. Field studies, except for the ATLN studies, have largely been cross-sectional and under-powered with relatively small sample sizes. Obtaining the information required for these analyses is challenging: i) cattle productivity is difficult to measure, and ii) farm level interviews are time-consuming and inclusion of longitudinal studies increases project costs. Studies have almost exclusively directly measured or focused on cattle production parameters (such as deaths, births, weight, milk yields) rather than on the effects on livestock keepers' incomes. Defining a comparator has also been challenging; these have often been based on comparing households or animals who participated in trypanosomiasis control activities (usually referred to as 'with' intervention) to those who didn't ('without' intervention). Other counterfactual estimates have been based on measured prevalence (in the case of the ATLN work), but in an era before the use of molecular techniques or, more often, on comparing sites with high and low AAT prevalence or before and after intervention situations, but without using a control (no intervention) site or livestock population.

For insecticide-treated cattle, there has been little information about the optimal proportion of cattle (live baits) to be sprayed in order to control trypanosomiasis, and therefore calculations had been based on estimates [17]. However, in 2014, Kajunguri and colleagues calculated, that using RAP treating 27% of the herd was sufficient to control *T. brucei sensu lato* [26].

Field studies were undertaken to confirm the modeling work and showed that spraying 25% of cattle using RAP could be effective in preventing clinical re-infection of cattle with trypanosomes in south-eastern Uganda, protecting humans from zoonotic HAT as well as controlling AAT [27]. In south-eastern Uganda, it has been shown that cattle act as the main reservoir for *T. b. rhodesiense*, zoonotic HAT [28], [29], [30]. A study in Dokolo and Kaberamaido districts in south-eastern Uganda found that use of RAP and injection of cattle with the trypanocide diminazene aceturate reduced the prevalence of *T. vivax* from 5.9% to 0.5% in cattle [31].

Our study aimed to gain an understanding of the cost and impact of RAP on cattle farmers including: i) what are the costs and benefits of controlling African trypanosomiasis using RAP from the cattle keeper's perspective? ii) how do these vary with different RAP treatment regimens?, and iii) what are the implications of the findings for effective disease control? To provide a full counterfactual, the study examined farmers' income both before and after the introduction of RAP, and then for the after scenario, for using no RAP as compared to spraying different proportions of the population. By combining this information with both farmer and project costs for RAP, the average and incremental societal benefit-cost ratios from the control of African trypanosomiasis and TBDs by spraying 25%, 50% and 75% of village cattle herds with deltamethrin were calculated.

Methodology

Selection of study villages, households and data collection

The intervention was undertaken from June 2012 to December 2013 in Tororo District, south-eastern Uganda. Tororo is semi-arid with small-holder crop-livestock systems dominating. It is estimated that there are over 400 villages keeping more than 37,345 cattle most of which are males used for draft work, usually referred to as work oxen, whether castrated or uncastrated [32]. The selection of villages for the economic study was based on a concurrent epidemiological study evaluating the effectiveness of controlling trypanosomiasis by spraying different proportions of the cattle population using RAP [27]. Fifty-seven villages were selected for evaluation to meet eligibility for the RAP epidemiological study. The parameters included: i) cattle AAT prevalence of 15% or more, ii) a population of 50 or more cattle in the village, and iii) villages being at least 5 kilometers apart. Of the 57 villages investigated, 20 villages met the criteria for RAP intervention [27].

The sample size (number of households to be studied) was determined using CSurvey software version 2.0 [33] where the prevalence of AAT was set as 30%, rate of homogeneity at 0.15 and the average eligible persons per household as 1. Thereafter, a sample size of 600 households (30 per village) comprising a total of 5,534 individuals was determined for the economic baseline survey.

The 20 selected villages were randomly allocated to five RAP treatments [27]. All cattle were given two doses forty days apart of Veriben B12 (CEVA Santé Animale, containing diminazene aceturate, vitamin B12 (cyanocobalamin) and B12a (hydroxocobalamin) at 0.01 g/kg live body weight) to treat any pre-existing trypanosome infection [27], [34]. Treatment 1 (T1) cattle received no further treatments whereas treatments 2 to 4 (i.e. T2, T3 and T4) consisted of villages where 25%, 50% and 75% of the cattle population were sprayed using RAP at 28 days interval. Treatment 5 (T5) comprised villages whose cattle were dewormed once every three months but received no other treatment. T1 and T5 were considered as control groups for the graded (25%, 50% and 75%) RAP regimes [27]. For this study T1 villages were used as the control for comparing benefit-cost ratios as well as the incremental cost benefit ratios.

Prior to data collection, two study enumerators were provided with 10 days training as to how to approach farmers, to identify study cattle (using ear tag numbers) and to appropriately complete questionnaires. Enumerators were deployed to the villages depending on their understanding of the local language with each covering 10 villages. Semi-structured questionnaires were pre-tested in two villages that were not included among those randomly selected for this study. Data were collected detailing whether the cattle in the household had had a blood sample taken by the epidemiology team, household characteristics (number of people, livestock kept, type of dwelling, animal health measures used) and components of livestock income.

Data were collected from 600 households in the 20 villages eligible for RAP intervention using six months recall over a period of 18 months (a total of 2,400 interviews before and during the RAP intervention). Six months recall enabled data on cattle ‘exits’ and ‘entries’, productivity, mortality, fertility, cattle-related expenses and revenues, the number of times farmers took their cattle for spraying and the related costs to the household to be updated.

Economic analysis

In the study villages, gross margin analysis and marginal analysis were used to establish the benefit of using RAP to control trypanosomiasis at the household/farm level. For a livestock enterprise, the gross margin is given by the value of livestock output, which includes not just production, but also all entries and exits of livestock and the change in the herd valuation, less the variable costs. This reflects the impact of disease, via mortality, fertility, draft days worked, etc. Marginal analysis consists of analyzing the relationship between small increases in costs and in output; formula for change in net benefit as adapted from [35] was as follows:

Change in net benefit = marginal benefit - marginal cost

where change in net benefit refers to change in income gained by the farmer with each increase in the proportion of the cattle population sprayed using RAP (from T1 to T2, T2 to T3 and T3 to T4). The marginal benefit referred to the difference between the annual income per bovine between the treatments whereas the marginal cost referred to the difference between the annual cost per bovine between the treatments. The annual income per bovine was calculated as a gross margin based on the questionnaire data and compared to the total annual costs to farmers and to the project for implementing the intervention under each treatment.

The marginal analysis involved analyzing the costs and benefits from stepwise increases in the proportion of cattle sprayed (the measure of output) up to the point at which the marginal cost is either equal to or greater than the marginal benefit. Until then it is considered economic to continue increasing output even though the ratio of marginal benefits divided by marginal costs may be reducing (diminishing returns). After this when the additional benefits received are less than the cost of achieving them, negative returns are experienced, and it is no longer profitable to increase output.

The gross margin information was combined with the total societal costs of each treatment to determine the incremental net benefit of spraying an extra 25% of the cattle using RAP i.e. 0% to 25%, 25% to 50% and 50% to 75%. The cost of implementation (delivery cost) for the epidemiological study on the RAP intervention have been previously calculated in detail [36]. Interviews with farmers in this study enabled their own costs to be collected over the 18-month period, to complete the calculation of the full societal cost of the intervention. The costs to the farmer included time required to collect animals and to take them for spraying, money spent on ropes, on maintenance of a crush, on hired labor, etc.

Monetary data collected from the household questionnaires was in Ugandan shillings which were converted to United States Dollars (USD) at 1 USD being equivalent to 2,575 Ugandan shillings (sourced from OANDA, historical currency exchange rates). It represents the average rate applicable for the period when the study was undertaken and is also the same rate used for the project costs [36].

Results

Intervention household characteristics and cattle production parameters

At the start of the intervention study, the total number of cattle in the study households was 2,341, with mean and standard deviation (SD) per household of 3.5 and 3.0 respectively. These included 869 draft cattle (37%) and 632 cows (27%). Additionally, sheep (149), goats (1,222), pigs (808), chickens (5,399) and other animals (184 ducks, 112 turkeys, 27 dogs and 9 cats) were kept by the farmers. Most households undertook some form of vector control, with only 17.2% reporting that they did nothing. The most common method of vector control for each household was hand tick picking (46.5% of the households) which was also the method most frequently applied (on average 11.3 times a year). Other vector control methods were infrequently used annually, and these included; spraying, 3.5 times, application of paraffin, 9.6 times, application of grease, 7.2 times, and pour-on, 1.1 times. Of the households that carried out some of vector control, 21.9% (109) treated work oxen only, 13.8% (69) cows only, and 13.2% (66) heifers only. The type of cattle treated for ticks and tsetse is summarized in Table 1.

At the end of the intervention, 213 of the RAP households (59.1%) each owned 2 draft cattle and the rest 1, 3 or 4 or more (Table 2). Given that 59.1% of draft cattle owning households had the same number of draft cattle (2 oxen) analyzing pooled data from the whole sample was deemed representative. The average days plowed per household over the 18-month study period was 88.0 post-intervention, equivalent to 58.7 days per year (Table 2). Most cattle keepers used their draft cattle to plow other people's farms as a way of generating income. In the year before the intervention, the average number of days plowed was 50.4 per year per household among the RAP households.

Gross margin calculation

Gross margin calculations were undertaken for pooled data for the villages where 25%, 50% and 75% cattle were sprayed with deltamethrin using RAP. The items valued included both cash income and expenses and the values of animals not bought or sold and estimated value of farm labor both in components of the variable costs and as an estimate of the value of the labor households saved by using their own work oxen. The variable costs included: mastitis treatments; farm labor on their own and other people's farms; the cost of buying and administering trypanocides, spraying against ticks and tsetse and hand-picking ticks and of borrowing draft cattle from others to plow on the households' own farms. A summary of the cattle numbers and gross margin calculations for T1, T2, T3 and T4 is shown in Table 4. The observed cattle numbers were similar across the different treatment groups, averaging 455 (range 407 – 491). The importance of draft power in the cattle economy of the district can be seen by the fact that the single largest item both pre- and post-intervention is income gained and labor saved from using draft power for plowing (Table 3). Overall, the income from hiring out draft cattle plus the value of the human labor saved comes to 66.9% (range 62.9% to 72.2%) of the cattle and produce 'out' category (a) component of livestock output. In addition, for all the treatment groups in the absence of RAP, the value of the herd was lower at the end than at the beginning of the year. The annual average variable cost per bovine for the control and RAP treatments were reduced by USD 3.1, USD 7.2, USD 9.9 and USD 13.4 for T1, T2, T3 and T4 respectively, this fall in variable costs was mostly due to reductions in expenditure on trypanosomiasis and vector control.

To obtain the mean annual income per bovine in the RAP and control households, the changes in gross margins were obtained from Table 3 and divided by the number of households (i.e. 120 households in each treatment). The mean annual income per RAP household ranged from USD 95.26 – USD 142.35, a mean of USD 125.22 across all the RAP households, whereas the mean increases in annual income per bovine in the RAP treatment varied between USD 26.93 and USD 35.44 (mean of USD 32.12 across all the RAP households) (Table 4). However, an income increase of USD 6.51 was also observed in T1 (who only received the initial trypanocide treatment) and of USD 35.44 in T4.

Cost of RAP to farmers, the project and marginal analysis of benefits and costs

In the cost analysis of the RAP intervention [36], the full costs of the epidemiological intervention study were calculated, including all staff costs, overheads and depreciation, and then adjusted to obtain the costs of the RAP component only, which came to USD 2.02, 3.75 and 5.47 per bovine per year for spraying 25%, 50% and 75% of cattle respectively. The average cost per bovine of diminazene aceturate, needles, syringes and sterile water was USD 0.81 per dose. The delivery cost was estimated at USD 0.61 per dose for T1, where no RAP or other intervention was undertaken [36]. For the RAP treatments, where the drug was administered at the same time as the RAP treatment, the need to include veterinarians for administering the drug was estimated to add USD 0.22 to the delivery cost of USD 0.39 per bovine for RAP alone also based on the figures in the RAP cost analysis [36]. Administering diminazene aceturate thus incurred a cost of USD 2.84 per bovine in T1, and 2.06 for T2, T3 and T4. By adding the farmers' additional expenditure to these costs and to the other RAP project costs cited above, the total societal cost of RAP per year was estimated to be USD 4.33, USD 6.11 and USD 7.94 for spraying 25%, 50% and 75% of cattle respectively. For T1, the total cost of diminazene aceturate and the slight increase in farmers' costs came to USD 2.90 per bovine, which when set against the increase in income of USD 6.51 yielded a benefit cost-ratio of 2.24. The marginal benefits and costs are calculated as the cost of changing from one treatment to the next. The average benefit-cost ratios were 6.22, 5.56 and 4.46 for T2, T3 and T4 respectively. The incremental benefit-cost ratios from spraying each additional 25% of the population cattle were 14.32, 3.97, and 0.79 respectively. Table 6 shows this in more detail

Discussion

This is the first AAT study to use a large sample size and longitudinal survey to focus on farm incomes rather than on cattle production parameters (such as mortality, fertility, weight, etc.). The most similar investigation was the multi-site ATLN which linked production parameters to trypanosomiasis status on individual animal basis, as well as to study sites and herds [22]. The intervention studied here was also unusual in including both a control group, different levels of control and a before and after comparison for the 600 households followed longitudinally. In terms of vector control, tick control requires repeated spraying (ideally twice a month) thus, it can be expensive in the long run. Consequently, most farmers practiced tick handpicking and sprayed for ticks infrequently, although they preferentially treated draft cattle.

The study demonstrated that investing in spraying 25% of cattle provides the highest average return with a benefit-cost ratio of 6.22. In addition, the study showed that changing from a scenario where farmers practiced minimal vector control to spraying 25% of cattle using RAP offered the best returns with an incremental benefit-cost ratio of 14.32. However, spraying an additional 25% (i.e. 50%) of the cattle population was subject to diminishing returns, as it yielded a much lower incremental benefit-cost ratio of 3.97. This was also the case with spraying a further 25% (i.e.75%) of the cattle population as the incremental benefit-cost ratio fell to 0.79 so that costs exceeded benefits, set alongside a negative incremental net benefit of USD -0.38 per bovine per year and thus negative returns set in at this point. These findings contrast with the observations in the trypanosomiasis prevalence studies [27], [34]. The authors state, "the increase in village RAP herd coverage was not significantly associated with a proportionate decrease in the trypanosomiasis prevalence. On the contrary, there was an inverse relationship between dose (increase in RAP coverage; 25% RAP, 50% RAP, 75% RAP) and response (reduction in trypanosome prevalence)" [27]. Similarly, the use of RAP to additionally control ticks was not proportionately related to a decrease in the prevalence of *Theileria parva* the infectious agent of East Coast fever [34]. This may reflect the fact that these previous studies were only looking at prevalence as opposed to the wider production benefits evaluated in this study.

This study shows that increasing the proportion of the herd sprayed does increase income per bovine, but with diminishing returns. In economic theory, investments in additional inputs should continue if these incremental investments yield a positive net benefit, or an incremental benefit-cost ratio greater than one. Therefore, theoretically investment should continue up until 50%, perhaps nearly 75% of cattle are sprayed. However, in practical terms, particularly in resource-poor settings, producers and investors will opt for a situation where the average return on investments is maximized, which would be 25% in this example. This also aligns with farmers' preferences for treating work oxen and cows, which respectively account for 37% and 27% of the cattle population.

It also complements the prediction of the earlier modeling study that spraying 27% of the cattle population is enough to control *T. brucei s.l.* [26]. This level of spraying should be sufficient to lower the risk of transmission of zoonotic HAT from animals to people while, as the calculations described here have shown, provide a very attractive benefit to cattle keepers.

In addition, the average benefit-cost ratio of 6.22 for the 25% RAP treatment regime compared well with the findings from Ghibe in Ethiopia [37] where the authors estimated a benefit-cost ratio of 4.3 for a tsetse control project based on applying pour-ons to cattle. After adding the cost incurred by the farmer, i.e. charges to farmers for the pour-on insecticides/ acaricides and the opportunity cost of farmers' time, they found that the benefit-cost ratio of RAP to farmers was 8.0. For the RAP intervention in Uganda, where the research project paid for the bulk of costs, the implied average benefit cost ratio to the farmers would be 107.7 for the example of T2 (25% RAP). This extremely high figure would change if livestock keepers were to bear some of the delivery and insecticide costs, for example, sourcing and applying the insecticide, which accounted for just over 10% of total costs. Furthermore, farmers would likely select the animals they value most (cows and draft animals) for treatment as shown in this study.

It has been shown that tsetse feed preferentially on larger animals, so the effect of spraying this selected 25% subset of their herds would have an enhanced effect on tsetse populations [38]; and even benefit non-participants since trypanosomiasis control is a public good. The study found the average increase in income per bovine over the three RAP regimes to be USD 32.12, a figure which seems to fit in well with other estimates. In the eastern Africa study, the modeled increase in average annual income per bovine in the agro-pastoral and mixed farming high oxen use systems if trypanosomiasis were absent, came to USD 20 and 25 respectively when converted to year 2015 USD values [24].

This study showed that the opportunity cost of cattle keepers' labor (a non-cash item) and buying ropes (a cash item) were the two most significant expenditures incurred by the farmers during the RAP intervention, accounting for 92.5% of their expenses. Farmers forgo certain activities such as herding, planting, harvesting, socializing, etc. to participate in spraying. Moreover, they have to gather the cattle, take them for spraying, participate in the spraying and then bring them back to the homestead. There are few communal crushes in Tororo district and so farmers frequently required ropes for tethering and restraint during spraying and substantial amounts of cash buying ropes. The location selected for application of spraying and efficiency in restraining cattle are critical factors to consider in communal spraying since they have a major influence on the cost incurred by the farmer. Such information could be used to lobby for communal crushes.

Conclusion

Based on four sets of household interviews at 6-month intervals, this study compared the costs and benefits of spraying different proportions of the cattle population using RAP both to the pre-intervention situation and to a control, thus looking at before and after as well as with or without intervention. The results showed that spraying only 25% of the cattle yielded the highest incremental benefit-cost ratio. Increasing the proportion of cattle sprayed using RAP led to an increased income per bovine but with diminishing returns and spraying of 75% of cattle no longer yielded a positive incremental benefit, as costs outweighed benefits. From a pragmatic perspective the study recommends spraying only the most valuable adult cattle using insecticides effective against tsetse. In some cattle production systems these would be cows and bulls, but in this area of Tororo for most farmers these would be draft cattle as which constitute 37% of the herd and thus well above 25%. This recommendation is reinforced by the fact that most farmers in this area would preferentially treat draft cattle.

Abbreviations

AAT: Animal African Trypanosomiasis

HAT: Human African Trypanosomiasis

RAP: Restricted Application Protocol

TBDs: Tick-borne diseases

SD: standard deviation

USD: United States Dollar

Declarations

Ethical approval

This study was among a set of related studies reviewed by the Makerere University College of Veterinary Medicine Animal Resources and Biosecurity ethical review board for compliance to Animal use and Care Standards. It was then forwarded to the Uganda National Council for Science and Technology and approved under approval number HS1336.

Consent for publication.

Not applicable.

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request. All relevant data are within the paper and its additional files.

Competing interests

The authors declare that they have no competing interests

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Authors' contribution

WO was responsible for conception, design, collection, drafting and analysis of data. DM was involved in design and data collection. EM was involved in design and drafting of the manuscript. SW was involved in revising the intellectual content and gave the final approval of the version to be published. AS was involved in conception, design and revising intellectual content. All authors read and approved the final version of the manuscript.

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References

1. Schofield CJ and Maudlin I. Trypanosomiasis control. Int J Parasitol. 2001;31:615–620.
2. Steverding D. The history of African trypanosomiasis. Parasit Vectors. 2008;1(1):3. doi: 1186/1756-3305-1-3
3. Maudlin I. African trypanosomiasis. Ann Trop Med Parasit. 2006;100(8):679–701.
4. Kotlyar S. Recommendations for Control of East African sleeping sickness in Uganda. J Global Infect Dis. 2010;2(1):43–48.
5. Grant IF. Insecticides for tsetse and trypanosomiasis control: is the environmental risk acceptable? Trends Parasitol. 2001;17:10–14.
6. Vale G, Torr S. Development of bait technology to control tsetse. In: Maudlin I, Holmes PH, Miles MA, editors. The trypanosomiases. Wallingford: CABI Publishing; 2004. p. 509–523.

7. Lancien J. Controlling Sleeping Sickness in Southeastern Uganda With Tsetse-Fly Traps. Ann Soc Belg Med Trop. 1991;71:35-47.
8. Torr SJ, Maudlin I, Vale GA. Less is more: restricted application of insecticide to cattle to improve the cost and efficacy of tsetse control. 2007. Med Vet Entomol. 2007a;21:53–64.
9. Bourn D, Grant I, Shaw A, Torr S. Cheap and safe tsetse control for livestock production and mixed farming in Africa. Asp Appl Biol. 2005;75:81–92.
10. Holmes PH, Eisler MC, Geerts S. Current chemotherapy of animal trypanosomiasis. In: Maudlin I, Holmes PH, Miles MA, editors. The trypanosomiases. Wallingford: CABI Publishing; 2004. p. 431–444.
11. Eisler MC, Torr SJ, Coleman PG, Machila N, Morton JF. Integrated control of vector-borne diseases of livestock - pyrethroids: panacea or poison? Trends Parasitol. 2003;19: 341–345.
12. Welburn SC, Coleman PG, Maudlin I, Fèvre EM, Odiit, M, Eisler MC. Crisis, what crisis? Control of Rhodesian sleeping sickness. Trends Parasitol. 2006;22(3):123–128.
13. Swallow BM. Impacts of trypanosomiasis on African agriculture. PAAT Technical and Scientific Series 2. Rome, Italy, FAO. 2002. http://www.fao.org/3/X4755EN/x4755en.pdf. Accessed 17 July 2018.
14. Shaw APM. The economics of African trypanosomiasis. In: Maudlin I, Holmes PH, Miles MA, editors. The trypanosomiases. Wallingford: CABI Publishing; 2004. p. 369-402.
15. Shaw A, Wint W, Cecchi G, Torr S, Waiswa, C. Alemu T, Eregae M, Abdi A, Muchina M, Mugasi M, Mattioli R, Robinson T. Intervening against bovine trypanosomosis in eastern Africa: mapping the costs and benefits. Rome: FAO, PAAT Technical and Scientific Series No. 11.2017. http://www.fao.org/3/a-i7342e.pdf. Accessed 18 March 2019.
16. Jahnke HE. The Economics of controlling tsetse flies and cattle trypanosomiasis examined for the case of Uganda. Forschungsberichte der Africa-studienstelle 48, IFO – Intitut für Wirtschaftsforschung, Weltforum Verlag, Munich, Germany; 1974.
17. Shaw APM, Torr SJ, Waiswa C, Cecchi G, Wint GRW, Mattioli RC, Robinson TP. Estimating the costs of tsetse control options: an example for Uganda. Prev Med Vet. 2013;110:290–303.
18. Shaw APM. Controlling tsetse – what does it cost? In: Garros C, Bouyer J, Takken, W, Smallegange RC, editors. Pests and vector-borne diseases in the livestock industry, Ecology and Control of Vector-borne diseases. Wageningen: Wageningen Academic Publishers; 2018. p. 509–536.
19. Laker CD. Assessment of the economic impact of bovine trypanosomosis and its control in dairy cattle in Mukono County, Uganda. PhD Thesis, Makerere University, Uganda; 1998.
20. Ocaido M, Otim CP, Okuna NM, Erume J, Ssekitto C, Wafula RZO, Kakaire D, Walubengo J, Monrad J. Socio-economic and livestock disease survey of agro-pastoral communities in Serere county, Soroti district, Uganda. Livest Res Rural Dev. 2005; 17(8);Article #93 http://www.lrrd.org/lrrd17/8/ocai17093.htm
21. Okello WO, Muhanguzi D, MacLeod ET, Welburn SC, Waiswa C, Shaw AP. Contribution of draft cattle to rural livelihoods in a district of southeastern Uganda endemic for bovine parasitic diseases: an

economic evaluation. Parasit Vectors. 2015; 8(571).

22. African Trypanotolerant Livestock Network (ATLN). Livestock Production in tsetse affected areas of Africa., Proceedings of an African Trypanotolerant Livestock Network meeting, Nairobi, 1987. p.3– http://www.fao.org/Wairdocs/ILRI/x5443E/x5443e00.htm. Accessed 23 February 2018.
23. Kristjanson PM, Swallow BM, Rowlands GJ, Kruska RL, De Leeuw PN. Measuring the costs of African animal trypanosomosis, the potential benefits of control and returns to research. Agr Syst. 1999;59:79–98.
24. Shaw AP, Wint GR, Cecchi G, Torr SJ, Mattioli RC, Robinson TP. Mapping the benefit-cost ratios of interventions against bovine trypanosomiasis in Eastern Africa. Prev Med Vet. 2015;122(4):406-416. doi: 10.1016/j.prevetmed.2015.06.013.
25. Meyer A, Holt HR, Oumarou F, Chilongo K, Gilbert W, Fauron A, Mumba C, Guitian J. Integrated cost-benefit analysis of tsetse control and herd productivity to inform control programs for animal African trypanosomiasis. Parasit Vectors. 2018;11:154. doi:10.1186/s13071-018-2679-x.
26. Kajunguri D, Hargrove JW, Ouifki R, Mugisha JY, Coleman PG, Welburn SC. Modelling the use of insecticide-treated cattle to control tsetse and *Trypanosoma brucei rhodesiense* in a multi-host population. Bull Math Biol. 2014;76(3):673–696. doi: 10.1007/s11538-014-9938-6.
27. Muhanguzi D, Picozzi K, Hattendorf J, Thrusfield M, Welburn SC, Kabasa JD, Waiswa, C. Improvements on Restricted Insecticide Application Protocol for Control of Human and Animal African Trypanosomiasis in Eastern Uganda. PLoS Negl Trop Dis. 2014;8(10). doi: 10.1371/journal.pntd.0003284.
28. Hide G, Tait A, Maudlin I, Welburn SC. The origins, dynamics and generation of *Trypanosoma brucei rhodesiense* epidemics in East Africa. Parasitol Today. 1996;12:50–55.
29. Fèvre EM, Coleman PG, Odiit M, Magona JW, Welburn SC, Woolhouse ME. The origins of a new *Trypanosoma brucei rhodesiense* sleeping sickness outbreak in eastern Uganda. Lancet. 2001;358(9282):625-628.
30. Waiswa C, Olaho-Mukani W, Katunguka-Rwakishaya E. Domestic animals as reservoirs for sleeping sickness in three endemic foci in south-eastern Uganda. Ann Trop Med Parasit. 2003;97:149–155.
31. Hamill L, Picozzi K, Fyfe J, von Wissmann B, Wastling S, Wardrop N, Selby R, Acup CA, Bardosh KL, Muhanguzi D, Kabasa JD, Waiswa C,Welburn SC. Evaluating the impact of targeting livestock for the prevention of human and animal trypanosomiasis, at village level, in districts newly affected with *b. rhodesiense* in Uganda. Infect Dis Poverty. 2017; 6: 16. http://doi.org/10.1186/s40249-016-0224-8.
32. Muhanguzi D, Picozzi K, Hattendorf J, Thrusfield M, Kabasa JD, Waiswa C, Welburn SC. The burden and spatial distribution of bovine African trypanosomes in small holder crop livestock production systems in Tororo District, south-eastern Uganda. Parasit Vectors. 2014; 7: 603. Doi: 10.1186/s13071-014-0603-6.
33. Farid MN, Frerich RR. CSurvey version 2.0, University of California, Los Angeles (UCLA). 2008
34. Muhanguzi D, Picozzi K, Hattendorf J, Thrusfield M, Welburn SC, Kabasa JD, Waiswa C. Collateral benefits of restricted insecticide application for control of African trypanosomiasis on Theileria parva

in cattle: a randomized controlled trial. Parasit Vectors. 2014;7, 432.

35. Rushton J, Thornton PK, Otte MJ. Methods of economic impact assessment. Rev Sci Tech. 1999; 18(2): 315-342. DOI:10.20506/rst.18.2.1172
36. Muhanguzi D, Okello WO, Kabasa JD, Waiswa C, Welburn SC, Shaw APM. Cost analysis of options for management of African animal trypanosomiasis using interventions targeted at cattle in Tororo District; south-eastern Uganda. Parasit Vectors. 2015; 8: 387.
37. Mulatu W, Swallow B, Rowlands G, Leak S, D'Ieteren G, Nagda S. Proceedings of 24th meeting of the International Scientific Council for trypanosomiasis research and control, Maputo, Mozambique. Economic benefits to farmers of six years of application of an insecticidal "Pour-on" to control tsetse in Ghibe, southwest Ethiopia.
38. Torr SJ, Prior A, Wilson PJ, Schofield S. Is there safety in numbers? The effect of cattle herding on biting risk from tsetse flies. Med Vet Entomol. 2007; 21: 301–311.

Tables

Table 1: Types of cattle most often treated for ticks and tsetse flies in each household

Type of cattle treated	Number of households	Number of households in %
Calf (young cattle aged 0 – 2 years) only	0	0.0
Calf and cow (adult female aged 4 years and above)	17	2.8
Calf and heifer (young female aged 2 – 4 years)	1	0.2
Calf and young male (young male aged 2 – 4 years)	0	0.0
Calf and non-work oxen	0	0.0
Calf and work oxen	0	0.0
Young male only	15	2.5
Non-work oxen only	7	1.2
Work oxen only	132	22.0
Work oxen and heifer	30	5.0
Work oxen and cow	51	8.5
Heifer only	80	13.3
Heifer and cow	28	4.7
Cow only	83	13.8
Young male and adult male	11	1.8
Young male and heifer	22	3.7
Young male and cow	15	2.5
Young male and calf	5	0.8
None	103	17.2
Total	**600**	100.0

Table 2: Draft oxen ownership and work patterns among the RAP households during the intervention

Number of work oxen per household	% of oxen owning households (n = 360)	Average draft oxen days worked per household		
		Total plowing days worked	Plowing on own farm (SD)	Plowing other people's farms (SD)
1	4.6	96.5	33.7 (12.3)	62.8 (7.6)
2	59.2	87.0	25.5 (10.0)	61.5 (9.0)
3	7.4	82.4	23.9 (9.1)	58.5 (7.3)
4+	28.8	86.4	24.5 (9.8)	61.9 (9.2)
Average recorded over the 18-month study		88.0	26.9	61.1
Adjusted figure for 12 months		58.7	17.9	40.7

Table 3: Cattle numbers and household gross margin

Item	Value							
Percentage of cattle sprayed using RAP	0%		25%		50%		75%	
Treatment	T1 (control)		(T2)		(T3)		(T4)	
Study period	Before	After	Before	After	Before	After	Before	After
1. Cattle population (number)								
At start of period (0 months)	465	456	423	407	481	473	458	451
At end of period (18 months)	456	440	407	430	473	491	451	485
Average number of cattle during period studied (12 months)	461	448	415	419	477	482	455	468
Average per household (12 months)	3.8	3.7	3.4	3.5	4.0	4.0	3.8	3 .9
2. Gross margin analysis (USD)								
a) Cattle and their produce 'out'								
Income from hiring out draft cattle for plowing	13 694	18 048	15 739	30 503	16 882	33 875	17 046	32 797
Income from hiring out draft cattle for other work	50	110	54	124	77	176	86	194
Value of cattle sold	6 290	9 618	9 896	14 130	6 648	16 884	8 016	15 751
Value of cattle given out as loan repayment	435	551	701	1 181	464	723	604	561
Value of cattle slaughtered	384	518	593	933	389	476	453	679
Value of human labor saved by using draft cattle	4 797	5 040	5 088	7 386	6 117	7 412	4 749	6 700
Value of milk sold	1 313	1 614	1 147	2 647	1 381	3 176	1 381	2 917
Subtotal	6 290	9 618	33 218	56 904	31 958	62 722	32 335	59 599
b) Cattle and produce 'in'								
Value of draft cattle bought	3 459	1 176	4 107	6 210	3 927	9 032	4 445	6 980
Value of cattle received as gifts or loan repayment	1 081	1 224	1 710	1 771	1 349	982	1 653	906
Subtotal	4 540	2 400	5 817	7 981	5 276	10 014	6 098	7 886
c) Change in herd value								
Opening valuation	111 439	109 447	100 610	97 453	116 379	113 120	104 639	102 037
Closing valuation	109 447	108 479	97 453	97 582	113 120	113 321	102 037	102 285
Change in herd value	-1 992	-968	-3 157	129	-3 259	201	-2 602	248
d) Total livestock output (a-b+c)	20 431	32 131	24 244	49 052	23 423	52 909	23 635	51 961
e) Total variable cost	3 971	3 761	4 947	2 959	6 052	2 004	6 955	1 318
f) Total gross margin (d-e)	**16 460**	**28 370**	**19 297**	**46 093**	**17 371**	**50 905**	**16 680**	**50 643**

Table 4: Annual cattle gross margin and benefit from using RAP compared to control

Percentage sprayed using RAP (treatment)	Total annual cattle gross margin across households (USD)		Difference in annual cattle gross margin (USD)		
	Before intervention	After intervention	Difference all households	Mean per household	Mean per bovine
0% (T1)	16 460	18 914	2 454	20.45	6.51
25% (T2)	19 297	30 729	11 432	95.26	26.93
50% (T3)	17 371	33 936	16 565	138.04	33.99
75% (T4)	16 680	33 762	17 082	142.35	35.44

Table 5: Livestock keepers' expenditure on RAP related items over 18 months

	Treatments (USD)			
Item	T1	T2	T3	T4
Value of farmers' time taking cattle for RAP	27	121	151	205
Payment to casual laborers/herdsmen	3	2	4	5
Cash spent on ropes	8	29	50	60
Crush repair	4	4	5	8
Payment to someone help restrain cattle	0	0	1	2
Payment for water to mix pyrethroids	0	2	4	5
Total	42	159	216	286
Expenditure per bovine per year	0.06	0.25	0.30	0.41

Table 6: Benefits and costs of different treatments per year per bovine

% RAP	Benefit USD	Marginal benefit USD	Cost of RAP USD	Cost of diminazene aceturate (double injection) USD	Cost of farmers' RAP inputs USD	Total intervention cost USD	Marginal cost USD	Net benefit USD	Incremental net benefit USD	Benefit cost ratio	Incremental benefit-cost-ratio
0% (T1)	6.51	-	0.00	2.84	0.06	2.90	-	3.61	-	2.24	-
25% (T2)	26.93	20.41	2.02	2.06	0.25	4.33	1.43	22.60	18.99	6.22	14.32
50% (T3)	33.99	7.06	3.75	2.06	0.30	6.11	1.78	27.88	5.28	5.56	3.97
75% (T4)	35.44	1.45	5.47	2.06	0.41	7.94	1.83	27.50	-0.38	4.46	0.79

Supplementary Files

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