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Effectiveness and limitations of the recently adopted acaricide application methods in tick control on dairy farms in South-Western Uganda

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In Uganda, control of ticks and tick-borne diseases (TTBDs) largely depends on the use of chemicals applied using different methods. This cross-sectional study assessed 17 factors to determine the effectiveness and limitations in the use of the recently adopted acaricide application methods on dairy cattle farms in south-western Uganda. The average annual morbidity and mortality due to tick-borne diseases were 42.6 and 30.0% for farms using bucket pumps, 9.3 and 4.2% for those using motorised pumps and 3.0 and 1.0% for spray races, respectively. For a 20-year period, the estimated cost of acaricide application for a herd of 80 head of cattle was US$ 71,042, US$ 38,694 and US$ 28,710 when using a bucket pump, spray race and a motorised pump, respectively. Bucket pump method may only be cost-effective on farms of 40 to 112 head of cattle, while a motorised pump was only economical for farms of 35 to 170 cattle and a spray race being a better option at farms of 100 to 600 cattle. Farmers should make the most appropriate choice of acaricide application method to achieve the most effective control of TTBDs on their farms.

Key words: Effectiveness, acaricide application methods, tick-borne diseases, Uganda.

INTRODUCTION

The high prevalence of ticks and tick-borne diseases (TTBDs) is a crucial hindrance to the development of the dairy industry in Uganda (Okello-Onen et al., 2003; Kasaija et al., 2021). The critical tick-borne diseases (TBDs) in Uganda are East Coast fever (ECF), babesiosis, anaplasmosis and heartwater (Byaruhanga et al., 2021; Kaiser et al., 1982; Vudriko et al., 2018). *Rhipicephalus appendiculatus* transmits the causative pathogen for ECF, *Rhipicephalus (Boophilus) decoloratus* spreads agents for babesiosis and anaplasmosis, while the pathogen for heartwater is transmitted by *Amblyomma variegatum* (Byaruhanga et al., 2021; Kasaija et al., 2021). Recent field observation in the country show an average tick burden of 21 *R. appendiculatus*, 7 *R. (Boophilus) decoloratus* and 3 *A. variegatum* ticks on grazed cattle (unpublished findings).

In Uganda, the prevention and control of TTBDs primarily rely on chemical acaricides targeted at the

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vector ticks and chemotherapy using antibiotic and anti-protozoan drugs against the livestock blood parasites (Kocan, 1995). In the country, chemical application for tick control is done using different methods. These mainly include hand spraying with a bucket pump, hand spraying with a motorised pump, and a plunge dip or non-communal spray race (Okello-Onen et al., 1992). Farmers use the different methods mainly based on convenience and cost (Mugisha et al., 2005) and application is done twice a week during the wet season and once a week in the dry season. While plunge dipping was the most common method used in tick control from early 1960s to the 1990s (Okello-Onen et al., 1992), hand spraying has become dominant (91%) in south-western Uganda (Otim, 2000; Vudriko et al., 2018), with a number of farmers adopting use of motorised pumps and non-communal spray races. The latter two methods are being adopted based on the hypothesis that they could be more convenient, more effective and less costly.

Regardless of the method used, tick control using chemical acaricides is still characterised by many distorted and inappropriate practices with likely health, environmental and tick acaricide resistance implications (Okello-Onen et al., 2003; Rubaire-Akiiki et al., 2004; Mugabi et al., 2010). By 2016, the efficacy of these chemicals in reducing tick infestations on livestock had become limited and, drawbacks such as selection for acaricide-resistant ticks (Vudriko et al., 2016) and high costs for farmers (Graf et al., 2004) were increasingly confirmed.

Measuring the effectiveness of production represents an assessment of the relationship between the results (outputs) achieved by the production system and the inputs consumed. Effectiveness is defined as producing the desired effect or the ability to produce desired output or adequate to accomplish a purpose. Effective production is that which makes the maximum outcomes by the given inputs, or which forms a certain level of outputs by the minimal level of inputs (Malega and Engel, 2006). Effectiveness of production is subjected to not only production process but also the advanced phases of production processes, which define the application of technologies in production, determine the technological conditions by which products are realised, and define time and space of exploitation of machinery (Malega and Engel, 2006). To improve efficiency, time is considered a factor of production (Gentile, 2011). While longer work hours are associated with higher productivity if a worker faces fixed set-up costs (Feldstein, 1967), worker fatigue can set in. The marginal effect on the productivity of an extra hour per worker then starts decreasing (Pencavel, 2015). Several studies have found diminishing returns to hours worked (DeBeaumont and Singell, 1999; Shepard and Clifton, 2000). Wilson (2014) provides the advantages of using automated production methods, which include reduced inconsistency, improved operations reliability, and reduced application costs.

It was hypothesised that longer hand spraying periods could be causing ineffective acaricide application, resulting in acaricide failure on the affected farms. Gaps in such information affect farmers' decisions when assessing investment options among methods of acaricide application on dairy farms in south-western Uganda. This study sought to determine the equipment and operational factors influencing the effectiveness of the most commonly used chemical acaricide application methods on dairy farms in the region.

MATERIALS AND METHODS

Study area

The study was undertaken in south-western Uganda (Figure 1) among three of the six beneficiary districts of the dairy development interventions by The Inclusive Dairy Enterprise (TIDE) project of the Stichting Nederlandse Vrijwilligers (Foundation of Netherlands Volunteers), more popularly known as SNV Netherlands Development Organisation. Districts with higher cattle numbers (UNLC, 2008) and field reports on tick resistance to acaricides were selected (Vudriko et al., 2016). These included Kiruhura (0.1928° S, 30.8039° E), Lyantonde (0.2241° S, 31.2168° E) and Mbarara (0.6072° S, 30.6545° E). These districts lie in the southern part of the cattle corridor of Uganda at an average elevation of 1800 m above sea level (Tibezinda et al., 2016), mainly in the Pastoral Rangelands Agro-Ecological Zones (AEZs). The predominant annual precipitation in this semi-arid zone is 900 to 1200 mm, distributed in a bimodal pattern (Gregory et al., 1985). Temperature ranges from 20 to 30°C with high-temperature peaks recorded in January and July each year (Gregory et al., 1985). In the study area the average live bodyweight of the adult cross-bred (Ankole Longhorn × Holstein Friesian) cattle is 390 kg (Galukande, 2010).

Study farms

A total of 15 farms, among those keeping 70 to 300 head of cattle, were selected. The farms included five where acaricide was applied using a bucket pump, five using motorised pump and five using a spray race. The selection was restricted to five farms in each category due to due to the fact that only five farms in the study area consistently used a spray race in tick control. Hence, a similar number of farms were sampled among each of the other two acaricide application categories. Farms using a bucket pump (Figure 2) were coded as BPF 1, BPF 2, BPF 3, BPF 4 and BPF 5. Likewise, those using a motorised pump were serially code numbered from MPF 1 to MPF 5 and spray race code numbered as SRF 1 - SRF 5.

In 13 of the farms, an amidine (amitraz) class of acaricides was used. Specifically, the farms applied Amitraz 12.5% (Norotraz® and Milbitraz®) reconstituted at a rate of 2 mL of acaricide to 1 litre of water. Comparatively, the acaricide class in use at one of the other two farms was a pyrethroid in the form of alpha-cypermethrin (Supertix®) mixed at a ratio of 1 mL to 2 L of water. In contrast, the 15th farm used a co-formulated acaricide containing organophosphate + pyrethroid. At the latter farm, Duodip® (Chlorpyrifos 50% + Cypermethrin 5%) was specifically used and the reconstitution rate was 1 mL of acaricide to 1 L of water. Regardless of the class of acaricide used, the reconstitution at all the farms was done as per the manufacturer's instructions. For all farms where a spray race was used, the charging (mixing) was only done once for every spraying activity since the holding tank for each pump had a capacity of 1,500 or 2,000 L, sufficient to spray a

Figure 1. Map of Uganda showing the study districts.

herd of 180 to 250 head of cattle cattle on the day of acaricide application.

Study design

This cross-sectional study was conducted for three months and four investigators involved in data collection. A questionnaire was administered per farm and observational data collected by each investigator on the day of the farm visit. To minimize investigator biases and errors, each of the investigators visited each farm to capture similar data. Every investigator recorded observations during acaricide application by three workers using either bucket pump or motorised pump. Related data were recorded during application using the spray race method.

After collecting baseline data, all workers responsible for acaricide application were trained in the recommended acaricide application

procedure. With a nozzle pressure of about 550 kPa (80 psi), the procedure follows the sequence of Backline, Belly, Brisket, Rear and then Head (BBBRH) aimed at spraying each animal with about 7 to 9 L of acaricide mixture. In a bit of detail, each animal is sprayed starting with the backline, followed by both sides of the belly and then the brisket, neck and fore legs (with adequate attention paid to the interdigital spaces). Spraying continues with the rear of the animal, including the hind legs (attention paid to the interdigital spaces), the udder and under the tail base, entire tail length and tail switch. Finally, the head is sprayed, paying particular attention to the ears. The training in the application procedure was done to ensure consistency in the acaricide application. Compliance with the method at each farm was checked up to four times of

Figure 2. Hand spraying methods including bucket pump [A] and motorised pump [B].

acaricide application before data collection. The farms maintained the days of the week on which cattle spraying was done.

Data collection

Questionnaire data

Data on tick control operations at each of these farms was captured and profiled using a semi-structured questionnaire. At each farm, the owner, manager, or attendant was interviewed to capture and/or compute data on the different parameters, including cattle kept and tick control practices. Additional data were on the cost of purchase or establishment of acaricide application equipment, operational costs, as well as the period each farm had used the existing method. Other factors of data collection were the animal restraint facility used, existing health and financial records, acaricide dilution rates, numbers of persons used during acaricide application, cost of acaricide during each time of application, cost of water used to mix acaricide and the expenditure on each person (used in acaricide application). The health data included the number of cattle that manifested clinical signs or died of a TBD during each previous 1 to 3 years. Reduction in milk yield per cow during each day a cow was sick of a TBD, cost of treatment of each animal against a TBD, annual loss due to dead animals or salvage value of those sold due to TBDs were the other variables of data collection.

Acaricide application using a bucket pump

During data collection, the first investigator visited Farm 1 (BPF 1) on a designated day of acaricide application and recorded the starting time as the exercise commenced. Concurrently, the other three counterparts were visiting Farm 2 (BPF 2), Farm 3 (BPF 3) and Farm 4 (BPF 4) under the same procedural arrangement. At each farm, the amount of water used and the distance from where it was collected were recorded. Observations were made about the person pumping the acaricide and the worker that directed the pump's nozzle to apply the acaricide mixture to the animals. In the observation, each investigator looked for adherence to the recommended application procedure and signs of fatigue, which included; (1) profuse sweating, (2) change in rhythm/pace of spraying, (3) resting/intermittent breaks, (4) change in posture, (5) yawning, (6) declaration of fatigue and (7) stopping to spray altogether. The other signs equally observed and recorded were; (8) observation of low spraying pressure and (9) complaint by co-workers about declining spraying speed. A particular worker was considered fatigued if any four of the signs and loss of concentration were observed. The number of cattle that were sprayed until the point of fatigue of the worker engaged in pumping

and the duration of pumping were immediately recorded. These observations were made and similar parameters recorded for all subsequent workers that were engaged in pumping. This procedure was followed by every investigator on each of the four farms. All investigators converged at Farm 5 (BPF 5) to jointly collect data on the same parameters on a different day.

Acaricide application using a motorised pump

Each of the four investigators visited each of the four sampled farms (MPF 1 - MPF 4), where a motorised pump was used. Likewise, each investigator arrived early enough to record the study parameters' starting time and record data.

Acaricide application a spray race

Under the method, each of the investigators visited each of the four farms (SRF 1 - SRF 4) where a spray race was used. During the exercise, the starting and ending time, amount of water, distance to the water source and amount of fuel used were recorded. Also recorded was data on mixing or any top-up of spray mixture, a total number of animals sprayed, the time animals were held in the drainage crush and the whole time taken to spray all the animals. The same variables were considered during joint data collection when all the four investigators visited Farm 5 (SRF 5) on a different day.

Number of cattle sprayed by each person

Based on observational data collected as described earlier, the maximum number of cattle effectively sprayed with acaricide by one person was determined by counting from the first to the last number of cattle sprayed when the worker got fatigued. The average number of cattle sprayed by a single worker using either the bucket or motorised pump was computed by summing up the number of animals sprayed by a single person at all the five study farms, divided by the number of workers that applied the acaricide by each method.

Limitations in application methods

To determine the critical limitations faced in use of each method, data were collected from the farm owner, Farm Manager and workers. Factors that constrained the use of a technique, cost of investment, costs of operation, frequency of repair, and labour required constituted the investigation variables.

Factors for suitability of application method

The effectiveness of using each of the methods was determined based on: (1) the annual morbidity rate (%); the proportion of cattle falling sick due to TBDs per year, (2) the annual mortality rate (%); the proportion of animals dying per year due to TBDs, (3) the cost-effectiveness (cost of treatment of animals sick due to a TBD) computed based on what existed on records or data provided on the cost of drugs, consultation fees and transport of the visiting animal health professional, (4) the cost of investment, (5) cost of operations, (6) cost of maintenance, and (7) Cost of acaricide application associated labour.

Data management and analysis

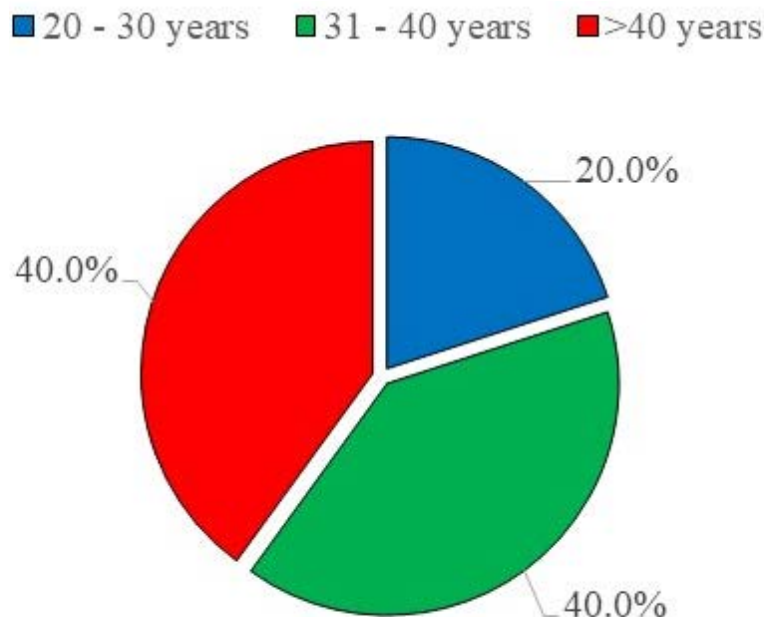The questionnaire data were entered in Microsoft Excel 2016 and

Figure 3. Age group of respondents.

the observational data presented as narratives and descriptive statistics. The costs involved in tick and disease control and the average losses due to morbidity and mortality were arithmetically computed. Statistical analysis was done in the R statistical software (R Core Team, 2020), using the FSA package (Ogle et a., 2020). A Kruskal-Wallis test was used to test for statistical differences among the group of farms using each of the three acaricide application methods studied (spray race, motorised pump or bucket pump). Statistical significances were considered at $p < 0.05$.

RESULTS

Demographic characteristics of the respondents

Most (80.0%, 12/15) of the respondents were males. Comparatively, 46.7% (7/15) were Farm Managers, 40.0% (6/15) were farm owners and the others (13.3%, 2/15) were farm workers. The majority of our respondents fell either in the 31- 40 year category or over 40 years of age (40.0%, 6/15) (Figure 3).

Factors affecting the use of acaricide application methods

Number of cattle sprayed by a single worker

A total of 51 workers were observed applying acaricide using a bucket pump and 51 others observed using a motorised pump. For the bucket pump method, an average of 14 head of cattle were sprayed by a worker taking 1 min and 4 s (64 s). Similarly, it took each worker 42 s to spray an animal with motorised pump and 24 s to

do so by the spray race.

Cost of acaricide application per head of cattle

The average purchasing cost of a bucket pump with a 5-year lifespan was US$ 187, while a motorised pump of the same lifespan cost US$ 720. The average volume of acaricide applied on each animal by a bucket pump was 2.9 to 5.2 (average of 4.3) L, while that by a motorised pump was 2.9 to 6.4 (average of 4.0) L and almost equal quantity (4.1 L) for a spray race. The average cost of a litre of acaricide was US$ 23. Whereas acaricides of different brand names were used, the average cost of 1 L of reconstituted acaricide was US$ 0.020. Based on cost computed per litre, farms using a bucket pump spent US$ 0.097 per animal sprayed, while the cost of acaricide per head of cattle sprayed by motorised pump was US$ 0.091 for motorised pump and US$ 0.092 for spray race (Table 1).

For the bucket pump method, the average labour cost per worker per month was US$ 34.7, water used per head of cattle was 4.3 L and the price of a jerrycan used to fetch water to fill a drum (water reservoir) was US$ 1.87. The price of the drum was US$ 40. On average, 10 jerrycans (US$ 18.7) were annually required per farm of about 80 head of cattle, while only one drum was used for about five years. Pump nozzles, bought at US$ 19.5, were replaced twice a year.

The monthly labour cost of acaricide application by a motorised pump was US$ 31.1, about 4.1 L of water was required per head of cattle and a jerrycan (bought at US$

Table 1. Fixed and operational costs per animal each time of acaricide application using the different methods.

Application method	Bucket pump (US$)	Motorised pump (US$)	Spray race (US$)
Cost of water for mixing acaricide	0.016	0.016	0.009
Cost of equipment including structures	0.306	0.025	0.096
Cost of jerrycans	0.003	0.003	0.003
Cost of water reservoir (drum)	0.001	0.001	0.001
Cost of fuel	-	0.032	0.013
Cost of acaricide	0.097	0.091	0.092
Cost of labour	0.005	0.005	0.005
Total	0.427	0.173	0.219

These figures were calculated based on the equipment used, volume of acaricide used and the labour involved in the exercise of applying acaricide to the entire herd.

Table 2. Cost of acaricide application per method.

Application method	Cost of acaricide application (US$)					
	1 head* each time	80 heads* each time	1 head* in a year	80 heads* in a year	1 head* in 20 years	80 heads* in 20 years
Bucket pump	0.427	34	44	3,552	888	71,042
Motorised pump	0.173	14	18	1,435	359	28,710
Spray race	0.219	17	24	1,935	484	38,694

*Head=Head of cattle.

1.87) was used to fetch water to fill a drum. A quantity of 2.2 L of fuel (petrol) was required to spray 80 cattle.

The cost of establishment of a spray race, inclusive of the water pump, sump, boma, building, spraying pipes and nozzles, and the drainage crush, was US$ 11,467 with an estimated lifespan of 20 years. The cost of labour per worker per month was US$ 32, while the method used 2.5 L of fuel (petrol) per exercise of spraying 80 head of cattle. The costs for each acaricide application per animal during each exercise are shown in Table 1.

Herd size most cost-effectively suitable per application method

Based on the lifespan of a spray race estimated at 20 years, the costs of the three methods were computed for each animal for a single year and 20 years. In Table 2, the costs of using these methods per head of cattle (and for the entire herd of 80) per year in 20 years are presented. Based on the calculated costs (Table 2), the motorised pump attracted the least cost of acaricide application while the bucket pump was the most expensive for a single application, in a year and for the 20 years.

Since it is discouraged to interrupt the daily routine activities of cattle, a maximum of 2 h of interruption of the

activities on the day of acaricide application was considered. Based on the estimate, the farm requirements for cost-effective use of each of the application methods showed that a farm using a bucket pump was appropriate for a herd of at least 40 cattle and a maximum of 112. With this method, only 112 head of cattle could be sprayed within 2 h. In a similar 2-h period, a motorised pump could only spray 35 to 170 animals. Comparatively, a spray race could only be cost-effective on farms with at least 100 cattle and a maximum of 600. With this method only 300 head of cattle can be sprayed within 2 h. Consequently, a herd of 600 head of cattle could be sprayed in two batches of 300 cattle, with each batch sprayed at a different time or on a different day.

Effect of existing method of acaricide application on tick-borne diseases

The lowest average annual morbidity (24.6%) and mortality (15.0%) due to TBDs was observed on farms using the bucket pump. The most minor annual morbidity (22.0%) and mortality (1.38%) was found on farms using the spray races (Table 3). Kruskal-Wallis rank sum test revealed no significant difference in morbidity (χ^2=0.12, df=2, p=0.94) or quantity of milk lost (χ^2=1.08, df=2, p=0.58) among farms using bucket pump, motorised

Table 3. Annual average loss for a herd of 80 head of cattle under the three acaricide application methods.

Application method	Average annual loss per herd of 80 head of cattle					
	Morbidity rate (%)	Loss in morbidity (US$)	Mortality rate (%)	Loss in mortality (US$)	Milk loss (L)	Milk loss (US$)
Bucket pump	24.6	1,310	15.00	8,378	3,017.2	805
Motorised pump	28.1	1,498	2.94	1,960	6,874.8	1,833
Spray race	22.0	1,104	1.38	1,104	5,251.3	1,400

Morbidity, mortality and milk loss due to TBDs under the acaricide application methods presented in percentage and translated into monetary loss in US dollars.

pump and spray race. In contrast, a significant difference (χ^2=7.84, df=2, p=0.02) in the annual mortality rate due to TBDs existed between the group of farms using a bucket pump and those where a spray race was used. Taking an average cost of treatment for a single case of TBD as US$ 40, the annual treatment costs at farms using bucket pumps amounted to US$ 1,310, while farms using a motorised pump and spray race spent US$ 1,498 and US$ 1,170, respectively (Table 3). Moreover, with the salvage value of US$ 53 for each head of cattle, the loss incurred due to TBD-caused death of an animal was highest (US$ 8,378) for farms using bucket pumps, followed by motorised pumps (US$ 1,960) and least (US$ 1,104) for those using spray races. Surprisingly, the highest loss (US$ 1,833) due to the farmer estimated TBD-induced reduction in milk production was mainly among farms using motorised pumps.

Critical limitations in the use of the application methods

The study observed that various limitations were faced by farm owners and workers depending on the method of acaricide application (Table 4). With the exception of wastage of acaricide mixture (20%, 1/5), the major limitations including regular breakdown of pumps and the low pump pressure were equally reported by 40% (2/5) of the farm owners who used a bucket pump method. Otherwise, frequent exhaustion (80.4%, 41/51) among workers using a bucket pump and the cost of investment in the establishment of a spray race (100%, 5/5) were the most critical limitations in tick control on the study farms.

DISCUSSION

Like elsewhere in Eastern Africa, dairy farms in Uganda largely depend on chemicals for tick control (Maingi and Njoroge, 2010; Nejash, 2016; Vudriko et al., 2018). Various methods, including dipping, spraying and pour-on, have globally been used to apply chemicals in tick control (George, 2000). While hand spraying using a bucket pump and Knapsack sprayers have been the most

used methods in Uganda, in the recent past farms have started adopting other methods. George et al. (2004) recommended that whichever method is chosen to apply acaricide on cattle, farmers must recognize the benefits, limitations and potential problems associated with the method. In Uganda since most (91%) of the farmers were using or adopting hand spraying methods, any benefits, limitations and potential problems associated these must be caused by factors related to labour (physical work and time taken) and equipment.

Recent literature (Collewet and Sauermann, 2017) shows that as the number of hours worked increases, the average work time increases, with workers becoming less productive due to fatigue. Unexceptionally, this study found that each worker using a bucket pump appeared fatigued after spraying only 14 head of cattle and thereafter signs of ineffectiveness were evident. This was contrary to the routine practice of using a single worker to spray a whole herd of 80 cattle. Due to this anomaly, the farms using the bucket pump method had higher morbidity and mortality and evidence of less efficient ways. The ineffective methods of bucket and the motorised pump could probably explain the emerging tick resistance to commercially available acaricides in Uganda.

Variation in the cost of using particular methods, as observed in the current study, was attributed to differences in automation. While the reduction in labour costs in automated processes (motorised pump and spray race) was not of surprise, it was unexpected that the costs of a motorised pump could be lower than those of a spray race. Nonetheless, the report by World Bank (2019) that technology/innovation reduces the time and cost of production was strongly corroborated by the findings of our study.

The fact that the quantity of acaricide mixture applied on each animal in the current study was lower than the recommended quantity (7 - 9 L) is evidence of farmers' continued hesitation in applying an adequate amount of acaricides in tick control. This reduction in the average volume of acaricide used was consistent with the investigators' occasional observation of inadequate coverage of the animals' body during farm visits. Surfaces occasionally missed included the limbs, tail

Table 3. Critical limitations in use of different acaricide application methods.

Limitation	Proportion of farms (%)	Proportion of workers (%)
Bucket pump method		
Regular breakdown of the pump	40 (2/5)	
Low pump pressure; application inefficiency	40 (2/5)	
Need for regular crush maintenance	40 (2/5)	
Wastage of time	40 (2/5)	
Wastage of acaricide mixture	20 (1/5)	
Frequent worker exhaustion		80.4 (41/51)
Irritation of skin by acaricide mixture		19.6 (10/51)
Motorised pump method		
Long distance to fuel station	25 (1/5)	-
Arm pain during spraying	-	25.5 (13/51)
Frequent spoiling of plugs	-	25.5 (13/51)
Labour involved in fetching of water	-	25.3 (13/51)
Spray race method		
Very high initial cost of investment	100 (5/5)	-
Regular blockage of 'ground' nozzles	20 (1/5)	-

switch and surfaces not reached due to close packing of animals during restraint in the crush. Continued use of less than the appropriate quantity of acaricide mixture as reported in this study is very likely because the costs of controlling TBDs in Uganda constitute about 80% of the total annual costs of livestock disease control (Ocaido et al., 2009).

While our study never revealed variation in morbidity and loss in milk yield among farms using the three different methods of acaricide application, this was a less likely situation. The contradiction could be due to the absence of reliable records since only a minority of surveyed farms kept written records. Besides, diagnosis in the study area was primarily based on endemicity, signs and symptoms and rarely on laboratory results. Additionally, there was a likely tendency of over-diagnosing of cases triggered by fears of death caused by TBDs or due to unscrupulous local practitioners who may want to earn more from increased treatment cases or charges. In the study area, veterinarians were less frequently used and consequently, diagnosis and treatment were mainly made by less qualified farm managers or farmers.

Conversely, it was surprising that average loss in milk was higher for farms using motorised pumps and spray races despite lower morbidity than for farms using bucket pumps. This could, however, have been confounded by the higher level of milk yield among the cows on farms using motorised pumps and spray races. It is common knowledge that farmers usually make higher level of investment with higher milk yielding cattle. Nonetheless, the fact that mortality due to TBDs was significantly

higher on farms using bucket pumps than on those of spray races demonstrated the higher level of effectiveness of the spray race compared to the bucket pump. This is not surprising since hand spraying has been reported to insufficiently wet cattle, which could be due to insufficient pump pressure or inadequate labour during application (Bianchi et al., 2003).

CONCLUSION AND RECOMMENDATIONS

The present study observed many limitations specifically associated with acaricide application methods or tick control in general that were not previously reported in published literature. Our study found limitations specific to farms using bucket pump such as worker exhaustion, wastage of acaricide, regular breakdown of pumps, frequent breakdown of crushes and time wastage among others. The most common constraints in several studies involving smallholder dairy farms include high input prices, inadequate capital investment, diseases and labour (Anh et al., 2013; Baker et al., 2015; Gebremichael and Hailemariam, 2019; Vudriko et al., 2016). This variation in observation is evidence of the addition of new information to the pool of knowledge.

The advantages and disadvantages and the cost-benefit of each alternative method should be assessed before a decision on a control programme is taken (Stafford et al., 2017). Based on our findings, it was concluded that, among the three, the use of motorised pump is the most cost-effective method of acaricide application, while the spray race is the most efficient.

Whereas the motorised pump was more effective, its use could only be feasible among herds of not more than 170 head of cattle and larger herds would require requiring a spray race. Moreover, the bucket pump has many critical limitations that affect its effectiveness compared to using a motorised pump or spray race.

Study limitations

The study used a questionnaire, which may not effectively capture the exact data (for periods beyond six months) on acaricide reconstitution and the quality of water used during reconstitution for periods beyond six months. We may also not have ruled out certain inaccuracies in the diagnosis of some cases of tick-borne infections on a few of the farms, especially where records were missing.

CONFLICT OF INTERESTS

The authors have not declared any conflict of interests.

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