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Chemical tick control practices in southwestern and northwestern Uganda

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ABSTRACT

Tick acaricide failure is one of the leading challenges to cattle production in Uganda. To gain an understanding into the possible drivers of acaricide failure, this study characterized the current chemical tick control practices in the southwestern (Mbarara, Mitooma and Rukungiri districts) and northwestern (Adjumani district) regions of Uganda. A total of 85 farms participated in a survey that utilized a semi-structured questionnaire. Moreover, ticks were collected to determine the most common species on the farms. Tick acaricide failure was mainly encountered in the districts where 95% (60/63) of the farms reared exotic cattle (dairy cross-breeds) under a paddocking (fenced) system. In the northwestern region, local cattle were reared in communal grazing areas. All farms used chemical acaricides for tick control, predominantly amidine (amitraz) (48%, 41/85) and co-formulated organophosphates and pyrethroids (38%, 32/85). The spraying method was the most common (91%, 77/85) acaricide application technique, with cattle crush (81%, 69/85) as a common means of physical restraint. Less than optimal tick control practices encountered included use of substandard equipment for spraying, inappropriate dilutions, frequent interaction between animals in neighboring farms despite lack of synchronized chemical tick control and malpractices in acaricide rotation. Only *Rhipicephalus appendiculatus* and *R.* (*Boophilus*) *decoloratus* ticks were found in the southwestern region, where 51% (32/63) of the farmers used high acaricide concentrations above the manufacturers' recommendation. Farmers in the northwestern region used 2.2 times less acaricide volume per cattle than those in the southwestern region, and more diverse tick species were encountered. Toxic effects of acaricide to cattle and workers were reported by 13% (11/85) and 32% (27/85) of the respondents, respectively. All 27 cases of human acaricide toxicity reported were from the southwestern region. Overall, our findings may inform strategies for more prudent chemical tick control and safe acaricide handling to benefit animal welfare, food safety and public health.

1. Introduction

Ticks and tick-borne diseases (TBD) have become one of the leading challenges to cattle production in Uganda. *Rhipicephalus appendiculatus*, *R.* (*Boophilus*) *decoloratus* and *Amblyomma variegatum* are among the most important tick species in the country (Byaruhanga et al., 2016). Besides the physical damage ticks cause on cattle (Brizuela et al., 1996), they also vector disease agents that are associated with severe economic loss. The climate in Uganda favors tick survival throughout the year. Thus, cattle farmers continuously have to use acaricides to reduce production losses associated with tick-borne diseases (Jongejan, 1999; Jongejan and Uilenberg, 2004). A recent study in Uganda reported that the most economically important ticks − *R. appendiculatus* and *R.* (*B.*) *decoloratus* − were resistant to commonly used acaricides (Vudriko et al., 2017a,b, 2016). However, the study did not sufficiently investigate the practices for usage of acaricides associated with resistant

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ticks. Acaricide resistance is a natural response to selection pressure (Robbertse et al., 2016) and inappropriate farm tick control practices may facilitate resistance development. Abbas et al. (2014) noted that acaricide application practices is the most important factor that influence the pace at which resistance develops. Consistent use of the same acaricide class on a farm is amongst the leading drivers of selection for resistance (Jonsson et al., 2000). In view of the wide spread complaints of acaricide failure, especially in western Uganda (Vudriko et al., 2016), this study sought to assess the practices involved in acaricide usage and determined the common tick species infesting cattle in four selected districts in southwestern and northwestern Uganda. The study also documented gaps in tick control as part of the baseline knowledge needed for developing better practices, including development of extension materials and farmer training. The study findings were also used for designing intervention strategies using evidence-based tick acaricide control practices (EBATIC) (Vudriko et al., 2017b). Therefore, this study adds to the body of knowledge on the challenges of tick control in smallholder farms, and highlights the key areas of concern that requires mitigation by authorities responsible for the animal industry to prevent a future acaricide resistance crisis in Uganda.

2. Materials and methods

2.1. Study area

The study was conducted in four districts, Adjumani, Mbarara, Mitooma and Rukungiri, in Uganda between July and September 2015 (Supplementary Fig. S1). Three of the districts in (Mbarara, Mitooma and Rukungiri) lie within the high acaricide pressure zone in Uganda's dairy shed areas (Balikowa, 2011) where in an earlier study we identified tick resistance against acaricides (Vudriko et al., 2016). Adjumani district on the other hand is located in the northwestern part of Uganda where acaricide pressure/use is generally lower. Adjumani is at an altitude of 900–1500 m above sea level and receives an average rainfall of 1125 mm per annum based on the district report. Mixed farming (crop-livestock) is the major economic activity with Zebu cattle as the dominant breed reared.

2.2. Study design

This was a cross sectional study that involved use of a semi-structured questionnaire to assess the knowledge, attitude and practice of farmers regarding tick control. Ticks were also collected from cattle and identified to determine species distribution in the four districts. In the southwestern region, farms with and without complaints of acaricide failure at the time of the study were identified by the local district veterinary office or drug shop outlet operators in the community. A total of 85 farms were purposively selected from the four districts by the district veterinary officers in charge of the study areas. A subjective score was used to rank acaricide failure based on the number of ticks recovered on animals in the southwestern region. Farms with a total of less than 10 ticks picked from half of the animals inspected were considered not to have acaricide failure and those with at least 10 ticks were categorized as having acaricide failure. Based on this criterion, 33 southwestern region farms were classified as having acaricide failure and another 30 farms were considered not to have acaricide failure. In Adjumani district, 22 farms were identified by the district veterinary office and used for obtaining data on chemical tick control practices in northwestern Uganda. Adjumani district was excluded from the criteria for southwestern due to low acaricide pressure and our earlier study showed ticks were susceptible (Vudriko et al., 2016; Vudriko et al., 2017a).

2.3. Survey to identify gaps in tick control

A semi-structured questionnaire was used to capture on-farm use of acaricides and possible factors that predispose to acaricide failure. The purpose of the research was explained to each farmer by the research team and the district veterinarian to obtain oral consent and permission. The questionnaire (Supplementary Fig. S2) was administered by the research assistants to either the owner or manager of a farm. Key variables captured included characteristics of the farm, equipment and facilities used for tick control, acaricide dilution and acaricide application practices, strategies used for coping with acaricide failure, and acaricide toxicity to animals and farm workers. Data on the types of acaricide used per farm was categorized into current (acaricide in-use at the time of data collection), intermediate (acaricide used just before the current one) and previous (acaricide used before the intermediate one). This was used to determine the acaricide brands and classes used and the correctness of rotational schemes. Acaricide rotation was considered incorrect if the change of acaricide was effected within the same class of acaricide, change from co-formulated acaricide to respective mono-formulations, or not being sure of the brand name of the acaricide used before (intermediate) changing to the current acaricide in use. The volume of acaricide mixed with 20 liters or per liter of water for application on animals was used to determine whether manufacturer's recommendation for dilution of the acaricide in use was followed. Dilution was deemed incorrect if the acaricide strength was higher (double, triple or quadruple) or lower than manufacturers' recommendation, estimated or the respondent was not sure. The number of animals sprayed with 20 liters of mixed acaricide solution was used to calculate the average volume (liters) of mixed acaricide solution used for spraying one cattle against the FAO recommended (FAO, 1998) ratio of 10 liters to 1 cattle.

2.4. Collection and identification of ticks

At each farm, at least half of the cattle were randomly taken to the holding yard or kraal (Fig. 1A). Animal handling procedures during sample collection were done by qualified personnel (district veterinarians and research team) to avoid any pain and distress to the animal. The cattle were restrained using either crush or ropes and visible ticks were hand-picked from their various attachment sites. The ticks were transferred into aerated sample bottles, sorted and identified to species level using a published key (Walker et al., 2014).

2.5. Data analysis

The data captured were coded and entered in MS Excel and analyzed in SPPS version 21 (IBM SPSS Statistics for Windows, Version 21.0; IBM Corp., Armonk, NY, USA). Fisher's Exact Test was used to determine the operational factors associated with acaricide failure in farms in southwestern Uganda at 95% confidence and p value ≤ 0.05 was considered statistically significant. Tick data were further analyzed to determine the distribution of tick species per district.

2.6. Ethical considerations

The study was approved by the College of Veterinary Medicine, Animal Resources and Biosecurity, Makerere University (Approval number: VAB/REC/15/104). Both questionnaire administration and sample collection were done in only farms that gave oral consent. Animals were handled by Veterinarians during sample collection to avoid distress. The identity of the respondents were kept confidential. Any mention of the brand name of an acaricide should not be taken as promotion or demotion of the product.

3. Results

3.1. Characteristics of the farms

A total of 85 farms participated in this survey, 63 of which were

Fig. 1. Tick control facilities used for restraint of cattle during spraying in southwestern and northwestern Uganda. **A:** A kraal with a spraying area known as *boma* indicated in white solid arrow. The white dashed arrow shows a crush that was abandoned due to poor design and difficulty in using it during acaricide application. **B**: A crush that is poorly cited (close to natural fence) and constructed with weak materials. **C**: A crush that is poorly constructed; too wide that animals form 3 rows in the crush, making it difficult to effectively spray.

from southwestern Uganda while 22 were from northwestern district of Adjumani (Table 1). Of the 85 respondents, 47% (40/85) carried out farming as a full time occupation while the rest had the farm as a secondary enterprise. All the farms in Adjumani district reared local cattle for multiple purposes (beef, milk, draft power). In contrast, 95%, (60/63) of the farms in southwestern Uganda reared mainly exotic cattle crosses for dairy production. Most of the farms had small (< 20 head) or medium (21–100 head) cattle herd sizes. Cattle were kept along with small ruminants in 53% (45/85) of the farms. Paddocking (rearing cattle on fenced land) was practiced by 86% (54/63) of the farms in southwestern Uganda while grazing animals on expansive community-owned land (communal grazing) was the main system of cattle management in Adjumani district (90%, 18/22). The interaction between livestock and wildlife was reported in 39% (33/85) of the farms, 55% (18/33) of which occurred in farms in southwestern Uganda.

3.2. Method of tick control and associated facilities

All the respondents reported that chemical (acaricide) application was the only means of tick control employed on their farms. Overall, spraying accounted for 91% (77/85) of the methods of acaricide application (Table 2). Up to 81% (69/85) of the farms used crush (Fig. 1B and C) for restraining cattle during acaricide application with the spray method. Dipping and scrubbing with cloth was encountered in 7% (6/85) and 2% (2/85) farms, respectively. Bucket pump (recommended spray equipment) was used by 68% (43/63) and 14% (3/22) of the farms in southwestern and northwestern regions, respectively. Of concern was that 39% (33/85) of the farms used inappropriate equipment such as knapsack sprayer (20%, 17/85), hand sprayer (16%, 14/85) and scrubbing cloth (2%, 2/85) for acaricide application. Hand-held 1 or 2 liters' spray pumps were predominantly used in Adjumani district (55%, 12/22). The most common equipment used for measurement of acaricide were graduated bottle tops (58%, 49/85) and syringes (31%, 26/85). However, ungraduated acaricide bottle tops were also used by 5% (4/85) of the farms. The most common sources of water for mixing acaricides were tap water (14%, 12/85) and water harvested directly from natural reservoirs (86%, 73/85) such as rivers, streams, valley dams, and swamps. The quality of swamp water from 15% (13/85) of the farms was characterized as dirty and not suitable for diluting acaricides. Almost all (97%, 32/33) farms that experienced tick acaricide failure in southwestern Uganda were applying acaricides using the spray method.

3.3. Source of advice, acaricide and application interval

The majority (72%, 61/85) of the respondents reported that veterinarians were their main source of advice on tick control (Table 3). However, 28% (24/85) of the respondents either relied on their personal judgement or sought advice on tick control from veterinary drug shop attendants and fellow farmers. Local veterinary drug shops were the main source of acaricides (69%, 59/85) although some farmers obtained acaricides from veterinary pharmacies/distributors (14%, 12/85) and illicit open markets (9%, 8/85). Mixing of acaricides were

Table 1
General characteristics of the study farms in southwestern and northwestern Uganda.

Query	Reponse	Region		Total	Percentage (%)
		Southwestern	Northwestern		
Location	Adjumani	0	22	22	26
	Mbarara	25	0	25	29
	Mitooma	19	0	19	22
	Rukungiri	19	0	19	22
Total		63	22	85	100
Occupation	Business	9	1	10	12
	Civil servant	7	17	24	28
	Engineer	2	1	3	4
	Farmer	38	2	40	47
	Livestock Technician	1	0	1	1
	Politician	3	1	4	4
	Retired	3	0	3	4
Position at the Farm?	Manager	11	7	18	21
	Owner	52	15	67	79
Breed of cattle reared?	Crosses	60	0	60	71
	Local	3	22	25	29
Purpose for keeping cattle?	Dairy	44	0	44	52
	Multipurpose	19	22	41	48
Herd size?	Small (< 20)	25	4	29	34
	Medium (21–100)	34	11	45	53
	Large (> 100)	4	7	11	13
Presence of small Ruminants?	Yes	41	4	45	53
	No	22	18	40	47
Wildlife-Livestock Interaction?	Yes	18	15	33	39
	No	45	7	52	61
Livestock management system?	Communal	6	18	24	28
	Paddocks	54	0	54	64
	Ranching	1	1	2	2
	Tethering	0	3	3	4
	Zero grazing	2	0	2	2

mainly done by farm workers (69%, 59/85) such as herdsmen (46%, 39/85), farm managers (20%, 17/85) and children (4%, 3/85). Acaricide application was carried out frequently by herdsmen (57%, 48/85) while supervision of mixing and application was done by the farm owner (46%, 39/85), farm manager (28%, 24/85) and fellow herdsmen (24%, 20/85). During the rainy season, the recommended weekly acaricide application was practiced by 81% (51/63) and 64% (14/22) of the farms in southwestern and northwestern regions, respectively. In the southwestern, the recommended fortnight and/or monthly acaricide application during dry season was practiced by only 5% (3/63) of

Table 2
Method of tick control on farms in southwestern and northwestern Uganda.

Query	Response	Region		Total	Percentage (%)
		Southwestern	Northwestern		
Method of acaricide application used?	Dipping	5	1	6	7
	Scrubbing	2	0	2	2
	Spraying	56	21	77	91
Equipments used for acaricide application?	Bucket pump	43	3	46	54
	Dip	5	1	6	7
	Hand sprayer	2	12	14	17
	Knapsack sprayer	11	6	17	20
	Scrubbing cloth	2	0	2	2
Method of restraint (during spraying)?	*Boma*[a]	1	3	4	5
	Cattle crush	62	7	69	81
	Ropes	0	12	12	14
Equipment used for acaricide Measurement?	Calibrated bottle top	38	11	49	58
	Acaricide bottle for dip	5	1	6	7
	Non calibrated bottle top	4	0	4	5
	Syringe	16	10	26	31
Water used for mixing acaricides?	Tap water	8	4	12	14
	Clean natural	50	10	60	71
	Dirty natural	5	8	13	15

[a] A holding yard in a cattle kraal where cattle are restrained during spray.

Table 3
Methods of acaricide application, sources of acaricides and sources of advice in farms in southwestern and northwestern Uganda.

Query	Response	Region		Total	Percentage (%)
		Southwestern	Northwestern		
How often do you spray/apply acaricide during rainy season?	Thrice a week	1	0	1	1
	Twice a week	10	4	14	16
	Weekly	51	14	65	77
	Fortnight	0	1	1	1
	Monthly	1	3	4	5
Total		63	22	85	100
How often do you spray/apply acaricide during dry season?	Twice a week	7	4	11	13
	Weekly	53	6	59	69
	Fortnight	1	1	2	2
	Monthly	2	11	13	15
Source of advice on tick control?	Drug shop attendant	5	0	5	6
	Drug shop attendant and fellow farmer	1	0	1	1
	Drug shop attendant and Veterinarian	2	0	2	2
	Fellow farmer	1	3	4	5
	Fellow farmer and Veterinarian	1	0	1	1
	Veterinarian	43	18	61	72
	None	10	1	11	13
Source of acaricide?	Local drug shop	46	13	59	69
	Open market	5	3	8	9
	Pharmacy	7	5	12	14
	Veterinarian	5	1	6	7
Who mixes the acaricide?	Children	3	0	3	4
	Farm manager	15	2	17	20
	Herdsman	25	14	39	46
	Owner	19	6	25	29
	Veterinary Pharmacy	1	0	1	1
Who applies acaricides?	Children	3	0	3	4
	Farm manager	8	1	9	11
	Herdsman	33	15	48	57
	Owner	19	6	25	29
Number of cattle sprayed with 20 liters of mixed acaricide wash?	FAO recommended (2 cattle)				
	At most 7	15	0	15	18
	8–20	40	6	48	57
	21–40	3	7	10	12
	> 40	0	6	6	7
	Not applicable (dip)	5	1	6	7
Who supervises mixing and application?	Children	2	0	2	2
	Farm manager	18	6	24	28
	Owner	33	6	39	46
	Herdsmen	10	10	20	24

the farmers since 84% (53/63) applied weekly. On the contrary, 50% (11/22) of the farmers in the northwestern applied acaricide once a month during the dry season. A major concern encountered was that, 24% (15/63) and 18% (11/63) of the farmers in the southwestern region applied acaricides on cattle at least twice a week during the rainy and dry seasons, respectively.

3.4. Type of acaricides used

Of the 20 brands of acaricides reported, 11 were currently used (Fig. 2A). Six of the seven brands of amidine, were currently used, with amitix (24%, 21/86) and milbitraz (12%, 10/86) being the most frequent. Eight brands of pyrethroids were mentioned, only two (alfapor and vectocid) were currently used. Of the 3 brands of co-formulated acaricides, two (duodip and protaid) were currently used. Only one brand of mono-formulated organophosphate (supona extra) was encountered. The proportion of uncertainty (not sure) in brands used currently, intermediate and previously was at 1% (1/86), 30% (26/88) and 59% (50/85), respectively.

Comparison of the classes of acaricides used currently, intermediate and previously, showed a general increase in the current usage of amidine and co-formulated acaricides but a decline for synthetic pyrethroid (Fig. 2B). Amidines (48%, 41/85) and co-formulation (38%, 32/85) accounted for 86% (73/85) of the currently used classes of acaricide (Fig. 2). In the southwestern region, 48% (30/63) of the farms used co-formulation, 53% (16/30) of which were from Mbarara district. Of the 41% (26/63) of the farms in southwestern region that used amidine, Rukungiri had the highest (46%, 12/26) while Mbarara and Mitooma had each 27% (7/26) farms. In the northwestern region, amidine and pyrethroid were currently used by 68% (15/22) and 23% (5/22) of the farms, respectively. Generally, mono-formulated pyrethroids (9%, 8/85) and organophosphate (4%, 3/85) acaricides were the least used in the 85 farms.

3.5. Acaricide dilution malpractices

Up to 81% (69/85) of the farmers diluted acaricide incorrectly while only 19% (16/85) diluted correctly following the manufacturers' recommendation (Fig. 3A and B). The proportion of farms that mixed acaricides incorrectly were 82% (18/22), 88% (22/25), 79% (15/19) and 74% (14/19) in Adjumani, Mbarara, Mitooma and Rukungiri districts, respectively (Fig. 3B). In the northwestern region, only 27% (6/22) of the farms followed the manufactures' dilution rate, the rest used estimate (22%, 5/22), lower acaricide strength (14%, 3/22), or higher

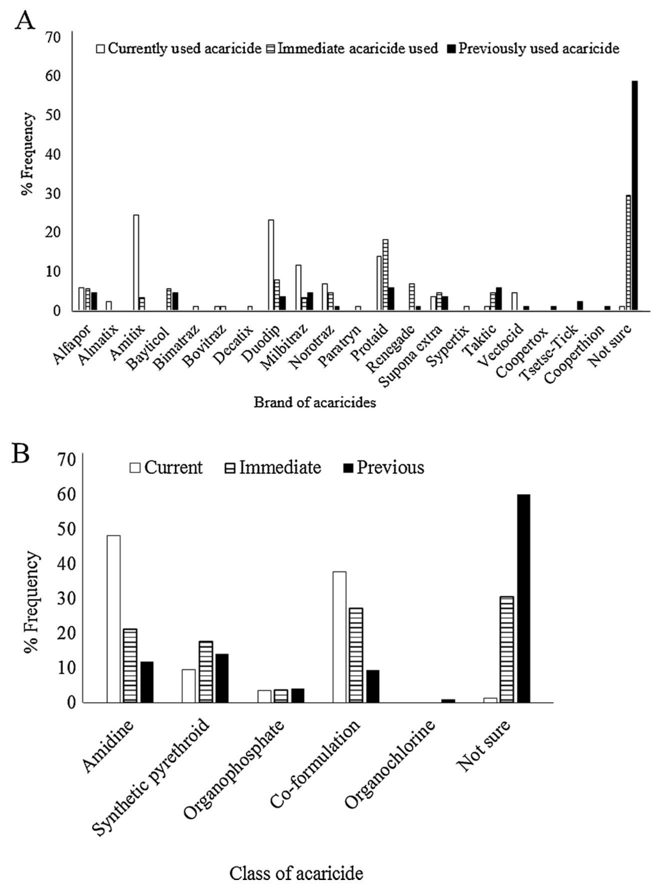

Fig. 2. Brands and classes of acaricides used for tick control in southwestern and northwestern Uganda.
A: Brands of acaricides used currently, intermediate and previously (1–10 years) for tick control;
B: Classes of acaricides used currently, intermediate and previously for tick control. Intermediate acaricide is the one used before the current acaricide; previously used acaricide refers to acaricides used before the intermediate.

acaricide strength (9%, 2/22), and 23% (5/22) were not sure of the dilution rate (Fig. 3C). Similarly, in the southwestern region, only 19% (12/63) of the farms followed the manufacturers' recommended dilution rate, the rest practiced dilution malpractices such as use of higher concentration (51%, 32/63), lower concentration (11%, 7/63), or estimate (2%, 1/63), and 18% (11/63) were not sure about the dilution rate (Fig. 3C). Apparently half of the farms with acaricide failure (49%, 16/33) and those without acaricide failure (53%, 16/30) were using higher acaricide strength (Fig. 3D).

3.6. Volume of acaricide applied on cattle

In both regions, no farmer applied the FAO recommended 10 liters of mixed acaricide solution per head of cattle. Only 18% (15/85) of the farms used 20 liters of mixed acaricide solution to spray utmost 7 heads of cattle, while the rest of the farmers applied the same quantity of mixed acaricide solution on 8 to over 40 heads of cattle (Table 3). The average number of cattle sprayed with 20 liters of mixed acaricide solution was 38 and 12 in the northwestern and southwestern regions, respectively (Fig. 4). Farmers in the northwestern region applied on average 0.98 liters of acaricide solution per head of cattle, compared to 2.15 liters in the southwestern region ($p = 0.0001$).

3.7. Coping strategies against acaricide failure

Acaricide failure was encountered in 33 out of 63 farms in southwestern Uganda (Table 4). The major coping strategies against acaricide failure in southwestern included change from one brand of acaricide to another (56%, 35/63), using higher (double to quadruple) acaricide concentration (19%, 12/63) and increasing frequency of acaricide application (3%, 2/63). However, 51% (25/49) of the farms that used the above strategies reported that they were not effective in the long term. Mixing of two or more brands of acaricides was thought to be effective against acaricide failure by 4% (3/85) of the respondents, but 29% (25/85) of them thought such approach was not effective against acaricide failure. Overall, only 48% (41/85) of the farms rotated acaricides correctly, the rest (52%, 44/85) either rotated improperly (21%, 18/85) or could not remember the previous acaricide used (31%, 26/85). No farm had written records on acaricides used for tick control in the last 2 years.

3.8. Interaction of animals in neighborhood and quarantine of newly introduced animals

The majority (68%, 58/85) of the farms were in close proximity to other neighboring farms (Table 5). Interactions between animals on neighboring farms was reported for 58% (49/85) of the farms. Moreover, 45% (38/85) of the farms reported that their animals interacted with those of neighbors' daily or weekly. Interestingly, 52% (44/85) of the respondents had no knowledge of acaricide usage by their neighboring farmers and another 46% (39/85) were also not aware when their neighbors applied acaricides. None of the neighboring farms attempted to synchronize either the days or the class of acaricide used for tick control. It was also found that 37% (31/85) of the farmers had introduced new animals on their farm from cattle markets, neighboring farms and neighboring districts. Apparently, half of the farms that brought in new animals neither quarantined nor sprayed the cattle with acaricides prior to introduction in their farms.

3.9. Acaricide safety concerns in animals and workers

Only 24% (20/85) of the farms kept acaricides in a designated storage facility (store) while 55% (47/85) kept acaricides in their residential houses (Table 6). Of concern was that 32% (27/85) of the farms reported occupational toxicity to farm workers during acaricide application. The most frequent signs of toxicity associated with human exposure to acaricides included dizziness, itching of the skin and the eye and coughing. Relatedly, 13% (11/85) of the respondents reported toxicity to cattle associated with acaricide application as evidenced by signs such as damaged skin, blindness and death of cattle.

3.10. Tick species identified from the farms

A total of 2520 ticks were collected from cattle and identified as *R. appendiculatus* (54.3%), *R.* (*B.*) *decoloratus* (22.2%), *A. variegatum* (18.2%), *R. evertsi* (2.7%) and *Hyalomma* spp. (2.7%) (Table 7). Of the 1023 ticks collected from Adjumani in the northwestern region, *A. variegatum* (44.8%) was most prevalent followed by *R. appendiculatus* (28.4%), *R.* (*B.*) *decoloratus* (13.7%) and *Hyalomma* spp. (6.5%). In contrast, *R. appendiculatus* (72%, 1078/1497) and *R.* (*B.*) *decoloratus* (28%, 1497) were the only tick species found on cattle from southwestern Uganda. Numbers of *R. appendiculatus* collected were consistently higher than for *R.* (*B.*) *decoloratus* in all three districts in the southwestern region.

3.11. Factors associated with acaricide failure in the southwestern region

Statistical analysis was carried out to clarify whether tick control operational practices differed between farms experiencing acaricide failure and those that claimed not to have experienced acaricide failure. In the southwestern region, acaricide failure was significantly associated with use of amitraz (Fisher's exact test, $p = 0.018$). However,

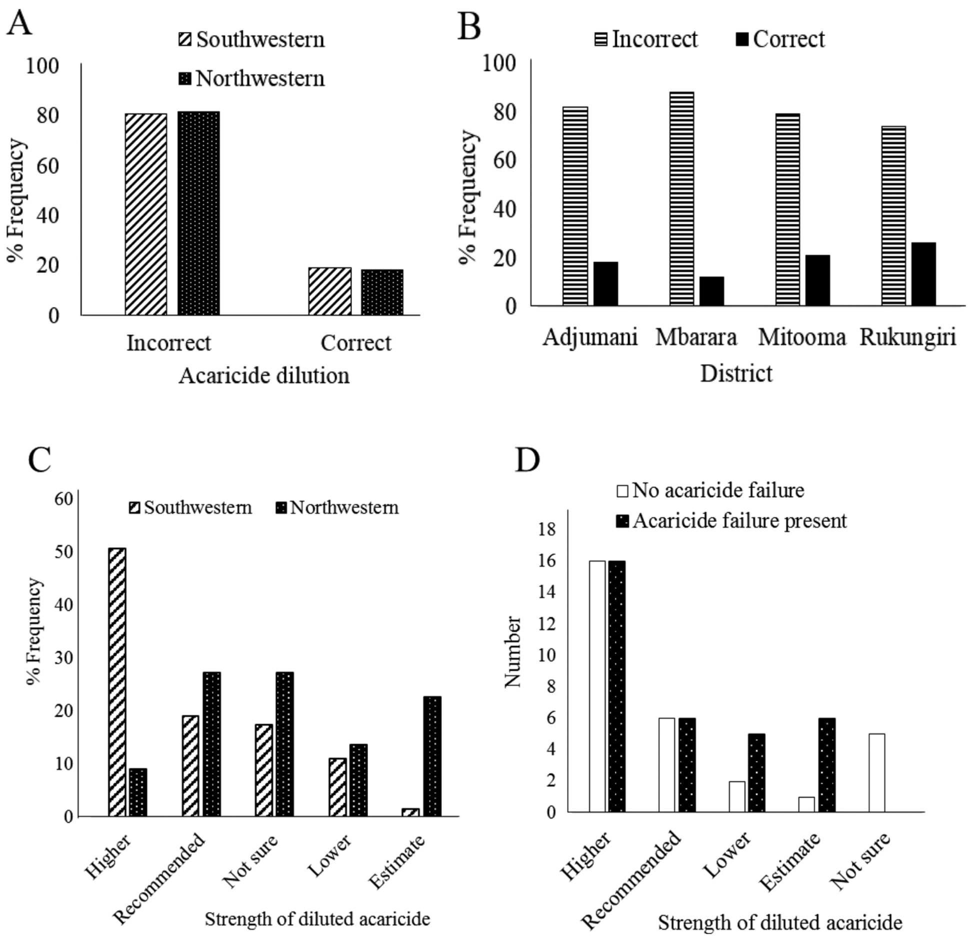

Fig. 3. Acaricide dilution practices in southwestern and northwestern Uganda.
A: Correctness of acaricide dilution based on manufacturers' recommendation in the southwestern and northwestern regions; B: Correctness of acaricide dilution per study districts; C: Strength of acaricide solution based on currently used acaricides in the southwestern and northwestern regions; D: Strength of currently used acaricides in farms with and those without acaricide failure.

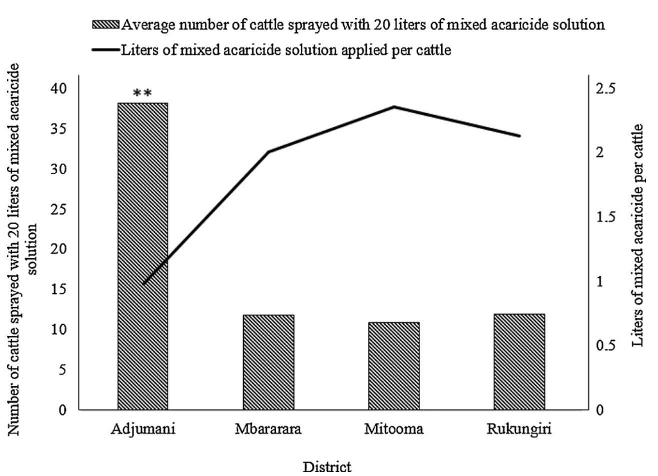

Fig. 4. Volume of acaricide applied on cattle in southwestern and northwestern Uganda.
Average number of cattle sprayed with 20 l of mixed acaricide solution and volume applied per cattle in the study districts. Southwestern districts included Mbarara, Mitooma and Rukungiri; Northwestern district included Adjumani.
** $p = 0.0001$ (The volume of mixed acaricide solution applied per cattle was significantly lower in the northwestern region compared to the southwestern region of Uganda).

there was no significant association ($p > 0.05$) between acaricide failure and correctness of acaricide rotation, correctness of dilution, number of animals sprayed with 20 liters of mixed acaricide solution, source of advice on tick control, type of equipment used for spraying or supervision of acaricide application. Overall, farm tick control practices were similar between the two categories of farms in the southwestern region.

4. Discussion

This study presents six fundamental findings that characterize the current tick control practices in the southwestern and northwestern regions of Uganda. I) In the southwestern region, farmers rely exclusively on chemicals (acaricides) for tick control as opposed to integrated tick control approaches. II) The exotic cattle (crossbreeds) keepers in southwestern Uganda have adopted high acaricide application pressure (high acaricide strength over recommended concentration) as a possible compensatory strategy against acaricide ineffectiveness. Thus, absence of ticks on cattle in the southwestern may not necessarily reflect acaricide effectiveness but also excessive use of acaricide to eliminate "stubborn" ticks. III) The agro-pastoral community in northwestern Uganda lack knowledge on appropriate tick control but their local cattle are tolerant and can survive high tick burdens with limited need for acaricides. IV) Less than optimal acaricide application practices were wide spread and does not only present a real threat to emergence and spread of acaricide resistance but also pose a serious public health threat. V) Even where animals interacted on neighboring farms, there was lack of evidence on synchronization of type of acaricides used and acaricide application practices due to lack of strategic tick control policy in the country to enforce mandatory rational acaricide rotation. VI) Chemical tick control records were not kept by the farms, making it difficult for farmers to implement appropriate acaricide rotation. The implications of these fundamental findings are discussed below.

This study found that spraying was the most common method

Table 4
Coping strategies used against tick acaricide failure by farmers in southwest and northwest Uganda.

Query	Response	Region		Total	Percentage (%)
		Southwestern	Northwestern		
History of acaricide failure	Yes	33	0	33	39
	No	30	22	52	61
Total		63	22	85	100
Strategies used for overcoming acaricide failure?	Change acaricide	35	0	35	41
	Double concentration and change of acaricide	6	0	6	7
	Double concertation	3	0	3	4
	Increase the frequency of spraying	2	0	2	2
	Triple acaricide concentration	3	0	3	4
	Not applicable	14	22	36	42
Are the coping strategies effective?	Yes	19	0	19	22
	Somehow	5	0	5	6
	No	25	0	25	29
	Not applicable	14	22	36	42
Time spent with previous acaricide before changing to current	Less than 5 months	11	0	11	13
	6–9 months	6	1	7	8.2
	1–2 years	15	0	15	18
	Above 2 years	14	3	17	20
	Not sure	17	18	35	41
Knowledge about people mixing two or more acaricides??	Yes	3	0	3	4
	No	60	22	82	97
Source of advice on mixing two or more acaricides together	Fellow farmer	2	0	2	2
	Trial and error	1	0	1	1
	Not applicable	60	22	82	97
Does mixing two or more acaricide together solve acaricide failure?	Yes	3	0	3	4
	No	25	0	25	29
	Not sure	35	22	57	67

Table 5
Proximity to neighbors, knowledge on tick control in neighborhood and quarantine of newly control of ticks on newly introduced animals in southwestern and northwestern Uganda.

Query	Response	Region		Total	Percentage (%)
		Southwestern	Northwestern		
Distance with neighboring farm (kilometers)?	0 (separated by fence)	57	1	58	68
	> 1	2	16	18	21
	1–3	3	3	6	7
	> 4	1	2	3	4
Total		63	22	85	100
Presence of fence?	No	5	19	24	28
	Yes	58	3	61	72
Interaction of your animals with that of neighbors?	Daily	14	15	29	34
	Weekly	5	4	9	11
	Monthly	8	3	11	13
	Never	35	0	35	41
	Not sure	1	0	1	1
Knowledge of acaricide use by neighbors?	Yes	24	17	41	48
	No	39	5	44	52
Knowledge on the days of the week when neighbor sprays?	Yes	29	17	46	54
	No	34	5	39	46
New animals (cattle) introduced in the farm	No	34	20	54	64
	Yes	29	2	31	37
Origin of new animals (cattle) introduced in the farm?	Cattle market	10	0	10	12
	Neighboring district	15	1	16	19
	Neighboring farm	4	1	5	6
	None	34	20	54	64
Did you quarantine any animal and sprayed before mixing with others?	No	13	2	15	18
	Yes	16	0	16	19
	Not applicable	34	20	54	64

Table 6
Acaricide safety concerns in animals and humans in southwestern and northwestern Uganda.

Query	Response	Region		Total	Percentage (%)
		Southwestern	Northwestern		
Location where acaricide is stored?	At dip tank	5	1	6	7
	Drug box	2	5	7	8
	In the bush at the kraal	0	1	1	1
	Designated store	20	0	20	24
	Residential house	35	12	47	55
	No response	1	3	4	5
Total		63	22	85	100
Have you seen or heard of animals with damaged skin damage & due to acaricide (poisoning)?	Yes	9	2	11	13
	No	48	8	56	66
	Not sure	6	12	18	21
Has any person applying acaricide on this farm suffered from adverse (bad) effects of acaricides?	No	36	22	58	68
	Yes	27	0	27	32
If yes, which effects?	Blindness	1	0	1	1
	Coughing	2	0	2	2
	Dizziness	8	0	8	9
	Eye and skin Itching	1	0	1	1
	Eye itching	8	0	8	9
	Skin itching	6	0	6	7
	Skin itching and Coughing	1	0	1	1
	None	36	22	58	68

(Table 2) of acaricide application since it is perceived as convenient and cheap for small farms (Mugisha et al., 2005; Mugabi et al., 2009). However, almost all the farms in the southwestern region that had acaricide failure were using the spray method, suggesting that this method may predispose to tick acaricide resistance if used inappropriately. A previous study in South Africa also reported that the spray method is one of the factors that promotes resistance against acaricides (Spickett and Fivaz, 1992). Associated with the spray method are other factors such as inappropriate restraint facilities (poor crush and use of *boma*) (Fig. 1), hardship of spraying large herds, lack of adequate supervision, frequent acaricide dilution and rotation malpractices which makes the spray method inefficient and vulnerable to acaricide failure (Tables 2–4). Less than optimal acaricide application practices during spraying were also reported by Mugabi et al. (2009) and Mugisha et al. (2005) as a potential precursor for acaricide resistance in Uganda. While dipping is considered the most effective technique for acaricide application, the initial cost of investment is prohibitive for small to medium size farms (De Meneghi et al., 2016). The spray-race method may be promoted as an alternative to dip plunge since it offers appropriate acaricide application and tick control outcome (Jonsson et al., 2000). However, proper construction and regular maintenance of the nozzles are key for effectiveness of the spray-race method (De Deken et al., 2013).

The study also found a general decline in the use of pyrethroids but an increase in the use of amidine and co-formulations (organophosphate and pyrethroid) in the southwestern region. The decline in the use of pyrethroids from an earlier report (Mugabi et al., 2009; Vudriko et al., 2016) may be attributed to wide spread resistance in *R. decoloratus* and *R. appendiculatus* ticks in the southwestern region (Vudriko et al., 2017a). The use of amitraz as an alternative in rotational control of pyrethroid resistant ticks has been widely reported (Abbas et al., 2014; Foil et al., 2004; Mugisha et al., 2008; Vudriko et al., 2016). Increase in the use of co-formulation further re-enforces the premise regarding possible emergence of resistance against mono-formulated pyrethroids. Increased marketing of co-formulated acaricides by the suppliers and Veterinary drug shops might have influenced the choice of the buyers (farmers) (Mugisha et al., 2008; Spickett and Fivaz, 1992). However, the short acaricide application interval (twice a week) and use of higher concentrations of amidine and co-formulation (Table 4) are early warning signs that resistance may be developing against amidine and co-formulation acaricides in the southwestern region. Continuous improper acaricide rotation and application practices can be expected to trigger and sustain acaricide resistance in the southwestern region if not attended to by the central and local government.

In northwestern Uganda, where farmers reared *Bos indicus*, amidine was widely used, possibly due to the low cost of amitraz. This is consistent with the observation that farmers in Adjumani purchased small volume of amitraz regardless of the herd size as previously reported by Mugabi et al. (2009) and Mugisha et al. (2005) in agro pastoral areas. Despite the poor acaricide application practices in the northwestern region, limited chemical acaricide use, reduced tick exposure to acaricides and extensive grazing systems helps to prevent development of

Table 7
Frequency of the tick species collected from farms in southwestern and northwestern Uganda.

Region	District	Tick species identified											
		R. appendiculatus		*R.* (*Boophilus*) *decoloratus*		*R. evertsi*		*A. variegatum*		*Hyalomma* spp.		Total	
		Number	%	Number	%	Number	%	Number	%	Number	%	Number	%
Southwestern	Mbarara	396	62.9	234	37.1	0	0.0	0	0.0	0	0.0	630	25.0
	Mitooma	198	71.5	79	28.5	0	0.0	0	0.0	0	0.0	277	11.0
	Rukungiri	484	82.0	106	18.0	0	0.0	0	0.0	0	0.0	590	23.4
Northwestern	Adjumani	291	28.4	140	13.7	67	6.5	458	44.8	67	6.5	1023	40.6
	Total	1369	54.3	559	22.2	67	2.7	458	18.2	67	2.7	2520	100.0

% percentage.

acaricide resistance. Nevertheless, farmers in the northwestern region (Adjumani district) needs to be trained in prudent use of acaricides to prevent emergence of resistance in the future.

It was also found that animals on neighboring farms mixed frequently (Table 5). This presents a threat especially in the southwestern region since acaricide resistant ticks can be easily exchanged across farms (Jonsson, 1997). In the absence of official tick control policy in Uganda, there is no regulation regarding the type of acaricides to be used in a particular area. As such, farmers use different classes of acaricides, even within the same location. It is therefore postulated that lack of synchronized rotation and movement of animals across farms may not only accelerate the rate of exchange and spread of resistant ticks but also hasten the rate at which resistance against multiple classes of acaricides occur. Such risks can be avoided by identifying the acaricides that work within an area or a region and enforcing compulsory rotation by the government. The state-led acaricide rotation is important in delaying acaricide resistance (Thullner et al., 2007), ensuring adherence to a specific acaricides (Bardosh et al., 2013; Mugabi et al., 2009) and creating reservoir acaricides for future use.

The current study also found that poor acaricide application practices occurred in almost equal measure among farmers with or without reported acaricide failure. Notably, farmers in the southwestern region that had no acaricide failure were likely using high (double or even quadruple) acaricide concentration above the manufacturers' recommendations (Fig. 3D). The use of high acaricide strength reported in this study contradicts an earlier finding by Mugisha et al. (2008) who reported that the majority of farmers in southwestern Uganda used either weak or very weak acaricide strength. The difference in the above findings may be attributed to change in tick population phenotypes over time due to the selection of resistant types, which are tolerant to acaricides. However, the finding in this study agrees with our earlier report (Vudriko et al., 2016) that found malpractices involving use of high strength acaricide solution in farms with acaricide resistance. Moreover, increasing the concentration of acaricides alone without addressing management practices would only cause a temporary relief against acaricide failure, but with the possibility of selecting for more stable resistance. With some farmers opting to source advice from fellow farmers and drug shop attendants (mostly unqualified), the threat of a complex acaricide crisis exists. Additional factors that may exacerbate acaricide crisis will be the absence of centralized acaricide rotation, inadequate technical farmer advisory services and lack of laboratory susceptibility tests to guide rational acaricide prescription.

Acaricide handling and safety (Table 6) appeared to be an emerging but neglected public health threat in areas with acaricide failure. The short acaricide application interval (twice a week) was practiced and increasing the concentration 2 or 3 folds above manufacturers recommendation is not only unsafe to the animal (and its product) but also the farm workers who handle acaricides. A farmer in Mitooma district who quadrupled the concentration of chlorfenvinfos almost killed his whole herd of cattle. Moreover, with 32% prevalence of human occupational toxicity, there is need to carry out mass sensitization of communities especially in Uganda on the risks involved in acaricide mishandling. At farm level, providing farm workers with personal protective materials such as overalls, gumboots, gloves, goggles and nose masks will prevent adverse effects of exposure to acaricides and motivate workers to apply acaricides correctly. Interventions on safe acaricide use should be a joint initiative between veterinarians and health officials in a one health approach. The effectiveness of one health intervention approach in chemical tick control was earlier reported in Zambia and Burkina Faso (De Meneghi et al., 2016). Such joint intervention is expected to avert the effect of acaricides (De Castro, 1997) on animal welfare, food safety and public health.

This study also identified *R. appendiculatus* and *R.* (*B.*) *decoloratus* as the most common species of ticks infesting cattle in Uganda (Table 7). This finding is contrary to previous report by Ocaido et al. (2006) who found more diverse tick species on cattle at the wildlife-domestic interface of Lake Mburo national park in southwestern Uganda. Worryingly, our study found a 140% (0.2% to 28%) increase in the population of *R.* (*B.*) *decoloratus* ticks in the southwestern region compared to the burden reported by Ocaido and his colleagues (2006). This observation suggests selection of an acaricide resistant *R.* (*B.*) *decoloratus* phenotype in the last 10 years in the southwestern region of Uganda. This agrees with our recent study that also found the two above-mentioned ticks as the most common species in farms experiencing tick acaricide resistance challenges (Vudriko et al., 2016). However, another possible explanation for the discrepancies in our findings from that of Ocaido et al. (2006) may be attributed to the management system since extensive grazing in and around the park increases likelihood of cattle picking ticks from various locations within the park where tick population is high. The northwestern region of Uganda had more diverse tick species that also included *A. variegatum* and *Hyalomma* spp. The difference in tick species dynamics between farms from the southwestern and northwestern regions could be attributed to high acaricide pressure in the southwestern which wipes out susceptible ticks on cattle. With the high population of susceptible exotic breeds, farmers in southwestern Uganda have to cleanse their cattle with acaricides weekly to prevent cases of tick-borne diseases such as East coast fever (ECF) (Byaruhanga et al., 2017), thereby reducing the population of susceptible tick population. This is consistent with a previous report (Jonsson et al., 2000) that related frequent application of acaricides to selection pressure and resistance in *R. microplus* ticks.

Major limitations of the study include a small sample size and subjective criteria for selection of farms with or without acaricide failure. Such criteria may not be able to truly predict acaricide failure since other factors, such as use of high acaricide strength and increased frequency of acaricide application, may temporarily reduce resistant tick populations, thus giving a false impression of absence of acaricide failure. In the absence of written records on tick control, response bias due to selective memorization by the study participant could have introduced bias in their response to the research questions on sequence of acaricides used. Nevertheless, the malpractices in chemical tick control in the two regions reflects the level of concern that requires urgent intervention to prevent a complex acaricide resistance crisis from emerging in Uganda.

Short-to-medium term actions should include extensive education of farmers on appropriate acaricide use, increased farmer access to veterinary advisory services, building human and laboratory capacity for prompt detection of and intervention against acaricide failure or resistance. The threat posed by uncoordinated tick control in neighboring farms, district and region requires harmonization by Ministry of Agriculture, Animal Industry and Fisheries. At farm level, strengthening biosecurity through proper fencing, proper inspection, quarantine and spraying of new animals brought to the farm is recommended. Foil et al. (2004) proposed that ensuring biosecurity on farm will reduce spread of acaricide-resistant ticks. One widely agreed recommendation for fighting acaricide failure is adoption of integrated tick control strategies for farm management that minimizes tick challenge, promotion of vaccination against ECF (Mugabi et al., 2009) and maximizing the benefits of indigenous breeds (Abbas et al., 2014; De Castro, 1997; Jonsson, 1997; Mondal et al., 2013). However, a national tick control policy for Uganda is needed to enforce a programmed acaricide rotation and use of other emerging technologies as integral part of integrated tick and tick-borne diseases control.

5. Conclusion

This study identified dependence on chemicals (acaricides) as the only method for tick control and widespread inappropriate acaricide application practices that may predispose to acaricide failure and emergence of resistance, especially in the southwestern region. The key recommendations include adoption of integrated tick control to reduce use of acaricides, educating farmers on acaricide stewardship, building national capacity for acaricide resistance detection and intervention and implementation of area-wide rotation policy by relevant government authorities to preserve the efficacy of acaricides on the market. Overall, the findings from this study provide a basis for developing prudent chemical tick control and safe acaricide handling practices that will ensure animal welfare, food safety and public health.

Declaration of interest

The authors have no conflict of interest to declare.

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Appendix A. Supplementary data

Supplementary data associated with this article can be found, in the online version, at https://doi.org/10.1016/j.ttbdis.2018.03.009.

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