EVALUATING ASSOCIATION OF PROPHYLACTIC STRATEGIES WITH PREVALENCE, MANAGEMENT AND ECONOMIC LOSSES FROM EAST COAST FEVER INFECTIONS ON SMALLHOLDER FARMS IN NORTH-RIFT KENYA

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A Thesis submitted to the Graduate School in Partial Fulfillment of the Requirements for the Master of Science Degree in Livestock Production Systems of Egerton University

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DECLARATION AND RECOMMENDATION

Declaration

This thesis is my original work and to the best of my knowledge has not been presented in this University or any other for the award of a degree or a diploma.

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Recommendation

This thesis has been submitted with our approval as university supervisors.

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DEDICATION

To God Almighty, this far Lord, you have brought me. I dedicate this work to my family and my siblings.

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ABSTRACT

East Coast Fever (ECF) is a tick borne disease endemic in the North Rift region of Kenya. The ECF infections lead to substantial economic loss to smallholder dairy farmers from veterinary costs incurred in using prophylactics and value loss associated with animal mortality and production decline during disease infection. Traditionally, prophylactic strategy of choice is application of acaricide in communal dips and hand spraying, but effectiveness of the strategy is a factor of good management practices, and it is at a cost to resource poor farmers. An alternative prophylactic strategy is vaccine but empirical evidence is scanty to inform use and effectiveness of vaccine in ECF management decisions. This study assessed whether the three prophylactic strategies of acaricide, vaccine and their combination significantly differ in ECF prevalence rates, associated management actions applied and economic losses. ECF infection was based on disease symptoms farmers observed. Data was obtained in a cross sectional survey of 164 smallholder dairy farms, randomly selected and stratified by agro-ecological zones and grazing systems in two Counties that are predominant in dairy production. Data analysis applied *Chi*-square test statistic to determine ECF prevalence rates and management practices and computed ECF induced economic loss when using any of the three prophylactic strategies. Among the animals examined (n=1038) on the sample farms, the ECF infection prevalence (18.7%) did not differ ($p>0.05$) between using a combination of acaricide and vaccine (22.9%), vaccine alone (18.4%) and acaricide alone (18.0%). The ECF infections was prevalent in about half of the sample farms (46%) and more farms used acaricide (79.9%), while a few used combined acaricide with vaccine (16.5%) but use of vaccine alone was unpopular (3.7%). The symptoms that farmers associate with ECF were; swollen lymph nodes, restlessness, passing of red urine and hard dung. Whenever farmers observed these symptoms they most frequently action was to seek professional vet services regardless of prophylactic strategy. Economic loss per farm per year was lowest for farms using vaccine (USD 2.27) compared to farms using acaricide and vaccine combined (USD 61.26.) or acaricide alone (USD 109.78). Disease prevention and non-vet cost accounted for the largest economic loss. These results show that use of vaccine alone is still unpopular among smallholder dairy farmers yet has a comparable effectiveness with acaricide regarding infection rates and is much cheaper. Farmers apply similar management responses whenever they suspect ECF case. Therefore extension service needs to popularize more use of vaccine because farmers would reduce the associated economic losses by up to 55.8 times when using the vaccine alone.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

LPS	Livestock Production System
CESAAM	Centre of Excellence in Sustainable Agriculture and Agribusiness Management
AEZ	Agro Ecological Zone
CBK	Central Bank of Kenya
ECF	East Coast Fever
ECFIM	East Coast Fever Infection Method
ITM	Infection and Treatment Method
MOALD	Ministry of Agriculture & Livestock Development
PCR	Polymerase Chain Reaction
RFLP-PCR	Restriction Fragments Length Polymorphism-Polymerase Chain Reaction
rRNA	Ribosomal Nucleic Acid
TBD	Tick-Borne Diseases
USD	United States Dollars

CHAPTER ONE
INTRODUCTION

1.1 Background information

East Coast Fever (ECF) is a tick-borne disease of cattle that is prevalent (Lawrence *et al.,* 2004) in eleven countries across Eastern (Kenya, Uganda, Tanzania, Burundi, South Sudan), Central (Malawi, Democratic Republic of Congo) and Southern Africa (Mozambique, Comoros Island, Zambia and Zimbabwe). The causative agent is a protozoan parasite, *Theileria parva.* The parasite is transmitted cyclopropagatively and trans-stadially by a three host brown ear tick, *Rhipicephalus appendiculatus,* which have dropped from infected cattle during the preceding stage of the life cycle (Norval *et al.,* 1992b; Gachohi *et al.*, 2012). In cyclopropagative and trans-stadially transmission*, Theileria parva* parasite multiplies and undergoes cyclical change within two development stages (nymph and adult) of the vector. The epidemiology of ECF varies between production environments which are reflected in the dynamics of tick vector (Gachohi *et al.,* 2010). Of importance in the epidemiology of ECF are the agro-ecological zone (AEZ), livestock production system (LPS), prophylactic strategies and to some extent, the breed of the animal. Geographical differences in the farm location imply differing AEZ with variable degree of exposure to ticks.

In a dairy herd, *Theileria parva* infections can cause substantial economic losses from mortality, morbidity, production losses and veterinary costs incurred in treatment and control practices. Tick control has traditionally used acaricides, but the costs are substantial, in the range of 6 to 36 USD$ per adult animal in the East African region (Gachohi *et al.,* 2012; MOALD, 2012). The change variation in cost used reflects different management practices. The cost however, represents a significant economic loss to resource-poor households; it is a loss of livelihood assets. In the attempts to manage the costs of acaricides in tick control, farmers are likely to under dose, but at the risk of facilitating development of tick resistance against acaricides. Use of acaricide requires good management and maintenance of cattle dips and use of correct dose to avoid ticks developing resistance to the acaricide (Gachohi *et al.,* 2012). These suggest that among resource poor farmers, consistency with good ECF disease management practices may be difficult to realize, subsequently exposing susceptible dairy cattle breeds to infections, which can cause farmers livelihood loss.

An alternative prophylactic control strategy is vaccine involving vaccination protocol for an infection, treatment and immunization, of animal with live *Theileria parva* parasites and treatment using chemotherapeutic antibiotics to develop immune response that protects animals against the disease. (Di Giulio *et al.*, 2009; Gachohi *et al.*, 2012; Marcelino *et al.*, 2012). This vaccine in the control of ticks can allow considerable relaxation of acaricide use (Mukhebi *et al.,* 1992). However, there are some technical limitations hindering farmers from using it as stand-alone. Strategy of use of the vaccine should reduce the need for acaricide application while the use of live parasites in the vaccine may pose some safety drawbacks for large-scale immunization purposes (Di Giulio *et al.*, 2009).

Some improvements have been made on the vaccine to enable more effective use and smallholder farmers are applying the vaccine in North Rift Kenya region (Karanja-Lumumba *et al.,* 2015). This ECF vaccine offers an integrated and intensive approach to vector control programme. It is sold in small doses that smallholders can afford and it is expected that use of the vaccine can reduce morbidity and mortality, increase milk production and raise net income to farmers (Bebe *et al.,* 2017). Though the vaccine has proved to be efficacious and feasible both in research and in field trials, evaluation under farmer circumstances has received little attention, especially comparison with other tick control strategies that farmers practice (Mukhebi *et al.,* 1989; Mukhebi *et al.,* 1990). In using the vaccine, farmers would be interested to substantially reduce the cost with reduction in morbidity and mortality, increase in milk production and earn more.

Since smallholder farmers have a choice of using acaricide, vaccine or a combination of both strategies to control ECF infections, they need evidence based information about the infection rates and economic losses associated with any of the control strategies to make informed management decisions. The effectiveness of acaricides in controlling ECF infections can be variable for several reasons including poor management and poor maintenance of communal cattle dips resulting in ticks developing acaricide resistance (Vahora *et al.,* 2012). The therapeutic effect of antibiotics on the *Theileria parva* parasites are limited to only early stages of the disease and are expensive, which may reduce their use in the field (Gachohi *et al.*, 2012).

Smallholder farmers use different management practices on suspicion and detection of ECF infections which include reporting to veterinarians, collecting and submitting blood samples to diagnostic veterinary laboratories, seeking treatment from veterinary surgeons and veterinary para-professionals and vaccinating animals. However, farmers are likely to only express preferences for some of these practices including use of herbs or self-treatment to manage ECF infections. It should be expected then that prophylactic strategies yield variable results in different agro- ecological zones depending on the system of grazing practiced.

1.2 Statement of the problem

Applying acaricide in communal dips and hand spraying is the traditional prophylactic strategy for controlling ECF infections in smallholder dairy farms in regions where ECF is endemic. However, the effectiveness of acaricide and associated cost is dependent on good management practice. Use of vaccine is an alternative prophylactic strategy being promoted as more effective in the control of ECF infections. In the field, smallholders hardly use the vaccine alone, indicating that farmers may be experiencing large variability with vaccine effectiveness. Despite the promotional campaigns to accelerate uptake of ECF vaccine, empirical evidence remains lacking on comparative prevalence rates, immediate management actions when the disease is suspected or detected and ECF induced economic losses that include infections, treatment and control when using the vaccine, acaricide or their combination. Closing on this knowledge gap would provide evidence based decision making to farmers and extension service to inform their choice of prophylactic strategy that results in lower infections rates with minimal economic loss from EFC infections.

1.3 Objectives

1.3.1. General objective

To promote a prophylactic strategy for ECF infections that results in lower infections with minimal economic loss in order to contribute to improved productivity of smallholder dairy herds.

1.3.2 Specific objectives

i. To quantify and compare ECF infection prevalence rates when using acaricide, vaccine or a combination of the two.

ii. To determine and compare management of ECF infections when using acaricide, vaccine or a combination of the two whenever the disease symptoms are observed.

iii. To quantify and compare ECF infection induced economic losses when using acaricide, vaccine or a combination of the two.

1.4 Research questions

i. Is the ECF infection prevalence rate significantly different when using acaricide, vaccine, or combination of these control strategies?
ii. Whenever farmers observed symptoms of ECF infection, are their management actions significantly different when using acaricide, vaccine or combination of these control strategies?
iii. Is the economic loss from ECF infections significantly different when using acaricide, vaccine or combination of these control strategies?

1.5 Justification

Due to poor management practices in the use of acaricide in control of ECF infections, there is the risk of development of acaricide resistance by tick vectors. Vaccine for ECF is currently used in Kenya and is envisaged to provide a breakthrough in control of the disease in susceptible dairy cattle mainly *Bos Taurus* and their crosses with *Bos indicus*. In addition, use of vaccine is more environmental friendly since acaricides are likely to pollute the environment and also leave residues in animal products consumed by human such as milk and meat. Vaccine may reduce cost of tick control as well as reduce economic losses in vector control programmes. The economic losses due to ECF amount to US$ 168 million a year in the region. The reduction in milk production represented the greatest financial loss (47%) relative to the cost of acaricide (20%), animal traction loss (13%) and beef loss (12%). Empirical evidence on the prevalence rates, management actions on detection of the disease and quantified economic losses associated with the ECF is valuable to inform ECF prophylactic strategies.

CHAPTER TWO
LITERATURE REVIEW

2.1 Theileria species

Theileria species cause severe, mild and benign theileriosis in some domestic and some wild animals. There are about seventeen *Theileria* species but the most highly pathogenic ones are *T. parva, T. annulata, T. hirci, T. lestoquadi***,** ***T.*** *ovis* and ***T.*** *capreoli*. Hard ticks of the genera *Rhipicephalus, Hyalomma, Amblyomma, Dermacentor*, *Boophilus* and *Haemaphysalis* are known to be the vectors of *Theileria* species (Tarimo, 2013). Life cycle of *Theileria* species involves sexually reproduction and finally developments to infective stage that occur in the salivary glands of tick vector.

Theileria parva and *Theileria annulata* are responsible for theileriosis in most endemic areas and are the most pathogenic and economically important among all *Theileria* species (Kohli *et al.,* 2014). *Theileria annulata* can infect both cattle and buffaloes (El-Deeb and Younis 2009). *Theileria parva*, the causative agent of ECF, Corridor disease and January disease, occurs in Eastern, Central and South Africa (Gachohi *et al.,* 2012) whereas *Theileria annulata* occurs around the Mediterranean basin, in the Middle East and in Southern Asia (Santos *et al.*, 2007). Buffalo (*Syncerus caffer*) is known to be the carrier of multiple *Theileria* species (Sibeko, 2009).

There are several methods used to determine different species of *Theileria*. These include; schizont, merozoite and piroplasm morphology, host immunological responses, monoclonal antibodies, biochemical, genome, chromosome and specific conserved molecular markers, infectivity in arthropod vectors and mammalian hosts, and specificity to vectors and mammal hosts (Tarimo, 2013). Different molecular markers and methods have been used to differentiate and to detect different species of *Theileria* (Bazarusanga *et al*., 2007). Coexistence of *Theileria* spp. is possible as was reported by Bazarusanga *et al.* (2007) who detect four spp. (*T. parva, T. mutans*, *T. taurotragi* and *T. velifera*) in Rwanda by RFLP-PCR analysis of 18S rRNA gene using enzyme digestion assay.

2.2 *Theileria parva* parasite

Theileria parva is a protozoan parasite, transmitted by the tick vector *Rhipicephalus appendiculatus (*Tarimo, 2013). It parasitizes T and B cells of cattle and some wild animals such as Cape buffalo, (*Syncerus caffer*) causing classical East Coast fever in cattle (Mbizeni *et al.,* 2013). Wildlife such as Cape buffalo (*Syncerus caffer*) are considered to be an important reservoir of various tick-borne haemo-parasites of veterinary importance and which are pathogenic to cattle including *Theileria parva* (Mbizeni *et al.,* 2013). *Theileria parva* parasite is most important tick- borne parasite of cattle in East and Central Africa and also is the most pathogenic and economically significant (Malak *et al*., 2012).

Theileria parva belong to Kingdom: Protista, Sub-kingdom: Protozoa, Phylum: Apicomplexa, Class: Sporozea, Subclass: Piroplasmia (piroform, round, rod-shaped parasites), Order: Piroplasmida, Family: Theileriidae, Genus: *Theileria* and Species: *Theileria parva* (Gou *et al.,* 2012). Trinomial system of classification of the three forms of *Theileria parva* was proposed, *Theileria parva* for parasites causing classical ECF, *Theileria parva lawrencei* for parasites causing Corridor disease and *T. parva bovis* for those parasites causing January disease (Kuo *et al.,* 2008; Lack *et al.,* 2012; Schnittger *et al.,* 2012). However recent system of classifying *Theileria parva,* classify this parasite according to their host of origin, as cattle-derived or buffalo-derived (Sibeko, 2009). It was therefore recommended that *Theileria. parva* parasites which cause ECF and January disease to be classified as cattle-derived because transmission occur from cattle to cattle by ticks and those which cause corridor disease to be classified as buffalo-derived because transmission occurs from buffalo to cattle through infected ticks (Sibeko *et al.*, 2009 and Oura *et al*., 2011).

2.3 Vectors of *Theileria parva*

The three-host tick, *Rhipicephalus appendiculatus* is the chief transmitter of ECF to cattle (Odongo *et al*., 2009). *Rhipicephalus appendiculatus* occurs over large areas in Kenya, Uganda, Rwanda, Burundi, Tanzania, Zambia, Malawi, Zimbabwe, Swaziland and South Africa (Malak *et al.,* 2012). Tick population dynamics is a main factor affecting the efficiency in transmission of tick-borne diseases. The concept of endemic stability is an important hypothesis that has been developed during years of observations on ECF and other TBDs in the field (Gachohi *et al.,* 2010). Climatic conditions, vegetation and host availability are factors known to determine the distribution of the vector, which in turn determines the distribution of the parasite itself (Gachohi *et al.,* 2012). These vector ticks are very numerous in tropical areas, particularly East Africa, whereby the problem is attributed to communal pastoral grazing of livestock and sharing of pastures between domestic and wild animals.

2.4 Hosts of *Theileria parva*

The hosts of *Theileria parva* include, *Bos indicus*, *Bos taurus*, African buffalo (*Syncerus caffer*) waterbuck (*Kobus deffassa*) and Egyptian buffalo (*Bubalus bubalis*) (Mbassa *et al.,* 1998b). The African buffalo (*Syncerus caffer*) are natural reservoir host of *T. parva* parasite. Wherever the suitable tick species of *R. appendiculatus* and *R. zambeziensis* are present cattle may become infected but the presence of that parasite in this animal does not mean disease (Sibeko *et al*., 2011). The studies conducted in livestock-wildlife overlap areas reported *T. parva* 100% infection in growing calves and high prevalence in adults mainly of the buffalo-derived type indicating a broad sharing of parasites between cattle and buffaloes (Mbassa *et al*., 1998b; Sibeko *et al.,* 2011).

2.4 Diseases caused by *Theileria parva*

Three major disease syndromes caused by *Theileria parva* in cattle are Theileriosis, Corridor disease and January disease. East Coast fever and January disease results from cattle-cattle transmission while corridor disease is buffalo-to-cattle transmission.

2.4.1 East Coast fever

Among the three disease syndromes East Coast fever is a fatal disease of cattle and is caused by the cattle derived strains. The severity of the disease differs depending on cattle breed, exotic cattle being more prone to infection, than zebu cattle (Di Giulio *et al*., 2009). Also the severity of the disease may vary depending on factors such as the virulence of the parasite strain, sporozoite infection rates in ticks and previous exposure to the parasite. Indigenous cattle in East Coast fever-endemic areas are observed to experience mild disease or subclinical infection, while newly introduced indigenous or exotic cattle usually develop severe disease (Salih *et al.,* 2007). Under experimental conditions incubation period may ranges from 8 to 12 days, while under field conditions incubation period may extend up to three weeks after attachment of infected ticks depending on environmental conditions and other challenges (Fandamu, 2005). ECF is characterized by high schizont parasitosis and piroplasms parasitaemia. Initially the disease syndrome is characterized by elevated body temperature (40-42°C) and swollen lymph nodes (Matovelo *et al*., 2002). The schizont is the pathogenic stage of *T. parva* infection. It initially causes a lympho proliferative, and later a lympho destructive disease. The infected animal shows enlarged lymph nodes, fever, a gradually increasing respiratory rate, dyspnoea and/or diarrhoea. If untreated anorexia develops, loss of condition follows and nervous signs may be observed (Mbassa *et al*., 2006).

A nervous syndrome called 'turning sickness' can be observed in *Theileria parva* endemic areas, and is suspected to be associated with the presence of aggregated schizont-infected lymphocytes, causing thrombosis and ischaemic necrosis throughout the brain (Mbassa *et al*., 2006). Death usually occurs within 30 days after infection in susceptible cattle. Mortality in fully susceptible cattle can be nearly 100% (Mbassa *et al*., 2008).

In dead animals the postmortem reveals haemorrhages in mucous membranes, heart, subcutaneous, pulmonary oedema, and froth in lungs, trachea and nostrils. Some of the infected animals may recover, however the recovered animals may remain emaciated and unproductive for months (Mbassa *et al.,* 2006)

2.4.2 Corridor disease

Corridor disease is an acute, usually fatal disease of cattle resembling ECF (Nene *et al.,* 2016). It is caused by infection with *T. parva* strains from African buffaloes, one of the wild ruminant species that is a carrier of the causative organism (Sibeko, 2009). Corridor disease occurs in Southern and East Africa especially in areas where there is contact between cattle and infected buffalo. The main vectors for corridor disease are *R. appendiculatus, R. zambeziensis* and *R. duttoni* (Kohli *et al.,* 2014). The disease was diagnosed in a corridor land between Hluhluwe and Umfolozi Game Reserve in South Africa, hence the name Corridor disease (Sibeko, 2009). Transmission of the disease occurs in cattle sharing the same grazing area with infected buffalo in the presence of the tick vector. The pathogenesis and pathology of Corridor disease are similar to those of ECF. Clinical features exhibited are also the same as ECF except that the course is usually shorter, death occurring only three to four days after the onset of the first clinical sign (Muhanguzi *et al.,* 2014). Corridor disease is generally regarded as self-limiting as cattle usually die in the acute stage before the parasite develops into erythrocytic piroplasm stage which is the one picked up by the feeding tick (Oura *et al.,* 2011). Among the important diseases transmitted from buffalo to cattle, Corridor disease is currently the second after foot-and-mouth disease in South Africa (Sibeko, 2009).

2.4.3 January Disease

January disease is the type of theileriosis which is found in Zimbabwe where the disease adheres to the strict seasonality which is between December and March, coinciding with the seasonal activity of adult *Rhipicephalus appendiculatus* (Sibeko 2009) It is an acute, fatal disease caused by the cattle-derived *Theileria parva* parasite formally known as *Theileria* *parva bovis*. January disease exhibits the same clinical features as ECF. The pathogenesis and pathology of the disease are also very similar to those of ECF (Gachohi *et al.,* 2012).

2.5 Prevalence of *Theileriosis*

The prevalence of *theileriosis* depends upon geographical region and several other factors like tick density, climatic conditions, age, gender, management practices and immunity (Magona *et al.,* 2011; Gul *et al.,* 2015). Prevalence is also influenced by cattle breed as cattle usually differ in tick resistance and innate susceptibility to infection (Radostits *et al.,* 2007). Tropical theileriosis is more severe in exotic and cross-bred breeds (*Bos taurus*) than indigenous animals (*Bos indicus*). Tropical theileriosis is prevalent in south Eastern Europe, the near Middle East, India, China and Central Asia (Bakor, 2008).

A survey was conducted in Eastern Turkey by collecting blood samples from apparently healthy cattle and 39% prevalence of *Theileria annulata* was established by PCR (Aktas *et al.,* 2006). Further studies conducted in the Kayseri province (Turkey) indicated 9.3% prevalence of *theileriosis* (Ica *et al.,* 2007). Aysul *et al*. (2008) reported that Tropical theileriosis is the most prevalent disease transmitted by the ticks in the Aydin region of Turkey (Aysul *et al.,* 2008). The prevalence in south-west Iran was reported to be 28.11% (Dehkordi *et al.,* 2012). A reverse line blotting assay was carried out in Portugal and the prevalence was found to be 21.3% for *Theileria annulata* (Gomes *et al.,* 2013).

The disease became significant in India when a program was launched to increase milk production by introducing exotic breeds. Mostly, disease occurs in its sub-clinical form, leading to significant economic losses; without treatment or control. Case fatality rates can reach 80% in exotic breeds, compared with 20% in indigenous breeds (Jabbar *et al.,* 2015). Age is one of the risk factors (Saeed *et al.,* 2016); the prevalence of tropical theileriosis in young animals (23.4%) showed a higher prevalence than did adults (15%). Innate immunity in calves is not developed enough to combat *Theileria annulata*.

Theileria parva is found in sub Saharan Africa and is prevalent in 14 countries in Southern, Central, and Eastern Africa (Tarimo 2013). The affected countries are Kenya, South Sudan, Burundi, Tanzania, Malawi, Rwanda, DRC, Mozambique Zambia, Uganda and Zimbabwe (Gachohi *et al.,* 2012). Muhanguzi *et al.* (2014) reported 5.3 % prevalence of *Theileria parva* in Tororo District of Eastern Uganda using PCR. It is important to emphasize that endemic region of *Theileria annulata* and *Theileria parva* do not overlap (OIE, 2014), however there were reports of coexistence in South Sudan (Spickler *et al.,* 2010). Tropical theileriosis has also been reported in Ethiopian cattle by Gebrekidan *et al.*, (2014). The infection is generally sub-clinical; however, disease can occur in cattle depending on a number of epidemiological factors including previous exposure to theleiriae, stress, or health status and variations in the species pathogenicity (OIE, 2014).

In Kenya, *Theileria parva* infection poses a significant threat to livestock sector in two folds; through the economic impact of the disease from cattle morbidity and mortality and production losses in all production systems, as well as from the cost of the measures taken to control tick and the disease (Gachohi *et al.*, 2012). The cost of acaricide application which is the primary means of tick control, was estimated to range between 6 and 36 USD ($) per adult animal in Kenya, Tanzania and Uganda (Minjauw *et al.*, 2003). Furthermore, in the result of reviewed study, prevalence was found to be higher in females (24.6%) than males (13.1%) ticks. The gender of tick has been reported to play a significant role in the transmission, prevalence as well as intensity of infection (Sayin *et al.*, 2003). Male ticks of genus *Hyalomma* have a limited number of type III acini in salivary gland as compared to the female. Thus, female ticks have more potential of disease transmission than male (Aktas *et al.*, 2001). Moreover, female ticks have two histamine binding proteins to counteract host response to tick attachment (Anim *et al.*, 2013).

2.6 ECF infection in smallholder dairy farms

Generally, smallholder dairy production systems are characterized by different management practices at farm level, agro-ecological characteristics and grazing systems (Gachohi *et al.*, 2010). Consequently, they exhibit varying ECF prevalence, incidence and ECF specific morbidity and mortality rates. In a study by Gachohi *et al.* (2012) in Central Kenya on antibody prevalence and incidence of ECF in areas where smallholder systems predominate, *Theileria parva* antibody prevalence and incidence were high in the lower agro-ecological zones under open grazing systems. On the other hand, the *Theileria parva* antibody prevalence and incidence were lower in high agro-ecological zones under zero grazing systems (stall-feeding). In Kiambu County, where exotic breeds predominate, contrasting results to those reported from Murang'a showed general low ECF specific mortality risk but moderate to high antibody prevalence to *Theileria parva* which may be indicators of near endemic stability in the area. This is contrary to earlier assumptions that exotic cattle breeds are associated with endemic instability (Giachohi *et al.*, 2010). In a longitudinal study conducted in Nakuru County in the

Central Rift Valley within a single ecological zone reported comparable results to the studies in Murang'a and Kiambu in cattle under different production systems (Gachohi *et al.,* 2012).

However, in coastal areas of Kenya, ECF was the predominant disease diagnosed and accounted for 2/3 of all reported deaths in major production systems (zero and open grazing) within two agro-ecological zones (Maloo *et al.,* 2001). In the cross-sectional study, open grazed cattle in both Agro-ecological zones (AEZs) had a mean sero-prevalence of >75% for both dairy and zebu breeds although sero-prevalence in calves < 6 months of age in the cashew-nut-cassava zone were less than 50% (Maloo *et al.,* 2001). This clearly indicated endemic stability in open grazing systems in both zones regardless of cattle breeds. Moreover, in the longitudinal study in the same area, the mean monthly ECF incidence rate in animals less than 18 months of age was lower in zero-grazing compared to the open grazing systems (Maloo *et al.,* 2001). Overall, the ECF prevalence and incidence in the Kenya coast was high than those reported from Central and Rift Valley Counties (Gachohi *et al.,* 2012).

2.7 Risk factors for ECF infections

2.7.1 Agro-ecological zones

Epidemiological factors affecting ECF, gives rise to different ECF epidemiological states. Endemic stability is expected to occur in tick suitable areas that are warmer and more humid with landscapes characterized by a mixture of grass and tree cover (Gachohi *et al.,* 2010; 2012). These are found in the Lake Victoria basin, the Kenyan Coastal strip and parts of the central and eastern highlands representing zones I, III, and V in these areas antibody prevalence is high. Endemic instability and epidemic ECF occur in marginal areas and regions where the tick can barely survive where vector unsuitable areas are harsh, hot and dry, have sparse vegetation and often grassland. In the context of ECF, these conditions can be found particularly in semi-arid north eastern and Upper Eastern provinces in Kenya which represent zones V-VII. In these areas prevalence is low. Unsuitable areas also include regions where overgrazing and environmental degradation has occurred and in deep forests (Gachohi *et al.,* 2012).

2.7.2 Livestock production system

Livestock production system (LPS) has an important influence on exposure of cattle to the different ecological characteristics (Gachohi *et al*., 2012). LPS range from the unrestricted tick exposure in open grazing systems through limited exposure in mixed grazing, where animals are alternately open grazed and stall fed, to no exposures where cattle are kept under total confinement as in the smallholder zero grazing units. The change in exposures results in a considerable difference in tick infestation levels and corresponding infection prevalence and incidence (Maloo *et al.,* 2001; Gachohi *et al.,* 2012).

As ECF can only be transmitted by ticks that have dropped from infected cattle during the preceding stage of life, the spatial spread of infection is mainly through cattle movement during grazing (Zajac *et al.,* 2006). In certain, situations, open grazed cattle could be the source of tick-borne infection in both ticks and zero grazed cattle either in the same farm or in the neighborhood if grazing areas are also the main source of cut and carried forage for the zero-grazed cattle (Maloo *et al.,* 2001).

The grazing systems employed in an area have a habit to correspond to the consequences of social, social economic, technological and demographic processes. Thus, zero grazing systems, characterized by exotic cattle breeds are mainly practiced in the medium to high potential farming areas (zones II-III), in response to decreasing land sizes due to increasing human population and consequently higher livestock product demand (McDermott *et al.,* 2010). Only a few cattle can be supported in a zero grazing system as the available land is small. By default, the cattle ought to be productive and ECF susceptible exotic breeds for income generation and satisfaction of the ready milk market.

2.7.3 ECF Host Susceptibility

Examination of host genetic susceptibility was experimentally conducted and this reflected the variation in susceptibility of cattle to *Theileria parva* infection (Ndung'u *et al.,* 2005). In further studies, this genetic gradient was unclear between the exotic animals, crosses, indigenous and purebred bred under tick free conditions are highly susceptible to ECF. Zebu breeds bred in tick free conditions are moderately susceptible to the disease (Ndung'u *et al.,* 2005). However, zebu cattle bred in ECF endemic areas have low susceptibility for the disease (Ndung'u *et al.,* 2005). This factor is associated with grazing systems as ECF susceptible exotic breeds are mainly kept in smallholder dairy systems under restricted tick exposure whereas the ECF resistant indigenous breeds are kept under an open system that permits exposure to infected ticks (Gachohi *et al.,* 2012).

2.7.4 The age gradient

Increasing age is associated with *Theileria parva* sero-prevalence and this was particularly noted in studies conducted in the Kenyan coast in agro-ecological zones of coconut-cassava, cashewnut-cassava and livestock-millet (Maloo *et al.,* 2001). This result may be expected since age is a proxy for *Theileria parva* as it persists in the circulation for as long as 6 months, sero-prevalence in a population is likely to increase with age (Gachohi *et al.*, 2012).

In their study, Maloo *et al.* (2001) reported further that there were no overall significant effect of age on prevalence of *Theileria parva* in herds in the coconut-cassava zone but the average sero-prevalence in herds where cattle grazed (0.79± 0.03) was higher than in herds where cattle were fed in stalls (0.57±0.08) *p* (0.001). Calves < 6 months of age in herded grazed systems had a particularly high antibody prevalence of (0.87 ±0.07). The prevalence of *Theileria parva* antibodies increased with age from 0.49± 0.12 in claves < 6 months of age to 0.88± 0.06 in cattle between 19 and 36 months of age in the cashew nut-cassava zone (p<0.001), and from 0.14± 0.14 in calves < 6 months of age to 0.62±0.11 in cattle over 36 months of age in the livestock-millet zone.

2.8. Ethno-veterinary treatment (Non-conventional Method)

Pastoralists, agro-pastoralists and other, small-scale farmers in the East Africa region have engaged in a long tradition of ethno-veterinary practices to care for their animals, involving the use of many plants to prevent and treat different diseases and health conditions (Dharani *et al.,* 2015). These practices are used often because of the lack of availability or the prohibitive costs of modern veterinary medicines and approaches. Sometimes, 'modern' veterinary practices for particular contagious diseases and ethno-veterinary medicine for other conditions are employed in tandem by livestock owners, and this situation is likely to continue in the future (Dharani *et al.,* 2015).

Hundreds of plant species have been identified by traditional practitioners for treating a wide range of livestock (and human) ailments, although the efficacy of plant treatments has often not been tested through formal trials, on which more work is required. Nevertheless, a large body of information on traditional use, over a number of centuries in many cases for indigenous plants, supports their utility for treatment and control (Dharani *et al.,* 2015). The following plants are used for treating ECF disease in cattle by various ethnic groups in East Africa.

Adansonia digitata

The Tree is up to 25m tall. The trunk girth is up to 25m when mature. The branches are short, stout and twiggy at ends. Bark red-brown to purple-grey in colour. The tree is commonly known as baobab tree native to tropical African countries, including South Africa, Botswana, Namibia, and Mozambique (Wickens *et al.,* 2008). Leaves are simple to digitate, with up to 9 dark green and glossy leaflets but usually five in number. A 1 kg of leaves are cut into small pieces. A few fruit from the same species crushed and mixed with the leaves. Add a little saltlick and allow infected animal to eat the mixture freely.

Vernonia amygdalina or Vernonia auriculifera and Sesbania sesban

This is widely grown shrub in Africa consumed as vegetable and has high medicinal value. It has general wide application in the treatment and management of various diseases. Leaves are used as components of herbal medicine constitution (Ifeoluwa *et al.,* 2018). A 0.5 kg of fresh leaves of above plants and roots are crushed and mixed with 1 litre of water. A teaspoon of salt added and boils for 20 minutes. Drench the sick animal.

Warburgia ugandensis

This is ever green tree native to Africa found in Kenya, Ethiopia and some parts of Western Africa (Were *et al.,* 2010). A 0.5 kg of fresh bark of *Warburgia ugandensis* and a few fruit of *Solanum incanum*, is mixed with crushed limestone (calcium carbonate) and a little clean water to make a paste. It is applied where ticks have bitten the skin. Add 0.5 kg of fresh stem bark of *Warburgia ugandensis* to 1 litre of water, drench cattle with 0.3 l per day for 2 to 3 days.

2.9 Conventional Methods

Chemotherapeutic application

In a study on smallholder dairy farms in Kiambu, demonstrated that early and prolonged treatment with chlortetracycline prevented the development of ECF following infection with *Theileria parva* as reported by (Gachohi et al., 2012; Di Giulio *et al.*, 2009); Qayyum *et al.,* 2010) utilized concurrent application of *Theileria parva* infected ticks and oral tetracycline as a technique for immunization. These results formed the basis for the "infection and treatment" method of immunization; however, certain stocks of *Theileria parva* broke through the protective chemoprophylaxis such that it was necessary to establish an immunizing dose which would not overcome the oxytetracycline regimen (de la Fuente *et al.*, 2007).

Gachohi *et al*. (2012) subsequently reported that oxytetracycline acts by slowing down the division of schizonts and their host cells and thus exerts only a limited suppressive effect in the early stages of infection. It was not until the 1980's that three therapeutic agents were developed and registered for the treatment of theileriosis, namely parvaquone (Clexon®) and buparvaquone®utaiex) (Welcome Pharmaceutical, United Kingdom), and halofuginone (Terit®, Hoechst Pharmaceutical, Germany). Successful field trials of parvaquone and halofuginone (McHardy 1989; Mhadhbi *et al.*, 2010; Sharifiyazdi *et al.,* 2012) were conducted in Kenya. These naphthoquinone compounds are not only effective for curing theileriosis but can also be used as a remarkable prophylactic measure against the disease (Qayyum *et al.,* 2010). These Theileriacidal drugs specifically target the etiological agent, but don't affect edema directly. Furosemide, a loop diuretic, can be used to reduce cardiovascular and pulmonary edema as well as renal and hepatic dysfunction (Musoke *et al.*, 2004).

However, Dolan (1986a; l986b) also demonstrated a high prevalence of carriage of *Theileria parva* in cattle treated with these drugs. While all three compounds are efficacious in the treatment of ECF, this depends on an early diagnosis and administration of a full therapeutic dose (Gachohi *et al.*, 2012). Unfortunately, the prohibitively high cost of these drugs has resulted in their limited use by smallholder farmers.

Acaricide application

At farm level, smallholder dairy farmers use acaricide for vector control. Ticks can be controlled with acaricides by plunge-dipping, where animals are completely submerged by plunging into and swim through dipping tanks containing an aqueous emulsion, suspension or solution of acaricide (Vahora *et al.,* 2012). Complete or almost complete immersion of cattle during dipping ensures adequate exposure of ticks to acaricide. The frequency of treatment depends on the acaricide used. Other widely used methods of acaricide application involve hand or engine-powered spraying (Vahora *et al.,* 2012). These methods of spraying seldom achieve complete wetting of the animal, usually resulting in poor tick control (Mukhebi *et al.*, 1992). Excess acaricide solution drips off the animal and is not recycled as in dipping tanks, where cattle are held in draining pens after treatment. Nevertheless, if used correctly, spraying offers small-scale farmers a means to control ticks. The spray race is very common at commercial dairy farms (Mukhebi *et al.*, 1992) but virtually absent in the traditional sector. To control ticks at specific body sites only, such as the ears or the perineum, tick grease, an acaricide in a petroleum jelly base, is applied with a brush. More recently 'spot-on' and 'pour-on' acaricides have become available. These formulations include repellants that spread readily over the surface of skin and hair (Vahora *et al.,* 2012). Acaricides are thus applied to limited areas of the body, from where they spread too much larger areas. Spot-ons are normally used to control ticks on a particular body part such as the head, while pour-ons are applied in a strip down the length of the back to give tick control over the entire body.

Vaccine use

Smallholder dairy farmers with adoption of ECF vaccine have the opportunities for reducing reliance on intensive acaricide use in the region. The rolling out of ECF vaccine by the government have prompted the search for new, safer, cheaper and more sustainable control strategies through immunization (Karanja-Lumumba *et al.,* 2015). At present, the only practical method of immunization is by the infection and treatment method (Di Giulio *et al.,* 2009) and is still widely used (Weir, 2006). This involves the inoculation of cattle with a previously characterized and potentially lethal dose of sporozoites of *Theileria parva* and simultaneous treatment with antibiotics (Marcelino *et al.,* 2012). As a consequence of this practice, a mild reaction appears to parasitic infection and the cattle acquire immunity to succeeding attacks. Broad spectrum vaccines may be developed using multiple antigens to target various tick species and reduce transmission of parasite (de la Fuente *et al.,* 2007). This confers life- long immunity to the animal (Gachohi *et al.,* 2012). The method has been shown to be technically efficacious in field trials carried out in different countries of the region (Di Giulio *et al.,* 2009).

The application of the partial budgeting technique to estimate the economic gains from investments in East Coast Fever Infection Method (ECFIM) and the related schedule of vaccinations of dairy animals as opposed to the use of the conventional ticks and ECF control through dipping in acaricides, found that the vaccinating households were realizing a net gain of KES 44,575 per cow per year from the adoption of the ECFIM vaccine, while the ECF non-vaccinating households were incurring a net loss of at least KES 9,975 per cow per year by not adopting the ECFIM vaccine (Sitawa *et al*.,2016).

The vaccine, however, has some technical limitations. It does not eliminate the need for acaricide application due to the potential existence of other tick-borne diseases, although it allows considerable relaxation of acaricide use (Mukhebi *et al.,* 1992). In addition, the use of live parasites in the vaccine poses some safety drawbacks for large-scale immunization purposes (Mukhebi *et al.,* 1992). Furthermore, the application of the infection and treatment vaccine requires a liquid nitrogen system for cold storage and transportation and during the pilot application stage, an extended monitoring period post-immunization to detect and treat any breakthrough infections. Both these aspects currently constitute high cost items in the delivery of the vaccine (Di Giulio *et al.,* 2009).

2.10 Economic importance of ECF infections

The *Theileria parva* infections is distributed within 14 countries in Eastern, Central and southern Africa where it is a major constraint to cattle production (Minjauw *et al.*, 2003). In the affected countries, about one million cattle per year die, with a further 28 million of 47 million cattle in the region being at risk of contracting the disease (Patel *et al.,* 2011). *Theileria parva* is the most pathogenic and economically significant Theileriosis species in Eastern, Central and Southern Africa (Kohli *et al.,* 2014). ECF is characterized by high morbidity and mortality, and is considered as the important impediment to the improvement of livestock industry in Africa (Yamada *et al.,* 2009; Kivaria *et al.,* 2007).

Mbassa *et al.* (2008) in a study conducted in calves in traditional cattle herds in Tanzania in the cool months of year (May-July) stated that clinical prevalence of ECF was close to 100 % and mortality rate can reach 100% if there is no treatment. *Theileria* parasites can infect new born animals in their early life causing big losses if no treatment is provided (Bazarusnga *et al.,* 2007; Mbassa *et al.,* 2009a; 2009b). A part from death, farmers face a lot of losses such as impaired weight gain, weak calves, low grade meat, decreased milk production and enhanced costs of veterinary services (drugs, laboratory diagnosis, surveillance, vaccination, administration, training, prophylaxis, dipping and others (Mukhebi *et al.,* 1992). It is estimated that losses of more than USD 300M per year occur in East, Central and Southern Africa regions (Malak *et al.,* 2012) where losses of USD 168M occur in Eastern Africa alone (Mukhebi *et al.,* 1992).

2.10.1 ECF and economics of animal disease control

The effect of disease on the economic losses in livestock production is classified as direct and indirect (Kivaria *et al.,* 2006). The direct losses may occur when disease destroys the basic resource of the livestock production process (mortality of breeding or productive animals), lowers the efficiency of the production process and the productivity of resources employed (e.g. reduced feed conversion efficiency), and reduces the quantity and/or quality of product (Singh *et al.,* 2014). The indirect losses include additional costs incurred to avoid or reduce the incidence of the disease, detriment to human health well-being through revenue foregone as a result of denied access to better markets and sub-optimal exploitation of otherwise available resources through forced adoption of production methods which do not allow the full exploitation of the available resources (Otte *et al.,* 2000).

Bennett (2003) stated that the presence of a livestock disease may have an effect, not only on production, but also on both output and input prices. For example, if the majority of producers adhere to the programs of disease control, the output supplied in the market increases and, as a result, the price of the product in the market may decrease. Mukhebi (1989) noted that the direct ECF production losses can be attributed to morbidity and mortality. Homewood *et al.* (2006) estimated mortality rates under endemically stable conditions occur mostly in calves and vary from zero to 50%. Where endemic instability exists, mortality may be as high as 80 to 100%.

Animals which recover from ECF may suffer from long term debilitating effects such as weight loss, produce low milk output, provide less draft power and possibly suffer from reduced fertility and delays in reaching maturity. In addition, recovered animals also remain carriers and can spread infection (Gachohi *et al.,* 2010). Minjauw *et al*. (2003) found that many farmers are therefore constrained from utilizing improved genotypes and improving livestock productivity and efficiency in areas that are endemic to ECF. In the affected areas, farmers face a substantial risk if they try to keep exotic and crossbred cattle due to their high susceptibility to the disease.

Indirect production losses due to ECF occur when the disease acts as a constraint to the use of improved cattle. Other costs include tick control costs, losses incurred whilst driving animals through dip tanks from stress-induced abortions, drowning and physical injury (Mukhebi *et al.,* 1992). The constant trekking of animals to dip tanks often creates gullies and the frequent concentration of animals around the tanks leads to overgrazing, both of which cause erosion and environmental degradation, thus further contributing to indirect costs (Mukhebi *et al.,* 1992).

Nyangito *et al.* (1996) found that ECF immunization as a strategy is financially and economically viable for small-scale farms in Kenya. The most preferred strategy was to adopt vaccination and combine it with a 75% reduction in acaricide use. Muraguri *et al.* (1998) developed and used a spreadsheet model to estimate the total cost of immunizing cattle against ECF based on the infection-and-treatment method. Using data from an immunization trial carried out on 102 calves and yearlings on 64 farms in the Githunguri division, Kiambu district, Kenya, a reference base scenario of a mean herd of five animals, 10% rate of reaction to immunization and a 2-day interval monitoring regimen a total of 10 farm visits was simulated. Under these conditions, the mean cost of immunization per animal was (KES 955.78), which was equivalent to (KES 4778.90) per five-animal farm.

2.11 Influence of production environment on economic losses from ECF infection

2.11.1 Traditional extensive systems

Indigenous zebu cattle are kept under traditional extensive management conditions in vast areas of Kenya. These systems are characterized by little or no tick yet *Theileria parva* infections in these systems result in loss in productivity and/or mortality. (Minjauw *et al.,* 2003). This phenomenon has been termed as ‘endemic stability’ (Gachohi *et al.*, 2012). Endemic stability to ECF has been defined as the state in a cattle population where the large majority (>70%) of the population becomes infected and immune by 6 months of age and little or no clinical disease occurs (Gachohi *et al.*, 2012). Consequently, majority of cattle in such population are immune. Endemic instability describes a state in which only a small proportion (<30%) of the cattle in the population become infected and immune by 6 months of age leading to build up of susceptible population and therefore, clinical disease is experienced across all age species. The latter situation normally exists where animals are kept under low levels of tick challenge. These systems are characterized by variable population immunity to *Theileria parva*, probably due to periodic and varying environmental and climatic suitability for the survival and development of the vectors. This situation exists in highland areas of Kenya in which zebu cattle are maintained as well as Lake Victoria basin and parts of Kenyan coastal strip (Maloo *et al.,* 2001).

2.11.2 Livestock dependent systems

Livestock dependent systems commonly kept communally and extensively grazed (Minjauw *et al.,* 2003). These systems include nomadic and transhumant pastoralism and some agro-pastoralism, all of which are found in arid and semi-arid areas of Kenya. ECF has been identified as a major cause of calf deaths in these systems with (0.40-0.80) in unvaccinated calves at the Kenya-Tanzania border (Homewood *et al.,* 2006; Di Giulio *et al.,* 2009). Maasai pastoralists from Kajiado County perceive ECF to be the important cattle disease (Bedelian *et al.,* 2007) among the pastoralists, mobility has been a key feature in traditional livestock disease management techniques.

However, the ability to move between alternative seasonal pastures is becoming increasingly limited (Homewood *et al.*, 2006). For many infections, (including TBDs) this mobility used to allow gradual exposure to infections, which stimulates immunity but avoiding serious disease challenge (Homewood *et al.,* 2006). These systems are characterized by variable levels of population immunity to *Theileria parva*. However, in certain regions, the pastoralist's traditional grazing areas lay on very suitable habitats for the tick vector leading to the successful establishment of endemic stability. These areas are characterized as livestock-wildlife interface with presence of buffalo among other wildlife species. Although it is not evident that buffalo play a big role in the epidemiology of cattle *Theileria parva* strains (Sibeko 2009). Transmission of *Theileria parva* parasites between cattle, buffalo and the ticks cannot be ruled out.

2.11.3 Commercial systems

Commercial systems consist of dairy or beef units in which highly productive exotic breeds of cattle are kept. In the context of ECF, the systems are characterized by intensive acaricide application that leads to the disruption of *Theileria parva* transmission. This system has become less important in Kenya because the majorities of large farms have collapsed or have been sub-divided for human settlement (Gachohi *et al.,* 2012).

2.11.4 Intensive/semi-intensive smallholder dairy systems

They play a significant role as they produce >80% of the milk sold in the country (Minjauw *et al.,* 2003). The population of cattle in small holder dairy systems in Kenya is estimated at approximately 2 million (Minjauw *et al.,* 2003). These systems are characterized by different management practices at farm level, agro-ecological characteristics and grazing systems. (Gachohi *et al.,* 2012). Consequently, they exhibit varying ECF prevalence, incidence and ECF specific morbidity and mortality rates.

2.12 Influence of control strategies on economic losses from ECF infections

Conventional control of ECF relies on regular use of chemical acaricides to control ticks, the vectors of the disease. The costs of this control strategy are estimated to vary from KES 40 to 170 per animal (Mukhebi *et al.*, 1989). Infected animals can be treated using chemotherapeutic drugs if applied in the early stages disease. This will cost KES. 200 to 400 per treatment (Mutugi *et al.*, 1989). An alternative ECF control method known as the infection and treatment method (ITM) (Di Giulio *et al.*, 2009) has proven to be efficacious and feasible both on research station and field trials. ITM is an immunization procedure whereby the animal is simultaneously infected with live *Theileria parva* parasites and treated using chemotherapeutic antibiotics.

The resulting immune response generally protects animals against the disease for life. Although ITM has been proven to be technically and economically viable on controlled field trials (Mukhebi *et al.*, 1989), its evaluation under farmer circumstances has received little attention. Economic viability of smallholder farms using ITM and existing technologies to control ECF have not been analyzed using methodologies which systematically consider the entire smallholder farm. The intention was to provide forecast on farm level financial and economic analysis of alternative ECF control methods for smallholder farms in two regions of Kenya, and to rank improved ECF disease control methods for risk against smallholder farmers in terms of their potential for adoption (Mukhebi *et al.*, 1989).

Generally, control strategies utilized by smallholder farmers in tackling ECF infections have an influence on economic losses but to a limited extent. Though not regularly applied due to lack of resources by smallholder farmers but have effect on disease reduction. Some control strategies require regular regiments to control as well as eradicate the vector but this is not adequately achieved because of poor management by farmers. Most smallholder farmers attach value on economic importance of the ECF but costs associated with treatment, immunization and control are prohibitive hence majority of them are not able to introduce exotic breeds to their production systems due to high costs involved in the management of the disease. Production system plays a vital role in the epidemiology of the disease as it exposes animals to ecological characteristics which are source of ticks. The production system may also result to considerable differences in tick infestation level, infection, prevalence and incidences for example, in confined system (zero-grazing) tick infestation is minimal. Finally, some agro ecological zones provide suitable conditions for vector proliferation than to others. For instance warmer and humid landscapes with mixture of grass and tree cover are conducive for tick infestation (zones II, III and IV) than areas that are hash, hot and dry with sparse vegetation and open grassland (zones V-VII).

2.13 Empirical estimation of Economic Losses from ECF Infections

Direct economic losses from ECF infection result from cost of disease treatment increase in expenditure on non-veterinary resources, cost of inputs used to treat ECF and the cost of disease prevention measures. The summation of these loss components is the estimated total economic loss. They are accounted in the formula and detailed in Table 1.

The cost of disease include; mortalities from ECF infections, acaricide poisoning, abortion, milk withdrawal, drop in yield and culling, drug treatment cost, consultation, acaricide application, equipment, diagnosis and surveillance. Bennett (2003) formula applied to estimate the economic losses is:

$$C = (L + R) + (T + P) \quad (1)$$

where:

C = Economic cost of disease

L = The cost of disease in terms of the loss in expected output due to ECF (direct production loss)

R = Increase in expenditure on non-veterinary resources due to ECF (Indirect costs)

T = The cost of inputs used to treat ECF (Disease treatment cost)

P = The cost of disease prevention measures

Table 1 Loss components as identified in the application of Bennett (2003) model

Loss component		Measurements	Reference
Veterinary costs	T	Drug treatment costs per dairy animal	Sitawa *et al.,* (2016)
		Consultation fee cost per visit	Sitawa *et al.* (2016)
Disease control	P	Acaricide application cost per animal – *spraying, dipping*	Norval *et al.* (1992b); Mukhebi *et al,* (1992)
		Vaccine administration per animal	Sitawa *et al.* (2016)
		Water in litres	
		Facilities and equipment (Dips, spray race)	Norval *et al.* (1992b)
		Diagnosis and surveillance per month	Gitau *et al.* (1999)
Production loss	L	Mortalities rate	Singh et *al.* (2014)
		Acaricide poisoning per herd	Norval *et al,* (1992b); Mukhebi *et al.* (1992)
		Abortions – extended CI, per animal	Singh *et al,* (2014); Mukhebi *et al,* (1992)
		Milk withdrawal, drop in yield per liter per animal	Singh *et al.* (2014)
		Pre mature culling – sale of infected animal number of animals	Singh *et al.* (2014)
Additional costs	R	Labour hire per person per day	Mukhebi *et al.* (1992); Sitawa *et al.* (2016)
		Transport/ purchase drugs costs	Mukhebi *et al.* (1992)
		Replacement of dead animal or sold one depreciation cost per animal	
		Reporting disease - airtime *calls –purchase* cost of purchased airtime	Sitawa *et al.* (2016)

2.14 Conceptual model describing hypothesized relationship between ECF prophylactic strategies and economic losses

ECF infection in dairy herds can be controlled by use of acaricide through dipping or spraying, vaccination or use of both prophylactic strategies. Besides this, farmers use a range of management practices in the event of outbreak. Figure 1 presents an illustration of these options and their associated economic loss. The choice of management actions coupled with prophylactic strategies used by the farmers has an influence on ECF prevalence rates in dairy herds at the farm level where the disease occurs. Farmers can take a management decision when they suspect or detect ECF infections and they base their actions on various symptoms. The symptoms may include; swollen lymph nodes, passing of red urine, restlessness and hard dung. Some symptoms are likely unique to ECF while others are not. The symptom that farmers most frequently base their management decision would be the unique symptom. This symptom is expected to prompt management decision by smallholder farmers to apply an intervention. Any intervention has associated cost which translates to ECF related economic losses. Where management decision is based on general symptom, control of ECF will be weak, resulting in economic losses. This implies that economic loss will vary with prophylactic strategy implemented on the farm.

Independent variable Intervening variable Dependent variable

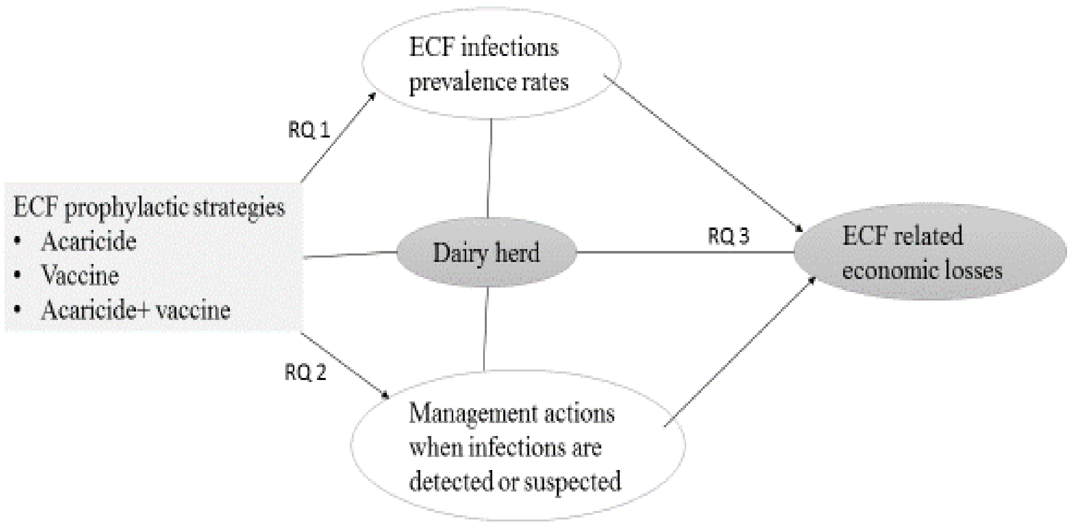

Figure 1 Conceptual model on ECF prophylactic strategies, prevalence rates, management actions and economic losses (Author)

CHAPTER THREE

METHODOLOGY

3.1 Study area

The selected study sites were Nandi and Uasin Gishu Counties in the North Rift region of Kenya. The two counties were purposely selected for studying ECF infection prevalence rates, disease management and associated economic losses under different prophylactic strategies because these are prominent dairy production areas with a good representation of an area where the three prophylactic measures have been applied. *Theileria parva* by far is the most pathogenic and economically significant *Theileria species* in region (Kohli *et al.*, 2014). East Coast fever, the disease caused by this parasite causes high morbidity and mortality, and is considered as the important restriction to the improvement of the livestock industry in the region (Kivaria *et al.*, 2007; Yamada *et al.*, 2009). In these two Counties, ECF infections are endemic; smallholder dairying is prominent with long history of using acaricide and growing sales of ECF vaccine (Bebe *et al.*, 2017). Dairy farming is integrated with tea plantation in Nandi County and with maize in Uasin Gishu County. There are 375,287 dairy animals of which 81,838 are high grade in Uasin Gishu compared to total cattle population of 62,459 in Nandi County (Ministry of Agriculture and Livestock Development, 2012). Three agro ecological zones, namely lower highland, upper highland and upper midland zones are distinct with bimodal rainfall, but higher in Nandi (1,200 to 2,000 mm per annum) than in Uasin Gishu (900 to1200 mm per annum).

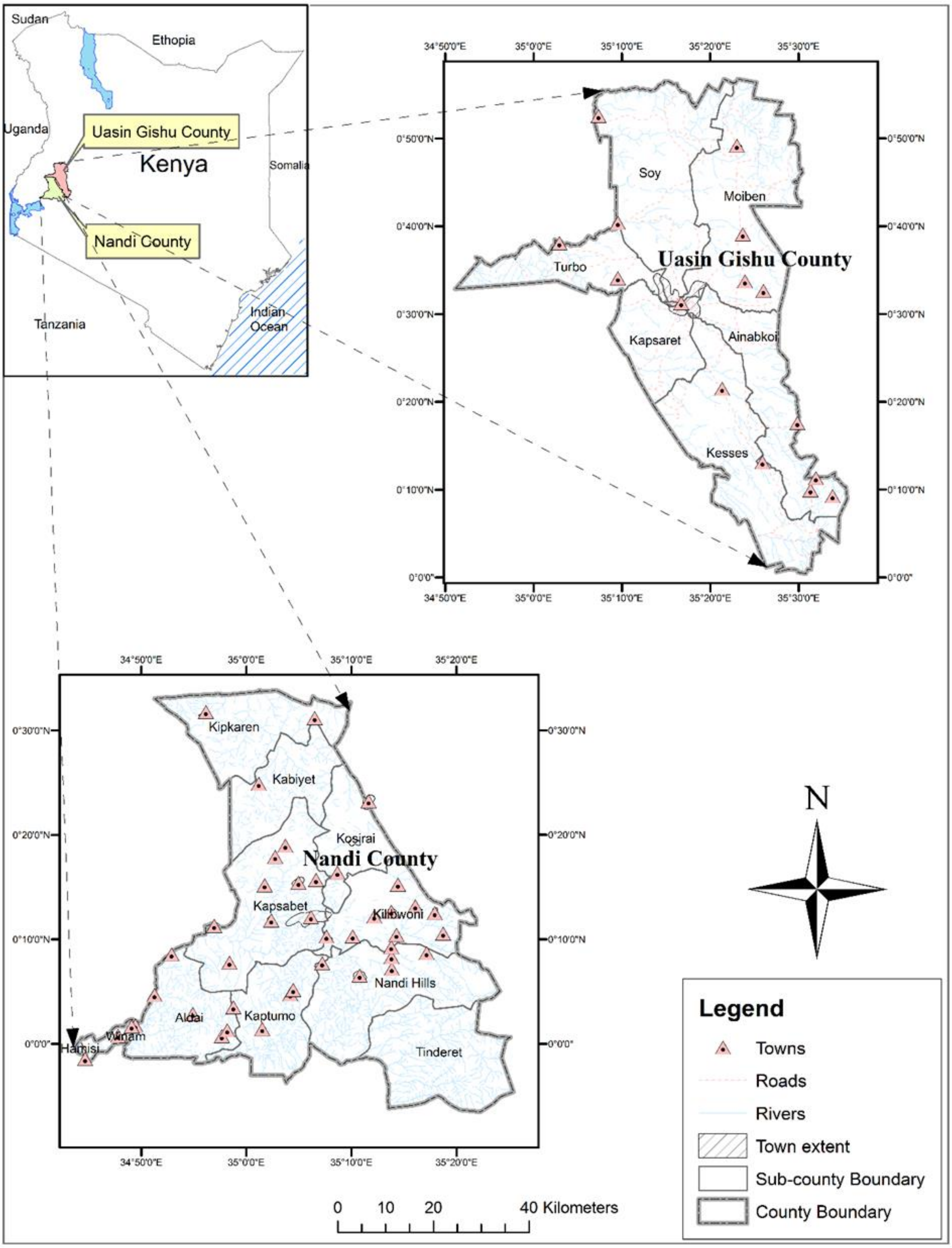

Figure 2 Map of Kenya showing selected study sites (Nandi and Uasin Gishu Counties)

3.2 Sample Size Determination

The minimum sample size needed (n) for the study was estimated at 162 farms in the two counties based on (Anderson *et al.,* 2003) formula:

$$n = \frac{z^2 * p * q}{e^2} \tag{2}$$

where z is desired confidence interval level set at 1.96 for 95% confidence interval, p is the proportion of the target farms with ECF infections set at 0.70 being the ECF prevalence in the Kenya highlands (Okuthe *et al.,* 2006), q = (1- p), and e is the error margin allowable for detecting a difference in the sample set at 0.05 to correspond to 95% confidence interval.

3.3. Study Design

A cross-sectional survey design was applied. In each county, the Sub-Counties were selected on the criteria of prominence of smallholder dairying, endemic ECF infection and use ECF prophylactics strategies. The selected sub-county levels have a high concentration of smallholder dairy and farms and for this study were stratified by agro ecological zones and production system (pasture, semi zero, zero-grazing). The local extension officers and the Agro-Vet dealers selling the acaricides and ECF vaccine assisted with listing and identification of the sample frame. Simple random selection was then applied to the list to obtain the farms which were visited on arranged interview date to collect the needed data for the study research questions.

3.4. Data Collection

On each farm visited, data was collected using a pre-tested structured questionnaire (Appendix I) on the basis of farmers' recall for the reference period of one year. The questionnaire design captured prophylactic strategies, animal population, ECF infection history, management actions applied whenever the disease is detected or suspected and the various costs related to ECF treatment, control and direct losses. Diseases were identified based on the standard symptoms and the number of animals infected. The data on management action upon observation of the symptoms of ECF disease included; seeking veterinary professional service, self-treat or isolate, culling and changing grazing area. These data were obtained by further probing of farmers about blood samples tests, quarantine of the infected animal and shift in grazing area in the event of disease infection. Data for estimating economic losses accounted for both direct and indirect costs, grouped as veterinary costs, disease control, production loss and additional costs, as detailed in Table 1.

3.5 Data Analysis

Data analysis implemented aimed to answer the research questions of whether there are significant differences between the three prophylactic strategies (acaricide, vaccine and their combination), in ECF infection prevalence rates, immediate management actions when disease is detected or suspected, and associated economic losses from the disease. The differences in ECF infection prevalence rates between the prophylactic strategies was determined from frequency counts computed from cross tabulation and testing for the associations between infection and prophylactic strategies using *Chi square* (χ^2) test statistics.

A comparison of management practices for ECF infection between the prophylactic strategies were based on frequency counts obtained in cross tabulation to compute percent observations then testing for association between management practices and prophylactic strategies with C*hi square* test statistics .The economic losses directly and indirectly related to ECF infections were computed from the summation of costs in monetary values categorized into model components defined by Bennett (2003) in the form of equation (3):

$$C = (L + R) + (T + P) \quad (3)$$

where: C = Economic cost of disease, L = the cost of disease in terms of the loss in expected output due to ECF, R = Increase in expenditure on non-veterinary resources due to ECF, T = the cost of inputs used to treat ECF, P = the cost of disease prevention measures (acaricide, vaccine and both acaricide/vaccine). The difference in mean economic loss between the three prophylactic strategies was determined on percentage differences.

CHAPTER FOUR
RESULTS

4.1 Characteristics of sampled farms

The observed proportion of the sample farms that used the three ECF prophylactic strategies are shown in Table 2. The prophylactic strategies used on the sample farms (n=164) was predominantly acaricide (79.9%) with only few using combined acaricide with vaccine (16.5%) or vaccine alone (3.7%). The use of acaricide predominated in the Counties, grazing systems and for the perceived prevalent tick-borne disease. The *Chi* square test showed that use of the prophylactic strategies was significantly between grazing systems (χ^2 (6) = 14.488; p = 0.025) and between prevalent tick-borne disease (χ^2 (8) = 58.334; p= 0.001) but not between the two different counties (χ^2 (2) = 1.663; p= 0.435).

Table 2 The observed distribution of sample farms that use various East Coast Fever prophylactic strategies by prevalent tick-borne diseases, county and grazing systems

Factors	**Level**	**Proportion by prophylactic strategy**			***Chi* square test**
		Acaricide	**Vaccine**	**Acaricide + vaccine**	
Prevalent Tick-borne disease	ECF (n=75)	0.920	0.027	0.053	**(p<0.01)
	Anaplasmosis (n=54)	0.833	0.037	0.130	
	Babesiosis (n=10)	1.000	0.000	0.000	
	Cowdriosis (n=20)	0.200	0.100	0.700	
	ECF piroplasm (n=5)	0.600	0.000	0.400	
County	Nandi (n=91)	0.769	0.033	0.198	NS
	Uasin Gishu (n=73)	0.836	0.041	0.123	
Grazing system	Only grazing (n=63)	0.841	0.048	0.111	*(p<0.05)
	Mostly grazing with some stall feeding (n=77)	0.831	0.026	0.143	
	Stall feeding with some grazing (n=19)	0.632	0.000	0.368	
	Zero grazing (n=5)	0.400	0.200	0.400	
Overall	*Overall (n=164)*	*0.799*	*0.037*	*0.165*	

Significance levels *p<0.05, **p<0.001, NS is not significant (p≥0.05)

4.2 Association between prophylactic strategies and ECF infection prevalence rates

The association of ECF infection with the prophylactic strategies, grazing systems and agro-ecological zones on the sample farms is shown in Table 3. The ECF infection prevalence among animals examined (n=1038) was 18.7% and did not differ (p>0.05) between the three prophylactic strategies i.e. vaccine (18.4%), acaricide (18.0%) and combination of acaricide and vaccine (22.9%). Even grazing systems were not different in the use of prophylactic strategies; only grazing (18.9%), semi-grazing (17.6%) and stall feeding (21.8%) and no difference was also observed between the agro-ecological zones; lower highland (17.3%) and upper highland (20.7%).

Table 3 East Coast Fever infections prevalence rates at animal level under different control strategies, grazing systems and Agro-ecological zones

Variable	Observation (n)	ECF infections		*Chi* square test
		Positive	Negative	
Prophylactic strategy				NS
Acaricide	845	0.180	0.820	
Vaccine	49	0.184	0.816	
Acaricide + Vaccine	144	0.229	0.771	
Grazing system				NS
Only grazing	380	0.189	0.811	
Semi-grazing	511	0.176	0.824	
Stall feeding	147	0.218	0.782	
Agro-ecological zone				
Lower highland	623	0.175	0827	NS
Upper highland	415	0.207	0.793	
Overall	*1038*	*0.187*	*0.813*	

Significance level: NS is not significant (p>0.05)

4.3 Association between prophylactic strategies and management action on suspicion or detection of ECF based on common symptom

Table 4 present symptoms that farmers suspected or detected to be indicative of ECF infection in sampled farms and their proportions reported under different prophylactic strategies. Farms using vaccine alone reported an overwhelmingly (100%) when they observe restlessness in animals while symptoms of swollen lymph nodes and red urine reported (93.1%) and (67.9%) respectively in farms using combination of acaricide and vaccine and hard dung symptom (75%) reported in those that applied acaricide strategy.

Table 4 .The symptoms and proportions farmers associated with ECF infection under various strategies.

Symptom	n	Acaricide %	Vaccine %	Acaricide + vaccine %	Overall %
Swollen lymph nodes	78	89.9	96.4	93.1	48.0
Restlessness	22	72.4	100.0	50.0	13.4
Red urine	6	53.3	50.0	67.9	3.6
Hard dung	58	75.0	50.0	51.8	35
	164				100

Figure 3 shows that farmers were more likely to seek for professional veterinary services, whether using vaccine (96.4%), acaricide +vaccine (93.1%) or using acaricide (89.9%) control when they observe swollen lymph nodes symptom for ECF infection. A few would do self-treatment or isolation or cull animals as an option (about 10 %).

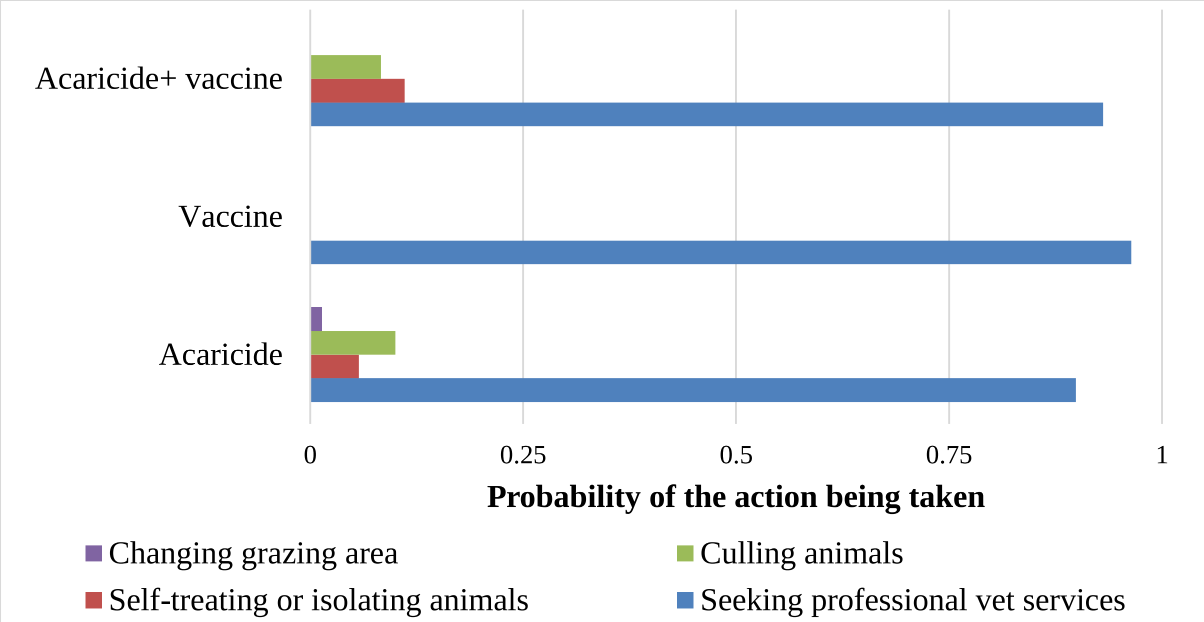

Figure 3 Conditional probability of a specific action when swollen lymph nodes observed was suspected to indicate ECF infection symptom

Similarly, when farmers observed symptom of restlessness in animals suspected to be due to ECF, they were more likely to promptly seek for professional veterinary services when using vaccine (100%), acaricide (72.4%) or when using a combination of acaricide and vaccine (50%). A small proportion of farmers would self-treat or isolate animals should they observe symptom suspected to be indicative of ECF infection when they were using vaccine (5%) or acaricide strategies(1.9%) is illustrated in Figure 4.

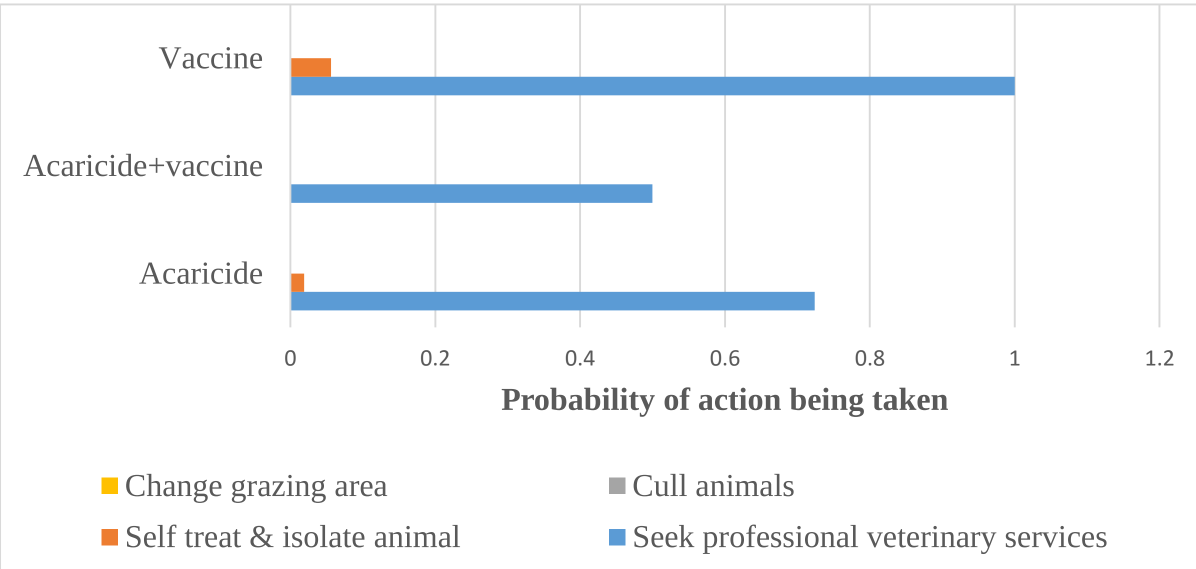

Figure 4 Conditional probability of specific action when restlessness observed was suspected to indicate ECF infection symptom

For the farmers who observed animals passing red urine as ECF infection symptom, most were likely to seek for professional veterinary services when they were using a combination of acaricide and vaccine (67.9%), acaricide (53.3%) or when they were using vaccine (50%). A few of the farmers would cull animals (16.7%) or resort to self-treat or isolate animals in vaccine (12.5%) as Figure 5 illustrates.

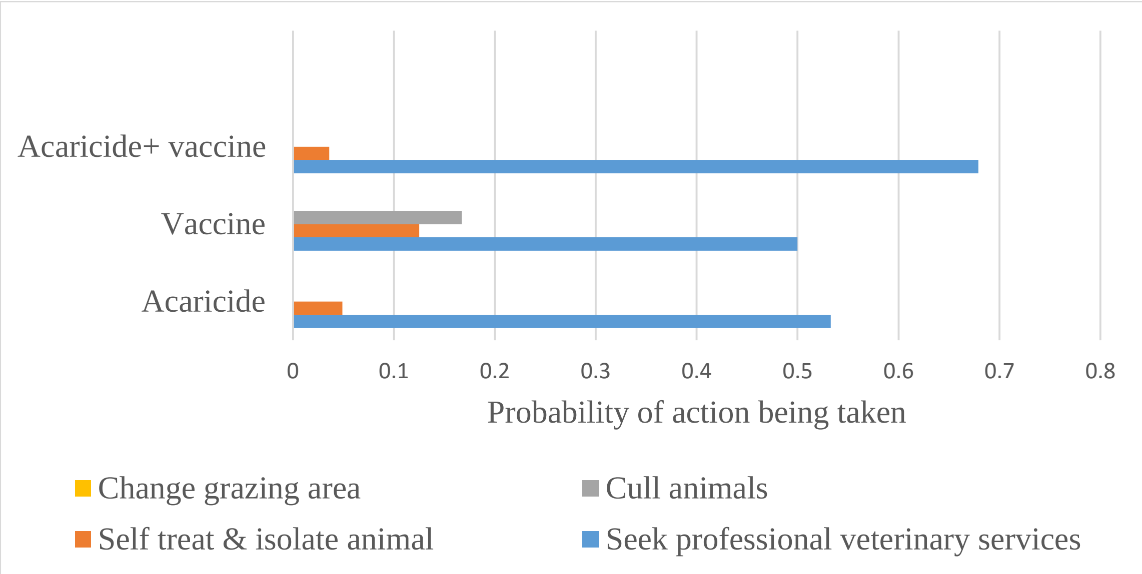

Figure 5 Conditional probability of specific action when animal passing red urine is suspected to indicate ECF infection symptom

When farmers observed symptom of hard dung as ECF infection symptom (Figure 6), they were more likely to seek for professional veterinary services when using acaricide (75%), when using both acaricide and vaccine (51.8%) or when using vaccine (50%) while a few (6.3%) would attempt to self-treat and isolate the animal.

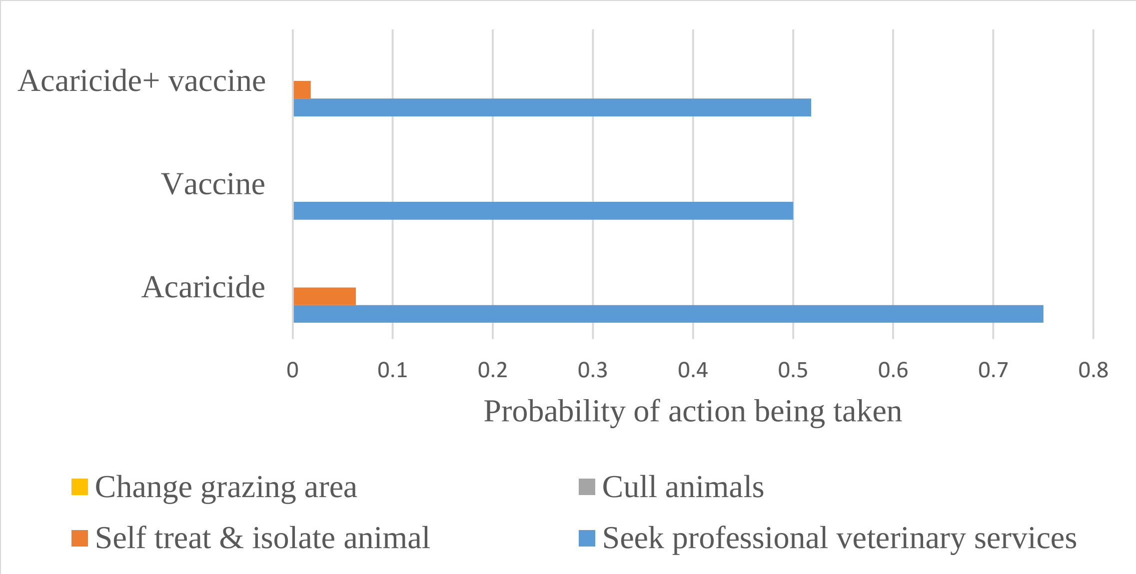

Figure 6 Conditional probability of specific action when hard dung was suspected to indicate ECF infection symptom

4.4 Association between prophylactic strategies and Economic losses estimates from ECF infections

The estimated total economic loss associated with ECF infections per farm per year in farms under different prophylactic strategies are presented in Table 5. The estimated economic loss when using acaricide was (USD 109.78) which was 2.0 times more than the loss in farms using a combination of acaricide and vaccine (USD 61.26) and 55.8 times more than the loss in farms using vaccine (USD 2.27)

Table 5 Economic loss estimates in USD/farm/year (with percent contribution) of the various sources of losses by prophylactic strategies practiced in sample farms.

Economic loss	**Acaricide**	**Vaccine**	**Acaricide & vaccine**	**Total**
Production loss (Reduced milk yield)	9.48 (0.09)	0.09 (0.04)	4.01 (0.06)	13.58 (8.0)
Disease prevention	47.54 (0.43)	0.49 (0.22)	41.46 (0.68)	89.49 (52.0)
Disease treatment	27.13 (0.25)	0.46 (0.20)	12.86 (0.21)	40.45 (23.0)
Non-veterinary costs	25.63 (0.23)	1.23 (0.54)	2.93 (0.05)	29.79 (17.0)
Total loss	109.78	2.27	61.26	173.31

1 USD=100 KES (source CBK)

The percentage contribution to the total economic losses from ECF infections under different prophylactic strategies in smallholder farms are presented in Figure 7. The findings show that the larger proportion of the economic loss was from disease prevention on farms using a combination of acaricide and vaccine (68%) and farms using acaricide alone (43%) while non-veterinary costs accounted for the largest economic loss on farms using vaccine alone (54%). The next greatest economic loss was from disease treatment (20 to 25%).

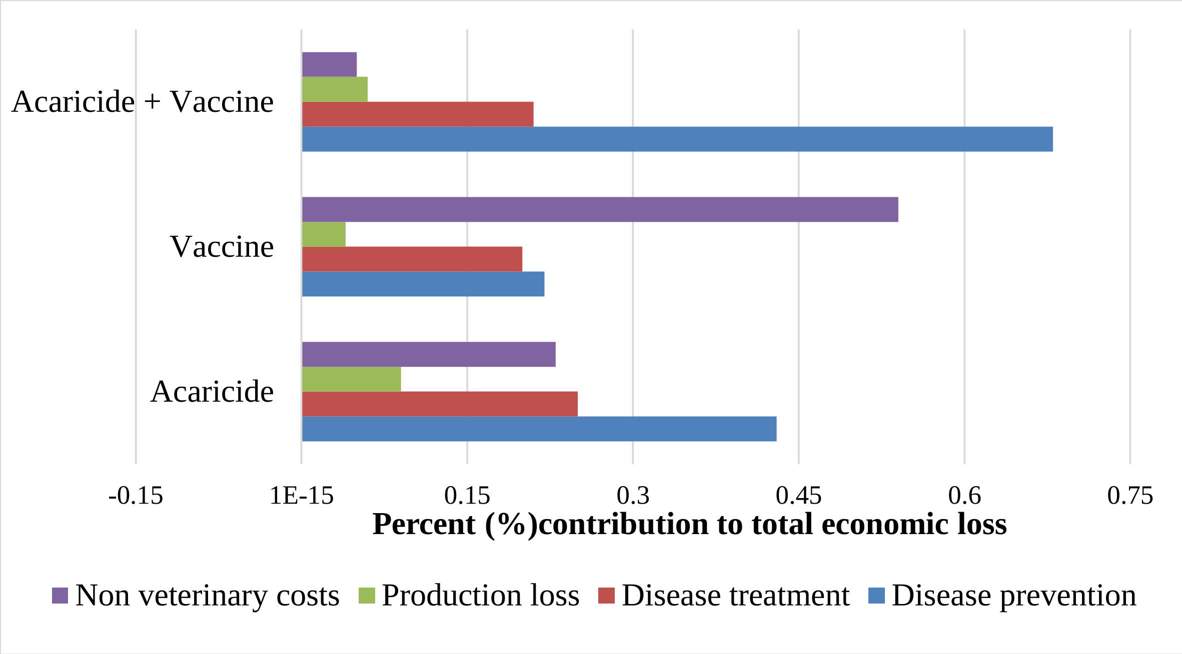

Figure 7 Percent contribution to total economic loss from ECF infections under different prophylactic strategies in smallholder farms.

CHAPTER FIVE

DISCUSSION

5.1 Prophylactic strategies and ECF infection prevalence

The ECF prevalence in this study used farmer observed symptoms. The prevalence rates observed on basis of antibody ranges and presents prevalence rates detected or estimated from other methods. This may be the first one using farmer observed symptoms in the field. ECF was the most prevalent TBD on the sample farms, pointing to the disease being a major challenge and threat to dairy development in the study region. Animal infections were as high as 20%, which warrants an effective control strategy for the disease on smallholder farms. Many authors have emphasized that East Coast fever is the most important disease of cattle in the region, followed by other tick borne diseases such as Anaplasmosis, Cowdriosis and babesiosis (Mugisha *et al.,* 2008; Kazungu *et al.*, 2015; Kerario *et al.,* 2017; Laisser *et al.,* 2017; Kerario *et al,.* 2018). ECF disease is major cause of deaths, especially among calves, causing calf mortality that can range from 40% to 80% (Walker *et al.*, 2003).

Kivaria *et al.* (2006) reported that Theileriosis account for largest proportion (68%) of the total economic loss, relative to anaplasmosis (13%), babesiosis (13%) and cowdriosis (6%). Gachohi *et al.* (2012) found out that economic losses due to ECF disease were substantial on small-scale resource-poor households, which subsequently expose them to vulnerable position with the loss of other sources of primary household income. Other losses are attributable to weight loss (9%), milk loss (6%) and infection and treatment method (1%) of the total annual loss (Kivaria *et al.,* 2006). In the study by Muraguri *et al. (*1998) monitoring, professional fees and transportation that were termed as fixed costs (in this study non-veterinary costs), attributable economic loss was more than half (53%) since they were charged uniformly, irrespective of the number of animals on the farm.

The sample farms predominantly used acaricide strategy to control ticks that are vectors of the *Theileria parva* infections. Farmers may apply the acaricides control strategy on weekly basis or twice a week based on tick vector infestation (Mukhebi *et al.,* 1992). Use of the acaricide has long history which has resulted in wider uptake among dairy farmers. The pharmaceutical firms have penetrated farming communities with acaricide in the absence of an alternative prophylactics strategy, until recently when vaccine development became successful and commercially viable (KDB, 2016).

In this study, the ECF infection prevalence among the sample animals did not differ ($p>0.05$) between the three prophylactic strategies. This implies that use of any of the three strategies would not disadvantage farmers in risks of ECF infection and cattle losses. The difference is in the cost involved in use of the strategy, which showed marked differences. Use of vaccine had the lowest cost and therefore would save farmers resources in ECF disease control.

However, the use of vaccine alone remains an unpopular strategy in ECF control. From this study, it can be deduced that vaccine effectiveness and affordability is not yet known to smallholder farmers. The areas of concern regarding the vaccine could be in costs, safety, effectiveness and sustainability of the vaccine in ECF control (Karanja-Lumumba *et al.,* 2015). The extension service and veterinary pharmaceutical companies need to do more promotional campaigns to penetrate the customer base, estimated at 1.5 million farmers who produce and derive livelihoods from milk production (KDB, 2016).

ECF prevalence reported in Kenya on smallholder farms is very variable, reflecting differences in ecological conditions and management practices. Practicing regular dipping/spraying with acaricide does effectively control ticks, and is associated with lower *Theileria parva* prevalence if good acaricide use practices are adhered to by farmers as reported by this study through farmer observed symptoms. Compared to other prevalence estimates ELISA and PCR techniques, Kerario *et al. (*2017) reported lower *Theileria parva* prevalence (14.2%) but other researchers reported higher prevalence. For example Laisser *et al. (*2014) study (27.7%) in the in the Lake region, Kazungu *et al. (*2015) study estimates (19.7%) in northern part of Tanzania while Tarimo (2013) study estimate (8.1%) in the eastern part of Tanzania. The additional factors likely to explain these observed differences could be animal genetics, prophylactic practices, virulence of the pathogens, and infection rate of ticks in the different regions (Moll *et al.,* 1988; Laisser *et al.,* 2016, 2017). The study prevalence estimates fall within estimates reported by other studies and imply that farmers can apply control strategies that reduce ECF prevalence in their farms and for governments to promote ECF prophylactic strategies through policy formulation and adopted by farmers in endemic regions to reduce losses due to ECF.

There are also observed differences in the ECF prevalence related to the prophylactic strategy in use. Prevalence is lower on farms neighbouring game reserves, as observed in Tanzanian Serengeti (38.3%) when using acaricide (Laisser *et al.,* 2014) than when using vaccine (50%) on Maasai cattle Kazungu *et al.* (2015). This corroborates the observations elsewhere in East Africa, for instance prevalence estimates (25.3% to 27.1%) in Rwanda between 1998 and 2003, based on p104 *Theileria parva* specific gene and 18S assays (Basarusinga *et al.,* 2007). In Rwanda, dairy cows are mostly confined in zero grazing units under the one cow programme, which would explain comparable ECF prevalence to Kenya where smallholders predominantly practice zero-grazing as well (Muhanguzi *et al.,* 2014).

5.2 Association between prophylactic strategies and management of ECF infections

Farmers in sampled farms mostly suspected or detected symptoms of swollen lymph nodes, restlessness, red urine and hard dung to be indicative of ECF infections. As a consequence, they relied on professional veterinary service in the event of observing these symptoms on their animals. This was in regardless of prophylactic strategy or specific symptom observed (Table 4, Figures 3, 4, 5 and 6). This suggests high level of awareness among farmers of the right action to take whenever ECF is suspected or detected. The disease is fatal, which would explain why farmers seek professional veterinary service (Both Government and private practitioners) in the study area. Ease of access to veterinary service is therefore of importance in managing ECF infections. In the study area, Agro-vet outlets and promotional services on ECF disease are available and easily accessible by farmers (Karanja-Lumumba *et al.*, 2015).

Professional veterinary services in ECF endemic region is provided by government and, often free or at highly subsidized charges, through veterinary investigation laboratories and the veterinary extension service or private practitioners (Onono *et al.,* 2013). Farmers paying for the service can spend as much as 10 to 20 USD$ per animal per treatment (Sitawa *et al.*, 2016). The relatively high cost of treatment, despite available veterinary services, especially to smallholder farmers imply that a considerable proportion of infected animals have access to treatment should they become sick.

The results are in agreement with those of Kerario *et al. (*2018) in which 92.9% of respondents sought assistance from government veterinarians or livestock extension officers for the treatment of their animals. A further corroboration of the present results are authors who observed that a third of the respondents (30%) sought assistance from government veterinarians or livestock extension officers for treatment of their animals when infected with TBD or report to the veterinary authorities nearest to them whenever animals show any major symptoms of ECF infections (Chenyambuga *et al.,* 2010; Sitawa *et al.,* 2016),

However, the high use of veterinarians by farmers could be they have not learnt to administer the drugs themselves while a few could administer. Evidence of this observation by (Kerario *et al.*, 2018) that 97.2% of farmers bought drugs and administered by themselves while 60% of the farmers self-treated the sick animals. Chenyambuga *et al.* (2010) also made similar observations; half (50%) of the farmers did buy the drug and administered, while a few (4%) even vaccinated their animals against ECF (Sitawa *et al.*, 2016). About half of the farmers (44%) used commercially available drugs only, another notable observation made by Kimaro *et al.* (2017).

5.3 Economic losses from ECF infections

The estimated economic loss associated with ECF infections per farm per year was highest when using acaricide (USD109.78); about 2.0 times higher than when using a combination of acaricide and vaccine (USD 61.26) and 55.8 times higher when using vaccine alone (USD 2.27).This shows that use of vaccine, immunization is presently a cheaper strategy to control ECF in smallholder dairy farms. Vaccine is life long and confers immunity to subsequent infections that challenge the immunized animal (Di Giulio *et al.*, 2009). Furthermore, vaccine reduces cost of livestock production and relaxes use of acaricides in control of ECF (Jumba *et al.*, 2016).

The higher loss in acaricide strategy could be attributed to cost of acaricide use which is the primary means of tick control estimated to range between USD$6 and 36 per adult animal in Kenya, Tanzania and Uganda (Minjauw *et al.*, 2003). Depending on the frequency of applications, annual costs of acaricide to farmers who are financially responsible for the purchase of these drugs range from US$ 2 to 20 per animal (Onono *et al.*, 2013; Sitawa *et al.*, 2016). In areas of heavy tick infestation, cattle are treated with acaricides as often as twice a week (Mukhebi *et al.*, 1992).

The effective treatment of ECF infection requires disease identification through surveillance and diagnosis followed by treatment of infected animals with drugs. In the study area, this service was provided by government and or private practitioners, through veterinary investigation laboratories and the veterinary extension service on charges that vary (Sitawa *et al.*, 2016). Farmers who pay for the service can spend as much as US$ 10 to 20 per animal per treatment but depends on professional cadre (Sitawa *et al.*, 2016)). The relatively high cost of treatment coupled with the limited availability of veterinary services to smallholder farmers imply that only a small proportion of infected animals have access to treatment.

The costs associated with ECF treatment (non-veterinary costs) could have led to economic loss variation in each prophylactic strategy. Farmers incur costs that were no longer considered in disease costing and spend money annually on reporting the disease to an animal health service providers, drug purchase and labor costs (Sitawa *et al.,* 2016). This is in agreement with report that some costs were treated as fixed (in this study non-veterinary costs) since they were charged uniformly, irrespective of the number of animals on the farm contributed up to 53% Muraguri *et al.,* (1998).

Control of tick vectors which cause ECF infection is managed by use of acaricide. This causes substantial economic loss to farmers and resource use (Mukhebi *et al.,* 1992). The consequences of the control of ECF by this method is therefore grim; extension staff generally do not have transport, most public dips are poorly managed and/ or are non-functional. The few operational ones are often use diluted acaricides whose concentration are often below the recommended concentration, rendering the acaricides ineffective besides contributing to development of resistance in ticks. Furthermore, drugs are not readily available to government veterinarians, and if they are available in local markets, they are too expensive for most smallholder farmers (Mukhebi *et al.,* 1992).

ECF timely management by chemotherapy is readily available but successful application requires correct and diagnosis of the disease at its early stage of development. This specialization is beyond the capacity of many smallholder farmers because of the poor state of the animal health service infrastructure (Onono *et al.*, 2013). This factor, coupled with the high cost of drugs, implies that only a small proportion of animals which become infected with the disease receive treatment (Mukhebi *et al.,* 1992).

The application of acaricides on vector ticks through dipping, spraying or hand-washing animals also contributes to the pollution of the environment and may endanger human health both directly and indirectly. This may arise from direct contact, spilled or misused acaricides and also from consumption of products that may contain residues of acaricides derived from animals treated with acaricides (Sonenshine *et al.,* 2006; Mirzaei 2007; Vahora *et al.,* 2012).

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This comparative study assessed whether ECF infection prevalence and their associated management actions and economic loss estimates significantly differ between use of acaricide, vaccine or a combination of acaricide and vaccine. From the results obtained, it is concluded that:

i. The ECF infection prevalence rates were not significantly different when using acaricide, vaccine or combination of these control strategies.

ii. Farmers were more likely to seek for professional veterinary services whenever they observed symptoms associated with ECF infection (swollen lymph nodes, restlessness, red urine and hard dung) regardless of the prophylactic strategy they were using.

iii. The estimated economic loss associated with ECF infections per farm per year in farms was highest when using acaricide (USD 109.78); about 2.0 times higher than when using a combination of acaricide and vaccine (USD 61.26) and 55.8 times higher when using vaccine alone (USD 2.27).

6.2 Recommendations

Vaccination against ECF infection reduces use of acaricides and associated costs, which improves financial benefits to farmer. This model can be worked out through the County governments. This study therefore recommends that:

i. Extension service of agriculture/livestock in the two counties needs to carry out extension education on the value of vaccination of dairy herds as a way of tackling the ECF infections in the two Counties.

ii. The County governments of Nandi and Uasin Gishu could support full roll out of ECF vaccination campaigns in the endemic areas for wider up scaling.

iii. Use of vaccine in ECF control is cheaper than acaricide. Smallholder dairy farmers in the two Counties should embrace vaccination in fight against ECF infection in endemic areas.

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APPENDICES

Appendix 1: Questionnaire

EGERTON UNIVERSITY

FACULTY OF AGRICULTURE

DEPARTMENT OF ANIMAL SCIENCES

QUESTIONNAIRE FOR THE RESEARCH ON EVALUATING ASSOCIATION OF PROPHYLACTIC STRATEGIES WITH PREVALENCE, MANAGEMENT AND ECONOMIC LOSESS FROM EAST COAST FEVER INFECTIONS ON SMALLHOLDER FARMS IN NORTH-RIFT KENYA

Consent seeking

This survey is conducted by a post-graduate student of Egerton University in the Department of Animal Sciences in partial fulfillment for a Master of Science Degree in Livestock Production Systems. The information provided will be used for academic purposes only and will be treated with ultimate confidentiality**.**

SECTION A: Household Head identity

Date-- Questionnaires no--------------------------

Enumerators name----------------------------------- Tel no----------------------------

County------------------------Sub-county-----------------------------

Location-------------------------Sub-location------------------------

Village---

Name of the farmer/spouse/herdsman (i.e. the person interviewed): ----------------------------

Gender [1= male; 2 = female] [ ] Mobile no--------------------------------

Educational level [1=none; 2=primary; 3=secondary; 4=post-secondary] [ ]

Age------------------

Years of dairy experience-----------------------

Herd characteristics

	Heifer calves	Heifers	Cow	Bull calves	Mature bull	Bull
Number						

SECTION B: ECF infection prevalence

Production objective	ECF control strategy frequently used	Best description of production system	Agro-ecological zone

Production objective	ECF control strategy within last 3 years	Production system	Agro-ecological zone
1 Home consumption *2 Mostly for home consumption with intension of selling* *3 Partly for Home consumption and for market*	*1 Acaricide* *2 Vaccine* *3 Both (Acaricide and Vaccine)* *4 None*	*1 Only grazing (free range or tethering)* *2 Mostly grazing with some stall feeding* *3 Zero grazing* *4 Stall feeding with some grazing*	*1 LH* *2 UH* *3 UMZ*

1. Name the tick-borne diseases you have experienced in your herd in the last 12 months?

Disease	Local name	Symptoms	Animal category affected

2. How frequently do you experience ECF infections in your farm? (*1=frequently; 2=occasionally; 3= none*) [ ]

3. For ECF infections experienced in the last 12 months, please indicate

Animal category	Total number of animals at risk	Number of animals affected with ECF	Number that recovered	Number that died
Heifer calves				
Heifers				
Cows				
Bull calves				
Mature bulls				
Bull				

SECTION C: ECF infections management actions

4. What do you do in case of ECF infection in your farm?

<table>
<tr><td colspan="3">Management practice</td><td>Action taken
(1 =Frequently 2 =Sometimes 3 =No any action).</td></tr>
<tr><td colspan="3">1.Reporting to veterinary department</td><td></td></tr>
<tr><td colspan="3">2. Collect blood samples for confirmatory tests at the lab</td><td></td></tr>
<tr><td rowspan="3">3. Treating</td><td rowspan="2">By Self</td><td>Drugs</td><td></td></tr>
<tr><td>Herbs</td><td></td></tr>
<tr><td colspan="2">By veterinarian</td><td></td></tr>
<tr><td rowspan="2">4.Vaccinate</td><td colspan="2">By self</td><td></td></tr>
<tr><td colspan="2">By veterinarian</td><td></td></tr>
<tr><td colspan="3">5. Slaughter the animal</td><td></td></tr>
<tr><td colspan="3">6. Sell the animal/give away</td><td></td></tr>
<tr><td colspan="3">7. Replace the sick animal by purchase of healthy animal</td><td></td></tr>
<tr><td colspan="3">8. Separation/Quarantine of infected animals</td><td></td></tr>
<tr><td colspan="3">9. Shift grazing area/or feed source</td><td></td></tr>
</table>

SECTION D: Economic losses associated with ECF infections.

Source of loss		Unit cost	Quantity / Number of cases	Total cost (KES)
Veterinary	Full dose per case			
	Vet charges per case			
	Consultation fee per case			
Disease control	Cost of home spraying per animal			
	Cost of public dipping per animal			
	Vaccine cost per animal			
Production loss	Milk withdrawal period (days)			
	Milk yield when animal normal			
	Milk yield when animal is infected			
	Drop in milk yield during treatment			
Additional costs	Transport to purchase drug (frequency)			
	Replacement of diseased animal per animal			
	Cost of reporting a case/airtime			

Checklist

ECF infection Clinical signs
Loss of appetite
Weakness
Decreased milk production
Rapid breath and high fever
Coughing and discharge from Nostrils
Swollen lymph nodes especially under the ear, in front of the shoulder and Knee
Some animals have Diarrhoea with blood spots or mucus
Occasionally small red spots in the gums, eyelids and at the base of the tongue
Cattle walk in cycles, their back legs paralyzed

Moisture availability zones in Kenya with rainfall and proportion of land

Agro-climatic zones	**Classification**	**Moisture index (%)**	**Annual Rainfall (mm)**	**Land area**
I	Humid	>80	1100-2700	-
II	Sub-humid	65-80	1000-1600	12
III	Semi-humid	50-65	800-1400	-
IV	Semi-humid to Semi-arid	40-50	600-1100	5
V	Semi-arid	25-40	450-900	15
VI	Arid	15-25	300-550	22
VII	Very Arid	<15	150-350	46

Source: Sombroek*et al.* (1982)

Appendix 2: Analyses

Table 6. Farm characteristics by County, ECF control strategy, grazing systems and distribution of TBDs

County * ECF control strategy Cross tabulation

			ECF control strategy			
			Acaricide	Vaccine	Both acaricide and vaccine	Total
County	Nandi	Count	70	3	18	91
		% within County	76.9%	3.3%	19.8%	100.0%
		% within ECF control strategy	53.4%	50.0%	66.7%	55.5%
		% of Total	42.7%	1.8%	11.0%	55.5%
	Uasin Gishu	Count	61	3	9	73
		% within County	83.6%	4.1%	12.3%	100.0%
		% within ECF control strategy	46.6%	50.0%	33.3%	44.5%
		% of Total	37.2%	1.8%	5.5%	44.5%
Total		Count	131	6	27	164
		% within County	79.9%	3.7%	16.5%	100.0%
		% within ECF control strategy	100.0%	100.0%	100.0%	100.0%
		% of Total	79.9%	3.7%	16.5%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	1.663[a]	2	.435
Likelihood Ratio	1.697	2	.428
N of Valid Cases	164		

a. 2 cells (33.3%) have expected count less than 5. The minimum expected count is 2.67.

Grazing system * ECF control strategy Crosstabulation

			ECF control strategy			
			Acaricide	Vaccine	Acaricide & vaccine	Total
Grazing system	Only grazing	Count	53	3	7	63
		% within Production system	84.1%	4.8%	11.1%	100.0%
		% within ECF control strategy	40.5%	50.0%	25.9%	38.4%
		% of Total	32.3%	1.8%	4.3%	38.4%
	Mostly grazing with some stall feeding	Count	64	2	11	77
		% within Production system	83.1%	2.6%	14.3%	100.0%
		% within ECF control strategy	48.9%	33.3%	40.7%	47.0%
		% of Total	39.0%	1.2%	6.7%	47.0%
	Zero grazing	Count	2	1	2	5
		% within Production system	40.0%	20.0%	40.0%	100.0%
		% within ECF control strategy	1.5%	16.7%	7.4%	3.0%
		% of Total	1.2%	0.6%	1.2%	3.0%
	Stall feeding with some grazing	Count	12	0	7	19
		% within Production system	63.2%	0.0%	36.8%	100.0%
		% within ECF control strategy	9.2%	0.0%	25.9%	11.6%
		% of Total	7.3%	0.0%	4.3%	11.6%
Total		Count	131	6	27	164
		% within Production system	79.9%	3.7%	16.5%	100.0%
		% within ECF control strategy	100.0%	100.0%	100.0%	100.0%
		% of Total	79.9%	3.7%	16.5%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	58.334[a]	8	.000
Likelihood Ratio	49.526	8	.000
N of Valid Cases	164		

a. 9 cells (60.0%) have expected count less than 5. The minimum expected count is .18.

ECF control strategy * Disease Cross tabulation								
			Disease					Total
			Anaplasmosis	Babesiosis	ECF	Heart water	Piroplasmosis	
ECF control strategy	Acaricide	Count	45	10	69	4	3	131
		% within ECF control strategy	34.4%	7.6%	52.7%	3.1%	2.3%	100.0%
		% within Disease	83.3%	100.0%	92.0%	20.0%	60.0%	79.9%
		% of Total	27.4%	6.1%	42.1%	2.4%	1.8%	79.9%
	vaccine	Count	2	0	2	2	0	6
		% within ECF control strategy	33.3%	0.0%	33.3%	33.3%	0.0%	100.0%
		% within Disease	3.7%	0.0%	2.7%	10.0%	0.0%	3.7%
		% of Total	1.2%	0.0%	1.2%	1.2%	0.0%	3.7%
	Acaricide + vaccine	Count	7	0	4	14	2	27
		% within ECF control strategy	25.9%	0.0%	14.8%	51.9%	7.4%	100.0%
		% within Disease	13.0%	0.0%	5.3%	70.0%	40.0%	16.5%
		% of Total	4.3%	0.0%	2.4%	8.5%	1.2%	16.5%
Total		Count	54	10	75	20	5	164
		% within ECF control strategy	32.9%	6.1%	45.7%	12.2%	3.0%	100.0%
		% within Disease	100.0%	100.0%	100.0%	100.0%	100.0%	100.0%
		% of Total	32.9%	6.1%	45.7%	12.2%	3.0%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)
Pearson Chi-Square	58.334[a]	8	.000
Likelihood Ratio	49.526	8	.000
N of Valid Cases	164		

a. 9 cells (60.0%) have expected count less than 5. The minimum expected count is .18.

Table 7. Number of cases of ECF and prevalence rates under different control strategies

strategy * case Crosstabulation

			case		Total
			positive	negative	
strategy	acaricide	Count	152	693	845
		% within strategy	18.0%	82.0%	100.0%
	vacinne	Count	9	40	49
		% within strategy	18.4%	81.6%	100.0%
	acaricie vaccine	Count	33	111	144
		% within strategy	22.9%	77.1%	100.0%
Total		Count	194	844	1038
		% within strategy	18.7%	81.3%	100.0%

Chi-Square Tests

	Value	df	Asymp. Sig. (2-sided)
Pearson Chi-Square	1.970[a]	2	.373
Likelihood Ratio	1.885	2	.390
Linear-by-Linear Association	1.841	1	.175
N of Valid Cases	1038		

a. 0 cells (0.0%) have expected count less than 5. The minimum expected count is 9.16.

Table 8. Symptom, control and Frequency of management actions

Control * Seeking professional vet services

			Observed			Total
			1	2	3	
Control	1	Count	107	4	8	119
		% within Control	89.9%	3.4%	6.7%	100.0%
	2	Count	27	1	0	28
		% within Control	96.4%	3.6%	0.0%	100.0%
	3	Count	149	3	8	160
		% within Control	93.1%	1.9%	5.0%	100.0%
Total		Count	283	8	16	307
		% within Control	92.2%	2.6%	5.2%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Monte Carlo Sig. (2-sided)			Monte Carlo Sig. (1-sided)		
				Significance	95% Confidence Interval		Significance	95% Confidence Interval	
					Lower Bound	Upper Bound		Lower Bound	Upper Bound
Pearson Chi-Square	2.820[a]	4	.588	.601[b]	.591	.610			
Likelihood Ratio	4.238	4	.375	.439[b]	.429	.448			
Fisher's Exact Test	2.776			.563[b]	.553	.573			
Linear-by-Linear Association	.674[c]	1	.412	.443[b]	.433	.453	.228[b]	.220	.236
N of Valid Cases	307								

a. 4 cells (44.4%) have expected count less than 5. The minimum expected count is .73.

b. Based on 10000 sampled tables with starting seed 624387341.

c. The standardized statistic is -.821.

Control * Self-treating or isolating animal

			Observed 1	Observed 2	Observed 3	Total
Control	1	Count	16	41	223	280
		% within Control	5.7%	14.6%	79.6%	100.0%
	2	Count	0	2	6	8
		% within Control	0.0%	25.0%	75.0%	100.0%
	3	Count	2	4	12	18
		% within Control	11.1%	22.2%	66.7%	100.0%
Total		Count	18	47	241	306
		% within Control	5.9%	15.4%	78.8%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Monte Carlo Sig. (2-sided) Significance	Monte Carlo Sig. (2-sided) 95% Confidence Interval Lower Bound	Monte Carlo Sig. (2-sided) 95% Confidence Interval Upper Bound	Monte Carlo Sig. (1-sided) Significance	Monte Carlo Sig. (1-sided) 95% Confidence Interval Lower Bound	Monte Carlo Sig. (1-sided) 95% Confidence Interval Upper Bound
Pearson Chi-Square	2.827[a]	4	.587	.554[b]	.544	.564			
Likelihood Ratio	2.997	4	.558	.713[b]	.704	.722			
Fisher's Exact Test	3.344			.418[b]	.408	.427			
Linear-by-Linear Association	1.578[c]	1	.209	.213[b]	.205	.221	.133[b]	.126	.140
N of Valid Cases	306								

a. 4 cells (44.4%) have expected count less than 5. The minimum expected count is .47.

b. Based on 10000 sampled tables with starting seed 624387341.

c. The standardized statistic is -1.256.

Control * Culling animals

			Observed			Total
			1	2	3	
Control	1	Count	2	14	194	210
		% within Control	1.0%	6.7%	92.4%	100.0%
	2	Count	0	0	6	6
		% within Control	0.0%	0.0%	100.0%	100.0%
	3	Count	1	3	8	12
		% within Control	8.3%	25.0%	66.7%	100.0%
Total		Count	3	17	208	228
		% within Control	1.3%	7.5%	91.2%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Monte Carlo Sig. (2-sided)			Monte Carlo Sig. (1-sided)		
				Significance	99% Confidence Interval		Significance	99% Confidence Interval	
					Lower Bound	Upper Bound		Lower Bound	Upper Bound
Pearson Chi-Square	11.232[a]	4	.024	.111[b]	.102	.119			
Likelihood Ratio	7.480	4	.113	.047[b]	.041	.052			
Fisher's Exact Test	9.812			.045[b]	.040	.051			
Linear-by-Linear Association	8.267[c]	1	.004	.015[b]	.012	.018	.015[b]	.012	.018
N of Valid Cases	228								

a. 5 cells (55.6%) have expected count less than 5. The minimum expected count is .08.

b. Based on 10000 sampled tables with starting seed 624387341.

c. The standardized statistic is -2.875.

Control * Changing grazing area

			Observed			Total
			1	2	3	
Control	1	Count	1	22	47	70
		% within Control	1.4%	31.4%	67.1%	100.0%
	2	Count	0	1	1	2
		% within Control	0.0%	50.0%	50.0%	100.0%
	3	Count	0	1	3	4
		% within Control	0.0%	25.0%	75.0%	100.0%
Total		Count	1	24	51	76
		% within Control	1.3%	31.6%	67.1%	100.0%

Chi-Square Tests

	Value	df	Asymptotic Significance (2-sided)	Monte Carlo Sig. (2-sided) Significance	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound	Monte Carlo Sig. (1-sided) Significance	95% Confidence Interval Lower Bound	95% Confidence Interval Upper Bound
Pearson Chi-Square	.480[a]	4	.975	1.000[b]	1.000	1.000			
Likelihood Ratio	.538	4	.970	1.000[b]	1.000	1.000			
Fisher's Exact Test	3.983			.831[b]	.823	.838			
Linear-by-Linear Association	.042[c]	1	.838	1.000[b]	1.000	1.000	.542[b]	.532	.551
N of Valid Cases	76								

a. 7 cells (77.8%) have expected count less than 5. The minimum expected count is .03.

b. Based on 10000 sampled tables with starting seed 957002199.

c. The standardized statistic is .204.

Table 9. Economic losses estimates associated with ECF infections under different control strategies

Control strategy	Overall (%)	Source of economic loss			
		Production loss	Disease prevention	Disease treatment	Non-veterinary costs
Acaricide	1	947.70 (0.09)	4754.20 (0.43)	2713.40 (0.25)	2563.10 (0.23)
Vaccine	1	9.10 (0.04)	48.80 (0.22)	45.70 (0.20)	123.20 (0.54)
Acaricide+vaccine	1	401.20 (0.06)	4146.30 (0.68)	1286.20 (0.21)	293.40 (0.05)

Appendix 3: Publications Abstracts

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Prevalence of east coast fever infections based on farmer-observed symptoms in smallholder dairy herds, North rift Kenya

MA Ikaal, CO Orenge, OB Kashongwe and BO Bebe

Abstract
East Coast fever prevalence is variable and causes economic loss to smallholder farmers. A cross-sectional survey involving 1038 cows on 164 farms stratified by agro-ecological zones, production systems and prophylactic strategies conducted. Acaricide use was dominant (79.9%) on sample farms and disease prevalence of cows examined on standard symptoms 18.7%. This did not differ ($p \geq 0.05$) between prophylactic strategies, different grazing systems and the agro-ecological zones. The estimated economic loss due to disease per farm per year on acaricide 1.8 times higher than acaricide and/or vaccine and 48.8 times high than vaccine loss. Disease prevention loss on farms using acaricide and/or vaccine (0.68), acaricide (0.43). Non-veterinary cost on vaccinating farms (0.54) while treatment costed a quarter of the economic loss. Use of any of the three prophylactic strategies hardly expose farmers to risks of disease. Vaccine is cheaper, effective and access to farmers should be beneficial in the smallholder dairy development.

Keywords: Agro-ecological strata, Control strategies, Economic loss, Tick-borne-Diseases, grazing systems

Vaccination is as efficient as acaricide in controlling *Theileria parva* infections in smallholder dairy herds in Kenya

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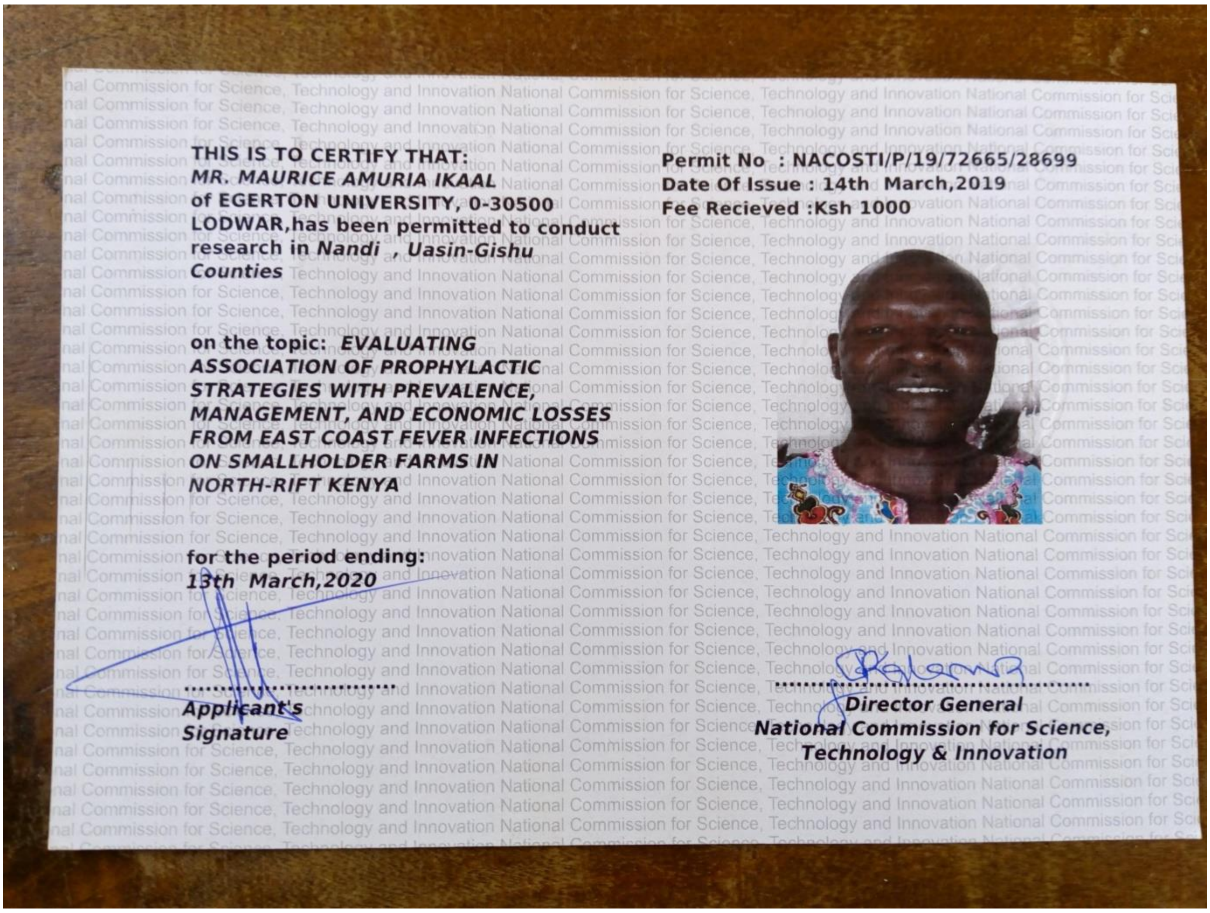
Abstract

The use of vaccine to control East Coast Fever (ECF) is relatively new in Kenya and is regarded as safer, cheaper and effective and it can be used together with other control strategies but its adoption remains low. The study compared ECF prevalence rates under three prophylactic strategies, namely acaricide, vaccine and a combination of acaricide and vaccine. A cross-sectional survey was conducted in Nandi and Uasin Gishu counties to obtain the sample frame using a stratified random sampling. Data of 1038 cows affected by ECF infection in 164 farms was subjected to *Chi* square test statistic to ascertain the estimate of ECF prevalence rates in the different control strategies. The estimated prevalence rates of ECF infection in acaricide, vaccine and both (acaricide & vaccine) control strategies was 14.64%, 3.18% and 0.87% respectively. No statistically significant association ($p=0.374$) was found between the control strategies and ECF prevalence rates. A logistic regression model was used to predict outcome (ECF infections) from independent variables of control strategy, production systems and agro ecological zones. The OR =0.811

Appendix 4: Nacosti Permit


THIS IS TO CERTIFY THAT:
MR. MAURICE AMURIA IKAAL
of EGERTON UNIVERSITY, 0-30500
LODWAR,has been permitted to conduct
research in *Nandi , Uasin-Gishu*
Counties

on the topic: *EVALUATING ASSOCIATION OF PROPHYLACTIC STRATEGIES WITH PREVALENCE, MANAGEMENT, AND ECONOMIC LOSSES FROM EAST COAST FEVER INFECTIONS ON SMALLHOLDER FARMS IN NORTH-RIFT KENYA*

for the period ending:
13th March,2020

Applicant's
Signature

Permit No : NACOSTI/P/19/72665/28699
Date Of Issue : 14th March,2019
Fee Recieved :Ksh 1000

Director General
National Commission for Science,
Technology & Innovation