QUANTIFYING PRODUCTION LOSSES ASSOCIATED WITH FOOT AND MOUTH DISEASE OUTBREAKS ON LARGE SCALE DAIRY FARMS IN NAKURU COUNTY, KENYA

REAGAN ANGUIE BOL LEWIS

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

EGERTON UNIVERSITY

MARCH, 2020

DECLARATION AND RECOMMENDATION

Declaration

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

Signature ………………………………… Date: …………………………………

Reagan Anguie Bol Lewis

KM112/12078/17

Recommendation

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

Signature ………………………………. Date…………………………………..

Prof. Bockline Omedo Bebe, PhD

Department of Animal Science

Egerton University, Njoro, Kenya

Signature ………………………………. Date………………………………….

Dr. Olivier Kashongwe Basole, PhD

Department of Animal Science

Egerton University, Njoro, Kenya

COPYRIGHT

DEDICATION

This work is dedicated to my wife the love of my life, Mrs. Asunta and my two children in whom I am pleased, Reuben and Ronald for standing with me during the time of my study.

ACKNOWLEDGMENT

First and for most, am thankful to the Lord Jesus for his protection, guidance and keeping me healthy throughout my study. I give him all the glory and honour. My sincere gratitude to Egerton University for offering me the opportunity to further my studies in Livestock Production Systems. The learning environment and experience during both course work and research was encouraging and motivating. I am grateful and giving a lot of thanks to the Center of Excellence in Agriculture and Agribusiness Management (CESAAM) headed by Prof. George Owuor, the center leader for the support and funding of my study. I express my deepest gratitude to my supervisors: Professor Bockline Omedo Bebe and Dr. Olivier Basole Kashongwe from the Department of Animal Sciences, Egerton University, Kenya. For guidance through the entire period of proposal development and preparation of this thesis, it is truly an honour to me. Thank you for all the advice, ideas, moral support and patience in guiding me through this project. Thank you for your enthusiasm for the study of livestock production systems. Your wealth of knowledge in the field in particular is inspiring. Thank you for giving me the opportunity to grow in this field of research. Finally, this project would never have been possible without the support and guidance of various farmers within Nakuru County and their provision for the necessary requirements that I was in need of. Thank you all and may the Almighty God bless you abundantly. I acknowledge the help of colleagues at the department of Animal Sciences, your devotion, unconditional love and support, sense of humor, patience, optimism and advice was more valuable than you could ever imagine.

ABSTRACT

Foot and Mouth Disease (FMD) is a contagious viral disease to which dairy cattle are highly susceptible. An outbreak of FMD in a dairy herd can cause drop in milk yield, increase mastitis infections, force culling, and impair fertility. These production losses can be substantial, but farmers undervalue the magnitude of the loss that they incur. To fill this knowledge gap, the study quantified the association of FMD outbreak with milk yield, mastitis incidences, culling rates and fertility impairments. Data was collected retrospectively from three large-scale dairy farms with a recent history (2008 to 2018) of FMD outbreaks in a region endemic for prevalence of serotype C of the FMD virus since mid-1980s in Nakuru County, Kenya. Records for a total of 507 cows were obtained from three farms for three consecutive periods of six weeks before, during and after FMD outbreaks. Data analysis used general linear model fitting the period of disease outbreak (six weeks before, during and after), farm and breed to explain change in milk production at the herd level. Logistic regression was used for cases of mastitis, culling and fertility impairments, in the three periods of FMD outbreak. The odds ratio was also used to compare between the three phases of FMD outbreaks (before, during, after). Relative to the period before and after FMD, production losses were marked during the outbreak. Disease outbreak was associated with up to 4.7% of the cows drying off (n=24) and milk production (111,466.52 ± 2201.21 Kg) dropped by 16.1% (93,476.32 ± 2181.65). The incidences of mastitis increased from 5.4% to 21.5% (Odd ratio=3.31, Confidence interval =2.27, 4.83) and culling rates increased from 0.59% to 3.8% (OR = 6.71, CI =1.99, 22.58). Incidences of abortion during FMD increased by 1.99% (OR=6.33, CI =2.34, 17.13) compared to the period prior FMD outbreak, retained placenta during FMD increased by 3.03 (OR=7.29, CI=0.88, 59.9) but conception failures marginally declined from 0.39% to 0.21% during FMD. The results suggest that FMD outbreak leads to substantial production losses: Milk production drops substantially and the recovery after the outbreak is slow. Mastitis incidences during FMD increased by 16.1% compared to the period before FMD. While both voluntary and involuntary cow exits increased 3.17% during the outbreak with comparison to the period prior FMD. Fertility is impaired while conception failure was increased the post outbreak period.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS AND ACRONYMS

AWMY	Average weekly milk yield
CI	Confidence interval
ELISA	Enzyme-linked immune sorbent assay
FMD	Foot and mouth disease
FMDV	Foot and mouth disease virus
FAO	Food and Agriculture Organization
KES	Kenyan Shillings
MY	Milk yield
OIE	Office international des epizooties
OR	Odds ratio
UK	United Kingdom
US	United States
USD	United States Dollar
SAS	Statistical Analysis System
SE	Standard error
SAT	South Africa Territories

CHAPTER ONE

INTRODUCTION

1.1 Background information

Foot and Mouth Disease (FMD) is a contagious viral disease to which cloven-hoofed ruminants such as cattle are susceptible (Pattnaik *et al.,* 2012). In cattle, initial signs are fever, dullness, anorexia and drop in milk yield production. These signs are always followed by excessive salivation and drooling, serious nasal discharge, kicking of the feet or lameness and vesicle on the lips and tongues (Rout *et al.*, 2012). The presence of FMD has been studied since sixteenth century in many countries. The disease has a negative impact on livestock productivity in countries where it is endemic (dos Santos *et al*., 2017).

Four serotypes of FMD virus (O, A, C, SAT1, SAT2) are endemic in Kenya (Brito *et al*., 2017), but prevalence of serotype C since mid-1980s has been geographically limited to two counties in the central Rift Valley: Baringo and Nakuru (Lyons *et al.*, 2015a). In Kenya, the outbreak of FMD in four commercial dairy farms in 1999, led to a range of direct and indirect impacts with estimated losses for the four farms of about 468,000 USD (Lyons *et al.,* 2015b). The last outbreak reported in Nakuru County affecting large dairy herds was in 2018 (Chaters *et al*., 2018) and the recurrence of these outbreaks despite vaccination programs is a concern in Kenya's dairy sector. This is even more impactful because the county is a home to prominent large commercial dairy farms. The differences between smallholders and large scale farms the two dairy systems are the sizes of operation, level of management within the farms and use of inputs. The feeding mainly in the smallhoder from forage and very small quantities of concentrate, but some smallholder dairy farmers are highly commercial and well versed in dairy production, with high-quality management (FAO, 2011).

Foot and mouth disease can spread within the same farm or from one farm to other farms through several means: direct contact during sharing one grazing unit or through sharing the equipment and indirect contact via animal products (Paton *et al*., 2018). Introduction of FMD virus into the region that is free from FMD cannot be prevented fully, therefore it is important to detect introduction of virus as soon as possible and take appropriate measures before the virus has spread to other herds (Hayama *et al*., 2012).

The severity of clinical FMD varies greatly depending on virus strain and animal species, as well as the previous exposures or vaccination history of the animal (Stenfeld *et al.*, 2016). The impact of reduced productivity of animals can be prolonged more than one month, and FMD can have lasting effect on herd output in a number of ways including impaired fertility leading to reproductive inefficiency and a reduction in herd size and profitability (Jibat *et al.*, 2013). The duration of FMD outbreak is generally three weeks to one month, during this period, production losses are variable, depending on the genetics, management of the livestock, and the systems inputs and outputs. In dairy cattle, the disease has associated production losses related to drop in milk yield, culling, calf mortality, impaired fertility or increased susceptibility to mastitis (Truong, 2018). Production losses can be due to death of young animals, and abortion in advanced stage of pregnancy and reduced quality and quantity of meat, loss or reduced efficiency of production, which lowers herd income (Forbes *et al.*, 2016).

The direct cost that is related to FMD can be: reduction in milk production, death of calves and voluntary culling. Additional indirect cost in FMD outbreak relate to sanitary measures and diagnosis of the disease. The diagnosis of FMD must be carried out at specialized laboratories. Laboratory diagnosis is usually made by ELISA detection on specific FMD antigens in epithelial tissue suspensions, often accompanied by concurrent cell culture isolation (Laanen *et al.*, 2014). The outbreak of FMD attracts trade bans (Hayama *et al.*, 2012).The annual global impact of FMD previously has been estimated at 11 billion USD (Pendell *et al.*, 2007). Moreover FMD outbreak has implications on the food nutrition and income security of the farming households and consumers as well with the threat of food supplies, security and safety (Stenfeld *et al.*, 2016).

Several researches have studied the impact of FMD on production losses in Nakuru County. Lyons *et al.* (2015), used multivariable model, to study influence of FMD on mastitis, culling in large scale farms and reported that mastitis was significantly greater than 1.0 one month after the beginning of FMD and cattle were culled during 12 months of DMD. Kimani *et al.* (2005) studied the financial impact assessment of FMD in four large scale farms used benefit cost analysis and reported 479105.75 USD losses in four farms. The current study was based on state main hypothesis. The methodological approaches included general linear model and logistic regression which aimed at providing quantitative estimates of production losses associated with FMD outbreaks in large scale farms.

In Kenya, dairy production is an important economic activity, contributing to household security in food, nutrition, and income and soil fertility. In commercial dairy herds, an outbreak of FMD may mean a collapse of the enterprise because of substantial direct and indirect production losses incurred. However, farmers are likely to under estimate the extent of the loss and this could lead to ineffective health response interventions.

1.2 Statement of the problem

The outbreaks of FMD in an endemic region can be annually recurrent with substantial production losses. In the event of an outbreak in large commercial dairy herd, the farmer incurs substantial production and economic losses related to drop in milk yield, forced culling, calf mortality, impaired fertility or increased mastitis incidences. The extent of the production loss is variable between farms, being a factor of herd health management interventions being implemented. However, farmers underestimate the extent of production loss and are likely unaware that the difference magnitude of the loss between the three phases: period before, during and soon after the disease outbreak. Knowledge of the extent of loss during these phases can inform targeted management interventions to reduce production losses from FMD outbreaks.

1.3 Objectives

1.3.1 Broad objective

The overall objective of the study was to contribute to reduction in production losses from FMD outbreaks in large scale dairy farms through estimation of production losses to inform implementation of bio-security measures in the three phase period of before, during and soon after the disease outbreak.

1.3.2 Specific objectives

i. To quantify herd milk production before, during and after FMD outbreak.
ii. To quantify herd incidences of mastitis cases before, during and after FMD outbreak.
iii. To quantify herd culling rates before, during and after FMD outbreak.

iv. To quantify herd fertility impairment cases before, during and after FMD outbreak.

1.4 Research questions

i. Was the herd milk production before, during and after FMD outbreak significantly different?
ii. Were the herd incidences of mastitis cases before, during and after FMD outbreak significantly different?
iii. Were the herd culling rates before, during and after FMD outbreak significantly different?
iv. Were the herd fertility impairments cases before, during and after FMD outbreak significantly different?

1.5 Justification

The study provided empirical evidence on the quantification and effects of foot and mouth disease outbreaks in large scale dairy farms on milk production, mastitis incidences, culling rates, calf mortality as well as infertility. Knowing the present status of FMD outbreak, and its effects on production will inform targeted interventions to prevent and reduce effects of FMD outbreaks, improve production performance and system recovery after outbreaks which will lead to reduction in economic losses and increase income in large scale dairy farms.

CHAPTER TWO

LITERATURE REVIEW

2.1 Epidemiological of Foot and Mouth Disease

The respiratory system is the main route of FMD infection. During the transmission of the virus with the help of blood and lymphatic the virus multiplies in mucous membrane of pharynx it multiplies to secondary multiplication sites such as: mouth, feet and mammary glands (Chang *et al*., 2013). In the bod fluids like; semen, urine, respiratory tract secretions and milk before the appearance of clinical in the animal, are where FMD is virus is found, the FMD virus can remain in the oral cavity of the animal that is infected for a long period of time, it can be more than three weeks (Rashid *et al*., 2020). In spite the major advances in our understanding of pathogenesis of the virus and the dramatic changes in vaccine development technology that are brought about by most of the intimate secrets enlightenment of how do the viruses interact with their host cells, FMD virus remains a major threat to the most sophisticated economies of the world (Nogueria *et al*., 2011).

The combined threats of free trade and bio-terrorism have shown how vulnerable the agricultural industries of North America and Europe are to attack by one of the smallest living organisms; an attack against which the defenses are little better than they were 50 years ago (Nogueria *et al*., 2011). It has been proposed in the past that the best protection for the developed countries that are free of FMD would be to eradicate the virus from countries in which it is endemic, but the events of the last few years clearly show that FMD is in the ascendency, and is far from dead. The Food and Agriculture Organization (FAO) is to make FMD its next target for global eradication, following its not yet fully successful eradication of rinderpest (Nampanya *et al*., 2012). But compared with rinderpest that is caused by a single virus serotype, against which there is a very effective vaccine that provides virtual lifelong immunity after a single inoculation, that does not produce persistent infection and that has a very limited host range, any program to eradicate FMD will certainly fail (Pattnaik *et al*., 2012). The tools are not yet available for such a task. The best that can be expected with current resources would be an attempt to bring the disease under control in as many of the endemic countries of the world as can sustain the recurrent cost of vaccine and the imposition of rigid animal movement restrictions (Rout *et al*., 2012). This is an unlikely proposition in those countries which see little economic benefit for such cost. Furthermore, until the consequences of the epidemiological differences between rinderpest and FMD are reduced by the development of a better vaccine or a cheap virucidal drug, FMD will remain a significant threat for the foreseeable future (LeBlanc *et al*., 2006). It is unwise to consider FMD as a single disease which always behaves in a pre-determined manner, and to do so can be an economically and socially expensive mistake (Nyaguthii *et al*., 2019). It was discovered by the British government when it chose to follow the advice of the modelers to bring the 2001 outbreak of FMD under control by slaughtering large numbers of animals (Nampanya *et al*., 2012). Which, because of the particular nature of the Pan Asia strain causing the outbreak, were never likely to have been exposed (Rafati *et al*., 2010). The models used at the start of the outbreak made no allowance for the differences between this strain and those on which they had been based, even though (Sarker *et al.,* 2011. The evident from the Pan Asia outbreaks in Japan and South Korea the previous year, and from the limited spread from the index case in the UK, that this virus was epidemiologically distinct (Soria *et al*., 2018). Foot and mouth disease is seven separate diseases, each serotype there is a spectrum of strains with their own antigenic and epidemiological characteristics, which make it impossible to generalize about what to expect in an outbreak (Laanen *et al*., 2014). Some of biosecurity measures in Europe ineffectiveness has been proved, like disinfecting farms, vehicles, and tools wasn't effective because the low temperature let disinfectants freeze (Brito *et al*., 2017). The hygiene status of livestock farms remained poor and animal disease could spread widely and rapidly.

2.2 Effects of Foot and Mouth Disease on milk yield

Foot and mouth disease (FMD) can cause severe losses in weight and milk production in dairy cattle, even though most adult livestock are able to recover clinically in a period of two to three weeks, but re-establishment of the production level prior to FMD onset may require longer period of time to regain the production losses (Garforth *et al.,* 2013).

Frequent outbreak of infectious disease hampers productivity in most of dairy cattle production systems in Kenya, this disease result in reduction in milk production (Onono *et al.,* 2013). Milk loss is due to acute food and mouth disease, and the loss in milk production is for two reasons: when a lactating cow is affected with the disease and the milk yield decreases or stops during the illness (Lyons *et al.,* 2015), secondly when the lactating cow dries off because of the loss of her calf (Jemberu *et al.,* 2014). Furthermore, the sick lactating animals show vesicular lesions in the cleft of feet and on teats. The vesicles soon rupture to ulcerative lesions. Followed by a significant reduction in milk production (Hassan, 2016).

A study conducted to evaluate the effect of FMD on milk yield at Andassa Government dairy farm in Ethiopia showed that the average milk yield 10 days ahead of FMD infection was found significantly higher than that of 10 days after the infection (Depa *et al.,* 2012). Foot-and mouth disease in Ethiopia is endemic, having national economic impact due to the costs of management, the annual costs were assessed based on the production losses, export losses and control costs. The total annual cost under the current status quo of no official control program were estimated 47,852,391.00 USD (Jemberu *et al.,* 2016), while in the previous outbreak of FMD in 2001 in the United Kingdom (UK) in 2001 the estimated cost was 9 billion USD. Estimation of the milk loss due to an FMD outbreak is an important step for evaluation of its economic impact. It has been suggested that the impact of foot and mouth disease is not equal across all countries and livestock population due to different genetics of animals as well as management practices (Ansari-Lari *et al*., 2017). Recently FMD had become the major constraint hampering export of livestock and its products to the Middle East and African countries. For instance, the Egyptian trade ban export of live animal livestock products from Ethiopia after the series of FMD outbreaks in Ethiopia, in which Ethiopia can lose in terms of money (Mazengia *et al*., 2010).

Direct losses from FMD are estimated at fourteen million united state dollars annually (Leforban, 2005). Such losses and the strict requirements of international trade warn Ethiopia to control the disease. Foot-and mouth disease is considered as the most important livestock disease in the world in terms of its of economic impact (Jemberu *et al.,* 2014). The annual cost worldwide that is estimated for vaccination of FMD outbreaks is 0.4-3 USD. Occasionally 9 USD per dose including delivery and application (Knight-Jones and Rushton, 2013), FMD causes restrictions concerning cattle trade as well as the livestock products among the affected or the endemic countries because it is a trans-boundary animal disease which spreads easily and fast (Alemayehu *et al.,* 2014).

Previous experiments have shown that the mammary gland is an organ that is highly susceptible to FMD virus, and that the FMD virus can be detected in milk before the appearance of clinical sings. Therefore, milk represents a potentially valuable sample source for FMDV detection and surveillance, after FMD outbreak (Armson *et al*., 2018). Reduction in milk production is not caused by FMD directly, but through the complications caused by FMD, for example lameness is the direct impact of FMD which causes reduction in milk yield. During lameness, the cow suffers a serve pain that is caused by the sores on the feet which makes it difficult for the animal to access feeds. However, the evidence for the impact of lameness on milk yield is highly influential on estimates of economic loss from clinical lameness (Green *et al*., 2002).

2.3 Influence of Foot and Mouth Disease on Mastitis incidences

In developed countries, mastitis is considered as the most economically important disease in dairy (Musser *et al.*, 2004). Parasitic infection is the major cause of mastitis, during FMD the animal can experience, lesions on the teats caused by FMD, which exposed the dairy animals to secondary bacterial infection leading to mastitis (Sharma *et al*., 2016). Although mastitis is an animal welfare problem, but also is considered as food safety problem. Mastitis is characterized by physical, chemical and bacteriological changes that occur in the glandular tissue of the infected udder (Sharma *et al*., 2011). Mastitis is a complex disease, mainly caused by a variety of pathogens that inter the wounds caused by FMD lesions, with substantial differences in infection patterns (Jingar *et al*., 2014).

Mastitis is usually caused by bacterial pathogens which can be classified into two groups; the contagious pathogens including *Streptococcus agalactiae, Staphylococcus aureus and Mycoplasma bovis* which reside predominantly in the udder and spread during milking (Moris *et al*.,2000). The environmental pathogens including *Streptococcus species (Streptoco -ccus uberis and Streptococcus dysgalactiae)* and environmental coliforms (Gram negative bacteria *Escherichia coli, Klebsiella spp., Citrobacter spp., Enterobacter spp., Enterobacter faecalis* and *Enterobacter faecium*; and other gram negative bacteria such as *Serratia, Pseudomonas and Proteus*) (Reshi *et al*., 2015). The mammary gland is protected by innate and specific immune responses however; abnormal environmental and physiological factors could compromise the defense mechanism of the mammary gland (Sharma *et al*., 2010).

Mastitis represents a serious potential constraint to further the development of dairy production in developing countries and might drive rural smallholders into chronic poverty or starvation (Abrahmsén *et al*., 2014). Mastitis classification whether is clinical or subclinical depending on the visibility of effects of inflammation of the mammary gland. Subclinical mastitis does not produce visible effects on udder or milk quality; rather it has effects on milk composition mainly an increase in somatic cell count (Romero *et al*., 2018). Mastitis is one of the most widespread and common diseases, is characterized as an endemic disease affecting dairy herds worldwide (Reshi *et al*., 2015). Mastitis is considered as a major cause of morbidity among smallholders in Eastern and southern Africa region. Farm profitability is affected or reduced through the decrease in milk production, due to FMD infection (Nicholas *et al.,* 2015). The animal is likely to contact viral infection and replication within the udder and teat lesion, leading to clinical and sub-clinical mastitis. Mastitis affects the milk quality and quantity causing economic loss for the farmers (Halasa *et al.,* 2009).

Foot-and mouth disease virus has the ability to live in the tissue for 3-7 weeks, during these weeks' vesicles may occur on the teats and when the teats orifice is involved, severe mastitis often follows (Nampanya *et al.*, 2012). During Mastitis incidence there is physical changes in which the milk color changes because of the presence of blood in milk, there is also chemical and bacteriological changes in milk causing an undesired milk odor. The development of pathological and inflammatory changes in the parenchyma and glandular tissue of mammary gland is due to Mastitis. In India mastitis stands as the second most challenging disease after FMD, due to the lost in milk production (Neelesh *et al.*, 2008).

2.4 The effects of Foot and Mouth Disease on cow culling

Culling is a removal of the animal from the herd, due to any disease or death. Cows also can be defined as culled if the observed or recorded reason was low milk production (Lyons *et al.,* 2015a). Culling is a complex issue, and many factors are involved. Dairy cows may be culled for either involuntary reason such as death, acute disease, infertility and low milk yield. Both biology and management affect the decision to cull, when making a decision, the dairy farmer should consider five major reasons: illness, low yield, conception failure and stage of lactation (Elnekave *et al.,* 2016). There are more than eight diseases which are clinically identifiable of economic importance to the dairy industry that can lead to the culling in the farm: milk fever, retained placenta, metritis, ketosis, left displaced abomasum, cystic ovarian disease, lameness, clinical mastitis and foot and mouth disease (Kelton *et al.,* 1998).

Foot and mouth disease outbreaks occurred in Taiwan in the past years, nearly seventy years after the disease was eradicated in 1930, during the outbreak animals on more than 6,000 farms was infected followed by slaughter of four millions animals, and the financial cost due to the slaughter was estimated at 379 USD million (Carpenter *et al.,* 2011). Another study that was done in Nakuru by Kimani *et al*. (2005), where he assessed the financial impact of foot and mouth disease in four large scale farms and the estimated losses of FMD was 479105.75 USD, the major losses were the death of animals.

The daily risk of culling within parity is typically greater in early lactation, and then increases again later in lactation. Hazard functions for different parities and survival curves for remaining productive life, defines as the time from calving to culling, per parity are scarce but would provide further insight into when cows leave the herd (Vries*et al.,* 2010). Mastitis is an economic important disease in dairy herds, and is also reported as a major cause or reduction in milk production, increase in milk discard, treatment costs and associated culling (Elnekave*et al.,* 2015). Postpartum uterine diseases, metritis are common in dairy cows causing infertility leading to conception failure, causing the animal to be culled (Dubuc *et al.,* 2011).

Once a virus develops into an epidemic, the consequences for dairy cattle and livestock industry can be deeply affected (Golde *et al.,* 2005). When the disease is first detected on the farm after a period of "silent spread", according to the EU regulations demand the culling of detected farm (Gunn *et al.,* 2008; Dukpa *et al.,* 2011).

Foot and mouth disease induces the risk of Myocarditis especially in calves younger than six months (Aktas *et al.,* 2015), Mycocarditis is considered fatal form of FMD that occurs without vesiculation in young animals (Gulbahar *et al.,* 2007).

2.5 Impact of Foot and Mouth Disease on dairy cow's fertility

The effects of FMD on fertility performance are categorized as an invisible loss and is difficult to measure, particularly in the less intensive system where FMD is endemic (Chaters *et al.,* 2018). During the outbreak of FMD its effects can include: irregularity of oestrus in cattle (not seasonal), therefore extending calving interval, increase of abortion rate (Şentürk *et al.,* 2008).

2.5.1 Abortion

Abortion is the termination of pregnancy at a stage where the expelled fetus is of recognizable size ranging from 45 to 260 days of gestation and not viable (Sarder *et al*., 2010). Abortion is also defined as a condition in which fetus is delivered live or dead before reaching the stage of viability where the delivered fetus is visible by naked eyes. Some diseases that cause abortion in cattle, such as FMD, brucellosis, Leptospirosis are also zoonotic (Levett, 2005; De Vries, 2006). The important infectious agents that have been reported to cause abortion in cattle can be viral, bacterial, protozoa as well as several fungal species among others (Dos Santos *et al*., 2017). In addition, any disease causing high fever may also cause abortion like FMD (Radostits *et al.*, 2007). Several causative factors, including external, maternal and genetic factors, have been reported for abortion in dairy cattle (Elnekave *et al*., 2015). These include heat stress, season, milk production, cow parity, serum progesterone level after conception, the inseminating bull, twin pregnancy and the herd (Lee and Kim, 2007). However, other investigations have reported that milk production and cow parity were not associated with abortion (Moore *et al*., 2005). Parity status and breed were significant factors affecting the incidence of abortion (Yakubu *et al*., 2015). However, Haileselassie *et al*. (2011) reported that parity status had no significant effect on the incidence of abortion. Factors that have been reported to increase the risk of abortion in dairy cattle herds include: being a heifer; being a cow of more than 10 years old; feeding on communal pastures; lack of vaccination against abortifacient diseases, hygiene, animal management and reproductive problems such as retained placentae, dystocia, uterine prolapse and stillbirth in the previous pregnancies (Waldner and Garcia, 2013; Waldner, 2014). Risk factors such as environmental (nutrition, temperature extremes and toxins, among others), management (crowding and use of natural mating), geographical factors and infectious factors, with infections contributing up to 90% of the abortions also reported (Konnai *et al*., 2008; Mekonen *et al*., 2010). Environmental high temperature may affect inside-pens temperature and performance of dairy cattle. Omori *et al*. (2014) reported that hyperthermia during pregnancy causes abortion in dairy cattle.

Normal annual abortion rate was cited to be 3 to 5% once cows are above 42 days of pregnancy (Hovingh, 2009), or similarly, an observable 2 to 5% in most dairies (Kirk, 2003). While some suggest the annual abortion rate should be less than 3% in dairy, others believe this is not typical (Gaafar *et al*., 2010). This difference may arise from the fact that many abortions may be due to early embryonic death where cows are identified as pregnant and then found to be open without visible signs of an abortion (Forbes *et al*., 2014). As a consequence, many early abortions may go undetected or even dismissed as an unsuccessful insemination rather than a failed pregnancy (Carpenter *et al*., 2006). A low rate of abortions from 2 to 5% per 100 pregnancies per year is usually considered within the expected rate as sporadic abortions occur in any herd. However, occurrence of several abortions in a short period or high rate of abortions warrants investigation to detect the cause and take control measures (Esheti and Moges, 2014; Al Humam, 2014). Abortions in dairy cattle due to foot and mouth disease cause a significant loss in production, especially those occurring during late gestation. The cost of abortion varies according to effective factors as the time of gestation, milk production, days in milk, the time of insemination after parturition and the cost of nutrition which differ from farm to farm (Rafati *et al*., 2010).

Abortion in dairy is defined as a loss of the fetus between the age of 42 days and approximately 260 days (Hossein *et al*., 2013). The reported cost of abortions to a producer range from 90 to 1,900 USD (Ponsar t*et al.,* 2014). The abortion can occur due to foot and mouth disease virus transmission from the dam to the embryo through vertical transmission, in cattle, transplacental transmission has previously been demonstrated for bovine immunodeficiency virus (Ranjan *et al*., 2016). The main cause of abortion is the increase in body temperature which leads to the release of different hormones that change the uterine environment in which the embryo is developing (Hatem and Talal, 2016). The compound effect of fertility problems due to abortion and reduced conception rates is a need to have a greater proportion of breeding animals in a population for a given period. And this is considered one of the problems in the farm that is associated to the direct impact of foot and mouth disease (Knight-Jones *et al*., 2013).

Abortion can occur due to specific disease not necessarily FMD, particularly in the late pregnancies and leads to increased calving index, besides loss of calf. Therefore, is very important to record the reproductive performance of the cow by recording every disease that is related to impaired fertility to know which disease affected the production performance in dairy herd (Singh *et al*., 2014). Pregnancy lost (abortion), is one of the major sources of decreased fertility, and this in turn has an adverse economic effects of the dairy farm. The reported incidences of abortion by Lee and Kim, (2007), showed the pregnancy lost ranged from 0.4 to 10.6%. While the infectious causes of pregnancy lost have been their primary focus. Various factors including external, maternal and genetic factors have been reported in their findings.

2.5.2 Retained placenta

Retention of placenta is the inability of fetal membrane to be expelled from 8 to 48 hours, average 8 hours after parturition. The incidence of retained placenta varies from 4-18% of calving (Tucho *et al.,* 2017). Placental retention is usually accompanied by delayed involution of the uterus and negatively affects reproductive performance. Cows with reproductive disorders have longer intervals from calving to first service and to conception and required more services per conception and lower pregnancy rate (Gaafar *et al*., 2010). Retained placenta occurs because of the immune system is depressed in cows around the time of parturition (Hossein-Zadeh *et al*., 2013). During this period the most important factor causing impairment of the immune system in high yielding cows is per parturient stress caused by hormonal and metabolic fluctuations, especially, a negative energy balance (Hovingh, 2009). Shortage of proteins, minerals and vitamins associated with the demands of a mature fetus, as well as the onset of lactation (Mordak and Stewart, 2015). Retention of fetal membrane (RFM) in dairy cows is a common complication after parturition. The placenta is normally expelled within 8-12 hours following parturition in cows (Tucho *et al*., 2017). When this physiological episode fails to take place within the said period of time, then the condition is considered pathological, the retained fetal membrane is occurred due to failure of the separation of villi of fetal cotyledon from crypts of maternal caruncles (Wathes *et al*., 2012). The incidence retained fetal membrane varies from 4.0% -16.1 % and there are several factors influencing the case of retained fetal membrane which includes gestation length, nutrition, dystocia, age of the animals, abortion, and season of the year (Rabbani *et al*., 2010). In most of the cases, retained fetal membrane usually causes metritis and delayed involution of uterus and consequently affects the reproductive performance rigorously (Mulligan *et al*., 2008). Thus a retained fetal membrane case usually prolongs the resumption of ovarian cyclicity post-partum and having increase time from calving to conception of next calf (Mordak *et al*., 2015). Until now several numbers of therapeutic approaches like manual removal of placenta, administration of intra-uterine and/or systemic antibiotics, injection of oxytocin, PGF2α and β2-receptor blockers and other different protocol have been implicated for removal of the retained fetal membrane but none of them are proved to be fully successful for treatment of RFM. Sylhet is situated in the north east hilly region of Bangladesh and the dairy industry is developing gradually (Kimura *et al*., 2002). Retained fetal membrane is one the important constraints here for efficient reproductive performance in dairy cows, till date, a very few study has been conducted to analyze the factors of retained placenta and their therapeutic management (Kuster *et al*., 2013).

Cattle is an important factor in agricultural operation which provides valuable food of animal origin like milk, meat, milk products; industrial raw materials like skin and manures. Diseases of dairy cattle substantially limit production performances (Muleme *et al*., 2013). Among the reproductive diseases retained placenta is an important reproductive cyclical problem that has repercussions on the next calving. The retained placenta usually causes the cow to delay the next pregnancy for 2-6 months, late calving date in the following year and may result in an open cow next year (Lee *et al*., 2007). In the occurrence of placenta retention, a six-month delay may result in an open cow next year at pregnancy checking time. The tetanus, an important complication of retained placenta, caused by *Clostridium tetani* which can be found in the soil or in the feces and gets into the uterus where it set up an infection resulting lockjaw (Ranjan *et al*., 2016). In dairy cows, retained placenta may be the cause of serious economic losses in the herd due to decreased milk production, illness and treatment cost, beside a decreased market value of the animal (Hossein-Zadeh *et al*., 2013). There are many factors influencing the incidence of retained fetal membranes like abortion, dystocia, multiple birth, poor body condition score, age, nutritional deficiencies, hormonal imbalance (Ponsart *et al*., 2014). Aged cows showed a higher incidence of retained fetal membrane than 4, 5, 6, 7 years old. The number of calving was negatively correlated with the incidence of retained fetal membrane.

2.5.3 Conception failure/repeated insemination

Reproductive performance is crucially important to maintain profitability in the dairy industry. Conception at the first service after calving is the key to optimal reproductive performance in the dairy cows, although the percentage success of first service has been shown to range between 26.7% and 50.7% in previous studies (Kim and Jeong, 2019). Conception failure occurs as a result of so many factors; nutritional deficiencies, diseases or excess social influence which may arise from modern husbandry methods. The grouping of large numbers of cows thus interfering with the establishment of a stable social hierarchy;

and the stress of production (Abraham, 2017). Reproductive failure due to FMD can have multiple causes and animals may not be inseminated because of a failure to ovulate or to detect estrus or because of poor health, low milk yield, poor conformation (Wathes, 2012). The failure of conception in the first service may lead to an increase in the number of days open, repeated insemination, reproductive treatment, culling, feeding and heifers replacement (Ill-Hwa *et al.,* 2018).

The impact of FMD on conception failure is categorized as an invisible loss as the effects are difficult to measure, particularly in the less intensive farming systems where FMD is endemic (Knight-Jones et al., 2016). The conception failure leads to inefficiency in the farming system as more input per unit output is required (Chaters *et al*., 2018). This combined with changes in herd structure results in less animal derived protein and micronutrients available for the individuals and societies depending on these nutritional sources. Foot and Mouth disease impact on fertility performance could be extended incur far greater costs to the industry and livelihoods than previously estimated. It is important that appropriate data are collected on the effects of FMD on fertility so that a robust economic analysis of FMD impact can be performed enabling policy makers to make informed decisions on resource allocation to mitigate disease impact (Knight-Jones and Rushton, 2013).

2.6 Symptoms and lesions of Foot and Mouth Disease

Typical symptoms of FMD include sores on the hoof, mouth, tongue, and teat. Excessive salivation is also observed (Table 1), the consequence is lameness, reduced feed intake and drop in milk production due to insufficient feeding.

Table 1: Typical Foot and Mouth Disease lesions

Lesions	Description
	Sores on the hoof
	Sores on the mouth and tongue
	Sores on the teat
	Excessive salivation

Source: www.agric.wa.gov.au, www.cresa.cat, www.phys.org (23/09/2017)

Foot and mouth disease has impacts felt directly by the production system and others that are indirect and sometimes not immediate. Direct impacts include drop in milk production, calves' mortality and culling resulting from reduced in feed intake due to mouth and tongue lesions. Drop in milk yield may also result from mastitis cases due to teat lesions. Indirect impacts include fertility impairments such as abortion, retained placenta, number of service/ insemination per conception. The most direct economic impact of FMD in endemic countries is the loss or reduced efficiency of production, which lowers farmers' income. The impact of reduced productivity of animals can be prolonged, and diseases can have lasting effects on livestock output in a number of 'hidden' ways such as delays in reproduction leading to fewer offspring, resulting in a reduced livestock population. At the local level, FMD reduces farmers' income and food availability for consumption (Jibat *et al*., 2013)

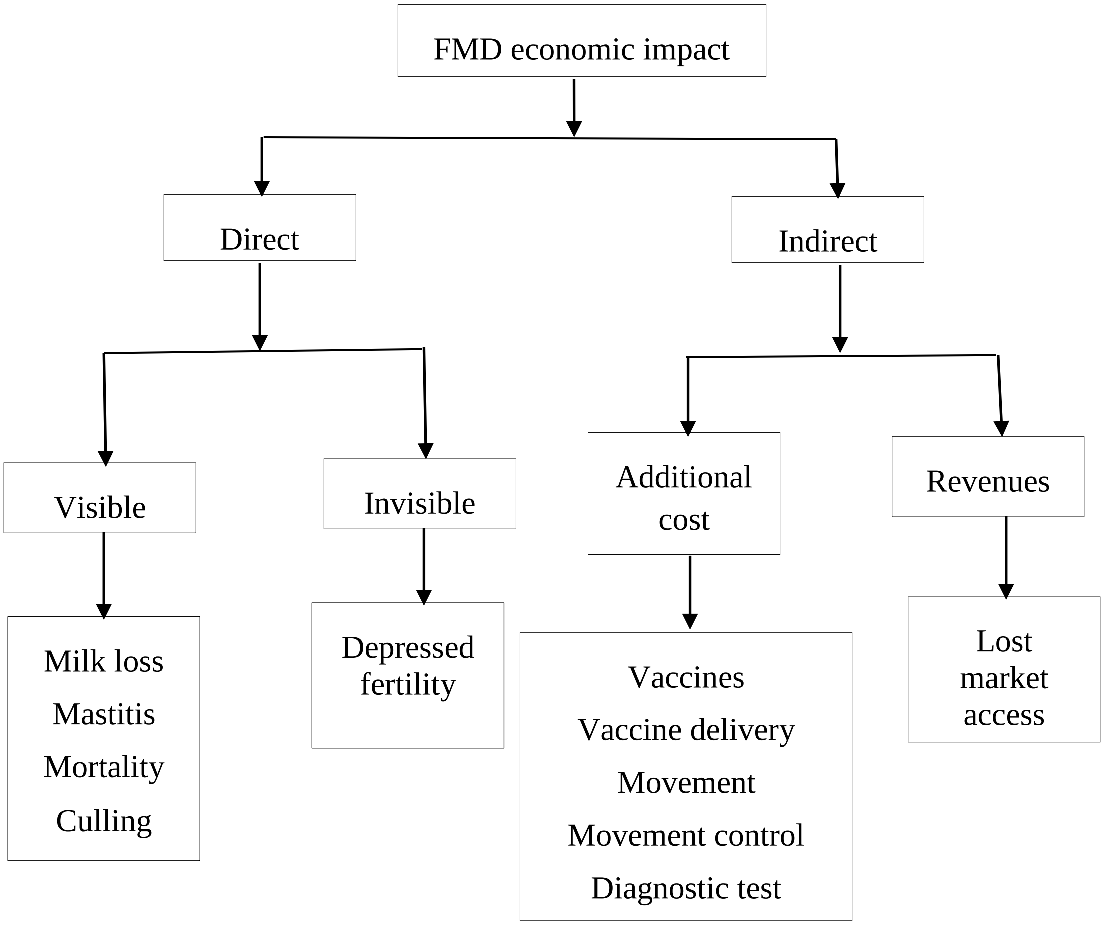


Figure 1: Impact of Foot and Mouth Disease in a large scale dairy farm. Source: (Author conceptualization)

2.7 Study designs of Foot and Mouth Disease

The epidemiological studies are based on particular population followed by a particular period of time, within this framework the most fundamental distinction is between studies of disease ‘incidence’ and studies disease ‘prevalence’. Once this distinction has been drawn, the different epidemiological study designs differ primarily in the manner in which information is drawn from the source population and risk period (Neil, 2012).

A cross sectional study is to obtain a representative sample by taking a cross section of the population and the study is suitable for estimating the prevalence of a behavior or disease in a population. In across sectional study, all the measurements for a sample member are obtained at a single point in time, although recruitment may take place across a longer period of time.

A study done by Lynos *et al.* (2015) in Nakuru county Kenya, the researcher used cross sectional survey to collect data in four dairy commercial farms, where each of the selected farms were visited once to see the effect of foot and mouth disease on mastitis and culling after the outbreak. The farms were selected by simple random sampling techniques. In a longitudinal study, each participant is observed at multiple time points, allowing trends in an outcome to be monitored over time. Longitudinal studies may be prospective or retrospective. Observational study is a process in which researcher observe ongoing behavior and measure or survey members of a sample without imposing an intervention.

2.8 Management of Foot and Mouth Disease outbreaks

A successful management and control programs, such as mass vaccination and willingness of farming community participation in the implementation of the control programs and their motivation to implement a specific disease control measures (Rodriguez *et al*., 2011). Not only that alone but the effectiveness of farming technologies, including that of livestock disease control, are known to be important of the eventual technology uptake, farmer's adaption for specific livestock control measures or their participation national animal disease control have a significant change in the farming system (Jemberu *et al*., 2015). Farmers' perception has an influence with regards to disease control and prevention in their farms. Economic impacts of FMD in these production systems, cattle farmers could have different perceptions about the disease risk and, therefore, different intentions towards the uptake of control measures (Shortall *et al*., 2017). Understanding farmers' perceptions of FMD and its control in the different production systems and their intentions to apply control measures (Probert *et al*., 2016). Therefore, important in designing a national FMD control promotion program that insures the comprehensive participation of all cattle farmers. Currently this understanding is seriously lacking (Rout *et al*., 2012).

The major goal of livestock protection is the enhancement of animal welfare and animal health through prevention of disease, with the less use of synthetic chemicals. Health and welfare may be among the distinctive of a more nature-friendly production (Valle *et al*., 2007). Preparedness for infectious disease outbreaks such as FMD can be greatly enhanced by the availability of models that can predict the transmission of pathogens and assess the potential effectiveness of control measures. Quantitative information on the transmission dynamics of FMD is essential in order to make right decisions about its control. Despite the occurrences of FMD outbreaks every year, its transmission dynamics have not been properly quantified before (Tadesse *et al*., 2019). The reliability of such models depends upon the epidemiologic parameters for the disease, as well as a strong understanding of the transmission dynamics in susceptible populations and the effect of intervention strategies on preventing disease spread (Artz *et al*., 2019).

Antibiotic treatment of dairy cows for infectious diseases is a relatively common and necessary occurrence. While the usage of antimicrobials has been estimated in the United States of America population-based survey. It is very difficult to measure antimicrobial usage on farms, because of the difficulty of obtaining an accurate assessment of dosage and duration of treatment (Zwald *et al*., 2004). To gain access to the international markets, the dairy industry should meet the international standards together with the traceability and safety aspects of the production system and environmental impact. Meanwhile animal welfare is increasingly becoming an issue in international policy and business operations (Costa *et al*., 2013).

Livestock movement is among the main contributing factor to the disease outbreaks. Notably epidemics of high economic consequence, such as foot and mouth disease, have been facilitated by high rates of livestock movement. Animal traceability is the key to understand the infectious disease outbreaks, and many countries in our modern days require all movements of cattle between premises to be registered (Vander Waal *et al*., 2016). It is becoming increasingly evident that there is a need to re-ordinate the dairy farmers towards prevention rather than cure medicine by implementing the best practice of farm management (Sayers *et al*., 2014). Cattle herds can be protected from various diseases through application of biosecurity measures to minimize the risk of disease infection (Mughini *et al*., 2014). Metrics of FMD management are not all positively correlated, for instance FMD management approach where susceptible animals are culled in a wide area surrounding a confirmed case, may be highly effective in reducing outbreak duration (Probert *et al*., 2016). Foot and Mouth Disease control program requires updating the state of knowledge on the disease epidemiology, including evaluating potential risk factors that are likely to modify the disease incidence, so that appropriate measures can be designed and implemented (Yahya *et al*., 2013).

Kenya is currently in stage 1, which involves collecting information "to gain an understanding of the epidemiology of FMD in the country and develop a risk-based approach to reduce the impact of FMD. A control strategy has been developed but has not been fully implemented and is undergoing revision in line with the devolution of veterinary authority to the County level (Nyanguthii *et al*., 2019).

2.9 Biosecurity measures of Foot and Mouth Disease

Biosecurity refers to all hygienic practices designed to prevent occurrences of infectious diseases. This includes preventing introduction of infectious agents, controlling their spread within populations or facilities and containment or disinfection of infectious materials (Morley, 2002). Bio-security defined as a series of measures aiming to stop disease causing agents entering or leaving an area where farm animals are present (Shortall *et al*., 2017). In livestock sciences the term bio-security is used to describe all measures implemented to protect animals from infectious diseases. In addition to official actions (e.g. mandatory, vaccination, import restrictions), numerous on-farm bio-security measures also contribute to safeguarding livestock health (Kuster, 2013).

The control and possible eventual eradication of diseases is a major challenge for many countries (Nampanya *et al*., 2012). Foot-and mouth disease outbreak can be controlled by three methods: stamping out (slaughter of all the infected animals), routine vaccination disinfection, quarantines, emergency vaccination applied during outbreaks and routine annual vaccination of all Livestock (Elnekave *et al*., 2015). Beside vaccination of animals at entry points should be enforced especially before high risk seasons for example toward the draught period, regular surveillance of all animal species (at least once in a year) to ascertain the type of FMD virus in animal population (Muleme *et al*., 2013).

Restriction use of bio-security measures for animals, animal's products, vehicles, people and equipment, also observation and report any sign of the disease. The access to the farm should be limited by having only one gated entrance to the animal's area to better control and monitor all visitors and vehicles arriving at the farm. The gate should be kept closed when not in use, moreover bio-security measures should be taken for farm employee (Heffernan *et al*., 2008).

Bio-security is very important since it embraces all measures preventing pathogens from entering a farm and reducing spread of pathogens within a farm, it involves bio-exclusion, bio-containment and bio-management (Laanen *et al*., 2014) . Inadequate attention to the implementation of bio-security could lead to a negative impact on animal health, with attendant economical loss. Therefore bio-security is the management systems implemented to reduce the risk of introducing infectious disease to the herd (Sayers *et al*., 2013). Sustainability of the system after the disease outbreaks depends on the maintenance of production level after the outbreak and also on how much inputs are invested in the farm. Two factors are important for the system to be stable: sustainability and resiliency (Duru *et al*., 2015).

2.10 System analysis of Foot and Mouth Disease outbreaks in dairy farms

System analysis is the process of gathering and interpreting the facts, identifying problems, and decomposition of a system into its components. The management and the system task in agriculture is shifting to a new paradigm, whereby requiring more attention on the interaction with the surrounding (environment, terms of delivery and documentation of quality and growing conditions) (Sørensen *et al*., 2010). The disease outbreaks usher significant changes in cattle farming practices which include: herd size, breeds/pedigree of animals, and type of farming system (from pasture-based to house) and such modifications would have impact on animal health (Lawrence *et al*., 2013). The biggest advance in the dairy industry in the last twenty years has been the shift from the treatment of clinical illness to disease prevention. Shifts in philosophy, key assumptions, and priorities underline the specific advances in science and technology. The advancement has been recognition of the multifactorial nature of almost all diseases of importance in dairy cattle (LeBlanc *et al*., 2006). Epidemiology has been a critical new influence and tool to describe and quantify the interconnected risk factors that produce disease. In turn, health management or production medicine is characterized by an integrated, holistic, proactive, databased, and economically framed approach to prevention of disease and enhancement of performance (Derks *et al*., 2013). Health management has been defined as the promotion of health, improvement of productivity, and prevention of disease in animals within the economic framework of the owner and industry, while recognizing animal welfare, food safety, public health, and environmental sustainability (Backer *et al*., 2012). Accordingly, disease prevention, considered broadly, is no longer the sole domain of veterinarians. Conversely, to deliver health management and effective disease prevention veterinarians must integrate consideration of nutrition, housing, and whole farm management systems into recommendations of best practices.

Effective animal disease control is crucial to the development of the optimal contribution of livestock to the economies of the nations. The region is affected by many diseases that constrain the productivity of different livestock species (Artz *et al*., 2019), and these include haemorrhagic septicaemia *(Pasteurella multocida* infection), gastro-intestinal parasitism, *Trypanosoma evansi* infection, and foot and mouth disease (FMD), among many others. Much discussion has focused on the identification of the priorities for disease control, as different diseases, and different control options for these diseases, have varying impacts which can be felt at different levels (Baluka *et al*., 2016). For example, crucial to the enhancement of trade within and outside the region is improved control of highly infectious diseases, and in this category, FMD is considered as the top priority (Kuster *et al*., 2013). At the same time, crucial to the development of smallholder crop-livestock production systems is the improved control of endemic parasitic diseases and haemorrhagic septicaemia. In common to both categories of diseases is the need to improve the delivery of livestock services, through both private and public sector contributions (Mughini-Gras *et al*., 2014).

Animal diseases are the major threats in the agricultural industry, some of them are endemic and others are characterized by specific outbreaks with new diseases arriving from trade and climate change. The impact ranges from the small setback in the production system to a devastating infection leading to widespread culling and every disease contracted affects farmers' income (Garforth *et al*., 2013). Identification, description and quantification of the components of a disease cycle are foundational for the disease epidemiology and efficient disease management (Costa *et al*., 2013). Without this information, management efforts may not be targeted appropriately or efficiently. When there is sufficient understanding on how biological and environmental factors interact to drive disease outbreaks, then the prediction of the behavior of a system and the need of intervention can be made with some hope of success (Gent *et al*., 2013).

Foot and Mouth disease, probably is the most important disease in livestock industry in terms of economic importance because it is accompanied with restrictions on the trade of animals both internationally and locally (James *et al*., 2002). Foot and Mouth Disease production losses have a big impact on the developing countries, where majority are depending on livestock and its products for income and food (Knight-Jones *et al*., 2013). In Europe where there is a policy of no vaccination of FMD, but rather if there is an outbreak of FMD a stamp out policy is applied by slaughtering all the affected animals, the cost of culling as well as the economic loss is high (Orsel *et al*., 2007). The economic impacts of the incidences of FMD differ substantially from farm to farm, and also the optimum management strategy may differ depending upon where the disease might occur (Pendell *et al*., 2007). To understand the aspect of economic impact of the disease will then enable decision makers to help reduce that the costs associated with disease mitigation (Carpenter *et al*., 2011). In the recent years, FMD outbreaks have been described in several previously free countries including United Kingdom and others, these descriptions and subsequent risk factors have primarily focused on farm to farm level transmission, since control policies have restricted animal movement (Lyons *et al*., 2014). The Office International des Epizooties (OIE) has taken the initiative to promote the improved control of FMD within the region, and in late 1997 established a Regional Coordination Unit (RCU) to provide support for these activities, based in Bangkok, Thailand (Rodriguez *et al*., 2011). The OIE-coordinated programme has initial funding from the Governments of Australia, Japan and Switzerland, but this funding does not support the control operations themselves. As part of the initial phase of a proposed twelve-year eradication programme, a pilot study of the economic impact of FMD in the region has been embarked upon, with funding provided by the Government of Switzerland. One of the key roles of an economic impact assessment is to explore the effect of FMD control and eradication on different countries and production systems, in order to provide a sound scientific basis and justification for requests for future funding of the programme (Paton *et al*., 2018).

2.11 Analytical approaches of Foot and Mouth Disease

The incidence rate will be calculated by dividing the number of new cases before, during and after the FMD outbreaks to the population and multiplying the result by hundred (Mazengia *et al.*, 2010).

Incidence (%) = IC/N*100

The culling rate will be calculated as a percentage of the number of cows (CC) affected divided by the total number.

Culling (%) = CC*100/N

Where CC represents culled Cows rate and (N) represents the total number of cows (Mwangi *et al.,* 2008).

A study done by Thirunavukkarasu *et al*. (2010), calculated direct losses due to the disease by summing up the loss in milk yield during the affected period and multiplying it by the farm gate. In assessing direct production losses and treatment costs due to dairy cattle diseases (Weersink *et al.,* 2002), the estimated herd losses associated with disease on US dairy operations was calculated as value of production on a per cow basis for each of the farms.

Regression models are relevant for obtaining a mathematical model to describe the relationship between observations of outcome variable with a set of explanatory or predictor variables (Hosmer *et al.,* 1991). The outcome variable is quantified by applying multivariate analysis with logistic regression. Logistic regression model has two components with the first being the random component where the distribution of Y is assumed to be binomial (n, л) where л is the probability of success. The second component is the systematic component where Xs are the explanatory or predictor variables and can be continuous, discrete or both are linear in parameters ($\beta_0+\beta_1X_1+\ldots+\beta_nX_n$). It estimates the probability of occurrence of an event in terms of odds ratio (Reed and Wu, 2013), for culling and disease incidences the logistic regression model will be used because, the response variable is binary in nature (yes/no).

The general linear model is an analysis of variance procedure that describes a statistical relationship between one or more predictors and a continuous response variable. The measure of effect of size in a general linear model is the adjusted squared correlation (R^2) which is an estimate of the proportion of variance in the dependent variable explained by the model, the larger the R^2, the better the model predicts the data (Hosmer *et al.*, 1991).

2.12 Conceptual model of Foot and Mouth Disease outbreak

In the three periods of foot and mouth disease (before, during, after), a lot of changes do happen be it change in milk production, mastitis incidences, culling (death of cows, calves' death, cow sold) and fertility impairment (abortion, retained placenta, conception failure) (Figure 2).

Before the occurrence of FMD outbreak the system is at an equilibrium state in terms of production, disease occurrence and herd fertility. The study proposed to quantify changes in milk production, mastitis occurrence, culling and fertility due to FMD outbreak and how close the production system went back to equilibrium state after outbreak (Figure 2).

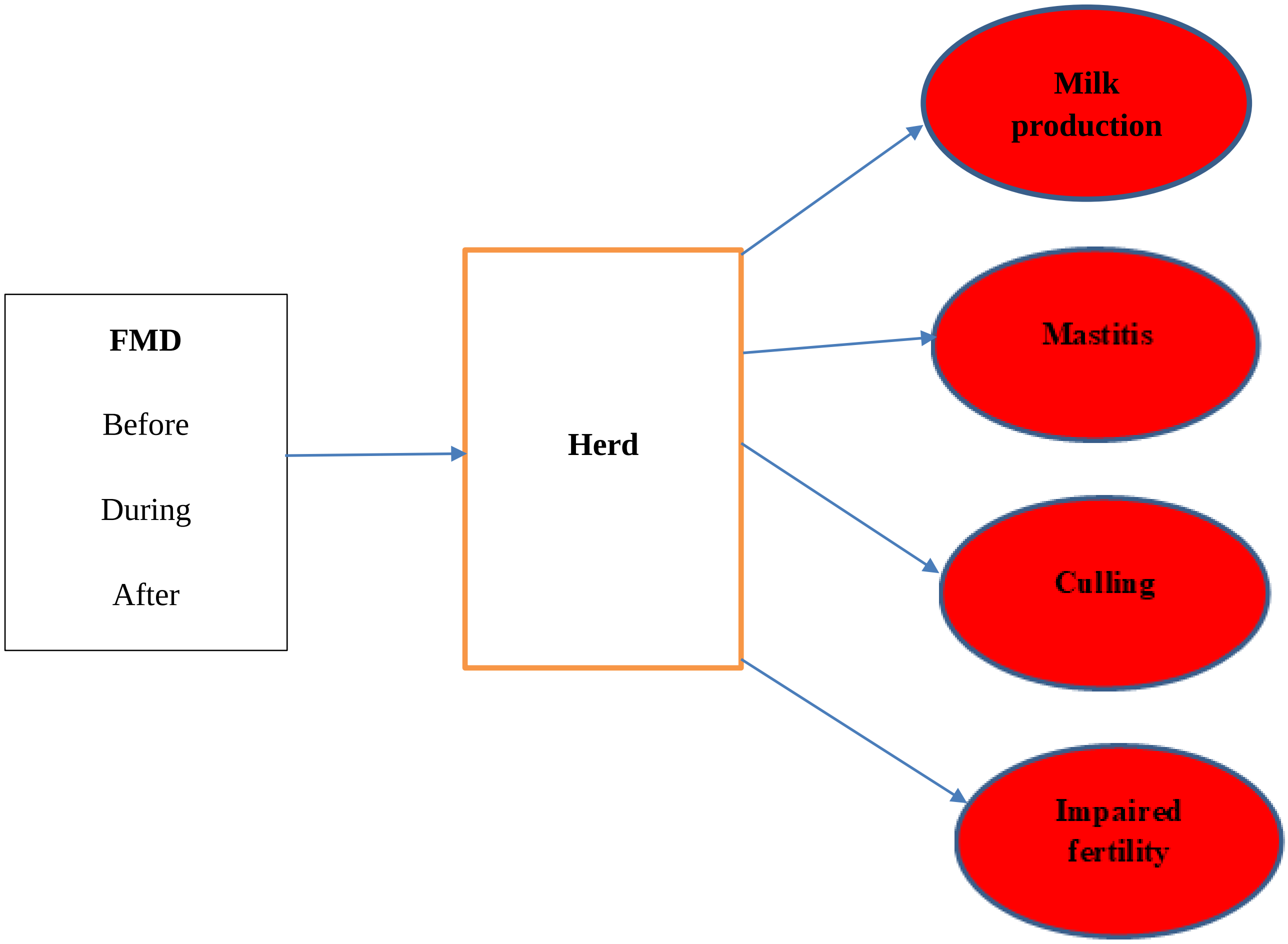


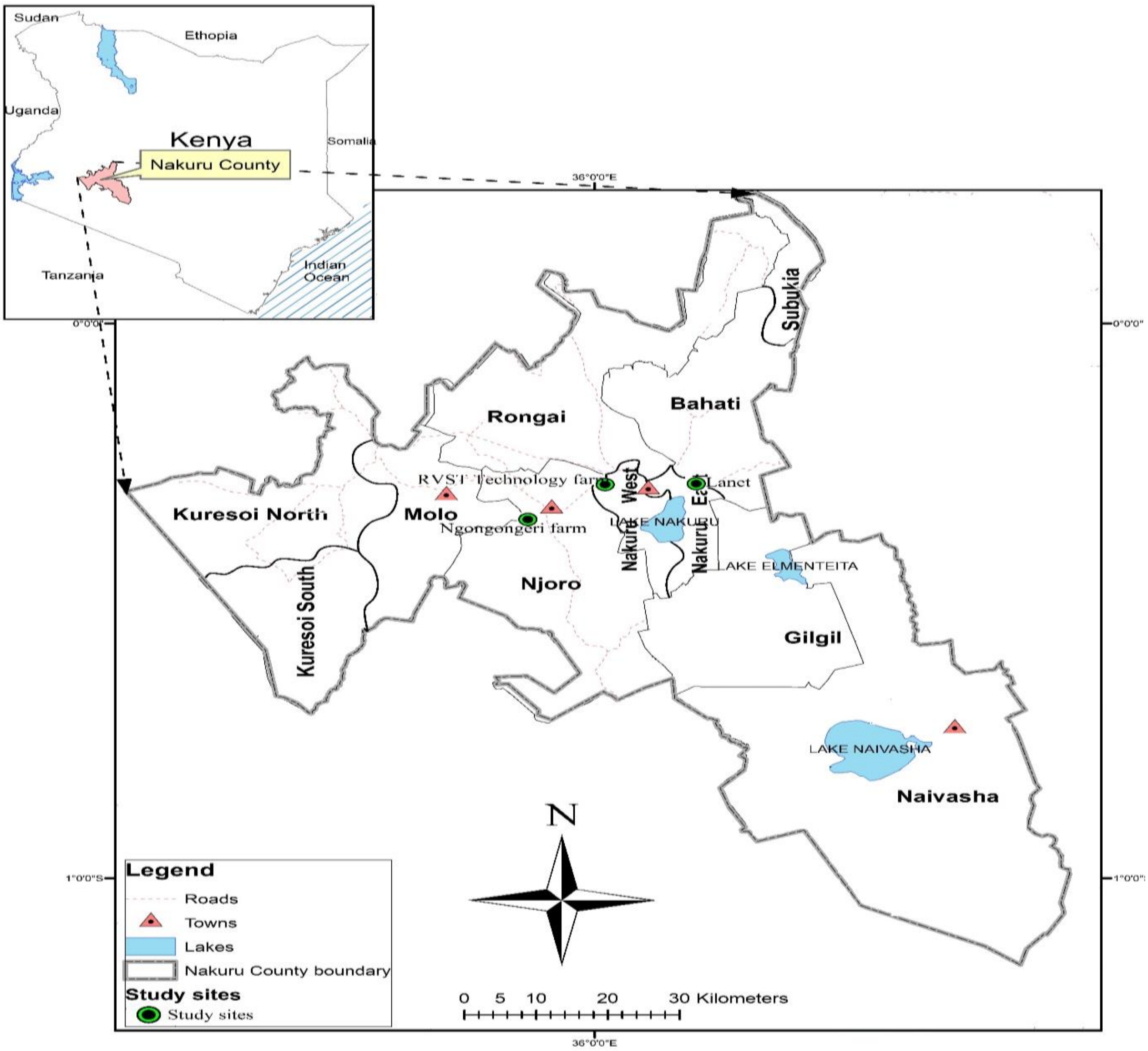
Figure 2: Conceptual model on the effects of Foot and Mouth Disease outbreak on production losses on large scale dairy farms

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The study was conducted in Nakuru County within the Kenyan Rift valley. It has a latitude of -0.3030099 and longitude of 36.080025, with the geographical coordinates of 0° 18' 11.1564" south and 36° 4' 48.0900" east (www.latlong.net, 2/06/2020). Nakuru County has an altitude of 1,800 m above sea level with temperatures ranging between 17.5 ˚C and 22 ˚C on average but can drop during cold season. Average annual rainfall in the area is up to 895 mm (en.climate-date.org, 10/9/2018). Nakuru County was selected because it is an endemic region for prevalence of serotype C of the FMD virus since mid-1980s, and has a history of FMD outbreaks in the recent past ten years.



3.2 Data collection

The study was conducted on three large scale dairy farms located in Nakuru County, Kenya. These three farms were selected due to the availability of the detailed records for individual animals before, during and after FMD outbreak. In three farms 507 exotic cows (Friesian, Ayrshire, Guernsey) were present before the outbreak, in farm 1 the number of cows was 205, farm 2 130 cows and in farm 3 172 cows. Farm1 belongs to the central government therefore, most of the workers in the farm are permanent and few are casuals, no restrictions for direct or indirect contact with the animals within the farm. The level of application of biosecurity measures in the farm was low. The main entrance of the farm did not have a disinfector for vehicles or people. Farm 2 is an enterprise of a public University where fencing is not completed for the whole farm and some people from the neighborhood use to cross the farm. The farm is a few kilometers away from the main road. Cattle are kept in extensive system, but in the dry season they share a grazing unit with the neighboring farms, making them to have a direct contact other cows, which may increase the risk of FMD and other diseases infection. Farm3 is private owned, the cattle are kept in intensive system and it's located near the main road, and the routine vaccination of FMD and other disease are done regularly. Biosecurity measures are in place, the farm is well fenced to prevent the contact of cows with other farms, since there are farms surrounding it. In the three farms the number of cows started to decrease during and after FMD outbreak, that’s why the number of cows at risk was different throughout the three phases of FMD outbreak. Each animal kept in the farm had an individual record for health events, treatments, breed and service. All cattle were uniquely identified with a number visible on an ear tag which was placed shortly after birth or upon arrival of the newly purchased animal. The dairy farm income was mainly through milk sales and heifer sales to other dairy farms. Foot and Mouth Disease outbreaks in three farms occurred in the year of 2012, 2014 and 2016, most of the outbreaks were in dry season especially in November, December and January, where there is scarcity of feed and water. Collection of data was carried out retrospectively from farm records and fitted in MS excel©. On each farm, herd level data were extracted when FMD outbreak occurred. The phases of FMD outbreak, were partitioned into three phases: six weeks before, six weeks during and six weeks after the disease outbreak. This period partitioning corresponds to three to four weeks of duration that FMD outbreak may last. Data on milk yield was obtained from farm daily milk production record, the daily milk production per hard was summed to get the total milk production per week.

The number of mastitis incidences before, during and after was counted to get the total number of mastitis. Cows that were culled whether sold or died in the three phases of FMD were also counted to get the total number of culled animals in each period. In this study abortion, retained placenta and conception failure/repeated insemination were considered for fertility impairments. Data was obtained retrospectively from the farm records from the year of 2008 to 2018.

3.3 Data Analysis

During the process of data visualization, it was noted distinct demarcation of cows' production difference, disease incidence and culling rates. This led to further grouping cows in three groups based on production levels using quartiles from descriptive statistics. They were grouped in high, average and low producers. The effects of the farm and the breed of cows were not significant for mastitis, fertility impairments and culling. Breed was not significant for milk production. Therefore, these effects were excluded for final analysis while only the effect of the period (before, during and after) was kept in the final model. Summary tables of all tested effects are included in the appendix.

Three variables of fertility impairments were tested: abortion, retained placenta, conception failure. The study focus was on herd's reaction to a disease outbreak, hence only herd level variables rather than animal level such as breed, stage of lactation, parity were not included in the analysis. In every farm in the three periods of FMD one outbreak event effect was analyzed. For mastitis incidences, culling, abortion, retained placenta and conception failure the prevalence percentage was calculated as follows:

$$\frac{\text{No of cases}}{\text{No of cows at risk}} \times 100 \qquad (1)$$

3.3.1 Effect of Foot and Mouth Disease on milk production

Effect of FMD outbreak on herd milk production was quantified using general linear model fitting the period of disease outbreak (six weeks before, during and after), farm and breed to explain change in milk production at the herd level. The mean differences between the three periods were tested at 0.05 level of significance using Tukey's HSD means separation technique. Milk production was categorized into three levels: low, medium and high, low milk production producers were those producing ≥75 Kg/week, medium producers were producing between 23-75 Kg/week and low milk producers were producing <22 Kg/week.

$$Y = \mu + \text{Period} + \text{Farm} + \text{Breed} + \varepsilon \qquad (2)$$

where:

Y = milk overall observation

μ = overall mean

ε = error term

3.3.2 Effect of Foot and Mouth Disease on mastitis, culling and fertility impairments

A logistic regression model was fitted to quantify herd incidences of mastitis, culling and fertility impairments.

To compare between the farms and breeds, a non-parametric test was used (Chi square) to test the significance difference of the categorical data. The odds ratio was also used to compare between the three phases of FMD outbreaks (before, during, after).

$$\text{Log}(a/b) = \beta_0 + \text{Period} + \text{Farm} + \text{Breed} + \varepsilon \qquad (3)$$

where;

a = the number of animals with mastitis cases, culled or with fertility impairment

b = total population at risk

β_0 = the intercept

ε = error term

CHAPTER FOUR

RESULTS

4.1 Description of herd milk production

Majority of the cows that were producing between 25 and 35 Kg/week before FMD outbreak dropped milk production to between 10 to 20 Kg/week during the outbreak. Majority of cows showed recovery after the period of outbreak with milk production increasing to between 15 and 25 Kg/week and some produced more than 50Kg per week. (Figure 3).

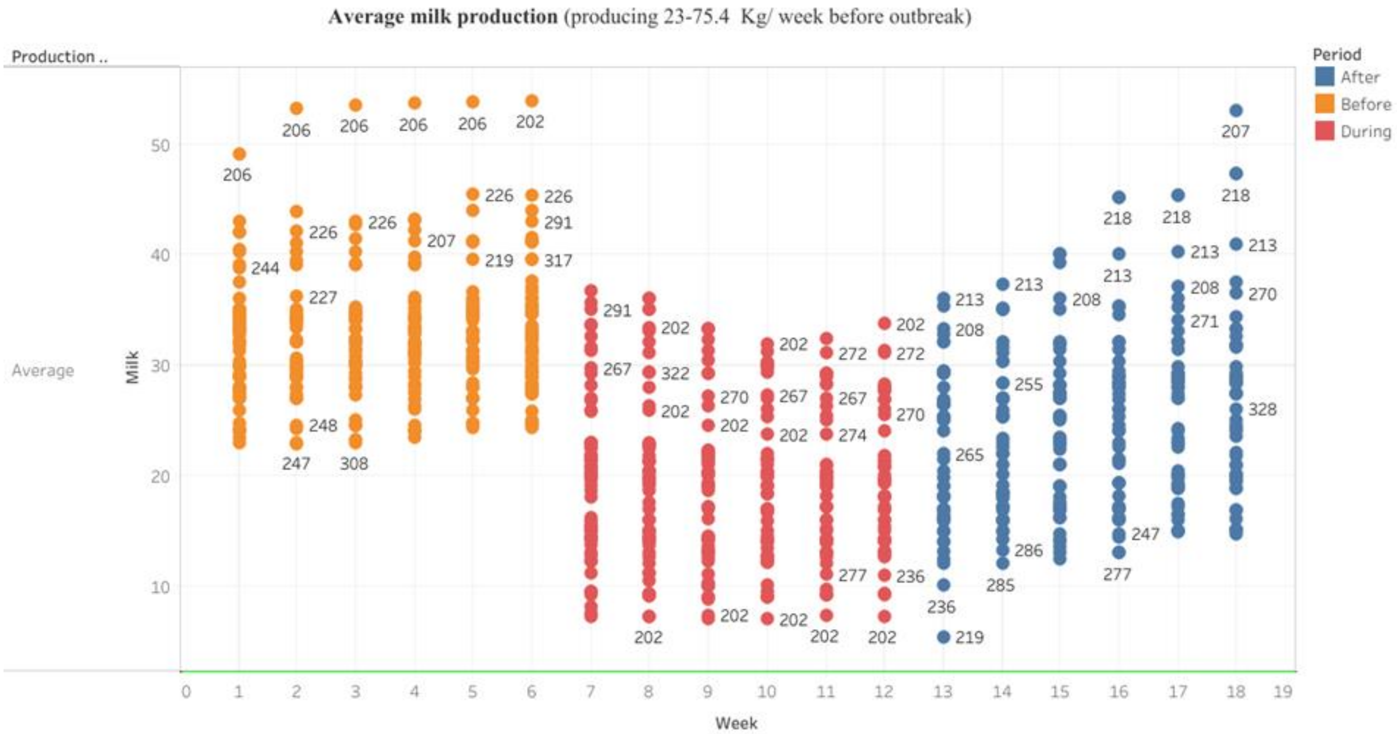


Figure 3. Average milk production trend before, during and after the FMD outbreak

In figure 4, Milk production for cows producing more than 75.5 Kg/week reduced to about 60 Kg/week during the FMD outbreak. Production increased to about 75Kg/week after the outbreak.

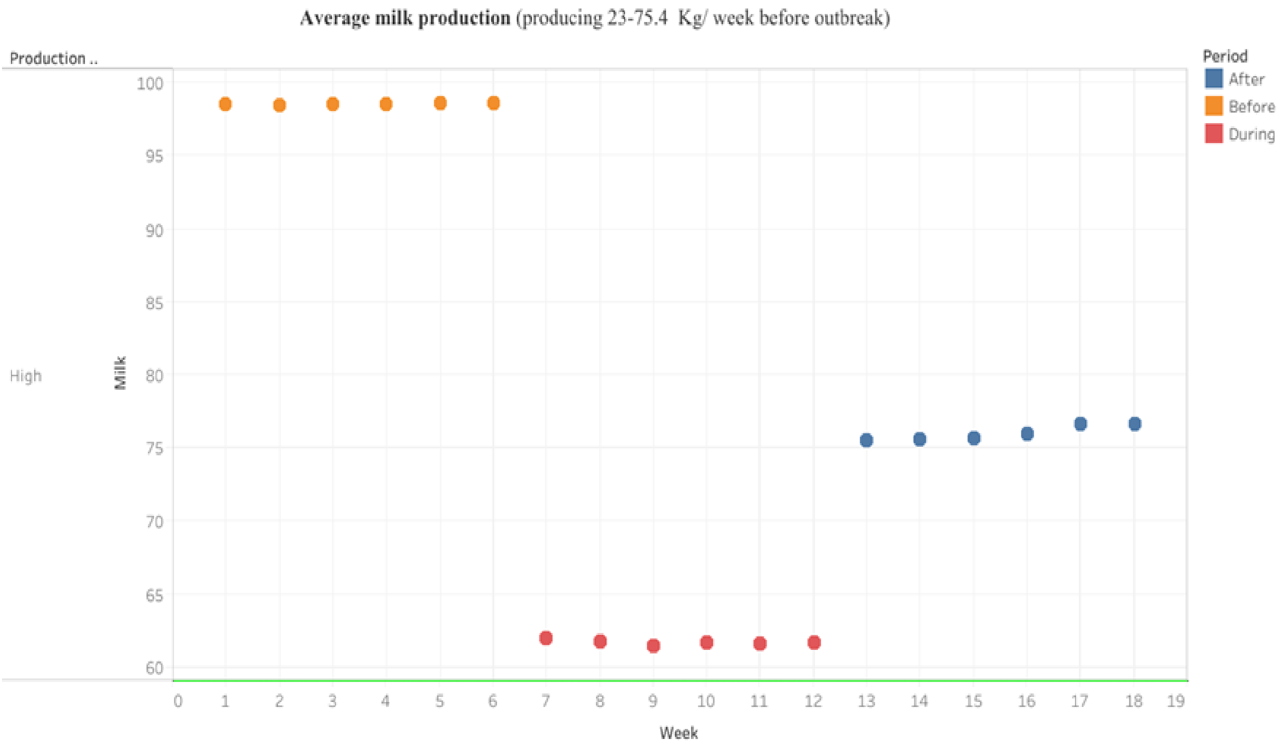


Figure 4. High milk producers before, during and after FMD

4.2 Effect of Foot and Mouth Disease outbreak on herd milk production

Table 2 shows effect of outbreak, farm and breed on herd milk production measured in weekly basis. The milk production before the outbreak (111,466.52 ± 2201.21 Kg) dropped by 16.1% during the outbreak (93,476.32 ± 2181.65) and by 7.6% after the outbreak (102,952.05 ± 1993.02). Outbreak and farm had significant effect ($p<0.05$) while breed did not ($p>0.05$) have effect on herd milk production.

Table 2: Milk production before, during and after Foot Mouth Disease

Period	Cows at risk (n)	AWMY*	MY** Mean ± S.E.
Before	464	178.2	111,466.52 ± 2201.21^{a}
During	436	85.9	93,476.32 ± 2181.65^{b}
After	433	123.9	102,952.05 ± 1993.02^{c}

AWMY*: Average weekly milk yield/cow; MY**: Milk yield; means with different letter superscript differ at 0.05 significance level

For high milk producing cows (>75.5 Kg/week), there was a significant drop of 15Kg/week/cow during FMD and 5KG/wee/cow lost compared to the period before the outbreak. In the average cows' producers (23-75 Kg/week), there was a drop of 15 Kg during FMD and 10 Kg after FMD compared to the period before. Low milk producers (<22Kg/week), milk production dropped by 10 Kg during FMD and 10 Kg after the recovery with the reference to the period before FMD. The drop in herd milk production was associated with drying off, which was 10.3% of the high producing cows and 5.1% of low producing cows (Table 3).

Table 3: Milk production level before, during and after Foot and Mouth Disease

Production level	Period	Number of cows	% drying off	Milk/Cow/week Mean ± S.E
High (>75.5 Kg/week)	Before	170	0	98.54±0.008[a]
	During	170	0	61.67±0.008[b]
	After	170	0	75.98±0.008[c]
Average (23-75 Kg/week)	Before	64	0	32.66±0.38[a]
	During	58	9.4	19.16±0.36[b]
	After	51	12.1	24.49±0.38[c]
Low (<22 Kg/week)	Before	228	0	21.09±0.13[a]
	During	217	4.8	11.78±0.13[b]
	After	210	7.9	19.33±0.13[c]

Means followed by a different letter in superscript are significantly different at 0.05

4.3 Effect of Foot and Mouth Disease outbreak on mastitis infections

Mastitis incidences increased from 5.4% before the outbreak to 21.5% (OR=3.31, CI=2.27, 4.83) during the outbreak then decreased to 2.5% after the outbreak (OR=0.33, CI=0.17, 0.64). The period during was significantly different from the period before FMD outbreak (P<0.05), while the period after the outbreak was also significantly different in regards to the period prior the outbreak (P<0.05).

Table 4: Mastitis incidences before, during and after Foot and Mouth Disease

Period	Cows at risk (n)	Cows infected (n)	Prevalence (%)	Odds ratio (95% CI)
Before	504	27	5.4	Reference
During	484	104	21.5	3.31 (2.27, 4.83) **
After	481	12	2.5	0.33 (0.17, 0.64) *

*, **, Indicate level of significance at 0.05 and 0.01 respectively; CI: confidence interval.

4.4 Effect of Foot and Mouth Disease outbreaks on culling

Result in table 5 show that culling rate during FMD outbreak was higher compared to the period before FMD 7.45 (3.84, 14.46), it was also higher after the outbreak than the period before FMD 2.57 (1.26, 5.25). Culling rate was significantly higher (p<0.01) during FMD than the period before. Although the odds of culling were higher after the outbreak than before, the difference was not significant (p>0.05).

Table 5: Culling rate before, during and after Foot and Mouth Disease

Period	**Cows at risk (n)**	**Cows culled (n)**	**Herd culling rate (%)**	**Odd ratio (95% CI)**
Before	507	3	0.59	Reference
During	504	19	3.76	7.45 (3.84, 14.46) ***
After	485	3	0.61	2.57 (1.26, 5.25) ^{NS}

*** Indicate level of significance at 0.01; CI: confidence interval; NS: not significant.

4.5 Effect of Foot and Mouth Disease outbreaks on fertility impairment

Incidences of abortion were higher during the outbreak (OR=16.08, CI=2.13, 121.32) and after recovery (OR=1.26, CI=1.26, 15.99) relative to the period before outbreak. Abortion incidences was significantly different from the period before the outbreak (P<0.05), it was also observed that, the period after the outbreak was not significant different from the period before FMD outbreak (P>0.05).

Table 6: Abortion cases before, during and after Foot and Mouth Disease

Period	Cows at risk (n)	Cows aborting (n)	Prevalence (%)	Odds ratio (95% CI)
Before	507	2	0.39	Reference
During	504	12	2.38	6.33 (2.34, 17.13) ***
After	485	4	0.82	2.11 (0.70, 6.31) ^{NS}

*** Indicate level of significance at 0.01, CI: confidence interval; NS: not significant.

Retained placenta cases before FMD were 0.22% and increased to 3.25% during FMD outbreak. The prevalence dropped to 0.93% after FMD. Likelihood of occurrence of retained placenta cases was higher during and after (OR= 7.29 and 3.05, respectively) than the period before FMD outbreak. There was no significant difference in the three periods of FMD.

Table 7: Retained placenta before, during and after Foot and Mouth Disease

Outbreak period	Cows at risk (n)	Cows with retained placenta (n)	Prevalence (%)	Odds ratio (95% CI)
Before	464	1	0.22	Reference
During	462	15	3.25	7.29 (0.88,59.9)**
After	433	5	1.15	3.05 (0.32,29.6)^{NS}

**, Indicate level of significance at 0.05; CI: confidence interval; NS: not significant.

4.6 Effect of Foot and Mouth Disease on conception failure

Table 8 shows results of conception failure or repeated insemination for the three periods: before, during and after FMD. Prevalence of conception failure before FMD outbreak was 0.39%, it decreased to 0.21% during FMD and increased after the outbreak to 1.13%. The period after FMD was significantly higher than the period before FMD outbreak ($P < 0.05$). During the outbreak the number of cows that were served/inseminated were very few, therefore the conception failure during the outbreak was not significantly different from the period before FMD ($P>0.05$).

Table 8: Insemination number before, during and after Foot Mouth Disease

Period	Inseminated cows (n)	Conception failure (n)	Conception failure (%)	Odd ratio (95% CI)
Before	45	2	0.39	Reference
During	13	1	0.21	1.61 (0.81, 3.24) ^{NS}
After	25	7	1.52	3.73 (2.02, 6.91) *

*, Indicate level of significance at 0.05. CI; confidence interval; NS: not Significant.

CHAPTER FIVE

DISCUSSION

5.1 Effect of Foot and Mouth Disease outbreak on milk production

The study quantified milk production, animals exiting the herd, mastitis incidence and fertility impairments (abortion, retained placenta and conception failure/repeated insemination) in three successive periods of six weeks before, during and after occurrence of FMD outbreak. The outbreaks were recorded between 2008 and 2018 in three large-scale dairy farms with a total of 507 dairy cows. The period between 2008 and 2018 corresponded with the period that the three farms had experienced FMD outbreak in the year of 2012, 2014, and 2016. The objective was to provide empirical estimates of the extent of production losses that farmers are not aware of but may incur due to FMD outbreaks.

It was found that milk production dropped by 16% during FMD outbreak. This reduction in milk production was expected because during FMD outbreak the affected cows, especially those in mid and late lactation, dry off (Singh *et al*., 2013). Furthermore, this study reported that average and low milk producing cows have higher drying off rate (12 and 8% respectively) than high producers that only recorded a drop in milk yield. Milk loss due to acute FMD can arise from two situations; either when a lactating cow is affected, her milk yield decreases or stops during the period of infection. In the period during FMD the infected cows stop eating, due to the pain caused by the sores on the mouth and the lip as well as tongue (Mazengia *et al*., 2010). This leads to reduced feed and water intake, hence lower the energy levels impacting negatively on milk production. Lactating cows also dry off due to the stress caused by FMD (Jemberu *et al*., 2014).

Another reason for milk reduction during FMD was that there were more cows that exited the herd during the outbreak, and milk discarded from quarantined cows during the period of FMD infection (Nampanya *et al*., 2015). The lesions of FMD that are around the teats caused a severe damage to the udder, making the cow unable to produce milk, not only that but the odor and the color of the milk changes (Senturk *et al*., 2005). The longevity of FMD in the farm more than four weeks leads to the increase of the amount of milk loss in the herd level if the necessary biosecurity were not done. A study was done by Jemberu *et al*. (2014) in

Ethiopia, found that 75% loss in daily milk production in duration of FMD in the farm more 33.6 days.

During FMD the farmers incur a high economic loss, due to the drop in milk yield which will affect the milk sales (Baluka, 2016). The 16% drop in milk during an FMD outbreak represent substantial loss, of revenue of KES 113,320 for milk sold at 40 KES per animal per liter in the dry season when outbreaks occurred. This finding concurs with a study by Ansari-Lari *et al*. (2017) in Iran, where the recorded milk production during FMD dropped up to 70%. The drop in milk yield represents a magnificent decrease in household income especially in the rural areas, where most of the people depend on livestock yielding. Though most of adult livestock are able to recover clinically in 3-4 week, but the re-establishment of the production may require longer period of time to go back to normal (Ferrari *et al*., 2012). On the farm level the farmer will be forced to spend more money on the feed of animals as well as treatment cost, but without making a profit on the sick cows (Pendell *et al*., 2007).

Culling due to FMD causes a significant change in milk production at the herd level, and this is one of the factors that could explain drop in herd milk production observed in this study (Singh *et al*., 2013). This study concurs with Bhism *et al*. (2015), in which a 50% reduction in milk production reported during the FMD outbreak. Although they are able to resume milk production after the outbreak, it only mounts to about 85% of the initial milk production (60 days after onset of outbreak) (Ferrari *et al*., 2011).

Additionally, mid to late lactation cows often do not resume milk production after outbreak (Lyons *et al*., 2015). However, milk production can resume to normal levels in the subsequent lactations. But at the present, farms need to put an accurate and effective biosecurity measures especially during the period of FMD to reduce devastating loss in milk production. Milk production loss can be linked to the spread of FMD within the herd. Therefore, good management and supportive care of clinically affected animals can reduce the effect of FMD as well as reduce the spread of FMD among the healthy ones (Ansari-Lari *et al*., 2017).

In intensive dairy production it is almost impossible to operate during the outbreak of FMD; and the disease must be prevented in two ways either by vaccination or eradication for the production system to be stable and sustainable (Knight-Jones *et al*., 2013). Where intensive dairy production is practice in the areas of high risk of FMD, cows must be vaccinated each year four time or more to maintain an adequate degree of protection, even then there remains a risk of outbreaks occurrence. Because the virus strains different from those used in the vaccine (Garforth *et al*., 2013). Moreover, FMD remains a challenge in the face of cattle production till this date, it is a major global animal health problem. In the present efforts have been done to contain the disease impact in international and national level which may be of help in reducing the adverse effect of FMD (Depa *et al*., 2012).

5.2 Effect of Foot and Mouth Disease outbreak on Mastitis incidences

Mastitis incidences were higher during FMD (OR= 3.31) compared to the period before the outbreak, while after the FMD mastitis was lower (OR=2.5) with the comparison to the period prior FMD. This could be due to the fact that farmers fail to distinguish the clinical sings of FMD from mastitis because of their similarities, or to the failure of farm managers to diagnose mastitis early (Chakraborty *et al*., 2014).

Mastitis incidence increased during outbreak with 3.3 times more risk than before the outbreak and reduced to a level below the period before (OR= 0.3). Lyons *et al*. (2015) also reported an increase in mastitis incidences (62.1%) during the outbreak of FMD in commercial farms in Nakuru County. Foot and mouth disease is often followed by mastitis because the mammary gland tissue is the only place where the resilience take place and if the virus stayed for more than 7 weeks' severe wounds occurred around the teats causing a discomfort and pain at same to the cow. This is related to FMD lesions on the teats, which are likely to increase the cow's susceptibility to secondary bacterial infection which is essentially environmental (Lyons *et al*., 2015). The vesicles that occur in the teats and when the teat orifice is involved, then severe mastitis follows (Sharma *et al*., 2010). The coagulase-negative *staphylococci* (CNS) are the predominant cause of inflammatory infection and subclinical mastitis in dairy cattle, whereas *Staphylococcus aureus* and environmental pathogens cause a minority of the cases of mastitis (De Vliegher *et al*., 2012). Beside the bacterial infection of mammary gland an increase of somatic cells counts in cow's milk resulting in reduction of milk quality is observed. Jamrozik and Schaeffer (2012) showed that cases of clinical mastitis were significantly associated with an increase in Somatic cells count.

Furthermore, FMD virus replicates in the secretary epithelium of mammary gland. The acini in the necrotic areas mainly contain sloughed epithelial cells, cellular debris and small number of leukocytes, which leads to reduction of milk yield in the affected cow (Neelesh *et al*., 2008). Since the disease is characterized by changes in the physical and chemical properties of the milk and fat being an important component of milk, any change in its concentration in turn affect the suitability of milk processing and the quality of its products (Jingar *et al*., 2014). Mastitis is the second disease of economic importance in the dairy industry after FMD. In the occurrence of mastitis, the farmer incurs losses in various ways including milk rejection, labor cost and treatment cost (Halasa *et al*., 2009). Mastitis incidences lead to reduction in milk production which will directly affect the farmer's income. Treatment costs that may include various antibiotics, analgesics, anti-inflammatory drugs and intra mammary infusions are also incurred (Sinha *et al*., 2014). In smallholder farms, the impact of mastitis presents a serious potential constraint to further development of dairy industry and may lead to poverty and starvation (Abrahmsén *et al*., 2014).

The economic consequences of mastitis are not solely restricted on farm level only, but it can be expanded beyond the dairy farm (culling and changing in milk quantity) (Jingar *et al*., 2014; Reshi *et al*., 2015). Sinha *et al*. (2012) conducted a study on the economic losses due to mastitis in dairy, and found that dairy animals were losing up to 48.53% milk production due to mastitis. This result also was supported by Sharma *et al*. (2016), where they found that mastitis reduced milk production by up to 40.8%, because mastitis affects both milk quality and quantity.

The losses due to mastitis are not only economical, but issues such as animal health and welfare, milk quality, antibiotic usage and the image of the dairy sector are important reasons to focus on mastitis control. Mastitis is the second disease to foot and mouth disease as most challenging disease in high yielding dairy animals (Sharma, 2010), but is at first position due to high prevalence rate which was estimated (90%) in high yielding dairy cows and causes huge economics loss in dairy herds of developing and developed countries (Sharma *et al.*, 2007).

Despite the economic importance of mastitis to the dairy industry, reliable estimation of the losses in most of countries are still lacking. Moreover, the magnitude of losses varies with the influence of several factors such as: type of animal, age of the animal, seasonal variation, animal sanitation, hygiene management of the farm and the increase in the lactation number together with the geographical origin of the animal (Moris *et al*., 2000).

5.3 Effects of Foot Mouth Disease outbreak on culling rates

The proportion of cows that exited the herd during FMD was (OR=7.45). This finding is in agreement with Lyons *et al*. (2015) who reported that during FMD outbreaks, the total number of the animals that exited the herd was 166 higher than the period after the outbreak. Culling could be due to death or reduction of production for the cows that were quarantine. Low fertility is also reported as reason for culling dairy cows especially in the period after FMD outbreaks (Pritchard *et al*., 2013). Culling rate varies (voluntary, involuntary) among farms, where the decision making plays an important role in the case of voluntary culling, as well as the routine checkup of the herd to minimize the adverse effect of FMD (Booth *et al*., 2004). Farmers encounter losses due to the number of cows exited the herd and economic losses may be due to death of animal especially during FMD, but culling that extends beyond the period after FMD causes a devastating losses (Gohin *et al*., 2013).

The effect of FMD on culling was observed even after FMD outbreak, because the percentage cows' exits after the outbreak was almost half of the cows that exited the herd during FMD. This can explain the long-term effect of the disease, which includes extreme lameness caused by FMD, poor reproduction and death. Furthermore, there is a ban of sale of meat or dairy products during the outbreak that may cause the farmers to postpone culling and only sale after the outbreak (Olechnowicz *et al*., 2011).

Foot and Mouth Disease reduces the efficiency of production mainly in three ways: by decreasing milk production, by reducing reproductive performance, and thereby increasing the culling risk. Permanent lameness that was caused by FMD decreases milk yield, fertility and therefore increases the risk of culling. In a study by Cha *et al*. (2010), lameness was found to be associated with reduced fertility. Results presented by Espejo *et al*. (2006) indicated a larger increase in the interval from calving to conception in lame cows (14 days) than that for the interval from calving to the first service (4 days), suggesting that the main effect of lameness may be connected with conception or the maintenance of pregnancy.

5.4 Effects of Foot Mouth Disease outbreak on fertility impairments

Abortion, retained Placenta and insemination per conception (conception failure) were considered for fertility impairments for the three periods; before, during and after foot and mouth disease outbreaks. Abortion cases during FMD outbreak were higher than the period before and the period after the outbreak all together. The percentage of the aborted cows during the outbreak, are enough to raise an alarm, because acceptable rate of abortion per annum is reported to be around 1 to 2% (Tyagi *et al.,* 2017). Abortion rates in the current study could be explained by the fact that during FMD outbreak, affected cows went under stress which caused the animal to loose appetite as well as the energy to move and access the feed, which suppress the immunity of the cow and make it vulnerable to abortion (Zaher *et al*., 2008).

Another factor could be the transplacental transmission of FMD virus to fetal calves and subsequent FMDV – induced abortion (Ranjan *et al*., 2016). The cost of abortion is high, in that the farmer has to pay to keep the cow without it producing anything for another year or more, or cull the cow in either way abortion is an economic loss (Knight-Jones *et al*., 2013).

After the FMD outbreaks the system started to recover. Therefore, the recorded abortions cases after the outbreak was lower than during the outbreak of FMD. Abortion incidences decrease milk production and the potential number of herd replacement. An increase of feeding and medical treatment costs, increase on number of artificial insemination and culling rates is also reported due to abortion cases (Gädicke *et al*., 2010). To reduce the side effect of FMD that causes abortion, farmers need to work with the veterinarian to develop a proper vaccination program and make sure the heifers are also vaccinated according to veterinarian's instruction (Hovingh, 2009).

In this study most of the FMD outbreaks occurred during the dry season in Nakuru County which is always hot. Whereby the pregnant cows underwent stress and released hormones from adrenal gland related to stress (Corticosteriods). They liberate another hormone called endotoxin that alter the surrounding conditions in the uterus and lead to abortion. Heat stress is one of the factors that contribute to abortion during the period of FMD outbreak. This is confirmed by Hatem *et al*. (2016) who found that the FMD outbreaks occurred between the month of June and September which are the dry season in Iraq. During these period they found that the abortion cases were 21.6% due to the high temperature caused by FMD lesions.

Retained Placenta during outbreak was higher compared to the period before foot and mouth disease. Foot and mouth disease causes fever and discomfort, leading placenta to interfere with uterine contractility and provides bacteria with a substrate for rapid growth (Königsson *et al*., 2001). The incidences of retained placenta for dairy cows was 7.8±0.2% reported by Kimura *et al*., (2002). The hormonal changes caused by FMD, compelled neutrophils to impaired migration to placental interface in the periparturient period. The impaired neutrophils function extends into the postpartum period and probably mediates the recognized complications of retained fetal membranes

Retained placenta causes a significant economic loss, because retained placenta cows develop metritis and may suffer from infertility and also its decreases milk production. Immunosuppression is believed to be the main cause of retained placenta. Dry cows are also more likely to suffer from hypocalcaemia, which exacerbates immunosuppression and may cause dystocia and retained placenta (Mulligan *et al*., 2008). The prevalence of retained placenta in the study that was done Rabbani *et al*. (2010) was 4.63% higher than the prevalence of retained placenta in this study.

It was found that conception failure was high in the period after the FMD. This could be attributed to the long-term effect of the disease that could be felt even after the recovery, which leads to fertility depression. Moreover, fertility depression may lead at the end to culling (Singh *et al*., 2013). Also FMD has an effect on the ovarian activity specially the infected animals and to come on heat takes time even after FMD outbreak, therefore, the effect of FMD can be felt even after the recovery (Zaher et al., 2008). Conception failure among the exotic breeds could be associated the body size which requires more feed, but during FMD the feed intake is reduced due to the lesions on the mouth adding to postpartum nutritional imbalances further impairing fertility.

The reduction level of feed intake and inflammatory disease (mastitis) caused by FMD can lead to endocrinopathy that result in a poor quality of dominant follicle, corpus luteum and subsequent conception failure (Hassan, 2016). As foot and mouth disease has a direct association with lameness due to the lesions on the foot that will make the animal unable to walk. Therefore, this could be one of the reasons for conception failure/repeated insemination as it had been reported by Tyagi *et al*. (2017), where he found the lame cows were having longer calving to conception interval. A lame cows required a higher number of service per conception, because lameness negatively affects expression of estrus behavior in dairy cows due to painful nature of lameness. In addition, lower expression of estrus behavior, the ovarian activity and secretion of reproductive hormones related to follicular growth and ovulation in lame cows are negatively affected. The failure of breeding females to become pregnant directly impacts the economic viability of every dairy operation, yet few producers realize how infertility impacts their individual operations. Infertility that leads to the failure of a cow or heifer to calve during the subsequent calving season results in the single largest economic loss to dairy producers, because no economic return will be realized from those cows for at least one additional year.

Failure of a cow to conceive for a number of time leads to a removal of a cow from the herd. Previous reports (Bellows *et al*., 2002) indicate that approximately 4.5% of the cow herd is culled annually because they fail to become pregnant. 65.5% to 81.6% in the southeastern United States of America of dairy producers who fail to use pregnancy diagnosis in their operations, the first opportunity that they have to determine which cows are not pregnant is after the subsequent calving season. At that point, producers may decide to either retain the cows that failed to calve, or cull those cows prior to the next breeding season. Either way, there is a significant cost to the producer for maintaining those cows for a full year without producing a calf. With no calf sale, costs of supplemented feed, pasture, and other expenses directly decrease the lifetime profitability of open cows (Givens *et al*., 2006). Often overlooked or neglected facets of infertility are the cows that become pregnant but fail to calve or calve later in the calving season.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

It is concluded from the results of this study that:

i. Milk production drops substantially during an outbreak of Foot and Mouth Disease and recovery is slow following the outbreak but not up to initial production level.
ii. Mastitis incidences increase during an outbreak of Foot and Mouth Disease but drop back to normal levels after.
iii. Cows exits, both voluntary and involuntary increase during and after the outbreak of Foot and Mouth Disease, but reduce close to normal level after the outbreak.
iv. Fertility is impaired with the FMD outbreak, especially abortion and retained placenta while conception seems to be affected more in the post outbreak period.

6.2. Recommendations

i. The average and low milk producing cows affected by FMD should be culled and replaced to reduce further economic losses in the herd level.
ii. Foot and Mouth Disease lesions should be treated to reduce high infection of mastitis among the herd, especially during FMD outbreak.
iii. Upon FMD outbreak the healthy pregnant cows as well as calves should be provided with a recommended hygienic environment to reduce more abortions and calves' death.
iv. Cows should not be inseminated immediately after an outbreak of FMD to avoid fertility impairments (abortion, retained placenta and conception failure).

6.3. Further studies

i. Quantification of Foot and Mouth Disease associated with fertility impairments after six months after the outbreak.
ii. The effect of Foot and Mouth Disease vaccines on production performance in large scale dairy farms.
iii. Economic impact of Foot and Mouth Disease outbreaks on Mastitis incidences in smallholder farms.

REFERENCES

Abraham, F. (2017). An Overview on Functional Causes of Infertility in Cows. *Journal of Fertilization: In vitro - IVF-Worldwide, Reproductive Medicine, Genetics and Stem Cell Biology*, *5*, 203.

Alemayehu, G., Zewde, G., and Admassu, B. (2014). Seroprevalence of foot and mouth disease (FMD) and associated economic impact on Central Ethiopian cattle feedlots. *Journal of Veterniary Medicine and Animal Health*, *6*: 154–158.

Abrahmsén, M., Persson, Y., Kanyima, B. M., and Båge, R. (2014). Prevalence of subclinical mastitis in dairy farms in urban and peri-urban areas of Kampala, Uganda. *Tropical Animal Health and Production*, 46: 99-105.

Aktas, M. S., Ozkanlar, Y., Oruc, E., Sozdutmaz, I., and Kirbas, A. (2015). Myocarditis associated with foot-and-mouth disease in suckling calves. *VeterinarskiArhiv*, *85*: 273-282.

Ansari-Lari, M., Mohebbi-Fani, M., Lyons, N. A., and Azizi, N. (2017). Impact of FMD outbreak on milk production and heifers' growth on a dairy herd in southern Iran. *Preventive Veterinary Medicine*, *144*: 117-122.

Armson, B., Mioulet, V., Doel, C., Madi, M., Parida, S., Lemire, K. A., and King, D. P. (2018). Detection of foot-and-mouth disease virus in milk samples by real-time reverse transcription polymerase chain reaction: Optimisation and evaluation of a high-throughput screening method with potential for disease surveillance. *Veterinary Microbiology*, 223: 189–194.

Backer, J. A., Hagenaars, T. J., Nodelijk, G., and Roermund, H. J. W. Van. (2012). Vaccination against foot-and-mouth disease : Epidemiological consequences. *Preventive Veterinary Medicine*, 107: 27–40.

Baluka, S. A. (2016). Economic effects of foot and mouth disease outbreaks along the cattle marketing chain in Uganda. *Veterinary World*, 9: 544.

Bhism, S., Sanjay, K., Dohare, A. K., and Ajay, K. (2015). Foot and mouth disease and its effect on morbidity, mortality and milk yield in cattle of Chhattisgarh. *Environment and Ecology*, 33: 1055-1058.

Booth, C. J., Warnick, L. D., Gröhn, Y. T., Maizon, D. O., Guard, C. L., and Janssen, D. (2004). Effect of lameness on culling in dairy cows. *Journal of Dairy Science,* 87: 4115-4122.

Brito, B. P., Rodriguez, L. L., Hammond, J. M., Pinto, J., and Perez, A. M. (2017). Review of the global distribution of foot-and-mouth disease virus from 2007 to 2014. *Transboundary and Emerging Diseases*, 64: 316-332.

Carpenter, T. E., O'Brien, J. M., Hagerman, A. D., and McCarl, B. A. (2011). Epidemic and economic impacts of delayed detection of foot-and-mouth disease: a case study of a simulated outbreak in California. *Journal of Veterinary Diagnostic Investigation*, *23*: 26-33.

Cha, E., Hertl, J. A., Bar, D., and Gröhn, Y. T. (2010). The cost of different types of lameness in dairy cows calculated by dynamic programming. *Preventive veterinary medicine*, *97*: 1-8.

Chakraborty, S., Kumar, N., Dhama, K., Verma, A. K., Tiwari, R., Kumar, A., and Singh, S. V. (2014). Foot-and-mouth disease, an economically important disease of animals. *Advance Animal Veterinary Sci*ence *2*: 1-18.

Chang, H., Ma, Y., Lin, T., Cong, G., Du, J., and Ma, J. (2013). Foot and mouth disease virus carrier status in Bos grunniens yaks. *Virology Journal*, 10, 81.

Chaters, G., Rushton, J., Dulu, T. D., and Lyons, N. A. (2018). Impact of foot-and-mouth disease on fertility performance in a large dairy herd in Kenya. *Preventive Veterinary Medicine*, 159: 57-64.

Costa, J. H. C., Hötzel, M. J., Longo, C., and Balcão, L. F. (2013). A survey of management practices that influence production and welfare of dairy cattle on family farms in southern Brazil. *Journal of Dairy Science, 96*: 307-317.

De Vliegher, S., Fox, L. K., Piepers, S., McDougall, S., and Barkema, H. W. (2012). Invited review: Mastitis in dairy heifers: Nature of the disease, potential impact, prevention, and control. *Journal of Dairy Science*, *95*: 1025-1040.

Depa, PM, Dimri U, Sharma MC, Tiwari R (2012) Update on epidemiology and control of Foot and Mouth Disease - A menace to international trade and global animal enterprise. *Veterinary World*, 5 ,694-704.

Derks, M., van Werven, T., Hogeveen, H., and Kremer, W. D. J. (2013). Veterinary herd health management programs on dairy farms in the Netherlands: Use, execution, and relations to farmer characteristics. *Journal of Dairy Science, 96*: 1623–1637.

Dos Santos, D. V., e Silva, G. S., Weber, E. J., Hasenack, H., Groff, F. H. S., Todeschini, B., and Corbellini, L. G. (2017). Identification of foot and mouth disease risk areas using a multi-criteria analysis approach. *PloS One*, 12: 11-16.

Dubuc, J., Duffield, T. F., Leslie, K. E., Walton, J. S., and Leblanc, S. J. (2011). Effects of postpartum uterine diseases on milk production and culling in dairy cows. *Journal of Dairy Science*, *94*: 1339–1346.

Dukpa, K., Robertson, I. D., Edwards, J. R., Ellis, T. M., Tshering, P., Rinzin, K., and Dahal, N. (2011). Risk factors for foot-and-mouth disease in sedentary livestock herds in selected villages in four regions of Bhutan. *New Zealand Veterinary Journal*, *59*, 51-58.

Duru, M., and Therond, O. (2015). Livestock system sustainability and resilience in intensive production zones: which form of ecological modernization?. *Regional Environmental Change*, 15: 1651-1665.

Egerton University Meteorological Station. (2017). Climatic data. Egerton University, Njoro Campus. Kenya.

Elnekave, E., Dekker, A., Eble, P., van Hemert-Kluitenberg, F., Gelman, B., Storm, N., and Klement, E. (2016). The long term effect of age and maternally derived antibodies against foot and mouth disease on the serological response following vaccination in young dairy calves. *Vaccine*, *34*: 4927-4934.

Elnekave, E., Zamir, L., Hamd, F., Tov, B. E., and Klement, E. (2015). Risk factors for foot and mouth disease outbreaks in grazing beef cattle herds. *Preventive Veterinary Medicine*, *120*: 236-240.

Espejo, L. A., Endres, M. I., and Salfer, J. A. (2006). Prevalence of lameness in high-producing Holstein cows housed in freestall barns in Minnesota. *Journal of dairy science*, *89*(8), 3052-3058.

FAO. 2011. Dairy development in Kenya, by H.G. Muriuki. Rome

Ferrari, G., Tasciotti, L., Khan, E., and Kiani, A. (2014). Foot and mouth disease and its effect on milk yield: an economic analysis on livestock holders in Pakistan. *Transboundary and Emerging Diseases*, 61:52-59.

Forbes, B. R., and Halderen, A. Van. (2014). Foot-and-Mouth Disease Economic Impact Assessment*: What it means for New Zealand* (Vol. 3).

Gaafar, H. M. A., Shamiah, S. M., Shitta, A. A., and Ganah, H. A. B. (2010). Some factors affecting on retained placenta and its effects on postpartum reproductive performance and milk production of Friesian cows. *Slovak Journal of Animal Science*, 43, 6-12.

Gädicke, P., Vidal, R., and Monti, G. (2010). Economic effect of bovine abortion syndrome in commercial dairy herds in Southern Chile. *Preventive Veterinary Medicine*, 97: 9-19.

Garforth, C. J., Bailey, A. P., and Tranter, R. B. (2013). Farmers' attitudes to disease risk management in England: A comparative analysis of sheep and pig farmers. *Preventive Veterinary Medicine*, *110*: 456–466.

Gent, D. H., Mahaffee, W. F., McRoberts, N., and Pfender, W. F. (2013). The use and role of predictive systems in disease management. *Journal of Phytopathology, 51*: 267-289.

Gohin, A., and Rault, A. (2013). Assessing the economic costs of a foot and mouth disease outbreak on Brittany: A dynamic computable general equilibrium analysis. *Food Policy*, 39: 97-107.

Givens, M. D. (2006). A clinical, evidence-based approach to infectious causes of infertility in beef cattle. *Theriogenology*, 66, 648-654.

Green, L. E., Hedges, V. J., Schukken, Y. H., Blowey, R. W., and Packington, A. J. (2002). The impact of clinical lameness on the milk yield of dairy cows. *Journal of Dairy Science*, 85: 2250-2256.

Halasa.T, M. Nielen, A. P. W. De Roos, R. Van Hoorne, G. de Jong,T. J. G. M. Lam,T. van Werven, and H. Hogeveen (2009). Production loss due to new subclinical mastitis in Dutch dairy cows estimated with a test-day model. *Journal of Dairy Science*, 92: 599-606.

Hassan, A. I. (2016). Effect of different culture systems on the production of foot and mouth disease trivalent vaccine. *Veterinary world*, 9: 32.

Hatem, A. A., and Talal, M. A. (2016). The effect of FMD disease on 3rd trimester pregnant cows and their fetuses. *Basrah Journal of Veterinary Research, 15*: 475-480.

Hayama, Y., Muroga, N., Nishida, T., Kobayashi, S., and Tsutsui, T. (2012). Research in Veterinary Science Risk factors for local spread of foot-and-mouth disease, 2010 epidemic in Japan. *Research in Veterinary Science*, *93*: 631–635.

Hossein-Zadeh, N. G. (2013). Effects of main reproductive and health problems on the performance of dairy cows: a review. *Spanish Journal of Agricultural Research*, 3: 718-735.

Hovingh, E. (2009). Abortions in dairy cattle II: Diagnosing and preventing abortion problems. *Global Veterinaria*, 17:28-34

Ill-Hwa, K., and Jeong, J. K. (2018). Risk factors limiting first service conception rate in dairy cows, and their economic impact. *Asian-Australasian Journal of Animal Sciences*. 32: 519-526.

Islam, M. H., Sarder, M. J. U., Rahman, M., Kader, M. A., and Islam, M. A. (2012). Incidence of retained placenta in relation with breed, age, parity and body condition score of dairy cows. *International Journal of Natural Sciences*, *2*: 15-20.

Jamrozik, J., and Schaeffer, L. R. (2012). Test-day somatic cell score, fat-to-protein ratio and milk yield as indicator traits for sub-clinical mastitis in dairy cattle. *Journal of Animal Breeding and Genetics*, 129: 11-19.

Jemberu, W. T., Mourits, M. C. M., and Hogeveen, H. (2015). Farmers' Intentions to Implement Foot and Mouth Disease Control Measures in Ethiopia. *PloS One*, 10: 138-363.

Jemberu, W. T., Mourits, M. C. M., Woldehanna, T., and Hogeveen, H. (2014). Economic impact of foot and mouth disease outbreaks on smallholder farmers in Ethiopia. *Journal of Preventive Veterinary Medicine*, *116*: 26–36.

Jemberu, W. T., Mourits, M., Rushton, J., and Hogeveen, H. (2016). Cost-benefit analysis of foot and mouth disease control in Ethiopia. *Preventive Veterinary Medicine, 132*, 67-82.

Jibat, T., Admassu, B., Rufael, T., Baumann, M. P., &Pötzsch, C. J. (2013). Impacts of foot-and-mouth disease on livelihoods in the Borena Plateau of Ethiopia. *Pastoralism: Research, Policy and Practice, 3*: 5.

Jingar, S. C., Mehla, R. K., Singh, M., and Singh, P. K. (2014). Effect of stages and level of milk production on mastitis incidence in cows and murrah buffaloes. *Journal of Biological Innovation*, 3: 117-123.

Kim, I. H., and Jeong, J. K. (2019). Risk factors limiting first service conception rate in dairy cows and their economic impact. *Asian-Australasian Journal of Animal Sciences*, *32*: 519.

Kimani, T. M., Mwirigi, J. W., and Murithi, R. M. (2005). Financial impact assessment of foot and mouth disease in large scale farms in Nakuru District, Kenya. *Kenya Veterinarian*, 29: 7-9.

Kimura, K., Goff, J. P., Kehrli Jr, M. E., and Reinhardt, T. A. (2002). Decreased neutrophil function as a cause of retained placenta in dairy cattle. *Journal of Dairy Science*, 85: 544-550.

Knight-Jones, T. J. D., and Rushton, J. (2013). The economic impacts of foot and mouth disease - What are they, how big are they and where do they occur? *Preventive Veterinary Medicine*, *112*, 162–173.

Kuster, K. B. (2013). Effectiveness and importance of on-farm biosecurity measures in Switzerland. *Preventive Veterinary Medicine*, 56, 11-13.

Laanen, M., Maes, D., Hendriksen, C., Gelaude, P., De Vliegher, S., Rosseel, Y., and Dewulf, J. (2014). Pig, cattle and poultry farmers with a known interest in research have comparable perspectives on disease prevention and on-farm biosecurity. *Preventive Veterinary Medicine*, *115*: 1–9.

Lawrence, K., Tulley, W., and Laven, R. (2013). Observations on the incidence and seasonality of uterine torsion and left displaced abomasum following the 2001 outbreak of foot-and-mouth disease in the UK. *The Veterinary Journal*, *196*: 332-338.

LeBlanc, S. J., Lissemore, K. D., Kelton, D. F., Duffield, T. F., and Leslie, K. E. (2006). Major advances in disease prevention in dairy cattle. *Journal of Dairy Science*, 89: 1267-1279.

Lee, J. I., and Kim, I. H. (2007). Pregnancy loss in dairy cows: the contributing factors, the effects on reproductive performance and the economic impact. *Journal of Veterinary Science*, 8: 283-288.

Lyons, N. A., Alexander, N., Stärk, K. D. C., Dulu, T. D., Rushton, J., and Fine, P. E. (2015). Impact of foot-and-mouth disease on mastitis and culling on a large-scale dairy farm in Kenya. *Veterinary Research, 46*: 1–11.

Lyons, N. A., Alexander, N., Stärk, K. D. C., Dulu, T. D., Rushton, J., and Fine, P. E. (2015). Impact of foot-and-mouth disease on mastitis and culling on a large-scale dairy farm in Kenya. *Veterinary Research, 46*: 41.

Lyons, N. A., Stärk, K. D. C., van Maanen, C., Thomas, S. L., Chepkwony, E. C., Sangula, A. K., and Fine, P. E. M. (2015). Epidemiological analysis of an outbreak of foot-and-mouth disease (serotype SAT2) on a large dairy farm in Kenya using regular vaccination. *Actatropica*, *143*: 103-111.

Mazengia, H., Taye, M., Negussie, H., Alemu, S., and Tassew, A. (2010). Incidence of foot and mouth disease and its effect on milk yield in dairy cattle at Andassa dairy farm, Northwest Ethiopia. *Agriculture and Biology Journal of North America*, 1: 969-973.

Moris, M., Nagwa, Yousry Saleh, Hayam El Gazzar and Ashraf Hanafi (2000). Effect of Mastitis on Milk Fat Content. Pakistan *Journal of Biological Sciences,* 3: 196-200.

Moroak, R., and Stewart, P. A. (2015). Periparturient stress and immune suppression as a potential cause of retained placenta in highly productive dairy cows: examples of prevention. *Acta Veterinaria Scandinavica*, *57*: 84.

Morley, P. S. (2002). Biosecurity of veterinary practices. *Veterinary Clinics of North America Food Animal Practice*, *18*: 133-156.

Mughini-Gras, L., Bonfanti, L., Natale, A., Comin, A., Ferronato, A., La Greca, E., and Marangon, S. (2014). Application of an integrated outbreak management plan for the control of leptospirosis in dairy cattle herds. *Epidemiology and Infection*, *142*: 1172-1181.

Muleme, M., Barigye, R., Khaitsa, M. L., Kabasa, J. D., &Musubika, J. (2013). International Infectious Disease Management Perspectives Policy Research Brief January 2013 A Decade of Foot and Mouth Disease (FMD) Vaccination Failure in Uganda: Recommendations for effective FMD Control. *Preventive Medicine*, 44: 10–15.

Mulligan, F. J., and Doherty, M. L. (2008). Production diseases of the transition cow. *The Veterinary Journal*, 176: 3-9.

Nampanya, S., Khounsy, S., Phonvisay, A., Young, J. R., Bush, R. D., and Windsor, P. A. (2015). Financial impact of foot and mouth disease on large ruminant smallholder farmers in the Greater Mekong Subregion. *Transboundary and Emerging Diseases*, *62*: 555-564.

Nampanya, S., Suon, S., Rast, L., and Windsor, P. A. (2012). Improvement in smallholder farmer knowledge of cattle production, health and biosecurity in southern Cambodia between 2008 and 2010. *Transboundary and Emerging Diseases*, *59*: 117-127.

Neelesh, S., Maiti, S. K., & Vijay, P. (2008). Sensitivity of indirect tests in the detection of sub-clinical mastitis in buffaloes. *Veterinary Practitioner*, *9*, 29-31.

Neil P, (2012). Classification of epidemiological study designs. *International Journal of Epidemiology*, 41: 393-397.

Nyaguthii, D. M., Armson, B., Kitala, P. M., Sanz-Bernardo, B., Di Nardo, A., and Lyons, N. A. (2019). Knowledge and risk factors for foot-and-mouth disease among small-scale dairy farmers in an endemic setting. *Veterinary Research*, 50: 33.

Olechnowicz, J., andJaskowski, J. M. (2011). Reasons for culling, culling due to lameness, and economic losses in dairy cows. *Medycyna Weterynaryjna*, *67*: 618-621.

Onono, J. O., Wieland, B., and Rushton, J. (2013). Constraints to cattle production in a semiarid pastoral system in Kenya. *Tropical Animal Health and Production*, *5*: 1415-1422.

Orsel, K., De Jong, M. C. M., Bouma, A., Stegeman, J. A., and Dekker, A. (2007). The effect of vaccination on foot and mouth disease virus transmission among dairy cows. *Vaccine*, *25*(2), 327-335.

Paton, D. J., Gubbins, S., and King, D. P. (2018). Understanding the transmission of foot-and-mouth disease virus at different scales. *Current Opinion in Virology*, *28*: 85-91.

Pattnaik, B., Subramaniam, S., Sanyal, A., Mohapatra, J. K., Dash, B. B., Ranjan, R., and Rout, M. (2012). Foot-and-mouth Disease: Global Status and Future Road Map for Control and Prevention in India. *Agricultural Research*, 1: 132–147.

Ponsart, C. A. H. D., Le Bourhis, D., Knijn, H., Fritz, S., Guyader-Joly, C., Otter, T., and Mullaart, E. (2014). Reproductive technologies and genomic selection in dairy cattle. *Reproduction, Fertility and Development*, *26*: 12-21.

Pritchard, T., Coffey, M., Mrode, R., and Wall, E. (2013). Genetic parameters for production, health, fertility and longevity traits in dairy cows. *Animal*, *7*(1), 34-46.

Probert, W. J., Shea, K., Fonnesbeck, C. J., Runge, M. C., Carpenter, T. E., Dürr, S., and Werkman, M. (2016). Decision-making for foot-and-mouth disease control: objectives matter. *Journal of Epidemics*, 1: 10-19.

Rabbani, R. A., Ahmad, I., Lodhi, L. A., Ahmad, N., & Muhammad, G. (2010). Prevalence of various reproductive disorders and economic losses caused by genital prolapse in buffaloes and cattle. *Pak Veterinary Journal*, 30: 44-48.

Rafati, N., Mehrabani-Yeganeh, H., and Hanson, T. E. (2010). Risk factors for abortion in dairy cows from commercial Holstein dairy herds in the Tehran region. *Preventive Veterinary Medicine*, 96: 170-178.

Ranjan, R., Biswal, J. K., Subramaniam, S., Singh, K. P., Stenfeldt, C., Rodriguez, L. L., and Arzt, J. (2016). Foot-and-mouth disease virus-associated abortion and vertical transmission following acute infection in cattle under natural conditions. *PloS One*, 11:163-167.

Rashid, A. A. I., Hassan, M. M., Asad, M., Kaukab, G., Tehseen, A., and Aamir, S. (2020). A review on foot and mouth disease in dairy animals, etiology, pathogenesis and clinical findings. *Pure and Applied Biology*, 9:821-832.

Reshi, A. A., Husain, I., Bhat, S. A., Rehman, M. U., Razak, R., Bilal, S., and Mir, M. R. (2015). Bovine mastitis as an evolving disease and its impact on the dairy industry. *International Journal Curr Res Rev*, 7: 48-55.

Rodriguez, L. L., and Gay, C. G. (2011). Development of vaccines toward the global control and eradication of foot-and-mouth disease. *Expert Review of Vaccines*, *10*: 377-387.

Romero, J., Benavides, E., and Meza, C. (2018). Assessing Financial Impacts of Subclinical Mastitis on Colombian Dairy Farms. *Frontiers in Veterinary Science*, 5:9-15.

Rout, M., Sanyal, A., Subramaniam, S., Dash, B. B., Misri, J., Pattnaik, B., and Pathak, K. M. L. (2012). Foot and Mouth Disease: A Threat to Livestock Health, Productivity and Food Security. *Indian Farming*, 61: 3-6.

Sarker, S., Talukder, S., Haque, M. H., Islam, M. H., and Gupta, S. D. (2011). Epidemiological study on foot and mouth disease in cattle: prevalence and risk factor assessment in Rajshahi, Bangladesh. *Wayamba Journal of Animal Science, 3,* 71-73.

Sayers, R. G., Good, M., and Sayers, G. P. (2014). A survey of biosecurity-related practices, opinions and communications across dairy farm veterinarians and advisors. *The Veterinary Journal*, *200*: 261-269.

Senturk, B., and Yalcin, C. (2005). Financial impact of foot-and-mouth disease in Turkey: acquisition of required data via Delphi expert opinion survey. *Veterinarni Medicina-praha-*, *50*, 451.

Sharma, N. (2010). Foot and mouth disease-Mastitis cascade in dairy cattle: A field study. *International Journal of Zoological Research*, *6*: 356-359.

Sharma, N., Singh, N. K., and Bhadwal, M. S. (2011). Relationship of somatic cell count and mastitis: An overview. *Asian-Australasian Journal of Animal Sciences*, 24, 429-438.

Sharma, V. B., Verma, M. R., Qureshi, S., and Bharti, P. (2016). Effects of diseases on milk production and body weight of cattle in Uttar Pradesh. International Journal of Agriculture, *Environment and Biotechnology*, 9: 463-465.

Shortall, O., Green, M., Brennan, M., Wapenaar, W., and Kaler, J. (2017). Exploring expert opinion on the practicality and effectiveness of biosecurity measures on dairy farms in the United Kingdom using choice modeling. *Journal of Dairy Science*, *100*: 2225-2239.

Singh, B., Prasad, S., Sinha, D. K., and Verma, M. R. (2013). Estimation of economic losses due to foot and mouth disease in India. *Indian Journal of Animal Science*, *83*: 964-970.

Sinha, M. K., Thombare, N. N., and Mondal, B. (2014). Subclinical mastitis in dairy animals: incidence, economics, and predisposing factors. *The Scientific World Journal*, *2014*.

Sørensen, C. G., Fountas, S., Nash, E., Pesonen, L., Bochtis, D., Pedersen, S. M., and Blackmore, S. B. (2010). Conceptual model of a future farm management information system. *Computers and Electronics in Agriculture*, 72: 37-47.

Soria, I., Quattrocchi, V., Langellotti, C., Pérez-Filgueira, M., Pega, J., Gnazzo, V., ...and de la Torre, B. G. (2018). Immune response and partial protection against heterologous foot-and-mouth disease virus induced by dendrimer peptides in cattle. *Journal of Immunology Research*, 33: 434-477.

Stenfeld, C., Eschbaumer, M., Rekant, S. I., Pacheco, J. M., Smoliga, G. R., Hartwig, E. J., and Artz, J. (2016). The foot-and-mouth disease carrier state divergence in cattle. *Virology*, 28: 13-2.

Tadesse, B., Molla, W., Mengsitu, A., and Jemberu, W. T. (2019). Transmission dynamics of foot and mouth disease in selected outbreak areas of northwest Ethiopia. *Epidemiology and Infection*, 147: 1-6.

Tildesley, M. J., Bessell, P. R., Keeling, M. J., and Woolhouse, M. E. (2009). The role of pre-emptive culling in the control of foot-and-mouth disease. Proceedings of the Royal Society B: *Biological Sciences*, 276: 3239-3248.

Truong, D. B., Goutard, F. L., Bertagnoli, S., Delabouglise, A., Grosbois, V., and Peyre, M. (2018). Benefit–cost analysis of Foot-and-Mouth Disease Vaccination at the Farm-level in south Vietnam. *Frontiers in Veterinary Science*, 5: 26-33.

Tucho, T. T., and Ahmed, W. M. (2017). Economic and Reproductive Impacts of Retained Placenta in Dairy Cows. *Journal of Reproduction and Infertility*, *8*: 18-27.

Tyagi, K., Lathwal, S. S., Sharma, J., Devi, I., Gupta, R., Patbandha, T. K., and Tewari, H. (2017). Lameness in crossbred cows: Its effect on productive and reproductive performance. *Indian journal of Dairy Science*, 70: 443-446.

VanderWaal, K. L., Picasso, C., Enns, E. A., Craft, M. E., Alvarez, J., Fernandez, F., and Wells, S. (2016). Network analysis of cattle movements in Uruguay: quantifying heterogeneity for risk-based disease surveillance and control. *Preventive Veterinary Medicine*, *123*: 12-22.

Wathes, D. C. (2012). Mechanisms linking metabolic status and disease with reproductive outcome in the dairy cow. *Reproduction in Domestic Animals*, 47: 304-312.

Yahya, M., Hailemariam, Z., Amare, L. B., and Rufael, T. (2013). Seroprevalence of foot and mouth disease in traditionally managed cattle in East and West Hararghe zones, Ethiopia Séroprévalence de la fièvre aphteuse dans les élevages traditionnels des zones Est et Ouest du Hararghe, Ethiopie= Seroprevalencia de la fiebre aftosa en ganado bajo manejo tradicional en las zonas este y oeste de Hararghe, Etíopia. *Revue d'élevage et de médecine vétérinaire des pays tropicaux*, 66(1).

Zaher, Kawther and Ahmed, Wahid. (2008). Impact of Foot and Mouth Disease on Oxidative Status and Ovarian Activity in Egyptian Buffaloes. *World Journal of Zoology*. 3. 1-7.

APPENDIX A: CHECK LISTS

EGERTON UNIVERSITY

DEPARTMENT OF ANIMAL SCIENCE

Research on Quantification of Production Losses Associated with Foot and Mouth Disease Outbreaks on Large Scale Dairy Farms in Nakuru, Kenya

This checklist was conducted by a postgraduate student of Egerton University 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.

Please declare your consent {Yes/No}

Date………………………………….. **Check list no…………………………………**

SECTION A: Farm information

Farm owner (full name)	Production system	Location	Sub county/division	Telephone number

B/Milk Production

Milk yied (Kg) (Before, during and after FMD outbreak)	
Period	Breed

C/Mastitis cases

Mastitis cases (Before, during and after FMD outbreak		
Breed		
Number of Animals		

D/Culling

Culling cases (Before, during and after FMD outbreak		
Calf death		
Cow death		
Cow sold		

E/Fertility impairments

Fertility impairments (Before, during and after FMD outbreak)	
Abortion	
Retained Placenta	
Number of service/insemination per conception	

APPENDIX B: ANOVA TABLES

Effect of Foot and Mouth Disease on milk production

Source	DF	Type I SS	Mean Square	F Value	Pr > F
Period	2	185722094.62	92861047.308	487.57	<.0001
Farm	2	225511763631	112755881816	592025	<.0001
Breed	2	1373834.2259	686917.11293	3.61	0.0274

Effect of foot and mouth disease on mastitis incidences

Effect	DF	Wald Chi-Square	Pr > ChiSq
Period	2	86.5358	<.0001
Farm	2	5.5192	0.2391
Breed	2	2.8614	0.0633

Effect of Foot and Mouth Disease Culling

Effect	DF	Wald Chi-Square	Pr > ChiSq
Period	2	2.2642	0.3224
Farm	2	0.8291	0.6606
Breed	2	0.4216	0.8099

Effect of Foot and Mouth Disease on abortion

Effect	DF	Wald Chi-Square	Pr > ChiSq
Period	2	9.4241	0.0090
Farm	2	2.3906	0.3026
Breed	2	4.1272	0.1270

Effect of foot and mouth disease on retained placenta

Effect	DF	Wald Chi-Square	Pr > ChiSq
Period	2	4.3621	0.1129
Farm	2	24.2187	<.0001
Breed	2	5.4300	0.0662

Effect of foot and mouth disease on conception failure

Effect	DF	Wald Chi-Square	Pr > ChiSq
Period	2	4.2250	0.1209
Farm	2	6.0118	0.0495
Breed	2	3.9935	0.1358

APPENDIX C: Research publication

International Journal of Veterinary Sciences and Animal Husbandry 2019; 4(5): 20-22

International Journal of Veterinary Sciences and Animal Husbandry

ISSN: 2456-2912
VET 2019; 4(5): 20-22
© 2019 VET
www.veterinarypaper.com
Received: 11-07-2019
Accepted: 15-10-2019

Reagan Anguie Lewis
1. Department of Animal Sciences, Faculty of Agriculture, University of Egerton, Kenya
2. Department of Animal Production, Faculty of Natural Resources and Environmental Studies, University of Juba, South Sudan

Olivier Kashongwe Basole
Department of Animal Sciences, Faculty of Agriculture, University of Egerton, Kenya

Bockline Omedo Bebe
Department of Animal Sciences, Faculty of Agriculture, University of Egerton, Kenya

Correspondence
Reagan Anguie Lewis
1. Department of Animal Sciences, Faculty of Agriculture, University of Egerton, Kenya
2. Department of Animal Production, Faculty of Natural Resources and Environmental Studies, University of Juba, South Sudan

Quantification of fertility impairments due to foot and mouth disease outbreaks in large scale dairy farms in Nakuru, Kenya

Reagan Anguie Lewis, Olivier Kashongwe Basole and Bockline Omedo Bebe

Abstract
Foot and Mouth Disease (FMD) is a contagious viral disease to which dairy cattle are highly susceptible. This study quantified the association of FMD outbreak with fertility impairments in large scale dairy
farms with a history of FMD outbreaks in the recent past. 507 cows were recorded for the period of six weeks before, six weeks during and six weeks after foot and mouth disease outbreaks. Data were subjected to general linear model and means comparison.
Results showed that abortion before foot and mouth disease outbreak was (0.19%), while during and after FMD was (2.77%, 0.99%). The retained placenta before FMD was significant (0.19%), but during the outbreak was (1.3%) and after the outbreak was (0.59%). The conception failure or the repeated insemination for the three periods: before, during and after foot and mouth disease outbreaks was (12.47%, 6.33%, and 4.95%).

Keywords: After, before, during, fertility impairments, foot and mouth disease

Introduction
Foot and Mouth Disease (FMD) is a contagious viral disease to which dairy cattle, cloven-hoofed ruminants are susceptible [9].
The duration of FMD outbreak is generally three weeks to one month [6]. During this period, production loses variable, depending on the genetics, management of the livestock, and the systems inputs and outputs [2]. In dairy cattle the disease has associated production losses are related to drop in milk yield, culling, calf mortality, impaired fertility or increased susceptibility to mastitis [13]. The most direct economic impact of FMD in endemic countries is the loss or reduced efficiency of production, which lowers farmers' income [4].
The outbreak of FMD attracts trade bans [7, 5]. The annual global impact of FMD previously has been estimated at US$11 billion [10], moreover FMD outbreak has implications on the food nutrition and income security of the farming households and consumers as well with the threat of food supplies, security and safety [8, 12].
The effects of foot and mouth disease on fertility performance are categorized as an invisible loss and is difficult to measure particularly in the less intensive system [1], during the outbreak of FMD its effects can include: irregularity of oestrus in cattle (not seasonal), therefore extending calving interval, increase of abortion rate [11].
Retention of placenta is the inability of fetal membrane to be expelled from 8 to 48 hours, average 8 hours after parturition. The incidence of retained placenta varies from 4-18% of calving [14].

Materials and Methods
The study was undertaken in Nakuru County within Kenya Highlands. It has an altitude of
1,800 m above sea level with temperatures ranging between 17.5 °C and 22 °C on average but can drop during cold season. Average annual rainfall in the area is up to 895 mm (en.climate-date.org).

APPENDIX D: RESEARCH AUTHORIZATION

NATIONAL COMMISSION FOR SCIENCE, TECHNOLOGY AND INNOVATION

Telephone:+254-20-2213471,
2241349,3310571,2219420
Fax:+254-20-318245,318249
Email: dg@nacosti.go.ke
Website : www.nacosti.go.ke
When replying please quote

NACOSTI, Upper Kabete
Off Waiyaki Way
P.O. Box 30623-00100
NAIROBI-KENYA

Ref: No. **NACOSTI/P/19/56275/30310**

Date: **27th June 2019**

Reagan Anguie Lewis
Egerton University
P.O. Box 536-20115
NJORO.

RE: RESEARCH AUTHORIZATION

Following your application for authority to carry out research on ***"Quantification of production losses associated with foot and mouth disease outbreaks in large scale dairy farms in Nakuru, Kenya."*** I am pleased to inform you that you have been authorized to undertake research in **Nakuru County** for the period ending **24th June, 2020.**

You are advised to report to **the County Commissioner, and the County Director of Education, Nakuru County** before embarking on the research project.

Kindly note that, as an applicant who has been licensed under the Science, Technology and Innovation Act, 2013 to conduct research in Kenya, you shall deposit **a copy** of the final research report to the Commission within **one year** of completion. The soft copy of the same should be submitted through the Online Research Information System.

DR. ROY B. MUGIRA, PhD.
FOR: DIRECTOR-GENERAL/CEO

Copy to:

The County Commissioner
Nakuru County.

The County Director of Education
Nakuru County.

National Commission for Science, Technology and Innovation is ISO9001: 2008 Certified