MODELING ASSOCIATIONS BETWEEN INTENSIFICATION INTERVENTIONS AND SUSTAINABILITY IN SMALLHOLDER DAIRY FARMS IN THE KENYAN HIGHLANDS

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A thesis submitted to Graduate School in partial fulfillment for the requirements of the Master of Science Degree in Livestock Production Systems of Egerton University

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DECARATION AND RECOMMENDATION

Declaration

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

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Recommendation

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DEDICATION

To my late parents Jack Agutu and Jenipher Adhiambo, to my guardians the late James Ongany and Nick Ouma and finally to my siblings Christine, Bounventure, Nick, Benard and Winnie, I love you all.

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ABSTRACT

Increased herd productivity and incomes can be obtained with the intensification of smallholder dairy production when applying genetics, ecological and socio-economic interventions. However, intensification can also result in negative externalities including depletion of natural resources, land use changes and human health risks. This study evaluated the association of intensification interventions with herd productivity, natural resource depletion and human health risks using a set of indicator variables. Data were from a sample of 140 smallholder dairy farms in two Counties (Kiambu and Meru) benefitting from the Kenya Market Led Dairy Program. Analysis proceeded in two stages. Firstly, Principle Component Analysis (PCA) to select indicator variables for second stage regression analysis to select optimal models which quantified the contributions of each intervention to externalities. The indicator variables of herd productivity selected in PCA were milk yield (10 litres per cow/day) and margins per litre of milk (Kenya Shilling 4.2), which represent positive externalities of intensification. In the optimal model, socio-economic interventions (concentrate use, credit uptake and milk sales) had greater contribution to variations in both milk yield and margins earned compared to genetic (insemination costs) or ecological (manure recycled) interventions. The indicator variable of natural resource depletion of significance was the volume of drinking and service water on the farms (5.1 litres/ Kg of milk produced), which represent negative externality. The variations in water use were higher from socio-economic interventions (milk sales) than was from ecological intervention (manure recycling), and suggested that depletion of water would increase with sale of more milk and recycling of more manure on the farm. The indicator variable significant for human health risks was the volume of milk rejected (7.7 Kg/month), representing negative externality, but the optimal regression model had very low explanatory power (8.3%) and still, the socio-economic intervention had the largest contribution to explained variation. Results indicated that the volume of milk rejected would increase with sale of more milk, but decrease when feeding more concentrates and recycling more manure on the farm. Results imply that greater attention to socio-economic interventions is important in dairy intensification process, but require continuous monitoring to provide early warning about negative externalities that emerge.

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LIST OF ABBREVIATIONS

AEZ	Agro ecological zone
AI	Artificial insemination
CF	Crude Fibre
CP	Crude Protein
DM	Dry Matter
ECM	Energy Corrected Milk
FAO	Food Agricultural Organization
GDP	Gross Domestic Product
GHG	Green House Gases
GLM	General Linear Model
ILRI	International Livestock Research Institute
KES	Kenya Shilling
Kg	Kilogram
KCC	Kenya Cooperative Creameries
KMDP	Kenya Market Led Dairy Program
MDG	Millennium Development Goals
NGO	Non-Governmental Organization
NPK	Nitrogen, Phosphorous and Potassium
OIE	World Organization for Animal Health
PCA	Principle Component Analysis
PC	Principle Components
RVF	Rift Valley Fever
SAS	Statistical Analysis System
SPSS	Statistical Package for Social Sciences
SSA	Sub-Saharan Africa
TLU	Tropical Livestock Unit
ZDU	Zoonosis Disease Unit of Kenya

CHAPTER ONE
INTRODUCTION

1.1 Background information

Dairying is an attractive livestock enterprise in Kenya for generating income and improving food and nutrition security for smallholder farmers (Muthui *et al*., 2014). This is attributable to a higher growth rate of 3-4% experienced in the dairy sub sector which now contributes 40% to the livestock gross domestic product (GDP) and 4% to the national GDP (Ministry of Livestock Development, 2010). It is projected that meeting the growing demand for milk for the increasing population, urbanization and expanding economic growth and changes in consumer preferences will be met from continued dairy intensification process.

Intensification is the increased use of external inputs and services to increase the output quantity and/or value per unit input (Bebe *et al.*, 2002). It involves producing more units of output per unit of input through innovations in input use and marketing with the aim of raising production, yields and/ or income. Intensification requires that farmers adjust their input use, and this is associated with changes in use of the genetics, ecological processes and facilitation support farmers derive from the improved socio-economic infrastructure (Bebe, 2008; The Montpellier Panel, 2013).

Technological and socio-economic interventions that support intensification are key packages promoted for uptake in smallholder dairy farming. Technological interventions include the ecological and genetics, while socio-economic are the enabling environment to support technology adoption and development of markets for inputs and outputs in dairy production (The Montpellier Panel, 2013). A growing challenge being experienced by farmers is to identify and balance benefits and trade-offs that occur due to the use of these intensification interventions.

Trade-offs experienced have adverse effects on productivity and sustainability both in the short-run and long-run (FAO, 2014a). Escalating production costs involving feed, drugs and labour impacts on profit margins in the short run while resource depletion of water and nutrients (Nitrogen, Phosphorous and Potassium (NPK)) used in fodder production can have long-term consequences on the environment or production system. Application on interventions that optimize dairy productivity levels while at the same time minimize negative externalities would be desirable for sustainable intensification. This necessitates the need for knowledge of the associations that intensification interventions have with sustainability indicators, in order to caution those resulting in adverse negative effects in the process of intensifying dairy production.

1.2 Statement of the problem

In the Kenya highlands, application of genetics, ecological and socio-economics interventions increases herd productivity and incomes for smallholder dairy farmers intensifying their production. However, some intensification interventions result in negative externalities which lead to depletion of natural resources, land use changes and human health risks. This suggest some variability in the contributions that an intervention may make to the externalities. Some are likely to contribute more to the negative or to the positive externalities, but knowledge is limited or lacking on such relationships in smallholder dairy farms that are intensifying their production. Several indicators may measure the impact of intensification interventions and the associated externalities, but their associations with the externalities remains not quantified. This limits informed design of good farming practices to attain sustainable dairy intensification with minimal negative externalities in the production system.

1.3 Objectives

1.3.1 Broad Objective

The overall objective was to contribute towards sustainable dairy intensification through identification of intensification interventions that minimize negative externalities in dairy production in the Kenya highlands.

1.3.2 Specific objectives

i. To establish the associations between intensification interventions and herd productivity
ii. To establish the associations between intensification interventions and depletion of natural resources
iii. To establish the associations between intensification interventions and human health risks

1.4 Research questions

i. Which of the indicators of genetics, ecological or socio-economic interventions for dairy intensification do significantly contribute to herd productivity?
ii. Which of the indicators of genetics, ecological or socio-economic interventions for dairy intensification do significantly contribute to depletion of natural resources?
iii. Which of the indicators of genetics, ecological or socio-economic interventions for dairy intensification do significantly contribute to human health risks incidences?

1.5 Justification

The demand for sustainable intensification which in some cases is regulated with noncompliance and being penalized to ensure adverse impacts are contained. To ensure sustainability of smallholder dairy intensification on economic, ecological and societal issues of concern to public and authorities, farmers need evidence based knowledge of the interventions that will increase herd productivity (milk yields, profitability). The interventions should also be able to minimize negative externalities of depletion of natural resources (water, land use changes, soil nutrients) that support dairy production and the health risk incidences (zoonotic diseases, antibiotic residual effects) that are of concern to the public, consumers and the authorities. Knowledge of the contribution of interventions to positive externalities is essential in providing measures that will ensure higher productivity and providing relevant evidence for designing management interventions that counteracts the trade-offs associated with intensification on smallholder dairy farms.

CHAPTER TWO
LITERATURE REVIEW

2.1 Dairy intensification in Kenya

Dairy production systems in Kenya can be classified into two general categories: large-scale and small-scale. Small scale dairy farming predominates, with farmers owning less than three cows and produce 80 percent of total milk produced in the country (SNV, 2013a). They mostly keep exotic cattle breeds (Bebe *et al.*, 2000) which were introduced in Kenya in the 20th century by the European settlers. After independence, a rapid transfer of dairy cattle from the settler farms to the smallholder farms resulted in a rapid decline in their population on large scale farms (Muriuki, 2003). Many of the European settlers opted to leave the country and sold their large scale farms to Africans or to the government resulting in a rapid sub-division of these large farms and expansion of smallholder herds (Thorpe *et al.*, 2000).

This together with provision of livestock production and marketing services by government resulted in highly subsidized services which encouraged dairy production by smallholder farmers. Marketing of milk was boosted by the abolishment of quota system to formation of KCC which allowed for the inclusion of smallholder producers (Muriuki 2003). Besides formation of KCC, the reduced cost and accessibility of Artificial Insemination (AI) services to the small scale dairy farmers up to mid '80s (1987), ensured the success of dairy industry in Kenya. Kavoi *et al.* (2010) identified agro-climatic factors as some of the key determinants of dairy development in Kenya.

2.2 Dairy Intensification interventions

Intensification aims at producing more units of outputs per unit of all inputs through new combinations of inputs and related innovations besides improving physical input-output relations and increasing the overall efficiency of production (The Montpellier Panel, 2013). It involves a whole package of innovations based on external inputs implying that farmers have to produce more for the market and depend less on livestock functions for the livelihoods of their households (Udo *et al.*, 2011). The use of intensification interventions mainly comprises of technological and socio-economic interventions.

Technological involve ecological and genetic interventions while socio-economic intervention provide an enabling environment (The Montpellier Panel, 2013). Rapid intensification of smallholder dairy production is occurring as a result of shrinking land holdings within the

Kenyan highlands (Staal *et al.*, 2001) that have encouraged the continuous use of intensification interventions so as to meet the farmer's objectives. This has been accompanied by drastic shift to exotic breeds (Bebe *et al.*, 2003a), on the basis of their corresponding high milk production which intern relates to higher milk volume sales hence higher income generation (Bebe *et al.*, 2000). Due to this, many farmers prefer Friesians and Ayrshires thereby explaining their predominance in smallholder dairy systems within the Kenyan highlands (Bebe *et al.*, 2003a).

2.2.1 Genetic interventions

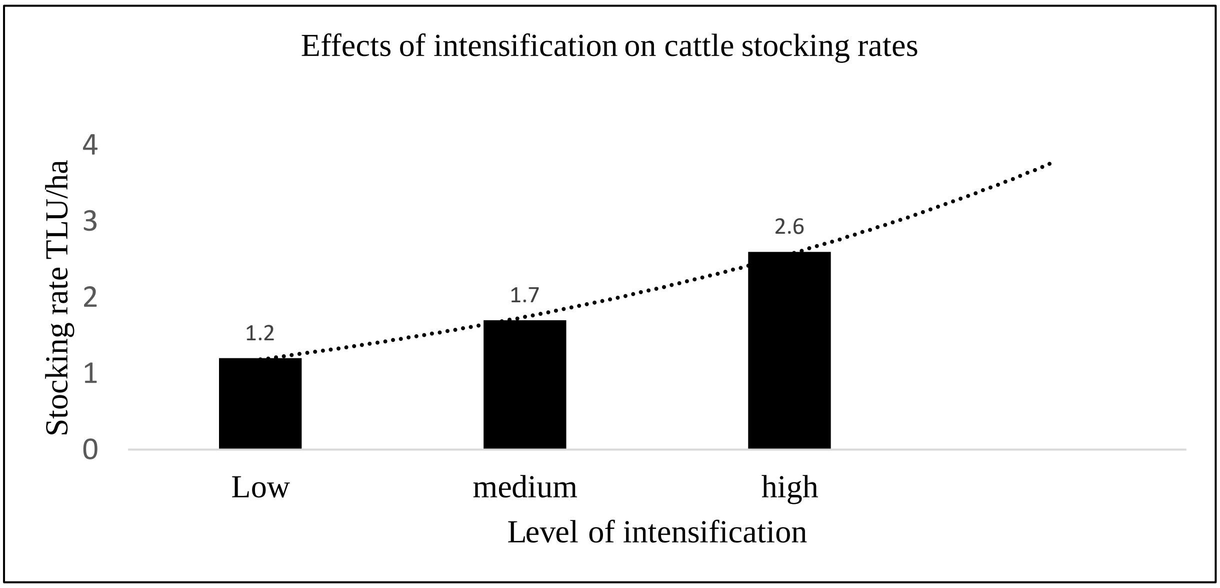
Animal breeding add support to livestock production though provision of genetic resources to the changing production circumstances (Madalena, 2012). In Kenya, the well-organized dairy cattle breeding system that was subsidized by the government, contributed to the growth of smallholder dairy farming until the mid-1980's when it was privatized (Thorpe *et al.*, 2000). This in turn, encouraged the use of intensification interventions so as to enable the farmers to meet their production objectives. Intensification of smallholder dairy production systems typically involved the adoption of exotic cattle breeds which had increased genetic potential for milk production and other complementary inputs (Nicholson *et al.*, 2004).

These exotic breeds have higher feed consumption in terms of quality and quantity as well as quality semen for insemination to achieve genetically superior offspring (Muia *et al.*, 2011). Private provision of insemination through A.I by individuals or farmer groups accelerated the provision of superior germplasm to smallholder dairy farms. A.I services mainly provided by technicians and technologists, cost farmers between KES 600 and KES 3000 depending on the region and bull quality (SNV, 2013a). In response to the costs involved, most dairy cooperatives have pooled efforts to provide the insemination services at reduced costs to their members as ways of minimizing exploitation from private inseminators while ensuring provision of good quality semen to their farmers.

Despite this, the high cost of imported semen and failure rates have made smallholder farmers to opt opt for bull services which are associated with risks of inbreeding and diseases (Muriuki *et al.*, 2003). According to Muriuki (2011), some Kenyan smallholder dairy farmers, do not fully give the best dairy practices. They do not use AI, do not feed and water the cows properly thereby leading to low production levels despite their genetic potential. In relation to breeding stock, large scale farms and other smallholdings are the main sources of cows and heifers for smallholder dairy farmers (Bebe *et al.*, 2003b). Majority of the purchases are done within the local community for easy verification of fertility and milk yield as compared to purchases done outside the community.

Stocking rates

Intensification interventions have great effects on the stocking rates of cattle within dairy farms. A study done by Bebe *et al.* (2003b), indicated a positive trend in the number of stocking rate for increased levels of intensification in dairy farms within the Kenyan highlands (Figure 1). The study showed that stocking rate increased with shifts from low to high intensive farming within the Kenya highlands. This further indicates that despite the smaller farm sizes, the farmers keep smaller herds but with higher stocking rates to achieve their production objectives.



Source: Adapted from Bebe *et al.* (2003b)
Figure 1. Stocking rates in various farming systems within Kenyan highlands

Higher stocking rates are intended to increase productivity in terms of milk and income at farm levels. On the other hand, with increased stocking rates, there is increased utilization of feed resources, GHG, manure production, and higher level of water use for drinking and service within these farms. In the long run, this could lead to environmental pollution and depletion of resources if not adequately addressed.

2.2.2 Ecological interventions

Milk production in dairy cows is normally influenced by seasonality in feed availability and quality. To meet their body requirements of 3-4% dry matter intake, dairy cows need to be fed with adequate quantity and quality feedstuffs for maximum production (Lukuyu *et al.*, 2012). Farmers with limited land face the challenge of getting sufficient fodder to feed their dairy cows during various seasons of the year. Stall-feeding of crop residues, natural and planted fodder especially Napier grass, is common within smallholder dairy farms practicing zero grazing (Omore *et al.*, 1999). In areas where dairy farming systems becomes more intensive, feed and fodder is circumvented by purchase of fodder and concentrates from other areas and increased use of agro-industrial by products (Lee *et al.*, 2014).

Napier grass is mostly used as the main feed within smallholder dairy cows, supplemented with crop residues such as maize stover, bean haulms, banana leaves, pseudo- stems and indigenous fodder trees (Mwendia *et al.*, 2006). Napier grass is fast growing, deeply rooted perennial grass growing up to 4 meters tall and can spread by underground stems to form thick ground cover. Its tender young leaves and stems are very palatable to livestock and yield 12 to 25 tonnes per hectare of dry matter per year depending on agro ecological zone and management (Ouma *et al.*, 2007). The author further reported that higher yields are always achieved by fertilizer application and better management thereby enabling surplus production which is conserved for feeding in the dry seasons.

The higher yields are also accompanied by continuous drains of nutrients especially Nitrogen (N), phosphorous (P) and potassium (K) from the soils (FAO, 2004). Napier grass is grown with little or no chemical or organic fertilizer and the dry matter is low. The digestibility and the nitrogen content of Napier grass declines rapidly as it matures especially during the dry season thereby curtailing milk production within smallholder dairy farms.

Lukuyu *et al.* (2012) described crop residues as fibrous plant materials of the harvested crop that remains after the grain or other primary products are removed and are available in many areas where crop agriculture is practiced. They are readily available, high in fibre, low in digestibility, low in Crude Protein and form the principle feed in ruminant livestock during dry seasons on smallholder farms (Lukuyu *et al.*, 2012). They mostly include stover (maize, sorghum), straws (wheat, barley or oat), banana pseudo stems and leaves. Table 1 gives a summary of the common crop residues used in dairy cattle feeding in smallholder farms and their nutritive values in terms of Dry matter (DM), Crude Protein (CP) and Crude Fibre (CF).

This further indicates that despite them being readily available and having higher dry matter content, the low CP is insufficient in meeting dairy animal's body requirements of 15-18%.

Table 1. Nutrient content of main crop residues used as animal feed

Crop residue	**DM %**	**CP%**	**CF%**
Maize stover	91	6.0	42.0
Sorghum stover	25	6.0	28.1
Banana stem	5	3.2	19.1
Wheat straw	86	4.0	42.0
Barley straw	86	4.0	42.0

Source: Adapted from Lukuyu *et al*. (2012).
DM- Dry Matter: CP- Crude Protein: CF- Crude Fibre

Maize stover is an abundant crop residue for feeding livestock in Kenya because maize is a staple diet in most communities. Although highly acknowledged as ruminant livestock useful feed, they are not effectively utilized resulting to less than 50% being consumed by livestock. These residues are used for feeding dairy cattle but cannot supply adequate nutrients without supplementation to counter the deficit (Lukuyu *et al*., 2012). Most roughages especially napier grass and crop residues used as animal feeds, are generally low in crude protein while commercial protein sources that could supplement these roughages are too expensive for many smallholder farmers to afford on regular basis and in adequate amounts (Ouma *et al.*, 2007). This necessitates supplementation by provision of protein-rich leguminous fodder and /or dairy meals within these dairy farms.

Forage legumes are important especially in intensive systems because of their high protein content ranging between 15-34%, rich in minerals (calcium and phosphorous) (Lukuyu *et al*., 2012) and ability to fix atmospheric nitrogen thereby improving fertility. Most dairy cows within smallholder farms produce average milk yields below their genetic potential partly due to lack of quality feeds (Muia *et al.*, 2011). Utilization of forage legumes provides a low cost method for improving both the quality and quantity of livestock feeds on smallholder farms. Ecologically, they can reduce the rate of decline of soil fertility, enhance crop yields and can reduce the length of the fallow period. Examples of these forage legumes and trees include Desmodium, Calliandra, Lucerne, Leucaena, Sesbania amongst others (Lukuyu *et al*., 2012).

2.2.3 Socio-economic intervention

Adoption of genetic and ecological approaches will only happen when an enabling environment is created that not only favors intensification but also its sustainability (The Montpellier Panel, 2013). Smallholders have equitable access to input and output markets through farmers associations including self-help groups and Cooperative. According to Omore *et al.* (1999), 64% of the milk produced by smallholder farmers is marketed while the remaining 36% is non-marketed or consumed at home. Of the marketed milk, 32% flows through formal channels (processors) (SNV, 2013b), while the remainder is sold as non-processed milk either through direct sales to consumers or through dairy cooperatives, self-help groups and individual milk traders.

This therefore indicates that informal markets dominate the milk sales and that most traded milk are sold either directly from farm to consumer or through informal traders (Staal *et al.*, 1998). The rapid growth of raw milk market has been attributed to the preference of raw milk by consumers and relatively higher price paid to producers by informal market agents (Muriuki *et al.*, 2003). Besides marketed milk sales, home consumption also constitute the production aims of smallholder farms with some dairy households not selling their milk but preserve for home consumption with an average of 2 litres/day of milk (Staal *et al.*, 2001).

Dissemination of proper dairy husbandry practices has always been done by government extension officers to ensure adequate dairy skills and knowledge are passed to farmers for optimum productivity (Staal *et al.*, 2001). These however, have declined with time and there is a keen shift towards demand driven extension services as farmers are left to seek for these information. Farmers groups and cooperatives have well-structured extension department that aids in provision of these services to their individual farmers. These departments in cooperation with other stakeholders carry out various activities involving farmer's visits, trainings, organizing demonstration farms (SNV, 2013a) as well as addressing farmers' individual challenges in relation to dairy production.

There is still need for these extension services so as to help disseminate new innovations, skills and knowledge to these dairy farmers for optimum productivity levels. Besides the need, there is still need for adequate private partners' participation in extension service provision. Besides the extension services, farmers attached to Cooperatives often access credit facilities for various dairy inputs involving concentrates, animal feeds and mineral licks amongst others through pay off systems offered by the Cooperatives to its members (SNV, 2013a). Through these services, farmers are able to access best inputs and services in relation to dairy production.

2.3 Externalities of intensification

2.3.1 Positive externalities

Intensification results in greater amounts of output in terms of production involving increased total amount or yield per unit input or income (The Montpellier Panel, 2013). Productivity in dairy farming is represented by the amount of milk yield produced resulting from improved high yielding livestock breeds, better feeding and nutrition and practicing best animal husbandry practices. Previous study by Muia *et al.* (2011) indicated that milk production per hectare tends to increase with increasing level of intensification. This was mainly attributed to access to extension services that aided in knowledge provision on better dairy husbandry management and practices (Muriuki, 2011).

Despite the increase in milk production, dairy animals under intensive management systems tends to have shorter productive life (Bebe *et al.*, 2003a) as compared to extensive production systems. As milk yield increases, gross margin and profit per litre of milk decreases with increase in the level of intensification within smallholder dairy farms (Kibiego *et al.*, 2015). This is mainly attributed to increase in production costs including higher feeds and labour costs. There is need for extension services and finances to improve on feed production and utilization technologies by dairy farmers to increase their profitability. This is partly achieved through cooperative movements where farmers are able to access supplementary feeding through provision of feeds on credit arrangements (Bebe *et al.*, 2003b). Table 2 outlines the effects of increasing intensification levels on animal production and reproductive performance.

Table 2. Intensification effect on average milk yield, calving interval, lactation length and age at first calving

Intensification level	Average milk yield (litres)	Calving interval (days)	Lactation length (days)	Age at fist calving (months)
Low	4.7	539	471	34.7
Medium	6.1	491	423	34.1
High	6.8	471	388	29.6

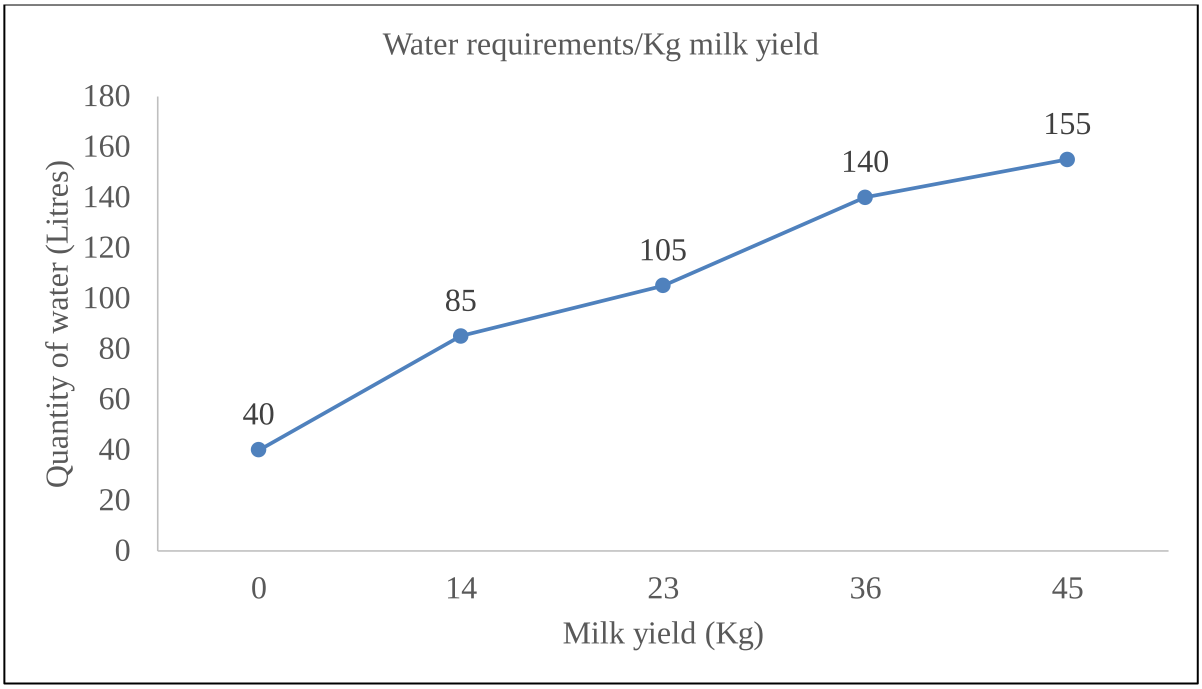
Source: Adapted from Staal *et al*., (2001)

2.3.2 Negative externalities

2.3.2.1 Water use

Satisfying the growing demands for livestock products while sustaining the natural resource base is an emerging issue confronting farming practices. Water is an essential part of livelihood and is needed for both domestic use and agricultural practices such as crop and livestock farming (Asfaw, 2013). Peden *et al*. (2009) defined livestock water productivity (LWP) as the ratio of net beneficial livestock-related products and services to the water depleted in producing them. Livestock utilize water and other feed resources in generating high value products such as milk, meat and eggs. According to Descheemaeker *et al.* (2009), variations in livestock-water relationship at farm level have been identified depending on animal herd, production objectives of farmers, management practices, livestock health and productivity. Intensification of production systems directly increases the need for water by productive animals and therefore constraints severely affect their overall productivity. Animals not only obtain water from drinking, but also from feed and metabolic processes in the body.

Around 6 litres of water per kg milk are used in the dairy farm for drinking, 2 or more litres water per kg milk are used for cleaning purposes and about 1.5 litres for the production of 1 Kg milk (Federation, 2009). Figure 2 gives an overview of various water requirements (litres) with variations in milk productivity within a dairy system. Higher milk production levels have corresponding higher water intake and this depends on various factors including the moisture content of feeds, amounts of dry matter consumed, environmental temperature, salt intake and physiological state of the animal. An increase in the factors above directly increase water intake of the animals and vice versa. Besides water intake by dairy animals, service water also varies with different levels of intensification with higher intensified systems experiencing higher water quantities as compared to low intensified systems (Asfaw, 2013).



Source: Adapted from Lukuyu *et al*., (2012)

Figure 2. Estimated water requirements in relation to increasing milk yields

2.3.2.2 Soil nutrients depletion

Soil fertility is the most important biophysical yield-determining factor besides water availability and absence of pests and diseases (FAO, 2004). Higher crop yields and biomass levels, are usually obtained from well drained fertile soils mostly in the highlands experiencing high rainfall levels throughout the year. However, in many places the already low level of fertility tends to decline further as farmers generate many nutrient outputs in crops and through processes such as leaching and erosion without applying matching inputs in the form of fertilizers, manure and biological nitrogen fixation (BNF) (FAO, 2004).

According to studies by Stoorvogel and Smaling, (1990), soil fertility in Africa is declining as shown by nitrogen (N), phosphorous (P) and potassium (K) balances. Much attention in Sub-Saharan Africa has focussed on the quantification and estimation of nutrients that enter and leave agricultural systems. Densely populated and hilly countries have the most negative balances, because of high ratio of cultivated land to arable land, relatively high crop yields and soil erosion (FAO, 2004). Table 3 shows strong negative nutrient balances for the tea-coffee-dairy zone from a previous study done in Embu District, Kenya.

Table 3. Effects of various fodder crops on soil nutrient balances in the Kenyan Highlands

Crop	Area (ha)	N	P (Kg/ha)	K
Maize	5,143	-172.2	-31.2	-73.0
Napier	602	-169.5	-22.6	-179.2
Sorghum	207	-104.5	-34.2	-30.8
Sweet potatoes	140	-177.8	-32.3	-91.9

Source: Adapted from FAO, (2004)
N-Nitrogen, P- Phosphorous, K-Potassium

From Table 3, it can be observed that with continuous feed and fodder production within dairy farms, strong negative nutrient balances are realized thereby decreasing the soil fertility levels especially in highly intensified production systems.

2.3.2.3 Feed resources

Proper feeding is a critical input in dairy production and comprises 60-70% of the total production costs. Feeding is an aspect of dairy farming which the farmers have most control of and some dairy producers in Kenya inadequately feed their animals due to deficiencies in the quality and quantity of feed (Muia *et al.,* 2011), limited access to feed and water in dry seasons, concentrates and mineral supplements. The bulk of dairy cattle feeding comprise mostly of natural forage, cultivated fodder and crop by-products (Lukuyu *et al.,* 2012). To meet the body requirements of exotic cattle breeds, adequate quantity and quality feed is required so as to achieve maximum production levels.

Forages require maximum nutrients from the soil for optimum quality and quantity yields hence well fertilized soils ensures maximum fodder yields with nutrient depletion especially NPK. Most dairy farms undertake fertilization either organically (through manures) or inorganically through use of fertilizers so as to replenish the lost nutrients in the soil (FAO, 2004). This however, tends to be expensive especially if the farms are involved in fodder production either as animal feed or for commercial purposes. The major constraint limiting dairy production in East Africa is the inadequacy of high quality forages on the farms. Various forages have been recommended for different agro ecological zones depending on the climatic conditions and soils (Lukuyu *et al.,* 2012).

2.3.2.4 Human health risks

Zoonotic diseases

Zoonoses are defined as infectious diseases that can be transmitted naturally between humans and animals (ZDU, 2013). They are particularly important in the context of some emerging human infectious diseases of humans of zoonotic origin (Slingenbergh *et al.*, 2004). It is noted that 60% of human diseases are shared with animals' with 75% of emerging diseases being zoonotic. Priority zoonotic diseases in Kenya include brucellosis, anthrax, Rift Valley Fever and bovine tuberculosis (ZDU, 2013). Livestock related zoonotic diseases cause 2.4 billion cases of human illness and 2.2 million deaths each year. The increasing role of informal non-processed milk pathways in urban areas have raised concerns over public health especially zoonosis of brucellosis and tuberculosis (Muriuki *et al*., 2003). Animal management within dairy farms should include measures to contain transmissible diseases.

Some of these measures include involving improving hygiene, quarantining new arrivals on farms and establishing coordinated, sustained surveillance for diseases (Eisler *et al*., 2014). This in turn will reduce the health risks associated with animal diseases to the community and consumers in the long run. Mastitis is still an ongoing problem among dairy farms with few farmers having experience with teat dips that could aid in its prevention (VanLeeuwen *et al.*, 2012).

Antibiotic loads

Antibiotics are naturally occurring semi-synthetic and synthetic compounds with anti-microbial activity that can be administered orally, parentally or topically (Phillips *et al*., 2004). They are used for therapeutic purposes to prevent or control the development of a disease in humans and animals. Therapeutic antibiotics use is often at higher doses than sub-therapeutic purposes and is generally administered in water or by injection. According to Landers *et al.* (2012), antibiotic use plays a major role in the emerging public health crisis of antibiotic resistance especially in human beings. With much emphasis on agricultural setting and little attention paid to how antibiotic use in farms, animals contributes to the overall problem of antibiotic resistance (Bailey *et al*., 2014). The use of antibiotics in food animals select for bacteria resistant to antibiotics used in humans (Phillips *et al*., 2004).

The main ways in which antibiotic residues are transferred to human beings includes food products and environment. Resistant bacteria remain in livestock and animal products and are passed along to humans who consume the products (Phillips *et al*., 2004). In the environment, bacteria are spread by manure on farmland through contaminated run off water bodies which lead to water reservoirs. These are then exposed to humans through drinking of contaminated water and direct transfer whereby bacteria such as enterococci are transferred to animals who work with them. Normally, antibiotic drugs have withdrawal periods which the animal product should not be consumed. Some farmers tend to ignore these instructions and will slaughter or even drink milk from treated animals (Bailey *et al.*, 2014).

This in the long run leads to ingestion of small quantities of antibiotics in to the human system giving the bacteria ample time to mutate and increase their resistance to future antibiotic agents. Due to this, the World Organization for Animal Health (OIE) raised issues on adulterations of antibiotics and their widespread use by untrained personnel leading to over exposure (Sapkota *et al.*, 2007).

2.4 Methodological approaches

2.4.1 Principle Component Analysis (PCA)

Principle Component Analysis is a statistical technique developed by Hotelling (1933) to simplify the description of a set of interrelated variables (Afifi and Clark, 1984; Rougoor *et al.*, 2000). It is used for exploring and making sense of datasets with a large number of measurements by reducing the dimensions to few principle components (Reich *et al.*, 2008). The first component (Factor 1) accounts for a maximal amount of total variance in the observed variables. This means that it will be correlated with most of the observed variables. Subsequent component account for maximal amount of variance that was not accounted for by the first component and also will be correlated with some of the observed variables that did not display strong correlations with the first component.

Besides this, they should be uncorrelated with the preceding components. Subsequent components that are further extracted in the analysis displays the same characteristics and each account for maximal amount of variance in the observed variables that are accounted for by the preceding components. The number of PCs selected is determined by examining the proportion of total variance explained by each component, or by the cumulative proportion of the total variance explained (Rougoor *et al.*, 2000). In most cases after completion of the analysis, only the first few components are usually retained and interpreted as they display varying degrees of correlation with the observed variables but are completely uncorrelated with one another.

The total variance within the data equals to the number of variables within the dataset. Significant associations are indicated by +/- factor loading ≥ 0.3 while the number of components to be retained is based on Eigen value which is set at 1. The scree plot graphically displays the size of the Eigen value associated with each component. In SAS, the PROC PRINCOMP statement requests the principle components to be computed from the correlation matrix formed from the dataset (SAS, 2009). An adopted rule of thumb for many investigators is to select only the PC's explaining at least 100/P percent of the total variance, with P being the total number of components (Afifi and Clark, 1984; Rougoor *et al*., 2000).

2.4.2 Application of Regression analysis

Regression analysis is a model of explaining linear relationship between quantitative variables defined as dependent and independent. The variability in the dependent variable is explained by a function of either one or several independent variables (Schaeffer, 2005). A model fitting several independent variables to explain or predict a change in the dependent variable is a multiple regression because it estimates several parameters but each varying in predictive value for the dependent variable.

The predictive ability of a multiple regression model is indicated by the F-test, coefficient of determination (R^2) or AIC and BIC values which are measures for the goodness of fit corrected for model complexity (Schaeffer, 2005). The smaller the AIC or BIC values indicates a good model fit while the larger values indicates poor model fit. In multiple regression analysis, the Variance Inflation Factors (VIF) is used as a measure of the amount of multi-collinearity among the variables and inform of which variables have the greatest contribution in explanatory and productive ability of the model (Rougoor *et al.*, 2000). VIF of ≤ 10 indicates a good model fit while VIF of > 10 indicates a poor model fit. Presence of multi-collinearity within a set of independent variables can cause problems in understanding the significance of individual independent variables in the regression model.

2.5 Conceptual frame work

Figure 3 illustrates the conceptualized interrelationships of various applied intensification interventions deemed to have an impact on the performance of smallholder dairy farms.

Smallholder farmers apply these approaches either at the level of individual animals or at the level of the whole herd to achieve their production objectives. This is aimed at increased milk yields and margins, while at the same time, possibilities of milk rejections at milk collection points due to poor quality milk that does not meet the standards. The environment suffers depletion of natural resources including N, P, K and water while the community at large suffers risks involving zoonotic attack, antibiotic residues in products and aflatoxin attacks.

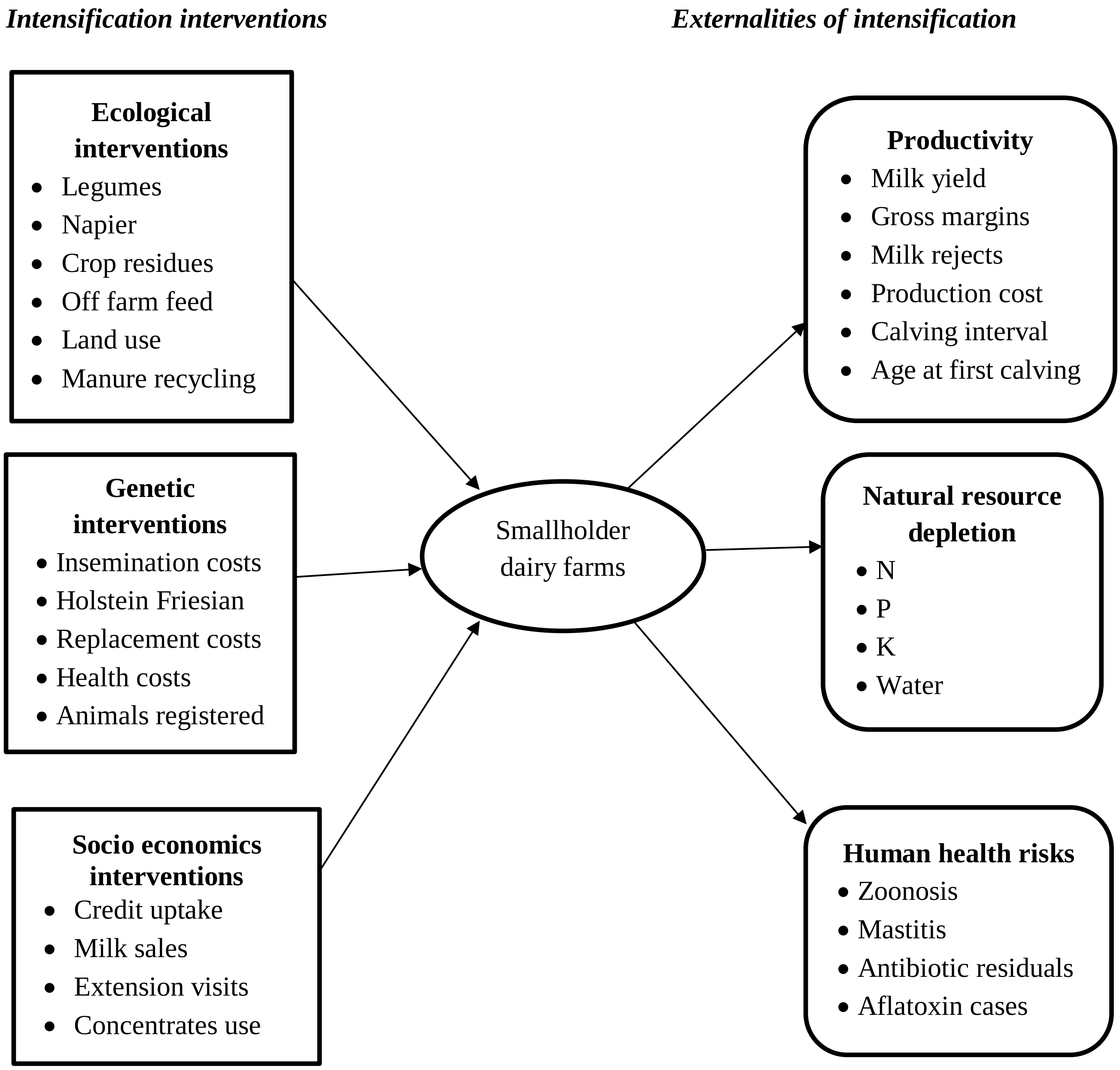


Figure 3. Conceptual framework indicating the relationship between intensification interventions and associated externalities in smallholder dairy farms

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study area

The study was undertaken on smallholder dairy farms benefitting from the Kenya Market Led Dairy Program (KMDP) in Kiambu and Meru Counties in the Kenya highlands. These counties were selected on the criteria of being beneficiaries of intensification interventions, the leading milk sheds in Kenya with a large population of smallholders adopting intensive dairy production, favorable climatic conditions for dairy production, high participation in dairy farmer cooperatives and small land holdings on which dairy is integrated with crops (Bebe *et al.,* 2002; Bebe, 2004). Smallholder farms generally are two acre farm holding on average with less than 10 cattle fed poor quality feeds, often crop residues- with limited supplemental concentrates and producing on average less than 10 litres of milk per cow per day (Bebe *et al.*, 2002).

3.2 Survey methodology

A cross sectional survey of KMDP supported smallholder dairy farms within the Kenya Highlands was undertaken between February and June 2016. A sample size of 140 farms was determined using the formulae by (Anderson *et al.*, 2003):-

$$n= \frac{z^2 \,.\, p.q}{e^2}$$

where:

z = desired confidence interval level set at 1.96 for 95% confidence interval,

p = the proportion of a characteristic of the population to be sampled, which was set at 0.735 being the proportion of households in the Kenya highlands that keep dairy animals (Bebe *et al.,* 2003b),

q = (1- p), and e is the error margin allowable for detecting a difference in the sample and was set at 0.1 to account for large variations typical of farmer recall data (Bebe *et al.*, 2002).

The SNV, the NGO implementing the KMDP program in Meru and Kiambu Counties provided the list of members of the Cooperatives from which the individual sample farms were randomly selected for farm visit and questionnaire administration.

3.3 Data collection and processing

Data were collected through observations and farm household interviews using a pre-tested structured questionnaire designed to capture individual animal and farm level data. The data collected were indicator variables of genetics, ecological and socio-economic interventions, herd productivity, natural resource depletion and human health risks as summarized in Table 4.

Table 4. Summary of indicator variables defining the intensification interventions and outcomes

Intensification interventions		
Ecological	***Genetics***	***Socio-economics***
Stocking density	Insemination cost	Milk sales volume
Napier	Health services cost	Extension visits
Leguminous fodder	Herd replacement cost	Distance to markets
Crop residues	% Holstein-Friesian in the herd	Concentrate use
Off-farm sourced feeds	% Animals registered	
Externalities of intensification		
Herd productivity	***Nutrient depletion***	***Human health risks***
Milk yield	Nitrogen (N)	Milk rejected volume
Calving interval	Phosphorous (P)	Zoonotic disease cases
Age at first calving	Potassium (K)	Mastitis
Production costs	Water use (drinking and service water)	Aflatoxin risk (feed with molds)
Gross margins		

The indicators were either measured directly in scale units or computed from the raw collected data. The computed indicator variables included concentrates (Kg), Napier (ha), crop residues (Kg), legumes (Kg) and off farm sourced feeds (Kg) per Tropical Livestock Units (TLU) on the farm. The TLU was computed from herd composition on the basis of 1 for bull, 0.7 for cow, 0.5 for heifer and 0.2 for calves (Bebe, 2004). Farm nutrients Nitrogen, Phosphorous and Potassium (NPK) balances was computed from estimated nutrient inflows less outflows associated with feeds, minerals, fertilizer, animal products and natural process (FAO, 2004). The quantities of drinking and service water per litre of milk produced were computed from the usage, herd composition and herd milk production within farm level. Production cost/litre of milk was computed from the costs of inputs while gross margin per litre of milk was computed from sales less input costs.

3.4 Data analysis

This aimed at detecting the association between intensification interventions and the resulting externalities defined by herd productivity, natural resource depletion, and human health risks. The analysis involved processing indicator variables on each sample farm in Excel spreadsheet to generate descriptive statistics for Principle Component Analysis (PCA) and multiple linear regression modelling to reduce dimensionality in the data set and to select indicator variables for regression analysis. The goodness of fit of PCA was assessed on basis of Varimax rotation with Kaiser-Meyer-Olkin Normalization procedure (KMO) (Afifi and Clark, 1984; Rougoor *et al*., 2000).

The Varimax rotation aided in extracting few PCs with highly correlated variables that maximize sum of variances. Hair *et al.* (2006) and Che *et al.* (2013) explains application of the KMO as a measure of sampling adequacy which is satisfied when KMO value is ≥ 0.5 and is significant ($P<0.05$). In addition, Bartlett's test of sphericity was computed to check that the correlation matrix was not an identity matrix for which a P value <0.05 is indicative. Three separate PCA models fitting and all of them had indicator variables of all the three categories of intensification but each separately run with indicator variables for herd productivity, natural resource depletion or human health risks.

A factor loading of ±0.3 was set prior and a rule of thumb applied in which an extracted PC had to explain at least 100/PC% of the variance to be selected for the next stage of regression modelling (Afifi and Clark, 1984; Rougoor *et al*., 2000). For instance, where PCA extracts five PC's, only those variables within PC accounting for at least 20% (100/5=20%) are selected for subsequent multiple linear regression model.

The second stage of data analysis involved fitting selected indicator variables from the PCA in a multiple regression model to determine optimal predictive model. This predictive model explains association of herd productivity, natural resource depletion or human health risks with the three groups of intensification interventions. The multiple linear regression model fitted was in the form:

$$Y_{ij} = a + b_1(x_1) + b_2(x_2) + b_3(x_3) + \ldots + b_n(x_n) + e_{ij}$$

where;

Y_{ij} = the dependent variable,

a = the intercept,

$b_1, b_2, b_3 \ldots b_n$ are the coefficients for indicator variable $x_1, x_2, x_3 \ldots x_n$ respectively

e_{ij} is the random error.

The x predictor variables represented indicators of the intensification interventions while the y dependent variables are herd productivity, natural resource depletion or human health risks. The model goodness of fit was judged on the criteria using AIC or BIC and SSE and largest adjusted R^2 values to obtain an optimal predictive model that define the association between intensification interventions and the externalities. The optimal predictive model was selected on the criteria of highest R^2 value and lowest AIC or BIC and SSE values.

CHAPTER FOUR

RESULTS

4.1 Description of the sample smallholder dairy farmers

The percentage distributions defining the characteristics of the sample households show differences between the two counties as presented in Table 5. Dairy farming within the two counties was male dominated (61%), with more educated farmers above secondary education (73.5%). They predominantly practiced mixed intensive farming (81%), integrating dairy with crops, but dairy was a primary livelihood base for only a few of the farmers (13%).

Table 5. Percent (%) distribution of the sample households by their factors and counties

Factors	Level	Pooled data (%)	Counties (%)		Chi square statistic
			Meru	Kiambu	
Gender	Male	61.4	68.8	51.7	4.22*
	Female	38.6	31.2	48.3	
Education level	Primary	16.4	23.8	6.7	13.12**
	Secondary	36.4	41.2	30.0	
	Tertiary	47.1	35.0	63.3	
Farming system	Intensive	80.7	75.0	88.3	3.916*
	Semi intensive	19.3	25.0	11.7	
Primary occupation	Mixed farming	83.6	91.2	73.3	10.43*
	Dairy farming	12.9	8.8	18.3	
	Business	1.4	0	3.3	
	Employed	2.1	0	2.1	

*P<0.05, **P<0.01, P<0.001

On average, the sample farmers obtained were below 50 years old with about 11 years of experience in dairy production, characterized by a herd size of less than 4 cattle on small farm holding of less than a hectare (Table 6).

Table 6. Mean estimates for farmer and farm characteristics by counties

Variables	Counties	Mean ±SD	P value
Age (years)	Meru	42.56±11.4	0.246
	Kiambu	46.23±12.9	
	Overall	44.14±12.2	
Dairy experience (years)	Meru	10.51±6.0	0.367
	Kiambu	12.68±6.4	
	Overall	11.44±6.2	
Farm size (area/ha)	Meru	0.95±0.5	0.767
	Kiambu	0.90±0.5	
	Overall	0.93±0.5	
Herd size (numbers)	Meru	3.79±1.8	0.466
	Kiambu	3.33±1.9	
	Overall	3.59±1.9	

The descriptive statistics of indicator variables for ecological, genetics and socio-economic interventions in intensifying dairy production in the sample farms are summarized in Table 7. Table 8 contain descriptive statistics for externalities of intensification represented by herd productivity, natural resource depletion, and human health risks.

The means for productivity, magnitude of natural resource depletion, or health risks with the intensification interventions implemented have large standard deviations, an indication of large heterogeneity between the farms.

Table 7. Descriptive statistics of the intensification interventions in the sample farms (n=140)

Variables	Units	Mean	SD
Ecological indicators			
Land use	% ha fodder	55	20.4
Napier	Kg DM/TLU/y	1629	1036.6
Legume	Kg DM/TLU/y	8.5	6.6
Crop residues	Kg DM/TLU/y	1057.1	531.0
Stocking density	TLU/ha	2.3	0.8
Manure recycling	Kg/y	5.4	2.7
Off farm feeds	Kg DM/TLU/y	990.84	675.76
Genetic indicators			
Insemination cost	KES/Cow	1,564	516.9
Replacement cost	KES/Cow	49,423	18,877.5
Veterinary cost	KES/Cow	1,364	693
Disease control	KES/herd	35,523	2,307.8
Herd registration	% animals	19	33.1
Holstein-Friesian breed	% animals	74	31.3
Socio-economic indicators			
Concentrates	Kg DM/TLU	3270	1501.4
Milk sales	Kg/herd /month	630.2	498.4
Credit uptake now	KES/year	61,794.87	32,453.50
Extension visits	Number/month	1.7	0.8
Distance to markets	Kilometers	1.9	1.5

Table 8. Descriptive statistics of indicator variables of herd productivity, natural resource depletion and human health risks in sample dairy farms (n=140)

Externalities indicators	Units	Mean	SD
Herd productivity			
Production Cost	KES/ Kg of milk	20.4	5.3
Milk yield	Kg/cow/month	342.4	130.3
Calving Interval	Months	17.0	2.0
Age at First Calving	Months	30.1	3.2
Margin/litre	KES/litre of milk	4.2	7.5
Natural resource depletion			
N	Kg/ha	-55.9	30.5
P	Kg/ha	-6.2	6.1
K	Kg/ha	-68.3	35.5
Total water use	Litres/Kg of milk	5.1	2.2
Human health risks			
Mastitis	% positive cases	66.1	24.4
Milk rejected at market delivery	Kg/herd/month	7.7	4.6
Zoonotic diseases	Number of cases/year	1.1	0.3
Aflatoxin risks	% feeds with molds	4.9	4.9

4.2 Association between herd productivity and intensification interventions

In Table 9, the PCA fitted for indicators defining intensification interventions and herd productivity was satisfactory in sampling adequacy (KMO=0.616) and the correlation matrix was not an identity matrix (Bartlett's test Chi square =1457.48, P=0.000). The PCA extracted two PCs that explained 99.63% of the total variance and applying the rule of thumb (100/2PCs=50%), only variables loading on PC 1 accounting for 90.06% of the total variance were selected for further regression analysis to derive optimal model. The variables loading highly on PC 1 are three socio-economic indicators (credit uptake, milk sales and concentrate use), one ecological indicator (manure recycling) and one indicator of genetic (insemination costs) interventions and all have positive associations with milk yield and margins per litre of milk. These two indicator variables of positive externality were subsequently fitted in two separate regression models to explain their association with the indicators of ecological, genetic and socio-economic interventions in intensification of dairy production.

Table 9. Retained variables for herd productivity and intensification interventions from PCA analysis

Indicator variables	Principle Component 1	Principle Component 2
Replacement cost		0.767
Credit uptake	0.944	
Milk sales	0.551	
Insemination cost	0.399	
Concentrates use	0.382	
Milk yield	0.342	
Manure recycling	0.340	
Margin per litre of milk	0.331	
Total variance explained (%)	**90.063**	**9.566**

Rotation method: Varimax with Kaiser-Meyer-Olkin Normalisation. Sampling adequacy (KMO=0.616). Bartlett's test of sphericity (Chi square =1457.477, Sig=0.000).

The results of the two regression models are presented in Table 10 for the derived optimal model from a selection of 15 and 31 models evaluated (Annex II) on the basis of smallest AIC, BIC, C(p) and SSE values and largest R^2. More than half (58%) of the variations in milk yield is explained by socio-economic interventions (concentrate use, milk sales and credit uptake) and genetic intervention (insemination costs) without ecological intervention indicators. In contrast, about half (45%) of the variations in margins per litre of milk were explained by socio-economic (concentrates use, milk sales), genetics (insemination costs) and ecological intervention (manure recycling) indicators.

Table 10. Optimal model selected for explaining milk yield and margin per litre of milk

Model	Variables in the model	Adj R^2	AIC	BIC	C(p)	SSE
Milk yield	Concentrates, Milk sales, Credit uptake, Insemination cost,	0.58	318.03	320.40	5.00	1263.75
Margin per litre of milk	Concentrates, Insemination cost, Milk sales, Manure recycling	0.45	498.71	501.15	4.06	4593.56

The optimal models derived for estimating the milk yields (M) and margin per litre of milk (G) respectively were:

$$M = 6.38007 + 0.00061571(C) + 0.23152(S) - 0.00001009(L) - 0.00051878(I)$$

$$G = 6.34086 + 0.59428(S) - 0.00111(C) - 0.00100(I) - 0.82356(MU)$$

where;
M= milk yield in Kg per cow,
G=margins per litre of milk
C= concentrates used in Kg dry matter per tropical livestock unit,
S= milk sales in Kg per herd,
L= credit uptake in Kenyan Shillings per year,
I= insemination costs in Kenya shillings per animal and
MU=manure recycling

In the derived optimal model on the basis of highest R^2 value and lowest AIC or BIC and SSE values for explaining milk yield, the socio-economic indicators of significance (Table 11) were concentrate use, credit uptake and milk sales which account for 50.7% of the variance and genetics had one indicator variable of significance, insemination costs, which accounted for only 6.7%. Concentrate use and milk sales showed positive association with milk yield while credit and insemination costs had negative associations. In the optimal model for explaining margins per litre of milk, the socio-economic indicators of significance were concentrate use and milk sales which accounted for 39.7% of the variance, much higher than variance accounted for by genetics (3.7%) intervention represented by insemination costs or ecological intervention (2.4%) represented by manure recycling. The margins per litre of milk was positively associated with milk sales but was negatively associated with manure recycling, insemination costs or concentrate use.

Table 11. Coefficients and variance contribution (%) by ecological, genetics and socio-economic indicators in the optimal models explaining milk yield and gross margins per litre of milk as proxies for herd productivity

Intensification indicators	Milk yield (Kg/cow/month)		Gross margin (KES/Litre milk)	
	Coefficients	Variance (%)	Coefficients	Variance (%)
Insemination costs (KES/cow)	-0.00051878	6.7	-0.00100	3.7
Concentrate use (Kg/TLU)	0.00061571	7.0	-0.00111	3.5
Milk sale (KES/herd/month)	0.23152	41.3	0.59428	36.2
Credit uptake (KES/year)	-0.00001009	2.4		
Manure recycling (Kg/year)			-0.82356	
Constant	6.38008		6.34086	
Total variance explained (%)		**57.5**		**45.8**

4.3 Association between natural resource depletion and intensification interventions

In Table 12, the PCA fitted for indicators defining nutrient depletion and intensification interventions was satisfactory in sampling adequacy (KMO=0.67) and the correlation matrix was not an identity matrix (Bartlett's test Chi square =382.25, p=0.000). The PCA extracted two principle components that explained 99.4% of the total variance and applying the rule of thumb (100/2PCs=50%), only variables loading on PC 1 that explain 64.32% of the total variance were retained. The retained variables were three socio-economic indicators (credit uptake, milk sales and extension visits), one ecological indicator (manure recycling) and one indicator of genetics (insemination costs) intervention, all of which had positive associations with total water use.

Table 12. Retained variables for natural resource depletion and intensification interventions after PCA analysis

Indicator variables	Principle component 1	Principle component 2
Replacement cost		0.903
Credit (Loans)	0.968	
Milk Sales	0.495	
Total water use	0.369	
Insemination cost	0.364	
Manure recycling	0.361	
Extension visits	0.315	
Total variance explained (%)	**64.32**	**35.06**

Rotation method: Varimax with Kaiser-Meyer-Olkin Normalisation. Sampling adequacy (KMO =0.670), Bartlett's test of sphericity (Chi square =382.246, Sig=000).

The derived optimal model explaining water use was selected out of 31 models evaluated on the basis of smallest AIC, BIC, C(p) and SSE values and largest adjusted R^2 (Appendix III). The model explained 73% of the variation in total water use in dairy farms and the explanatory indicator variables of socio-economic (milk sales) and ecological (manure recycling) interventions, without any indicator of genetic intervention as presented in Table 13. This model was:

Total water use = 18.47006 + 0.05021(MU) + 3.45141(S)

Where MU= manure recycling and S= milk sales in Kg per herd,

Table 13. Optimal model selection for dependent variable Total water use

Model	Variables in the model	Adj R^2	AIC	BIC	C(p)	SSE
Water use	Manure recycling, Milk sales	0.73	1096.1	1098.3	0.64	336956

The indicator variables of significance in the selected optimal model (Table 14) for total water use were milk sales (socio-economic intervention) and it accounted for 63.3%, and while manure recycling (ecological intervention), accounted for only 6.3% of the total variation. Both manure recycling and milk sales showed positive association with total water use in dairy farms.

Table 14. Coefficients and variance contribution (%) by ecological and socio-economic indicators in the optimal model explaining water use, a proxy for natural resource depletion

Intensification indicators	Coefficients	Variance (%)
Milk sales (KES/herd/month)	3.45141	66.3
Manure recycling (Kg/year)	0.05021	6.3
Constant	18.47006	
Total variance explained (%)		**72.6**

4.4 Association between human health risks and intensification interventions

Table 15 presents PCA fitted for indicators defining human health risks and intensification interventions was satisfactory in sampling adequacy (KMO=0.55) and has a correlation matrix that is non-identity matrix (Bartlett's test Chi square =112.631, P=0.000). Two PC's were extracted that explained 99.47% of the total variance and applying the rule of thumb (100/2PCs=50%), only variables loading on PC 1 that explained 81.5% of the variance were selected for subsequent linear regression analysis. The variables loading highly on PC 1 were three socio-economic indicators (credit uptake, milk sales, and concentrate use), two indicators of genetics (insemination cost, disease control) and one indicator of ecological (manure recycling) interventions. These indicators had positive associations with quantities of milk rejected while disease control has a negative association. These indicators were subsequently submitted to a regression model to explain milk rejected with the indicators of socio-economic, genetic and ecological interventions in intensification of dairy production.

Table 15. Retained variables for human health risks indicators and intensification interventions from PCA analysis

Indicator variables	Principle component 1	Principle component 2
Credit uptake	0.974	
Milk sales	0.303	
Milk rejected	0.283	
Concentrates	0.277	
Insemination cost	0.226	
Disease control	-0.224	
Manure recycling	0.213	
Replacement cost		0.856
Napier		-0.229
Stock density		0.208
Total variance explained (%)	**81.56**	**17.91**

Rotation method: Varimax with Kaiser-Meyer-Olkin Normalisation. Sampling adequacy (KMO=0.546), Bartlett's test of sphericity (Chi square =1127.631, Sig=0.000).

Table 16 presents the derived optimal model for explaining the volume of milk rejected selected out of 63 models evaluated (Annex IV) on the basis of smallest AIC, BIC, C(p) and SSE values and highest adjusted R^2. This model has very low explanatory power (8%) and the indicators of significance are socio-economic (concentrates use, milk sales) and ecological (manure recycling) interventions. The indicators of genetics intervention had no contribution in optimal model that explained the volume of milk rejected and this negative externality has a positive association with milk sales and negative associations with concentrate use or manure recycling. The model is in the form of:

$$R = 7.29974 + 0.29302(S) - 0.93090(MU) - 0.00090817(C)$$

Where R= rejected milk in Kg per herd, S= milk sales in Kg per herd, MU=manure recycling and C=concentrate use.

Table 16. Optimal model selection for dependent variable milk rejected representing human health risks

Model	Variables in the model	Adj R^2	AIC	BIC	C(p)	SSE
Milk rejected	Manure, Concentrates, Milk sales	0.08	581.17	588.49	2.6	8397.82

The optimal model for the volume of milk rejected (Table 17) show that socio-economic indicators of significance were concentrate use and milk sales, which accounted for the most (6.5%) of the total variance compared to manure recycling (1.8% of variance). Manure recycling and concentrate use were negatively associated with the volume of milk rejected while milk sales was positively associated with the volume of milk rejected.

Table 17. Coefficient and variance contribution (%) by ecological and socio-economic indicators in the optimal model explaining milk rejected, a proxy for human health risks

Intensification indicators	Coefficients	Variance (%)
Manure recycling (Kg/y)	-0.93090	1.8
Concentrates use (Kg/TLU)	-0.00090817	1.2
Milk sales (KES/herd/month)	0.29302	5.3
Constant	7.29974	
Total variance explained (%)		**8.3**

CHAPTER FIVE
DISCUSSION

This study evaluated the contribution of different intensification interventions to both positive and negative externalities in dairy production in order to inform implementation of sustainable smallholder dairy intensification. The underlying motive is that while smallholders undertake intensification of their dairy production with genetics, ecological and socio-economic interventions to increase herd productivity and incomes, intensification can also result in negative externalities. The evaluation was implemented in two stages, starting with PCA to select from a large number of indicator variables those with significant effects for regression analysis in the second stage of analysis to quantify the contribution of the interventions to externalities. In the PCA stages, all indicator variables for the genetics, ecological and socio-economic interventions were fitted each time with the indicators for herd productivity, natural resource depletion or human health risks. This approach enabled selection of indicator variables of significance which were evaluated with the aim of determining an optimal model to quantify the association between intensification interventions and the associated externalities.

5.1 Associations between herd productivity and intensification interventions

The indicator variables of significance in the association between intensification interventions and herd productivity were milk yield and margins per litre of milk, which represented positive externalities. Milk production was estimated at 324.4 litres per cow per month (Table 8), which translates to about 10 litres per cow per day, comparing well with 309 litres per cow per month observed in the Kenya Highlands (Mburu *et al.*, 2007; Tegemeo, 2016). The margins per litre of milk was estimated at KES 4.2 which is within range of KES 3.45 to 8.25 range obtained in previous empirical studies (Mburu *et al.*, 2007; Kibiego *et al*., 2015; Tegemeo, 2016). However, the means of milk yield and margins per litre of milk had large standard deviations, typical of recall data, which in this study was within one year recall data because record keeping is not a practice in smallholder farms (Murage and Ilatsia, 2011; Bett, 2016).

Means associated with large standard deviations also mean large heterogeneity between the individual farms in productivity levels attained with the intensification interventions that were adopted. Production costs of up to KES 20.40 per litre of milk are comparable to KES 18.10 and KES 19.00 reported by Mburu *et al*., (2007) and Wambugu *et al.*, (2011) respectively and do point to farmers spending more on inputs to maximize milk production. This stepping up of production costs erodes profitability despite supporting increased milk productivity. Milk production per cow per year is influenced by calving intervals that averages 17 months in a typical of smallholder farm (Bebe *et al.*, 2003b). This can be explained by imbalanced feeding, poor heat detection and insemination failures and long periods of lactation in excess of 330 days (Staal *et al.*, 1998).

The optimal model for milk yield had an explanatory power of 57.5% (Table 11) of which the socio-economic indicators contributed the most (50.7%) and the genetic indicators just a little (6.7%) while the ecological interventions had no contribution. The socio-economic indicator variables were concentrate use, credit uptake and milk sales while the genetics indicator variable was insemination costs. The socio-economic indicator variables of significance in the optimal model demonstrate importance of providing an enabling environment for accessing input and output markets. On the other hand, the genetic indicator variable demonstrate importance of improved genetic quality of the herd which can be achieved by investments in reproductive technology to attain high milk yielding potential.

Linking farmers with markets for both inputs and outputs provide a pathway to intensification adoption because milk is a perishable commodity that requires marketing arrangements for collection, distribution and sale. The study by Duncan *et al.* (2013) on the relationship between market quality and basic feeding and breeding practices in smallholder dairy farms in Ethiopia and India is supportive of this observation. In that study, the authors concluded that well-developed markets with good procurement arrangements support sustainable dairy intensification. The Montpellier Panel Report (2013) explains that market linkage is supportive to adoption of sustainable dairy intensification for smallholders who often have little contact with the market and so is their understanding of the market dynamics and requirements. Of importance, is compliance with the quality and safety standards for processing milk and market linkage to enable producers to benefit from increasing demand for quality milk for processing (KDB, 2015).

The current study showed that farmers would obtain more milk yield when feeding more concentrates as this indicator variable had positive association with milk yield. Lukuyu *et al.* (2007) in a study of the feeding regimes in smallholder dairy farms explained that concentrates provide balanced supplementary diets to milking cows which are pervasively underfed with crop residues and roughages of poor quality. Supplementing concentrates will therefore have marked effect on increasing milk yield in smallholder dairy cows, as demonstrated in several studies Duncan *et al*., (2013); Kashongwe *et al.*, (2014); Kashongwe *et al.*, (2017). The production of large volume of milk is expected to trigger market participation due to the surplus milk on the farm, hence the positive association between milk yield and milk sales.

On the other hand, uptake of credit and insemination costs had decreasing effects on milk yield. Several situations in smallholder farms could possible explain this. The credit though obtained for dairy investments, may be invested in other farm productive activities that support but take long to influence milk yield. These can include improving quality of the breed, housing and equipment and on-farm feed production. Results on the insemination costs imply that increased investments in insemination services were associated with a decline in milk yield. Increased insemination is likely aimed at improving quality of breeding stock but it may be that farmers failed to match quality of the breeding stock with their management standards, especially feeding and health, resulting in improved stock failing to express full genetic potential in milk yield.

The optimal model explaining margins per litre of milk had socio-economic, genetics and ecological intervention indicator variables. The model explained 45.8% (Table 11) of the variation in margins per litre of milk and the socio-economic indicator variables accounted for the largest variance (39.7%) compared to the genetic (3.7%) or ecological (2.4%) indicator variables. The socio-economic indicator variables were concentrate use and milk sales while the genetics indicator variable was insemination costs and ecological indicator variable was the amount of manure recycled on the farm. The large variations in margins per litre explained by the socio-economic indicators further serve to demonstrate the importance of an enabling environment for supporting intensification of dairy production because unreliable milk markets can impede commercialization and discourage intensification process.

Margins per litre of milk had positive associations with milk sales but negatively associated with concentrate use, manure recycling and insemination costs. The positive association of margins per litre of milk with milk sales may be explained by better milk price obtained by the farmers delivering more milk to cooperatives because they can negotiate price (Rademaker *et al.,* 2016) as the sample farmers were members of farmer cooperative societies. The negative association of insemination costs and concentrate use with the margins obtained per litre of milk could have resulted from increased production costs incurred in using these inputs, because they are highly priced in Kenyan markets, hence decreasing the margins as obtained in earlier studies (Kibiego *et al.*, 2015; Tegemeo, 2016).

Spending more on semen would mean that farmers were ordering for higher quality semen but not realizing immediate benefits of quality genetics, because of increased cost of production and hence the negative associations with the margins earned. This applies as well to feeding more concentrates purchased at high market price thereby increasing the production costs and subsequently lowered margins earned. This could be related to inefficient resource use on the farms following findings that economic efficiency in producing milk under intensive systems is 65% and that margins per litre of milk decreases with increasing costs of feeds (Kibiego *et al*., 2015) . The efficiency of intensive milk production can be improved via enhanced resource management and allocations. Cortez-Arriola *et al*. (2016) reported that by just re-allocating the current resources itself, smallholder dairy intensification in North-West Michoacán of Mexico led to economic, social and/or environmental improvements.

Livestock manures do offer alternative sources of cheap fertilizer for on-farm feed and fodder production in smallholder farms. Negative associations exhibited between manure recycling and margins per litre of milk means more manure recycled on the farms is associated less margins earned on milk. It may be that manure supplied inadequate nutrients for fodder production, forcing the farmers to purchase more feeds or alternative fertilizers for fodder production, pushing up the production costs. This is in agreement with a study by Kibiego *et al.*, (2015) which reported that producing milk at increased production costs reduces the margins per litre of milk.

5.2 Associations between natural resource depletion and intensification interventions

Natural resources of importance in smallholder dairy farms are soil nutrients (N, P, and K) and water for which the observed descriptive statistics of the current study show a status of ongoing depletion compared to studies by Stoorvogel and Smaling, (1990); FAO, 2004). The present study estimated nitrogen balance of -55.9 Kg/ha, representing a deepening depletion from -38Kg/ha in 1990 and -46 Kg/ha in 2004 (FAO, 2004). A similar trend is observed for Potassium balance of -68.3 Kg/ha, deepening from -23 Kg/ha in 1990 to -36 Kg/ha in 2004 and for Phosphorous balance of -6.2 Kg/ha from a balance of 0 to -1 Kg/ha between 1990 and 2004 in smallholder farms in the Kenya highlands. The higher negative balances depict a negative externality through depletion of soil nutrients (N, P, K) thereby raising an environmental concern.

With the model that evaluated the associations between natural resource depletion and intensification interventions adopted, water use was the indicator variable of importance identified in the selected optimal model. The model explained 72.6% (Table 14) of the variations in volume of total water use (drinking and service water) with one socio-economic intervention indicator variable – milk sales - and one ecological intervention indicator variable –manure recycling on the farm. The socio-economic indicator accounted for most of the explained variance (66.3%) with the little remainder variations contributed by ecological indicator (6.3%).

Water use was estimated at 5.1 litres for a Kg of milk produced, a value that is within the reported range of 4.6 and 6.0 litres of water per Kg of milk (Descheemaeker *et al*., 2009; Federation, 2009). With this volume of drinking and service water needed for every litre of milk produced, an average farm that has two cows, each producing 10 litres a day and milked for 300 days will on average need 30,600 litres of water in a year. This water resource demand demonstrates negative externality of intensification in high utilization and depletion rates of water from either underground or surface water sources in addition to increasing production costs in sourcing water. Water use was positively associated with volume of milk sold and manure recycled on the farm. This implies that farmers would deplete more water when selling more milk and recycling more manure on the farm. Depletion of water impacts on future water availability and production costs (Haileslassie *et al.*, 2010).

Farmers who produce and sell large volumes of milk have to observe high standards of hygiene by service cleaning of the dairy units and equipment within the farms. Higher milk sales also involve the use of bigger milk cans for storage and transportation purposes which in turn consumes more water and detergents during cleaning and rinsing. Positive association between water use and manure recycling within these farms, would entail use of more water for cleaning, hygiene maintenance and in slurry manure. This eases distribution within the farms for fodder production because feed production is the largest consumer of water in a crop-livestock system (Steinfeld *et al.*, 2006; Descheemaeker *et al*., 2009).

5.3 Associations between human health risks and intensification interventions

The potential negative externalities of intensification of importance to human health risks include incidences of zoonosis diseases, drug residues in products, aflatoxin risks, mastitis infections and volumes of milk rejected (Byarugaba *et al.*, 2008; FAO, 2014b). The study estimated the prevalence of mastitis infections at 66.1% which may trigger indiscriminate use of antibiotics in the treatment of sick cases within the farms. Besides this, observing the recommended withdrawal periods by these farmers means foregoing revenues from milk sales during that withdrawal period thereby lowering the overall income from milk sales. Indiscriminate use of antibiotics is a negative externality that poses public threats to milk and meat consumers. Other evidence of negative externalities in this study were 1.1 cases of zoonotic disease per year and 4.9% of the animal feeds with molds attack thereby posing threats to human health both in the short and long run.

The major indicator of human health risks was volume of milk rejected which was estimated at 7.7 Kg/month, slightly lower than 10 Kg estimated in wet seasons in smallholder dairy farms (Muriuki, 2003). However, the model had very low explanatory power, explaining only 8.3% (Table 17) of variations in volume of milk rejected. The intensification interventions associated with the volume of milk rejected were socio-economics represented by milk sales and concentrates use while ecological interventions represented by the amount of manure recycled on the farm. Genetic intervention had no contribution.

In the derived optimal explanatory model, the volume of milk rejected was positively associated with milk sales but negatively associated with manure recycling and concentrate use. Results indicate that the volume of milk rejected would increase with sale of more milk, but less would be rejected when increasing amount of concentrates fed and amount of manure recycled on the farm. This is contrary to expectations that selling large volume of milk should trigger farmers to practice high standards of hygiene to reduce post-harvest losses. Milk rejection is an indication of failures in hygienic milk handling practices which SNV, (2013b); Ndungu *et al.*, (2016) have reported that are related to higher bacterial counts and adulterations.

Negative relationship between milk rejections and manure recycling indicates decreased milk rejections with increased manure recycling within these farms. This could mean that when more manure is produced, farmers recycle more manure on the farm either for fodder and crop production or biogas production which thereby reduce manure accumulation within the farms.

This in turn would reduce possibilities of milk contamination with manure (dirt or faecal) (Ndungu *et al.* 2016) to explain negative associations with milk rejection . For concentrate use, more usage was associated with less volume of milk rejections, which could mean that farmers feeding more concentrates have better hygienic milking environment that minimize contamination. With high costs of concentrates, farmers tend to efficiently utilize the available quantities (Lukuyu *et al*., 2012) thereby minimizing wastes that could contaminate milk from the dairy cows.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The study evaluated the contributions of different intensification interventions to positive and negative externalities in smallholder dairy farms intensifying their milk production. The analysis of data obtained from a sample of 140 farms aimed at identifying the indicators of genetics, ecological or socio-economic interventions that are significantly associated with herd productivity, depletion of natural resources and human health risks. From the results, it can be concluded that;

i. Socio-economic interventions had the greatest contribution to both milk yield and margins earned. The indicator variables of socio-economic intervention with significant influence were concentrate use, credit uptake and milk sales while indicator variable of genetic intervention was insemination costs and the ecological indicator was the amount of manure recycled on the farm.

ii. The indicator variable of natural resource depletion of significance was the volume of water use for drinking and service in the farms, which represent negative externality. The variations in water use were greatest from socio-economic interventions and very little from ecological and genetic interventions. The indicator variable of socio-economic intervention was milk sales and the ecological indicator was amount of manure recycling on the farm. The depletion of water would increase with sale of more milk and recycling of more manure on the farm.

iii. The indicator variable significant for human health risks was the volume of milk rejected, representing negative externality. Though regression model had very low explanatory power (8.3%), socio-economic intervention had the largest contribution and a little from ecological interventions, represented by the amount of manure recycled on the farm. The volume of milk rejected would increase with sale of more milk, but less when feeding more concentrates and recycling more manure on the farm.

6.2 Recommendations

Results of this study demonstrate that socio-economic interventions are supportive and enablers to sustainable dairy intensification apart from human health risks. However, they require continuous monitoring to provide early warning about negative externalities that may emerge. Research for options for sustainable dairy intensification will need to pay attention to enhancing performance recording on the farms to provide necessary data and information for monitoring the trends towards sustainability. Another research area is participatory development of indicators for monitoring negative externalities associated with dairy intensification interventions.

REFERENCES

Afifi, A. A., & Clark, V. (1984). Computer-aided multivariate analysis. Lifetime Learning Publications, Belmont, California, 458 pp. CRC Press. Accessed on 22/09/2016.

Anderson, D. R., Sweeney, D. J., & Williams, T. (2003). *Essentials of statistics for business and economics.* Thomson South-Western, Mason. Accessed on 12/01/2016.

Asfaw, M. A. (2013). Livestock-Water interactions: The case of Gumara Watershed in the Upper Blue Nile Basin, Ethiopia. PhD Thesis. Department of Animal Sciences. Alemaya University of Agriculture, Ethiopia. Accessed on 12/01/2016.

Bailey, R., Froggatt, A., & Wellesley, L. (2014). Livestock – Climate Change's Forgotten Sector Global Public Opinion on 77 Meat and Dairy Consumption. Energy, Environment, and Resources (pp. 1–30). Accessed on 01/09/2016.

Bebe, B. O., Thorpe, W., Udo, H. M., & Mulinge, W. (2000). Breed preferences and breeding practices in smallholder dairy systems of the central highlands of Kenya. In 7th KARI Biennial Scientific Conference. Retrieved from https://doi.org/10.1007/s11548-012-0737-y. Accessed on 25/11/2015.

Bebe, B. O. (2004). Effects of feeding systems and breed of cattle on reproductive performance and milk production on smallholder farms. *Uganda Journal of Agricultural Sciences*, *9*(1- pt2), 558–563. Retrieved from www.ajol.info/index.php/ujas/article/viewFile/135521/125 028. Accessed on 12/01/2016.

Bebe, B. O., Udo, H. M., & Thorpe, W. (2002). Development of smallholder dairy systems in the Kenya highlands. *Outlook on Agriculture*, *31*(2), 113–120. Retrieved from https://doi.org/10.5367/0000 00002101293958. Accessed on 01/09/2016.

Bebe, B. O., Udo, H. M., Rowlands, G. J., & Thorpe, W. (2003a). Smallholder dairy systems in the Kenya highlands: Breed preferences and breeding practices. *Livestock Production Science*, *82*(2–3), 117–127. Retrieved from https://doi.org/10.1016/S0301-6226(03)000 29-0. Accessed on 01/09/2016.

Bebe, B. O., Udo, H. M., Rowlands, G. J., & Thorpe, W. (2003b). Smallholder dairy systems in the Kenya highlands: Cattle population dynamics under increasing intensification. *Livestock Production Science*, *82*(2–3), 211–221. Retrieved from https://doi.org/10.1016 /S0301-6226(03)00013-7. Accessed on 01/09/2016.

Bebe, B. O. (2008). Dairy heifer rearing under increasing intensification of smallholder dairy systems in the Kenya highlands. *Livestock Research for Rural Development*, *20*(22). Retrieved from http://www.lrrd.org/lrrd20/2/bebea20022.htm. Accessed on 09/12/2015.

Bett, K. B. (2016). Smallholders' use of animal information and trait preferences in insemination and herd replacement practices in dairy cattle in western Kenya. MSc Thesis, Egerton University. Accessed on 31/05/2017.

Byarugaba, D. K., Nakavuma, J. L., Vaarst, M., & Laker, C. (2008). Mastitis occurrence and constraints to mastitis control in smallholder dairy farming systems in Uganda. *Livestock Research for Rural Development*, *20*(1). Retrieved from http://www.lrrd.org/lrrd2 0/1/byar20005.htm. Accessed on 19/01/2017.

Che, M. S. R., Tasmin, R., Takala, J., & Norazlin, H. (2013). Factor Retention Decisions in Exploratory Factor Analysis Results: A Study Type of Knowledge Management Process at Malaysian University Libraries. *Asian Social Science*, *9*(15), 227. Retrieved from https://doi.org/10.5539 /ass.v9n15p227. Accessed on 10/10/2016.

Cortez-Arriola, J., Groot, J. C. J., Rossing, W. A. H., Scholberg, J. M. S., Améndola Massiotti, R. D., & Tittonell, P. (2016). Alternative options for sustainable intensification of smallholder dairy farms in North-West Michoacán, Mexico. *Agricultural Systems*, *144*(2), 22–32. https://doi.org/10.1016 /j.agsy.2016.02.001. Accessed on 31/05/2017.

Descheemaeker, K., Amede, T., & Haileslassie, A. (2009). Livestock and water interactions in mixed crop-livestock farming systems of sub-Saharan Africa: Interventions for improved productivity (No. 133). Colombo, Sri Lanka: International Water Management Institute.44p (IWMI Working Paper 133). https://doi.org/ISBN 978-92-9090-702-2. Accessed on 01/09/2016.

Duncan, A. J., Teufel, N., Mekonnen, K., Singh, V. K., Bitew, A., & Gebremedhin, B. (2013). Dairy intensification in developing countries: effects of market quality on farm-level feeding and breeding practices. *Animal*, *7*(12), 2054–2062. Retrieved from https://doi.org/10.1017/S1751731113001602. Accessed on 01/09/2016.

Eisler, M. C., Lee, M. R. F., Tarlton, J. F., Martin, G. B., Beddington, J., Dungait, J. A. J., … Winter, M. (2014). Agriculture: Steps to sustainable livestock. *Nature*, *507*(7490), 32–

34. Retrieved from https://doi.org/10.1038/507032a. Accessed on 01/02/2017.

FAO. (2004). Scaling soil nutrient balances. Enabling mesolevel applications for African realities. Rome. Retrieved from tp://ftp.fao.org/agl/agll/docs/fpnb15.pdf. Accessed on 01/09/2017. Accessed on 19/01/2017.

FAO. (2014a). Building a Common Vision for sustainable food and agriculture: Princples and approaches. Rome: FAO. Retrieved from https://doi.org/10.1177/109821408300400423. Accessed on 19/01/2017.

FAO. (2014b). Impact of mastitis in small scale dairy production. Animal Production and Health Working paper. No. 13. Rome. Retrieved from www.fao.org/3/a-i3377e.pdf. Accessed on 19/01/2017.

Federation, I. D. (2009). Environmental / Ecological Impact of the Dairy Sector:Literature review on dairy products for an inventory of key issues List of environmental initiatives and influences on the dairy sector. Brussels. Retrieved from http://www.fil-idf.org. Accessed on 11/09/2015.

Haileslassie, A., Peden, D., & Taddesse, G. (2010). Livestock water productivity concepts and practices: Experiences from mixed farming system in East African Highlands.IN: Proceedings of the 4th International Conference on Environment and Education, Ahmedabad, India, 24-28 November 2008. (pp. 1–17). Retrieved from http://hdl.handle.net/10568/3952. Accessed on 16/8/2016.

Hair, J. F., Black, W. C., Babin, B. J., & Anderson, R. E. (2006). Multivariate Data Analysis (6th ed.) Upper Saddle River, NJ: Pearson Prentice Hall. Accessed on 10/10/2016.

Kashongwe, O. B., Migwi, P., Bebe, B. O., Ooro, P. A., Onyango, T. A., & Osoo, J. O. (2014). Improving the nutritive value of wheat straw with urea and yeast culture for dry season feeding of dairy cows. *Tropical Animal Health and Production, 46*(6), 1009–1014. Retrieved from https://doi.org/10.1007/s11250-014-0598-1. Accessed on 19/01/2017.

Kashongwe, O. B., Bebe, B. O., Matofari, J. W., & Huelsebusch, C. G. (2017). Effects of feeding practices on milk yield and composition in peri-urban and rural smallholder dairy cow and pastoral camel herds in Kenya. *Tropical Animal Health and Production, 49*(5), 909–914. Retrieved from https://doi.org/10.1007/s11250-017-1270-3. Accessed on 31/05/2017.

Kavoi, M. M., Hoag, D. L., & Pritchett, J. (2010). Measurement of economic efficiency for smallholder dairy cattle in the marginal zones of Kenya. *Agricultural Economics*, *2*(4), 122–137. Retrieved from https://doi.org/10.1080/03031851003798603. Accessed on 19/01/2017.

KDB. (2015). Kenya Dairy Board Annual Report and Financial Statements for the year ended 30 June 2014. Kenya Dairy Board (KDB). Available at: http://kdb.co.ke/press/publications/reports/21-kdb-2014-annual-report/file.Kilelu, C.W., L. Klerkx, L., an. Accessed on 26/01/2018.

Kibiego, M. B., Lagat, J. K., & Bebe, B. O. (2015). Competitiveness of Smallholder Milk Production Systems in Uasin Gishu County of Kenya. *Journal of Economics and Sustainable Development*, *6*(10), 39–46. Accessed on 11/09/2016

Landers, T. F., Cohen, B., Wittum, T. E., & Larson, E. L. (2012). A review of antibiotic use in food animals: perspective, policy, and potential. *Public Health Reports* (Vol. 127). Retrieved from http://www.pubmedcentral.nih.gov/articlerender.fcgi?artid=3234384& tool =pmcentrez&rendertype=abstract. Accessed on 29/09/2015.

Lee, J. Van Der, Zijlstra, J., Wouters, B., & Vugt, S. Van. (2014). *Milking to Potential: Strategic Framework for Dairy Sector Development in Emerging Economies. Discussion paper.* Wageningen. Retrieved from www.wageningenUR.nl/en. Accessed on 07/12/2015.

Lukuyu, M., Romney, D., Ouma, R., & Sones, K. (2007). Feeding dairy cattle: a manual for smallholder dairy farmers and extension workers in East Africa. Smallholder Dairy Project/ Kenya Dairy Development Programme (SDP/KDDP), ILRI, Nairobi. (Kenya).ILRI Manuals and Guides. no. 2. 51p. Nairobi (Kenya): ILRI. Retrieved from http://hdl.handle. net/10568/478. Accessed on 18/01/2016.

Lukuyu, B., Gachuiri, C. K., Lukuyu, M. N., Lusweti, C., & Mwendia, S. (2012). *Feeding dairy cattle in East Africa*. *East Africa Dairy Development Project.* Nairobi, Kenya. Retrieved from https://scholar.google.com/scholar?cluster=8864360012852157201&hl =en&as_ sdt=2005&sciodt=0,5. Accessed on 18/01/2016.

Madalena, F. E. (2012). Animal breeding and development – South American perspective.

Journal of Animal Breeding and Genetics, *129*(3), 171–172. Retrieved from https://doi.org/ 10.1111/j.1439-0388.2012.01006.x. Accessed on 07/12/2015.

Mburu, L. M., Gitu, K. W., & Wakhungu, J. . W. (2007). A cost - benefit analysis of smallholder dairy cattle enterprises in different agro - ecological zones in Kenya highlands. *Livestock Research for Rural Development*, *19*(7). Retrieved from http://www.lrrd.org/lrrd19/7/mbur 19095.htm. Accessed on 09/08/2016.

Ministry of Livestock Development. (2010). *Kenya National Dairy Master Plan*. Nairobi. Accessed on 01/09/2016.

Muia, J. M. K., Kariuki, J. N., Mbugua, P. N., Gachuiri, C. K., Lukibisi, L. B., Ayako, W. O., & Ngunjiri, W. V. (2011). Smallholder dairy production in high altitude Nyandarua milk-shed in Kenya: Status, challenges and opportunities. *Livestock Research for Rural Development*, *23*(108). Retrieved from http://www.lrrd.org/lrrd23/5/muia23108.htm on 25/06/2016.

Murage, A. W., & Ilatsia, E. D. (2011). Factors that determine use of breeding services by smallholder dairy farmers in Central Kenya. *Tropical Animal Health and Production, 43*(1), 199–207. Retrieved from https://doi.org/10.1007/s11250-010-9674-3. Accessed on 10/10/2016.

Muriuki, H. G. (2003). Milk and dairy products, post-harvest losses and food safety in sub-Saharan Africa and the Near East: A review of the small-scale dairy sector-Kenya. Rome, Italy: Prevention of Food Losses Programme. Rome, Italy, 60. Food Agricultural Organization. Accessed on 11/09/2015.

Muriuki, H. G. (2011). Dairy development in Kenya. Food and agriculture organization of the united nations, Rome, Italy. *Pp 52*. Accessed on 11/09/2015.

Muriuki, H., Omore, A., Hooton, N., Waithaka, M., Ouma, R., Staal, S. J., & Odhiambo, P. (2003). The policy environment in the Kenya dairy sub-sector: a reviewSDP Research and Development Report No.2 Smallholder Dairy (R& D) Project. Nairobi. Retrieved from https://cgspace.cgiar.org/handle/10568/1784. Accessed on 08/12/2015.

Muthui, J. N., Mshenga, P. M., & Bebe, B. O. (2014). The influence of livestock market structure conduct and performance on herd productivity among smallholder dairy farmers in Western Kenya. *Journal of Agricultural Economics and Development*, *3*(1), 12–16. Retrieved from http://academeresearchjournals.org/journal/jaed ISSN 2327-3151 ?2014 Academe Research Journals. Accessed on 22/07/2015.

Mwendia, S. W., Wanyoike, M., Wahome, R. G., & Mwangi, D. M. (2006). Farmers' perceptions on importance and constraints facing Napier grass production in Central Kenya. *Livestock Research for Rural Development*, *18*(160). Retrieved from http://www.lrrd.org/lrrd18/11/mwen18160.htm. Accessed on 07/12/2015.

Ndungu, T. W., Muliro, P. S., Omwamba, M., Oosterwijk, G., & Jansen, A. (2016). Quality control of raw milk in the smallholder collection and bulking enterprises in Nakuru and Nyandarua Counties, Kenya. *African Journal of Food Science*, *10*(5), 70–78. Retrieved from https://doi.org/10.5897/AJFS2015.1412. Accessed on 14/10/2016.

Nicholson, C. F., Thornton, P. K., & Muinga, R. W. (2004). Household-level Impacts of Dairy Cow Ownership in Coastal Kenya. *Journal of Agricultural Economics*, *55*(2), 175–195. Retrieved from https://doi.org/10.1111/j.1477-9552.2004.tb00092.x. Accessed on 11/09/2015.

Omore, A., Muriuki, H., Kenyanjui, M., Owango, M., & Staal, S. (1999). The Kenyan Dairy Sub-Sector. A Rapid Appraisal. MOA/KARI/ILRI Smallholder Dairy (Research & Development) Project Report Funded by British Department for International Development (DFID) January, 1999. Retrieved from http://www.cgiar.org/ilri/info/databases.cfm. Accessed on 08/12/2015.

Ouma, R., Njoroge, L., Romney, D., Ochungo, P., Staal, S., & Baltenweck, I. (2007). Targeting Dairy Interventions in Kenya: A Guide for Development Planners, Researchers and Extension Worker. SDP/KDDP. Nairobi, Kenya. Retrieved from http://mahider.ilri.org/bit stream/handle/10568/483/Target_Dairy_Kenya_MG1.pdf ;jsessionid=2EC763D13E BFCB71C099143D87727205?sequence=1. Accessed on 12/01/2016.

Peden, D., Taddesse, G., & Haileslassie, A. (2009). Livestock water productivity: Implications for sub-Saharan Africa. *Rangeland Journal*, *31*(2), 187–193. Retrieved from https://doi.org/10.1071/RJ09002. Accessed on 23/08/2016.

Phillips, I., Casewell, M., Cox, T., Groot, B. De, Friis, C., Jones, R., … Waddell, J. (2004). Does the use of antibiotics in food animals pose a risk to human health ? A critical review of published data. *Journal of Antimicrobial Chemotherapy*, *53*(1), 28–52. Retrieved from https://doi.org/10.1093/jac/dkg483. Accessed on 11/09/2015.

Rademaker, C. J., Bebe, B. O., Lee, J. van der, & Kilelu, C. (2016). Sustainable growth of the Kenyan dairy sector: a quick scan of robustness, reliability and resilience (No. 979). Wageningen University & Research, Wageningen Livestock Research. Retrieved from https://doi.org/10.13140/RG.2.2.26350.41285. Accessed on 14/03/2017.

Reich, D., Price, A. L., & Patterson, N. (2008). Principal component analysis of genetic data. *Nature Genetics*, *40*(5), 491–492. Retrieved from https://doi.org/10.1038/ng0508-491. Accessed on 16/03/2016.

Rougoor, C. W., Sundaram, R., & Van Arendonk, J. A. M. (2000). The relation between breeding management and 305-day milk production, determined via principal components regression and partial least squares. *Livestock Production Science*, *66*(1), 71–83. Retrieved from https://doi.org/10.1016/S0301-6226(00)00156-1. Accessed on 22/09/2016.

Sapkota, A. R., Lefferts, L. Y., McKenzie, S., & Walker, P. (2007). What do we feed to food-production animals? A review of animal feed ingredients and their potential impacts on human health. *Environmental Health Perspectives*, *115*(5), 663–70. Retrieved from https://doi.org/10.1289/ehp.9760. Accessed on 11/09/2015.

SAS, I. (2009). *SAS/STAT ®9.2 User's Guide,*. (Cary, Ed.) (2nd ed., Vol. 2). North Carolina: SAS Institute Inc. Retrieved from https://support.sas.com/documentation/cdl/en/statugmcmc/63125/PDF/default/statugmcmc.pdf. Accessed on 20/01/2016.

Schaeffer, L. R. (2005). *Biostatistics for Animal Science*. (Vol. 122). London: CABI. Retrieved from https://doi.org/10.1111/j.1439-0388.2005.00495.x. Accessed on 12/10/2015

Slingenbergh, J., Gilbert, M., Balogh de, K., & Wint, W. (2004). Ecological sources of zoonotic diseases. *Revue Scientifique et Technique de l' Office international des épizooties, International Technical and Scientific Journal - Office of Epizooties 23*(2), 467–484. Retrieved from https://doi.org/10.20506/rst.23.2.1492. Accessed on 11/09/2015.

SNV. (2013a). Dairy Sector Policy Study and Capacity Needs Assessment of Stakeholder

Associations. SNV report. Nairobi, Kenya. Retrieved from http://www.snv.org/public/cms/sites/default/files/explore/download/kmdp_-_dairy_policy_study_report_2013.pdf. Accessed on 11/09/2015.

SNV, K. (2013b). Quality Based Milk Payment Study Kenya Dairy Sector. SNV KDMP Project report. Nairobi, Kenya. Retrieved from http://www.snv.org/public/cms/sites/default/files/ explore/download/kmdp_-_quality_based_milk_payment_study_2013.pdf. Accessed on 11/05/2017.

Staal, S. J., Chege, L., Kenyanjui, M., Kimari, A., Lukuyu, B., Njubi, D., … Wambugu, M. (1998). Characterisation of Dairy Systems Supplying the Nairobi Milk Market. A pilot survey in Kiambu district for the identification of target producers. KARI/MoA/ILRI Collaborative Research Project Report. Retrieved from www.smallholderdairy.org/publications/Collaborative R&D. Accessed on 11/12/2015.

Staal, S. J., Owango, M., Muriuki, H., Kenyanjui, M., Lukuyu, B., Njoroge, L., … Thorpe, W. (2001). *Dairy Systems Characterization Of The Greater Nairobi Milk Shed*. *Development - SDP Research Report*. Retrieved from http://hdl.handle.net/10568/1590 on 1/10/2015.

Steinfeld, H., Gerber, P. D. D., T., W., Castel, V., de Haan, C., D., W. T., … de Haan, C. (2006). Livestock's long shadow: environmental issues and options. *(Food and Agricultural Organization), UN.* Rome. Accessed on 30/01/2017.+

Stoorvogel, J.J. & Smaling, E. M. A. (1990). Assessment of soil nutrient depletion in sub-Saharan Africa: 1983-2000. Report 28. Wageningen, The Netherlands, Winand Staring Centre. Accessed on 19/01/2017.

Tegemeo. (2016). Report of a study on assessing the costs of production structures in dairy systems in Kenya. Nairobi: *Tegemeo Institute of Agricultural Policy and Development, Egerton University.* Nairobi, Kenya. Available at: http://www.tegemeo.org. Accessed on 31/01/2017.

The Montpellier Panel. (2013). *Sustainable Intensification: A New Paradigm for African Agriculture*. London. pp 36. Accessed on 15/07/2015.

Thorpe, W., Muriuki, H. G., Omore, A., Owango, M. O., & Staal, S. (2000). Development of smallholder dairying in Eastern Africa with particular reference to Kenya. In *a paper* *prepared for the UZ/RVAU/DIAS/DANIDA-ENRECA Project Review Workshop. 10-13 January 2000, Bronte Hotel, Harare, Zimbabwe. Africa* (p. 10). Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/1754/Thorpe *et al*-2000-Dev of smallholder dairying in EA-Zimbabwe.pdf?sequence=1. Accessed on 22/07/2015.

Udo, H. M., Aklilu, H. A., Phong, L. T., Bosma, R. H., Budisatria, I. G., Patil, B. R., … Bebe, B. O. (2011). Impact of intensification of different types of livestock production in smallholder crop-livestock systems. *Livestock Science*, *139*(1–2), 22–29. Retrieved from https://doi.org/10.1016/j.livsci.2011.03.020. Accessed on 22/07/2016.

VanLeeuwen, J. a., Mellish, T., Walton, C., Kaniaru, A., Gitau, R., Mellish, K., … Wichtel, J. (2012). Management, productivity and livelihood effects on Kenyan smallholder dairy farms from interventions addressing animal health and nutrition and milk quality. *Tropical Animal Health and Production*, *44*(2), 231–238. Retrieved from https://doi.org/10.1007/s11250-011-0003-2. Accessed on 22/07/2015.

Wambugu, S., Kirimi, L., & Opiyo, J. (2011). Productivity trends and performance of dairy farming in Kenya. Tegemeo Institute of agricultural policy and development. *WPS43/2011*. https://doi.org/WPS 43/2011. Accessed on 20/03/2016.

Zoonosis, Disease, & Unit Of Kenya. (2013). List of Priority Zoonotic Diseases for Kenya. Retrieved, from http://zdukenya.org/list-of-priority-zoonotic-diseases-for-kenya/.. on September 1, 2015

APPENDICES

APPENDIX I Data collection sheet

Dairy Intensification interventions and associated outcomes

Introduction

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

A: GENERAL INFORMATION

Serial number ________________________ Date ______________________________

County [____] Kiambu Sub County
[____] Meru ______________________________

A: HOUSE HOLD INFORMATION		
Name of respondent		Mobile Phone Number:
Respondent Sex:	[ ]	1=Male, 2=Female
Household headship	[ ]	1=Male headed 2=Female headed
Respondent Age	[ ]	Years
Respondent Education level	[ ]	1=None, 2=Primary, 3=Secondary, 4=Tertiary
Primary occupation		1=Dairy farming, 2=Mixed farming, 3=Cash and food crops:
Farming system used	[ ]	1=Intensive, 2=Semi intensive, 3=others (specify)
Total land area (acres)	[ ]	Area under dairy production [ ]
Dairy Farming experience in years	[ ]	

B: ANIMAL INFORMATION

Please give information on animals that have exited the farm in last 12 months

No.	Breed	State	Reason for exit	Age at first calving	Age at exit	Value price at exit (KES)	Productive life (years)

Reason for exit: 1= Death 2=Sales 3=Stolen 4=Donated 5=Others

SECTION C; ANIMAL PRODUCTIVITY

Give information on the various individual dairy cattle breeds on the farm in the order of farmer's preferences

No.	Breed	Registered Stud group 1=Yes 2=No	Milk Producti o n/day (Kg)	Age at first calvin g	Last Calving interval s	Lactatio n period (months)	State	Age	Inse min a tion	Insemin atio n cost	Insemin ation sourc e	Disease case	Treatment provider	Cost of treatme n t (KES)	Drugs used in treatmen t
1															
2															
3															
4															
5															
6															

Breed codes; 1= Friesian, 2= Aryshire, 3=Guernsey 4= Jersey, 5= Crosses, 6=Others (Specify)
State; 1=Dry, 2=Pregnant, 3=Lactating, 4=Calving, 5=Heifer
Insemination type ;1= AI 2= Bull, 3=others (specify)
Source of insemination;1=Private vet, 2=Cooperative vet 3= Govt vet, 4=Bull, 5=Others
Disease cases 1=Mastitis 2 = Milk fever 3 = Reproduction (abortion, fertility) 4 =tick-borne diseases 5= Respiratory / Pneumonia
6 = Diarrhea's 7 = Intestinal worms 8= Others (specify)
Drugs used in treatment; 1=Tetracycline, 2=Oxytetracycline, 3=Procaine, 4=Ampicillin, 5=Streptomycin, 6=Pen strep, 7:Others

SECTION D: HERD HEALTH

Please give information on the herd health status of the dairy breeds within the farm

Observe withdr a wal period 1=Yes, 2=No	Withdr awal time (hours)	Use of antihelminths (dewormers)	Total cost for whole herd if used	Control of Ectoparasi t e (ticks)	If acaricide s use , techniqu e applied	Frequency of applicati o n	Total cost of acaricide s for whole herd	Vaccinati ons types	No. of cattle vaccinat e d	Total Cost of vaccinati ons (KES)	Frequency of access to extension services/mo n th

Use of antihelminths; 1=Only on individual animals, 2=As a preventive measure

Ectoparasite control;1=None 2=Use acaricides 3=grazing 4=Traditional treatments 5=Others (specify) **Techniques in acaricides application**; 1=Dipping 2=Hand spray 3=Hand wash 4=Pour on 5=Others **Application frequency**; 1=Irregularly 2=Weekly 3= after 2 weeks 4=Monthly 5=Others

Vaccination types; 1=FMD, 2=LSD, 3=CBPP, 4=RVF, 5=Anthrax, 6=Brucellosis 7=Salmonellosis 8: Others
Extension service access/month: 1=None 2=Once 3=Twice 4=Thrice 5= 4 Times 6=More than 4 times

SECTION E: DAIRY HERD WATER AND MANURE RECYCLING;

Please fill in the details below in relation to water and labour use

Drinking water Litres/day	Service water Litres/day	Do you use hired labour in dairy production	If Yes what is the frequency of use	Labour cost/month

Frequency of hired labour use; 1=Occasionally 2=Daily 3=Weekly 4=Once every 2 weeks 5=Monthly
Do you use animal manure in fodder production at farm level? 1=Yes 2=No

____

If Yes, estimate the quantity applied on the farm for fodder production ____

SECTION F: INPUT AND MILK MARKET

Please give information on the input (minerals, dairy meal) and milk market experienced by the farmer

Source of input supply	Distance covered to input supply	Cost of transporting inputs to	Type of milk market	Distance covered to milk market	Cost (if any) incurred in reaching

Input supply source; 1=Agrovet 2=Shop 3=Market 4=Own 5=Others
Milk market type; 1=Formal market, 2=Informal market

SECTION G: FEEDS AND FEEDING

Please give information on the various animal feeds use in the farm

	Source	Units	Unit price	Quantity	Land area if on-farm(acres)	Cost of transport if off farm
Napier grass						
Fodder legumes						
Fodder trees						
Crop residues						
Pastures						
Supplements						
Garden weeds						
Others(Specify)						

Source of animal feeds;1= On farm, 2= Off farm,
Feeding units; 1=Kg, 2=wheelbarrows, 3=Pickups, 4=Bicycles, 5=Donkey/hand carts, 6=others

SECTION H: REPLACEMENT STOCK

If there were any dairy cattle bought within the last 12 months please answer the following

No.	Breed	Reason	Source	Age	State	Cull cow No.	Price	Parity	In calf heifer	Price
1										
2										
3										
4										
5										

Breed codes; 1= Friesian, 2= Aryshire, 3=Guernsey 4= Jersey, 5= Crosses, 6=Others (Specify
Reasons for purchase; 1=Increase milk for sale, 2=Expanding the herd, 3=Breeding stock, 4=Add social prestige, 5=Others (specify)
Source of stock; 1=Kept not owned, 2=Reared on the farm, 3=Bought from commercial large scale farm, 4=Bought from Government dairy farm, 5=Bought from smallholder farmer, 6=Gift, 7=Others
Source location; 1=within sub-county, 2= Outside sub-county
State at purchase; 1=Dry, 2=Pregnant, 3=Lactating, 4=Calving, 5=Heifer, 6=Others

SECTION I: MILK SALES

Please give information on the sales of milk in order of buyer's preference

Market outlet	Quantity sold	Sale price	Volume of Milk rejected	Why rejected	Credit access 1=yes, 2=no	If access how much within the last 5 years

Milk market outlets; 1= Dairy hub 2=Neighbors 3=Hawkers 4= Home consumption, 5= processors
Cause of milk rejection; 1=Mastitis, 2=Dirt in milk, 3=Bad smell, 4= Others (specify)
Intervention measure for correction; 1=Seek treatment 2=Did nothing 3= sold 4=Others

State some of the major challenges you experience at farm level

1…………………………………………………………………………………………

2……………………………………………………………………………………………

3……………………………………………………………………………………………

4……………………………………………………………………………………………

Any incidences of zoonotic diseases within the last 5 years [ ] 1=Yes, 2=No. If yes, please specify and give the number of cases [ ]

Other general comments

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

…………………………………………………………………………………………

Thank you

APPENDIX II Optimal model selection for dependent variables milk yield and gross margin representing herd productivity

Milk yield						
No	**Variables in the model**	**R^2**	**AIC**	**BIC**	**C(p)**	**SSE**
1	Concentrates, Insemination cost, Milk sales ,Credit (loans)	0.58	318.03	320.40	4.21	1263.75
2	Concentrates, Insemination cost, Milk sales	0.58	319.22	321.37	5.31	1292.86
3	Concentrates, Milk sales, Insemination cost, Credit (loans), Manure	0.58	319.80	322.36	6.00	1261.72
4	Concentrates, Milk sales, Insemination cost, Manure	0.58	320.95	323.16	7.05	1290.40
5	Concentrates, Milk sales	0.55	324.83	32.62	10.98	1365.09
6	Concentrates, Milk sales, Credit (loans)	0.56	324.90	326.73	11.00	1346.43
7	Insemination cost, Milk sales ,Credit (loans)	0.53	332.96	334.38	20.55	1446.75
8	Milk sales	0.52	333.68	335.21	21.58	1475.15
9	Concentrates, Insemination cost, Credit (loans)	0.42	363.39	363.17	57.35	1772.49
10	Concentrates, Insemination cost,	0.39	368.20	368.25	64.78	1860.82
11	Concentrates, Credit (loans)	0.37	374.18	374.02	73.46	1942.08
12	Insemination cost, Credit (loans)	0.32	383.86	383.37	88.31	2081.12
13	Concentrates	0.28	389.60	389.66	98.95	2199.40
14	Insemination cost	0.27	392.23	392.22	103.40	2241.01
15	Credit (loans)	0.20	404.11	403.84	124.61	2439.61

Optimal model selection for dependent variable Margin per litre of milk

1	Milk sales, Concentrates, Insemination cost, Manure	0.47	498.71	501.15	4.06	4593.56
2	Milk sales, Concentrates, Insemination cost, Credit (loans), Manure	0.47	500.65	503.18	6.00	4591.56
3	Milk sales, Concentrates, Insemination cost	0.45	501.66	503.73	6.89	4759.00
4	Milk sales, Concentrates, Insemination cost, Credit (loans)	0.46	502.87	505.00	8.10	4732.11
5	Milk sales, Insemination cost	0.44	503.79	505.66	9.04	4901.31
6	Milk sales, Insemination cost, Manure	0.44	504.09	506.01	9.32	4842.25
7	Milk sales, Concentrates, Manure	0.44	504.52	506.42	9.75	4857.05
8	Milk sales, Insemination cost, Credit (loans)	0.44	505.35	507.21	10.60	4886.22
9	Milk sales, Insemination cost, Credit (loans), Manure	0.44	506.02	507.93	11.25	4839.87
10	Milk sales, Concentrates, Credit (loans), Manure	0.44	506.34	508.23	11.57	4851.01
11	Milk sales, Manure	0.41	510.90	512.47	16.49	5156.67
12	Milk sales, Credit (loans), Manure	0.41	512.70	514.14	18.28	5149.44
13	Milk sales, Concentrates	0.39	514.80	516.21	20.75	5302.69
14	Milk sales	0.38	515.68	517.20	21.96	5412.53
15	Milk sales, Concentrates, Credit (loans)	0.39	516.67	517.89	22.60	5297.38
16	Milk sales, Credit (loans)	0.38	517.63	518.93	23.91	5410.93
17	Credit (loans), Manure	0.21	551.78	551.76	67.53	6905.55
18	Concentrates, Credit (loans), Manure	0.21	552.98	552.38	68.38	6866.03
19	Insemination cost, Credit (loans), Manure	0.21	553.74	553.12	69.48	6903.68
20	Concentrates, Insemination cost ,Credit (loans), Manure	0.21	554.97	553.78	70.37	6865.85
21	Concentrates, Manure,	0.18	557.22	557.01	75.52	7179.34
22	Insemination cost, Credit (loans)	0.18	557.47	557.25	75.89	7192.05
23	Concentrates, Insemination cost, Manure	0.18	558.47	557.63	76.39	7140.70
24	Insemination cost, Manure	0.17	557.94	557.71	76.60	7216.38
25	Concentrates, Insemination cost, Credit (loans)	0.18	559.18	558.31	77.46	7177.39
26	Manure	0.16	557.91	558.29	77.57	7318.26
27	Insemination cost	0.15	559.65	559.99	80.24	7409.69
28	Concentrates, Insemination cost	0.15	560.88	560.55	81.07	7369.55
29	Concentrates, Credit (loans)	0.15	566.75	566.21	90.27	7684.65
30	Credit (loans)	0.17	566.87	567.03	91.69	7801.94
31	Concentrates	0.05	575.80	575.75	106.69	8316.03

APPENDIX III Optimal model selection for dependent variable water use representing nutrient depletion

No	Variables in the model	R^2	AIC	BIC	C(p)	SSE
1	Milk sales, Manure	0.73	1096.05	1098.28	0.65	336956
2	Milk sales, Extvisits, Manure	0.73	1097.62	1099.96	2.24	335925
3	Milk sales, Credit (loans), Manure	0.73	1097.63	1099.97	2.24	335945
4	Insemination cost, Milk sales, Manure	0.73	1098.03	1100.34	2.62	336898
5	Milk sales, Credit (loans), Extvisits, Manure	0.73	1099.38	1101.83	4.01	335355
6	Insemination cost, Milk sales, Extvisits, Manure	0.73	1099.59	1102.02	4.21	335861
7	Insemination, cost Milk sales, Credit (loans), Manure	0.73	1099.62	1102.05	4.24	335934
8	Insemination cost, Milk sales, Credit (loans), Extvisits, Manure	0.73	1101.37	1103.91	6.00	335334
9	Milk sales	0.70	1106.34	1108.15	11.01	367888
10	Insemination cost, Milk sales	0.71	1107.70	1109.44	12.34	366210
11	Milk sales, Credit (loans)	0.70	1108.24	1109.96	12.90	367622
12	Milk sales, Extvisits	0.70	1108.34	1110.05	13.01	367881
13	Insemination cost, Milk sales, Credit (loans)	0.71	1109.51	1111.17	14.13	365689
14	Insemination cost, Milk sales, Extvisits	0.71	1109.70	1111.35	14.34	366209
15	Milk sales, Credit (loans), Extvisits	0.70	1110.22	1111.84	14.88	367563
16	Insemination cost, Milk sales, Credit (loans), Extvisits	0.71	1111.48	1113.06	16.11	365630
17	Insemination cost, Credit (loans), Manure	0.50	1182.69	1180.86	114.48	616808
18	Insemination cost, Credit (loans), Extvisits, Manure	0.51	1184.42	1181.74	115.99	615589
19	Insemination cost, Extvisits, Manure	0.50	1185.35	1183.41	119.19	628600
20	Insemination cost, Manure	0.49	1184.60	1183.52	119.46	634275
21	Credit (loans), Manure	0.49	1184.90	1183.80	119.99	635618
22	Credit (loans), Extvisits, Manure	0.49	1186.68	1184.69	121.59	634609
23	Extvisits, Manure	0.47	1189.47	1188.23	128.41	656688
24	Manure	0.47	1188.97	1188.64	129.25	663786
25	Insemination cost, Credit (loans), Extvisits	0.33	1225.46	1222.13	202.54	837193
26	Insemination cost, Credit (loans)	0.31	1228.04	1225.76	211.66	865001
27	Insemination cost, Extvisits	0.30	1228.53	1226.24	212.87	868026
28	Insemination cost	0.25	1236.22	1234.95	235.74	930276
29	Credit (loans), Extvisits	0.20	1247.40	1244.68	262.92	993296

31	Credit (loans)	0.17	1251.69	1250.16	279.15	1038907
31	Extvisits	0.12	1258.96	1257.32	301.30	1094349

APPENDIX IV Optimal model selection for dependent variable Milk rejection representing human health risks

No	Variables in the model	R^2	AIC	BIC	C(p)	SSE
1	Manure, Concentrates, Milk Sales	0.10	581.17	583.49	2.59	8397.82
2	Manure, Milk Sales	0.08	581.93	584.05	3.26	8564.81
3	Milk Sales	0.07	582.28	584.29	3.59	8710.01
4	Manure, Concentrates, Milk Sales, Credit (loans)	0.11	582.34	584.80	3.79	8347.99
5	Manure, Concentrates, Milk Sales, Insemination cost	0.11	582.61	585.05	4.05	8364.37
6	Manure, Concentrates, Milk Sales, Disease control	0.10	582.95	585.37	4.38	8384.68
7	Manure, Milk Sales, Credit (loans)	0.09	583.07	585.28	4.42	8512.53
8	Concentrates, Milk Sales	0.08	583.30	585.36	4.62	8649.40
9	Manure, Milk Sales, Insemination cost	0.09	583.27	585.47	4.62	8524.69
10	Manure, Milk Sales, Disease control	0.09	583.70	585.88	5.04	8551.13
11	Milk Sales, Insemination cost	0.07	583.87	585.90	5.18	8684.23
12	Milk Sales, Credit (loans)	0.07	584.01	586.04	5.32	8693.20
13	Manure, Concentrates, Milk Sales Insemination cost, Credit (loans)	0.11	583.93	586.52	5.39	8323.40
14	Manure, Concentrates, Milk Sales Disease control, Credit (loans)	0.11	583.95	586.53	5.41	8324.56
15	Milk Sales, Disease control	0.07	584.26	586.28	5.57	8708.68
16	Manure, Concentrates, Milk Sales Insemination cost, Disease control	0.11	584.36	586.91	5.81	8349.39
17	Manure, Milk Sales, Insemination cost Credit (loans)	0.09	584.57	586.87	5.94	8482.38
18	Manure Milk Sales Disease control Credit (loans)	0.09	584.67	586.96	6.03	8488.09
19	Concentrates, Milk Sales, Insemination cost	0.08	584.98	587.08	6.29	8629.18
20	Manure, Milk Sales, Disease control, Credit (loans), Insemination cost	0.09	585.01	587.27	6.37	8508.96
21	Concentrates, Milk Sales, Credit (loans)	0.08	585.12	587.21	6.44	8638.17
22	Concentrates, Disease control, Milk Sales	0.08	585.30	587.38	6.61	8649.10
23	Milk Sales, Insemination cost, Credit (loans)	0.07	585.68	587.74	6.99	8672.61
24	Manure, Concentrates, Milk Sales, Insemination cost, Disease control, Credit (loans)	0.11	585.51	588.24	7.00	8298.86

model selection for dependent variable Milk rejection (ctd)

25	Milk Sales, Insemination cost, Disease control	0.07	585.84	587.89	7.15	8682.67
26	Milk Sales, Disease control, Credit (loans)	0.07	585.97	588.01	7.28	8690.67
27	Manure, Milk Sales, Insemination cost, Disease control, Credit (loans)	0.10	586.15	588.54	7.53	8456.72
28	Concentrates, Insemination cost, Milk Sales, Credit (loans)	0.08	586.85	588.98	8.17	8621.54
29	Concentrates, Insemination cost, Milk Sales, Disease control	0.08	586.97	589.09	8.29	8628.74
30	Concentrates, Milk Sales, Disease control, Credit (loans)	0.08	587.11	589.22	8.42	8637.30
31	Insemination cost, Milk Sales, Disease control, Credit (loans)	0.07	587.64	589.71	8.95	8670.01
32	Concentrates, Insemination cost, Milk Sales, Disease control, Credit (loans)	0.08	588.84	591.00	10.16	8620.59
33	Manure	0.02	589.48	591.28	10.95	9169.42
34	Insemination cost	0.01	590.72	592.49	12.26	9251.23
35	Manure, Credit (loans)	0.02	590.99	592.72	12.44	9137.25
36	Credit (loans)	0.01	590.97	592.73	12.53	9267.70
37	Manure, Insemination cost	0.02	591.09	592.81	12.54	9143.73
38	Manure, Concentrates	0.02	591.33	593.05	12.80	9159.71
39	Manure, Disease control	0.02	591.45	593.16	12.92	9167.70
40	Concentrates	0.004	591.72	593.47	13.33	9317.66
41	Disease control	0.002	592.04	593.77	13.67	9338.82
42	Insemination cost, Credit (loans)	0.02	592.19	593.88	13.71	9216.45
43	Insemination cost, Disease control	0.01	592.55	594.21	14.08	9239.72
44	Concentrates, Insemination cost	0.01	592.59	594.26	14.13	9242.74
45	Manure, Insemination cost, Credit (loans)	0.02	592.80	594.45	14.24	9125.10
46	Concentrates, Credit (loans)	0.01	592.81	594.46	14.35	9256.71
47	Disease control, Credit (loans)	0.01	592.85	594.50	14.40	9259.54
48	Manure, Concentrates, Credit (loans)	0.02	592.95	594.59	14.40	9134.77
49	Manure, Disease control, Credit (loans)	0.02	592.98	594.62	14.43	9136.64
50	Manure, Concentrates, Insemination cost	0.02	593.04	594.68	14.49	9140.57
51	Manure, Insemination cost, Disease control	0.02	593.06	594.70	14.51	9141.95
52	Manure, Concentrates, Disease control	0.02	593.30	594.92	14.76	9157.48
53	Concentrates, Disease control	0.01	593.45	595.08	15.03	9299.26
54	Insemination cost, Disease control, Credit (loans)	0.02	594.09	595.67	15.03	9209.42
55	Concentrates, Insemination cost, Credit (loans)	0.02	594.16	595.73	15.66	9213.88

56	Concentrates, Insemination cost, Disease control	0.01	594.41	595.97	15.93	9230.49
57	Concentrates, Disease control, Credit (loans)	0.01	594.66	596.21	16.20	9247.36
58	Manure, Insemination cost, Disease control, Credit (loans)	0.02	594.79	596.36	16.23	9124.29
59	Manure, Concentrates, Insemination cost, Credit (loans)	0.02	594.79	596.36	16.23	9124.36
60	Manure, Concentrates, Disease control, Credit (loans)	0.02	594.94	596.50	16.38	9133.92
61	Manure, Concentrates, Insemination cost, Disease control	0.02	595.01	596.56	16.46	9138.49
62	Concentrates, Insemination cost, Disease control, Credit (loans)	0.02	596.04	597.52	17.54	9206.22
63	Manure, Concentrates, Insemination cost, Disease control, Credit (loans)	0.03	596.77	598.26	18.21	9123.40

List of publications and presentations

Publications

i. **Agutu F O, Ondiek J O and Bebe B O 2018** Associations between intensification interventions and negative externalities in smallholder dairy farms in the Kenyan Highlands. *Livestock Research for Rural Development*. Volume 30, Article #61 http://www.lrrd.org/lrrd30/4/agutu30061.html

ii. **Agutu, F., Bebe, B. O., Ondiek, J. O., (2017)** Associations between intensification interventions and herd productivity in smallholder dairy farms in the Kenyan Highlands. Forum for Agricultural Research in Africa (FARA) Research Reports (Accepted for Publication on 22nd March 2018).

Conference Presentations

i. Agutu, F., Bebe, B. O., Ondiek, J. O., (2018) Associations between intensification interventions and negative externalities in smallholder dairy farms in the Kenyan Highlands. In a paper prepared for the 12th Egerton international Conference. 'Knowledge solutions for the society, the economy'. 27th -29th March, 2018. Egerton University.

ii. Agutu, F.O, Bebe, B. O., Ondiek, J. O., (2017) Associations between intensification interventions and herd productivity in smallholder dairy farms in the Kenyan Highlands. 3rd AfricaLics International Conference. 'Emerging Innovation Systems for Sustainable Industrial Development in Africa'. November 27 - 29, 2017 in Oran, Algeria.