ENHANCING PRODUCTIVITY AND LIVELIHOODS OF SMALLHOLDER DAIRY FARMERS IN KENYA THROUGH AGROFORESTRY AND CELLPHONE-MEDIATED TRAINING

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University of Prince Edward Island

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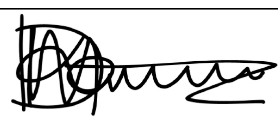
Signature: 	**Date:** 10th January 2019

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Enhancing productivity and livelihoods of smallholder dairy farmers in Kenya through agroforestry and cellphone-mediated training

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ABSTRACT

Semi-commercial smallholder dairy farmers in rural Kenya derive over 50% of their household income and livelihoods from dairy production; but they are faced with numerous challenges that constrain optimal growth and milk production of their calves and cows, respectively, with little research to address these challenges. The objectives of this research on semi-commercial smallholder farms (SDFs) were: 1) to determine the factors associated with weight gain in dairy calves and heifers on semi-commercial SDFs (cross-sectional study); 2) to determine the effects of nutritional advice and diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban* on ADG in dairy calves on semi-commercial SDFs based on an agroforestry land management model (randomized controlled feeding trial); 3) to determine the effectiveness of using cellphone technology as a dairy management training tool on knowledge of semi-commercial SDFs (randomized controlled training trial); 4) to determine the association between daily milk production and diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban* in dairy cows on semi-commercial SDFs (randomized controlled feeding trial); 5) to assess the impact of using *Calliandra* and *Sesbania* as feed supplements for dairy cattle on family income and livelihoods during a 16-month trial period on semi-commercial SDFs based on an agroforestry land management model.

Analyses in this thesis were based on a randomly selected study population of 200 semi-commercial SDFs and subsets of this study population. The entire study population of 200 farms was used for the cross-sectional study (objective 1). A random sample of 60 farms (of the 200) was used to evaluate objective 3. Another random sample of 80 farms (out of the 200) was used to evaluate objectives 2, 4 & 5.

For objective 1, the mixed multivariable linear regression model of 301 dairy calves and heifers demonstrated that supplementing with quality hay at least weekly during the dry season was associated with increased ADG. There was an interaction between the effect of breed and history of disease on ADG such that history of disease was associated with decreased ADG in *Bos taurus* breeds, while ADG in *Bos indicus* breeds was not affected by the history of disease as much. There was a significant interaction between education levels of the husband and wife caretakers; when the man's education was low (having less than or equal to primary school), ADG was highest when the woman had not completed primary school, but ADG was lower when the woman had completed primary, secondary or tertiary education.

For objective 2, analysis included 155 calves (≤ 12 months old) on 73 farms randomly allocated to either an intervention group (receiving nutritional education and *Calliandra* and *Sesbania* shrubs for feeding for 16 months) or a control group. The multivariable mixed linear regression model for calves < 6 months old showed that feeding at least 0.2 kg (wet weight) of *Calliandra / Sesbania* to a calf day $^{-1}$ would result in 33.2% increase in ADG, while controlling for confounding by breed and sex of the calf. For calves ≥ 6 months, when no *Calliandra / Sesbania* supplementation was provided, the mean ADG was low and relatively constant even with higher amounts of hay. By contrast, when some C*alliandra / Sesbania* supplement was added to the diet, the mean ADG increased from 0.17 kg to 0.48 kg when hay was fed at 1 and 5 kg, respectively (significant interaction), while controlling for confounding by amount of maize silage fed and prevailing season.

For objective 3, farmers were randomly allocated into intervention (n=30) and comparison (n=30) groups. Using an online short message service (SMS) interface, short messages on dairy management practices were sent daily, for 3 months, to the phones owned by the farmers in the intervention group. Within and between group comparisons and net changes in knowledge were determined using paired and unpaired t-tests and Chi-squared tests. Compared to comparison group, farmers in the intervention group were significantly more informed on: mastitis prevention, disease (calf diarrhea) prevention, stall management, the role of a balanced nutritious diet on immunity and the resolution of some health conditions post-intervention.

For objective 4, analysis included 80 semi-commercial SDFs randomly allocated to 4 treatment study groups of 20 (n=235 cows); 1) receiving *Calliandra* & *Sesbania* and nutritional advice; 2) receiving reproductive medicines and advice; 3) receiving both group 1 and 2 interventions; and 4) receiving neither intervention. Using multivariable mixed linear regression on the natural log transformed daily milk production of cows, controlling for clustering at the farm and cow levels during the 16-month trial, feeding *Calliandra / Sesbania* to cows was significantly (p <0.001) associated with a 9.4% increase in milk production cow $^{-1}$ day $^{-1}$ with every kg fed. Other variables positively associated with ln of daily milk production in the final model included: feeding of Napier grass, amount of silage and dairy meal fed, body condition and appetite of the cow. Variables negatively associated with ln of daily milk production in the final model included: amount of maize germ fed, days in milk, sudden feed changes, pregnancy and subclinical mastitis.

For objective 5, the assessment of impacts of agroforestry using *Calliandra* and *Sesbania* on dairy profits and dairy feed costs was based on the 80 dairy farms involved in the randomized controlled trial (objective 4). Farms were visited every 1-2 months during the trial (for 16 months) to collect data on milk production and feeding practices during the previous day. Seventy of these farms completed the trial - through wet and dry seasons - and were interviewed post-intervention. Partial budget analysis compared average monthly profits (from milk) and feeding costs cow $^{-1}$ during the first and last 6 months of the intervention. Milk and feed prices were averaged over the 16-month trial period. There was a KES 2,380.3 (USD 23.5) increase in average monthly profit cow $^{-1}$ in the nutrition group ($p < 0.05$). Average feeding costs significantly decreased across all groups except the nutrition group. Average profits in the nutrition group increased by 68.8% ($p = 0.02$). Knowledge on dairy cow nutrition, level of confidence on calf management, and feeling of empowerment were higher ($p < 0.05$) among farmers in the nutrition and combined groups than farmers in other groups.

Generally, the interventions had positive direct production and profit benefits and indirect impacts on productivity of the animals and the livelihoods of farmers in the trial groups. The cellphone-mediated training resulted in positive knowledge change among the farmers. This form of training may represent a cost-effective method to reduce production knowledge constraints of smallholder dairy farmers. Feeding cows and calves on *Calliandra* and *Sesbania* was associated with higher ADG and milk production. Improved calf nutrition would result in heifers calving earlier, thus generating more income per day of life through milk production. Better milk production would likely translate into increased household income, stronger household economies and more sustainable livelihoods. This agroforestry land management model enhances semi-commercial SDFs productivity, profitability and optimized utilization of farm resources for sustainable livelihoods.

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DEDICATION

To Dr. Maurine C Chepkwony

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List of abbreviations

ADG – Average daily weight gain

AFC – Age at first calving

BCS – Body condition score

BW – Body weight

CI – Confidence interval

CP – Crude protein

DIM – Days in milk

DM – Dry matter

DMI – Dry matter intake

ECF – East coast fever

FFS – Farmer field schools

FHF – Farmers Helping Farmers

G – Grams

GDP – Gross domestic product

ICT – Information and communication technology

KAP – Knowledge attitudes and practices

KES – Kenya shillings

Kg – Kilograms

LH – Luteinizing hormone

ME – Metabolizable energy

NDF – Neutral detergent fiber

NDFCS – Naari Dairy Farmers Cooperative Society

NEB – Negative energy balance

NGO – Nongovernmental organization

SDFs - Smallholder dairy farms

SMS – Short message service

UPEI - University of Prince Edward Island

USD – United states dollar

S.E. – Standard error

S.D. – Standard deviation

Chapter 1 General Introduction

1.1 Status of Dairy Production in Africa, and specifically Kenya

The dairy industry in Africa currently accounts for about 5% of the world's milk production (Mikkelsen, 2014). Between 1980 and 2002, the overall milk supply in Africa increased by about 122%, or about 3% annually (Food and Agriculture Organization, 2005). Increasing demand due to an increasing population, coupled with suboptimal production, have contributed to heavy reliance on imports of dairy products by many African countries. Countries import as much as 15% of milk supplied in their markets which demonstrates the opportunity for additional domestic supply (Blein et al., 2013). Over the last decade, the Eastern African region has been the leading milk producing region in Africa and accounted for 68% of milk production in the continent (Bingi & Tondel, 2015). The largest milk producing countries in this region, in order of total production, are Ethiopia, Kenya and Tanzania (Bingi & Tondel, 2015).

Semi-commercial smallholder dairy farmers (SDFs) are smallholder farmers who keep dairy animals with the intention of meeting household needs and selling milk or other animal products for money (Ngigi, 2005; Tanyanyiwa, 2016). Some of the production shortfalls on SDFs can be attributed to poor access to technology and limited farm management skills, which characterize smallholder dairy and agricultural production in Africa in general (Mikkelsen, 2014). In the past, African governments have employed different interventions to support and improve dairy production. These strategies have included policy reviews, market and price controls, incentivized production programs and infrastructural developments, among others (Bingi & Tondel, 2015). Implementation of these strategies was aimed at capacity-building of the dairy industry and the infrastructural frameworks to support a more stable macroeconomic environment for enhanced regional trade (Bingi & Tondel, 2015). These improvements notwithstanding, the African dairy industry has yet to maximize its productivity potential.

In addition to limitations in agricultural technology and know-how, agricultural productivity in sub-Saharan Africa is largely influenced by climate and available land (Yohannes, 2015; Veras, 2017). The proportion of land used for agricultural production in this region ranges between 38.5-50.7% of all land with agricultural potential (World Bank Group, 2013).

Kenya has a land area of 582,646 km^2 (Muriuki, 2011). Approximately 17-18% of this area has high to medium agricultural production potential. The rest is categorized as arid or semi-arid land, which without irrigation has low productivity potential for dairy production and other forms of agriculture (REGLAP Secretariat, 2012).

The Kenyan economy is heavily dependent on agriculture and the agricultural industries support 25% of the Gross Domestic Product (GDP). About 8% of this GDP contribution is attributed to the dairy sub-sector (Odero-Waitituh, 2017). The dairy value chain is one of the largest avenues for job creation and employment in the informal sector, with every 1000 liters of milk production creating about 77 jobs (Muriuki, 2011).

The milk value chain in Kenya is generally along two streams. Smallholder dairy farmers will either supply milk to the formal market (where milk processing or value addition is done before it reaches the retail market) or informal market (which involves the purchase of unprocessed milk for local consumption after boiling at home) (Amalie et al., 2015). It is estimated that 11% of milk produced in Kenya is marketed through formal channels, 44% is marketed through informal channels, and the remaining 45% is used on the farm for personal consumption or feeding farm animals (TechnoServe Kenya, 2008).

Annual milk production in Kenya in 2016 was estimated at 5.2 billion liters. This volume was produced by approximately 4 million cows with exotic blood lines (Friesian, Ayrshire, Jersey and Guernsey breeds and their crosses) and 17 million indigenous cattle and other milk-producing species (e.g. camels and goats) (Office of Auditor General-Kenya, 2016). Indigenous breeds and other species (small ruminants and camels) contribute approximately 30% of the total milk produced in Kenya (Muriuki, 2011). More than 80% of the milk produced in Kenya comes from semi-commercial smallholder dairy farms which are mainly concentrated in the medium productive areas (e.g. Mount Kenya slopes) where farms have limited land acreage (Odero-Waitituh, 2017). Large-scale farming is mainly practiced in the highly productive areas (e.g. Rift Valley) (Odero-Waitituh, 2017). Between January and May 2017, Kenyan milk production was approximately 215.9 million liters (223,456.5 metric tons), which was a 17.5% drop in volume compared with milk production in the same period in 2016 (Kariuki, 2017). This variability in milk production could be attributed to the various challenges facing the dairy industry (e.g. drought) and more specifically to the challenges facing SDFs that produce most of the milk in Kenya.

1.2 Challenges facing smallholder dairy production in Kenya

Low pricing of milk and milk products is a major factor that influences production and productivity of dairy production units in Kenya (Boor, 2012). Major contributors to this challenge are small farm size, instability of milk production through different seasons, and the involvement of middlemen to take milk from the farm to the consumer (Elijah, 2017). The estimated farm gate price averages between 30-40 Kenya shillings (KES), factoring in seasonal fluctuations (Andae, 2018). However for farmers in the informal channel, the final amount received by the farmer is usually 30-45% lower compared to the formal market (TechnoServe Kenya, 2008; Otieno, 2017). With the cost of milk production estimated to range between 20 – 25 KES per liter, sustainability and profitability for SDFs with few cows is difficult (Oyugi, 2018).

In East Africa, animal feed shortage is ranked as the second most important constraint in the dairy industry after low milk pricing (Lukuyu et al., 2011). In Tanzania (with similar SDFs to Kenya), it is estimated that SDFs use most (up to 77%) of the income from dairy farming on feed for their animals (Nkya et al., 2007). With such high cost of production, profitability and growth of the smallholder dairy industry is limited (Nkya et al., 2007).

The quality of dairy animal diets is another factor limiting milk productivity per cow in SDFs. In Kenya, compared to extensively managed farms, feed costs are higher in intensive production systems, such as on SDFs that practice zero-grazing and stall-feeding (Ministry of Livestock Developement, 2014). The ability to supplement diets with concentrates for optimum nutritional management is largely influenced by the economic ability of the farmer to purchase these feeds (Muia et al., 2011) or knowledge of improved forage supplements. For example, in Nyahururu (Kenya) only 44 % of the SDFs supplemented their dairy cattle with either improved forages or concentrates (Muia et al., 2011). Other challenges associated with feeding are insufficient water, inadequate knowledge and technology on feed conservation, and nutritional management of dairy animals (Lukuyu et al., 2011).

Climate change has resulted in additional feeding challenges due to longer dry periods and unpredictable rainfall patterns in Kenya, affecting small scale farm productivity substantially (Ochieng et al., 2016). Most of the aforementioned nutritional challenges are more acute during the dry seasons which usually occur from December to February and from June to September when good quality farm forages are not readily available unless SDFs store feed. Although feed conservation has been practiced to some extent, hay and silage from Napier grass and crop residues are often of poor nutritional quality due to late harvesting (Njarui et al., 2011; Odero-Waitituh, 2017).

As a result of these feeding challenges, inadequate feed quality and quantity have serious effects on the growth and optimal maturation of the replacement heifers. Also, underfeeding of dairy cows affects both immediate and lifetime production of the animal through poor reproduction (Smith & Chase, 2000). In Zambia, which is also similar to Kenya, most SDFs depend on natural pasture, and therefore various coping strategies are employed during feed shortages. These strategies include buying feed from neighbors, leasing/renting grazing fields, usage of crop residues such as maize stover, and/or conserving feeds (Smith, 2000; Njarui et al., 2011). In general, despite good breeding, the majority of heifers do not reach the recommended weight and height for optimal lifetime milk production (Wathes et al., 2014).

Poor genetics due to poor breeding practices, or inaccessibility to good quality semen and extension service, is also an important constraint for some dairy farmers in Kenya (TechnoServe Kenya, 2008; Abdullahi et al., 2011). Other challenges facing SDFs' milk production are: shrinking land per farm for dairy production, poor infrastructure and market access, inconsistent milk quality and hygiene and inadequate government policy support (Muriuki, et al., 2001; Mapiye et al., 2006; Bingi & Tondel, 2015).

1.3 Role of dairy production on livelihoods in Kenya

A livelihood is the means of living as constituted by various capabilities, assets and activities (Serrat, 2017). Livelihoods are considered sustainable if they can withstand and recover from stresses and situations that threaten the means of living. Such livelihoods have the ability to maintain resources and enhance interventions that mitigate vulnerability to the stressful situations (Krantz, 2001). Level of income / economic capital is one of the indicators used to gauge a sustainable livelihood (Department for International Development, 1999).

In 2008, Kenya launched a national development blueprint related to sustainable livelihoods dubbed 'Vision 2030'. The principal focus of this vision is to create a competitive middle-income country by 2030 with high quality of life through industrialization (Government of Kenya, 2007). The Vision 2030 document is founded on 3 pillars: 1) political pillar which aims to realize an issue-based, people-centered, result-oriented and accountable democratic system; 2) social pillar which seeks to engender just, cohesive and equitable social development in a clean and secure environment; and 3) economic pillar which aims to achieve an average economic growth rate of 10% per annum and sustaining the same until 2030.

Approximately 73.5% of the total population in Kenya lives in 'rural' areas and derive income from agriculture (IndexMundi, 2018). Agricultural targets of the Vision 2030 document are aligned to the Economic pillar (i.e. raising incomes generated from agriculture, livestock and fisheries through innovation for value addition of raw products). Some progress on this vision has been made, as at 2014, Kenya was reclassified as a low-middle-income country, although poverty and food insecurity still pose serious challenges (Elsadani, 2016).

Ruminant livestock contribute up to 318 billion KES to the national agricultural annual GDP in Kenya (Behnke & Muthami, 2011). Milk and milk products contribute to the GDP 4 times as much as meat and meat products (Behnke & Muthami, 2011). Agriculture also provides the raw materials for agro-industries, which are about 70% of all industries in Kenya, thus promoting job creation and employment. Agriculture and agro-industries support 53-60% of the national income, up to 40% national employment and 70% of employment in rural Kenya (Muriuki, 2003; Food and Agriculture Organization, 2018).

Smallholder dairy production systems play a major role in the farmers' livelihoods and development of rural areas in developing countries such as Kenya. In Kenya, SDFs play a major role in food security and wealth creation and there is a positive association between poverty and food insecurity (Muriuki et al., 2001). In a study done in Eldoret, Kenya, one of the dairy farming areas, households that delivered the lowest volumes of milk to collection and processing centers were poorer and were observed to be more food insecure (Boor, 2012). Dairy production in Kenya is arguably the main source of livelihood income for more than 1.5 million smallholder households (Eghwa, 2016). Smallholder dairy farms complement crop production through income generation, creation of employment and stimulation of infrastructural development (Muriuki, 2003). In view of this far-reaching interaction of dairy production and communities; economic recovery and wealth creation are directly related to the production level of the dairy sector (The Dairy Policy Forum, 2004).

Kenya’s dairy production is among the largest in the eastern and southern region of Africa. Given the large contribution made by SDFs to Kenya’s dairy value chain, their economic contribution cannot be downplayed. Dairy production directly contributes to more than 50% of the household income and livelihood support in SDFs in Kenya (VanLeeuwen et al., 2012). A study done in Eldoret, Kenya, revealed that farmers who sold most or part of their milk had better livelihoods than farmers who consumed most of the milk or sold none (Boor, 2012).

The commonly kept breeds in most semi-commercial SDFs in Kenya are exotic crosses, with a few improved indigenous breeds (Odero-Waitituh, 2017; Muraya et al., 2018). Livestock kept by SDFs in Kenya play different roles in the livelihoods of these farmers, in addition to milk for food and for sale (Behnke & Muthami, 2011; Makau, 2014). In Nyamira, Bomet and Bureti districts (Kenya), dairy farming has been reported to play a huge economic role as low poverty indices have been observed in households practicing dairy farming at any scale (Changwony & Kitilit, 2014). Dairy production also contributes to enhanced nutrient ‘cycling’ through use of manure in at least 625,000 SDFs, which in return supports better crop production (Muriuki, et al., 2001; Makau, 2014). Other roles played by livestock in SDFs include cultural practices, sources of food, or as a medium of transaction, insurance or savings, indirectly providing pathways out of poverty (Kristjanson et al., 2004; Behnke & Muthami, 2011). From the author’s observations, most semi-commercial SDFs typically sell their male calves for additional income. Livestock therefore contribute to poverty reduction in various ways such as:

better nutrition as a result of consumption of milk and milk products; increased amount of food and diet variability resulting from improved crop yields; improved income allowing for access to better education, medical care and other basic needs which all contribute to improved livelihood, food security and poverty reduction (Smith et al., 2013).

There is a huge potential in the dairy subsector for improving sustainable livelihoods, and if this potential is optimized, a sustainable and globally competitive dairy value chain in Kenya would be achieved (Muriuki, 2003). As a sequel to this improvement, wealth creation, poverty reduction and improved quality of life would be achieved for most of the rural population in Kenya (Boor, 2012). Therefore, improvement of the dairy sector productivity would result in substantial direct and indirect benefits on multiple household livelihood outcomes (Odero-Waitituh, 2017).

1.4 Dairy cow nutrition and milk production

The level of milk production in most tropical dairy enterprises in developing countries is approximately 25-30% of the milk production in developed countries (Blake, 2003; unpublished observations). While genetics explain some of this difference, management and environmental factors largely affect the production (Blake, 2003; Zhumanova et al., 2013).

Milk production is an energy-consuming process for dairy animals. Therefore, the amount of milk produced is closely related to the energy level consumed in feed (Broderick, 2003). Derivatives of plant-based carbohydrates account for approximately 60-70% of the energy in dairy cows necessary for supporting milk production (Ishler & Varga, 2001). The dry matter intake (DMI) of a cow depends on the physical capacity of the cow, as well as fulfillment of the metabolic requirements (National Research Council, 2001; Government of Alberta, 2018). On average, the total feed energy converted to milk in dairy cows ranges from 16% in multipurpose cows and cross-breeds to about 64% in pure-bred (Dutch) dairy cows (Phelan, 2007). Although various factors influence feed efficiency, the quantity and quality of feed during lactation is a key factor in milk productivity (Phelan, 2007). A commonly observed consequence of energy deficiency in dairy cattle is weight loss and poor body condition, followed by a decrease in milk production when the body condition score (BCS) becomes very low, while a protein deficiency usually manifests as just a decrease in milk production (Lukuyu, et al., 2012).

Although forage compositions vary temporally and in different livestock production systems, various supplements can be fed in an attempt to meet the energy requirements in the dairy cow (Mwebaze, 2002). It is however important that the amounts of carbohydrates in the diet be adequate since the carbohydrates influence health of the ruminal micro-flora and metabolic functionality (Rengman, et al., 2014). To ensure high milk production, most dairy animals (in large farms and in developed countries) are fed on diets containing commercially made concentrates and high-quality forages. Ruminal microflorae digest plant-based carbohydrates in fiber through a fermentation process, availing metabolizable energy (ME) to the cow (Hummel, et al., 2006). Depending on the rate of passage through the digestive tract, different plants have different levels of digestibility, which affects the amount of energy available for the animal to support milk production at a given time (Ishler & Varga, 2001). Neutral detergent fiber (NDF) is the portion of plant material that the animal takes longest to digest and is indirectly correlated to feed intake. Generally speaking, grasses have a lower NDF and longer retention times in the rumen compared to legumes (Ishler & Varga, 2001; Hummel et al., 2006). Longer retention times create a filling effect, resulting in reduced feed intake. Legumes on the other hand have a shorter fermentation period in the rumen, thus allowing for higher intake of feed (Ishler & Varga, 2001).

During the dry season and periods of drought farmers struggle to provide good quality feed for their dairy animals (Franzel et al., 2013). During this time one of the most commonly used coping strategies on Kenyan SDFs is use of crop residues (Njarui et al., 2011). In the eastern parts of Kenya (semi-arid climate), almost 80% of the SDFs use maize stover as the main feed for their dairy cows at the peak of the dry season; when there is extreme grass shortage (Njarui et al., 2011). An analysis done on the maize stover used in these SDFs established that it had an average nutritional composition of CP of 2.5% and NDF of 70%. Although other studies have documented different nutrient composition of various parts of maize stover, a primary diet of dry maize stover (mainly fed as stems with few leaves) will not sustain good milk production for dairy cows due to its low ruminal degradability and slow ruminal passage (Li, et al., 2014). Another approach to coping with dry season and drought was conservation of feed (as ‘hay’ or silage). However a study on SDFs in rift valley and central parts of Kenya found that the quantities conserved were inadequate to support good cow nutrition and milk production (Lukuyu et al., 2011). As well, the quality of feed conserved was usually inadequate because the Napier grass and crop residues were usually of poor quality due to late harvesting (Njarui et al., 2011).

Good quality feed is crucial for higher milk production and ideal reproduction. Inadequate intake of energy, protein, vitamins and minerals is associated with poor reproductive performance (Smith & Chase, 2000). Given the different physiological demands that the dairy animal faces, creating a balance between feed intake and utilization of nutrients in the body (for basal metabolism, production and reproduction) is crucial (Santos, 2008). Over the years, fertility in dairy cows has declined with the advancement of milk production (Santos, et al., 2010). Establishment and maintenance of pregnancy in lactating dairy cows is a complex biological process influenced by a multitude of factors, among them being nutrition (Santos, et al., 2010). Due to the high energy demand for milk production, cows receiving inadequate nutrition (especially in Kenya in the dry season) operate under negative energy balance (NEB). This NEB results in longer postpartum anestrous periods due to reduced peak luteinizing hormone (LH) frequencies and longer inter-calving intervals (Santos, 2001; Moran, 2005). Long inter-calving periods negatively affect the lifetime milk production of a cow (Lanyasunya et al., 2005). This poor reproductive performance is more challenging for SDFs who depend on fewer animals compared to medium / large scale farms.

In most cases, dairy animals on SDFs cannot build sufficient body reserves due to unavailability of adequate quality feed. This under-nutrition results in poor body condition and reduced milk production (Lanyasunya et al., 2005). In SDFs in parts of eastern Kenya and Uganda, the average milk production during the dry season was reported to be 3.4kg cow $^{-1}$ day $^{-1}$. This volume of milk production typically increases two to three times in the wet season, indicating that inadequate and poor-quality feed and water have greatly affected productivity in SDFs (Njarui et al., 2012). There is a need for farm-based feed sources that can withstand harsh climates such as drought conditions.

Fodder trees are becoming an important source of feed for livestock in different farming systems in Africa (Place et al., 2009). Over the last 3 decades, the use of different fodder trees has been promoted by different researchers and extension officers, especially in the highlands of the East African region, with some improvement in productivity and livelihoods (Franzel et al., 2013). The main advantage of fodder trees is the ability to tolerate harsh climatic conditions such as droughts and provide reasonable amounts of good quality nutrients (World Agroforestry Center, 2011). Seasonal fluctuation of CP content in grasses and other animal fodder is a common finding in tropical areas (Smith, 2000). However, because these leguminous trees are more drought-tolerant, they can play a major role in nitrogen provision to the soil and as a CP source for livestock production all year round. Protein supplementation improves carbohydrate and roughage conversion to volatile fatty acids in the rumen (Gusha, et al., 2013). As such, nitrogen remains the most limiting nutrient in agricultural production affecting crops, pasture and livestock productivity.

Some of the fodder trees used for feeding dairy cows in Kenya, Tanzania and Rwanda are *Calliandra calothyrsus*, *Leucaena diversifolia*, *Leucaena trichandra*, *Chamecytisus palmensis* and *Sesbania sesban* (Franzel et al., 2013). C*alliandra* and S*esbania* are highly recommended leguminous trees to supplement livestock fodder in Kenya (Okoth, 2009). From a study done in Kenya, one kilogram of C*alliandra* foliage fed to a dairy cow increased milk production by about 0.6-0.8 kg after controlling for breed, season and other feeds (Place et al., 2009). Similarly, two kilograms of *Calliandra* dry matter (DM) was estimated to provide 0.6 kilogram of CP; 3 kg of *Calliandra* leaves (wet weight) were reported to be a good replacement for 1 kg of dairy meal (Place et al., 2009).

Proper feeding of *Calliandra* to dairy cows can therefore reduce production costs by reducing / substituting the amount of dairy meal used.

Supplementation with dairy meal to dairy cows one month prior to calving (steaming up) is also significantly associated with increased milk production, particularly during the early post-calving period (Richards et al., 2016). With steaming up, the rumen microflora and papillae become reacclimatized to the high energy of the dairy meal prior to calving so that when milk production begins at calving and rapidly increases after calving, this ruminal adjustment has already taken place and ensures higher milk production at peak lactation. There's no documented research, to our knowledge, that replacing the dairy meal with leguminous fodder would be equally or more beneficial. However, the research on production benefits from leguminous fodder shrubs is primarily found within large-scale or research farms (Kaitho & Kariuki, 1998; Cook et al., 2005a), and therefore these studies do not demonstrate the shrub's benefits on livelihoods of semi-commercial SDFs in Kenya.

1.4.1 Calliandra

Calliandra calothyrsus is a small, perennial, leguminous tree that grows to about 12 m high if undisturbed. It has a trunk diameter of up to 30 cm with white-reddish brown bark, hence the name 'red calliandra' in some parts of the world. The leaves are bipinnate, alternate, and the rachis length ranges from 10-19 cm long. The pinnae are varied in size with a range of 3-20 jugate, and the rachilla are about 2-11 cm long, with about 19-60 pairs of leaflets. The leaflets are linear, oblong and acute, with dimensions of 5-8 mm x 1 mm. Inflorescences are particulate, with flowers arranged in umbelliferous patterns, 10-30 cm long. The flower sepals and petals are green with a calyx that is 2 mm long and a corolla that is 5-6 mm long. The flowers have numerous red staminal filaments that are 4-6 cm long, and the fruits are broadly linear, flattened, 8-11 cm x 1.0 cm, with thickened and raised margins. The fruits have fine smooth, brown seeds that are ellipsoid, flattened, 5-7 mm long, and mottled dark brown in appearance (Cook et al., 2005a).

Calliandra serves numerous purposes, although it's mainly grown for forage as a supplement to low quality roughages for ruminant livestock. It is also used for the provision of green manure on farms, as shade for coffee and tea plants, and with its soil erosion control properties, it is used for land rehabilitation. *Calliandra* leaves have been used previously to improve the utilization of low quality forages or even as a replacement for concentrate feeds in dairy farming (Cook et al., 2005a).

Benefits on weight gain have also been observed in cattle grazing C*alliandra* over a 12-month period in Indonesia, leading to gains of 0.33 kg head $^{-1}$ day $^{-1}$ compared with 0.16 kg head $^{-1}$ day $^{-1}$ for those grazing on *Imperata cylindrica* (Cook et al., 2005a). In Zambia, (Cook et al., 2005a) it was observed that goats fed a basal diet of poor-quality hay lost weight at a rate of 20 g day $^{-1}$. However, when the diet of those goats was supplemented with 140 g day $^{-1}$ DM of C*alliandra* leaves, they gained an average of 24 g day $^{-1}$. In a similar study in Indonesia, sheep were observed to gain twice as much (from 26 up to 52 g day $^{-1}$) when supplementation levels of fresh C*alliandra* leaves was increased from 0-35% of the total ration (Cook et al., 2005a).

On average, one hectare of properly grown *Calliandra* plants can produce up to 10 tons of DM year $^{-1}$ (Lukuyu et al., 2012). Five hundred trees can optimally be used by a farmer to feed a cow 2kg DM day $^{-1}$ for one year (Franzel et al., 2013). Direct and heavy browsing may lead to damage and death of the plant. It is estimated that a dairy cow in Kenya would adequately be supplemented with 300-500 C*alliandra* plants per year, managed in a hedgerow (Cook et al., 2005a). In an experimental study on dairy cattle in Kenya, 3 kg of fresh C*alliandra* leaves plus 2 kg of concentrate feed resulted in a similar response in milk yield and butterfat to 3 kg of concentrate feed. This response may be attributed to the provision of tannin-protected protein in *Calliandra* that can be efficiently absorbed post-ruminal. Tannins are astringent biomolecules widely distributed in many plant species that bind and precipitate proteins. Due to their high molecular weight, their binding with proteins acts as a protectant reducing their extensive breakdown in the rumen (Bunglavan & Dutta, 2013). Extensive ruminal degradation of proteins results in wastage of protein essential for production and growth (Bunglavan & Dutta, 2013).

1.4.2 Sesbania

Sesbania sesban, commonly known as Egyptian pea, is a shrub that grows to 8 m tall with a trunk of 12 cm in diameter. Its leaves are slightly larger, linear, and oblong, compared to those of *Calliandra* (26 mm x 5 mm), including a short petiole of 2-18 cm long, with 6-27 pairs of pinnately compound leaflets. On average the plant has 2-20 flowered racemes with 20 cm long smooth or sparsely pilose and 5 cm long peduncles. The pedicels are also smooth and about 4-12 mm long. The pods produced are sub-cylindrical, straight or slightly curved, up to 20-30 cm x 2-5 mm in size and straw-colored, often with a brown or reddish-brown blotch over each septum. Each pod contains about 10-15 glabrous seeds sub-cylindrical in shape, 3-4.5 mm x 2 mm x 2 mm in size, with an olive-green or brown color (Cook et al., 2005b).

Like C*alliandra*, S*esbania* serves a multiplicity of purposes, although it's mainly grown for forage as a supplement to low quality roughages for ruminant livestock; its leaves have been documented as a good source of proteins for cattle and sheep. It is also used for reclamation of saline soils in southern China, providing shade for coffee, and as live support for grapes and black pepper (Cook et al., 2005b) . In India, *Sesbania* is mainly used as a source of green manure and green cut forage (Cook et al., 2005b). When intercropped with other crops, such as maize, increased crop yields have been observed (Cook et al., 2005b). *Sesbania* provides a good source of firewood in southern and east Africa and is used as grazed forage for dairy cattle in sub-tropical Australia (Cook et al., 2005b).

Sesbania has a crude protein content ranging from 25-30% and can provide dry matter yields of up to 12 tons hectare $^{-1}$ year $^{-1}$ under the right conditions (Orwa et al., 2009). As with *Calliandra,* heavy browsing may lead to damage and death of the plant.

1.5 Calf management and nutrition

Good calf management is the cornerstone of future dairy cattle productivity. Calf management is of particular importance in countries such as Kenya where the dairy industry is working to expand (Odero-Waitituh, 2017). In the early stages of life, nutritional management is aimed at building immunity and ensuring proper ruminal development (Lukuyu et al., 2012). Post weaning, when the rumen is functional, provision of high quality forage is key to maintaining a healthy growth rate (Moran, 2005).

Calf-hood diseases negatively affect subsequent heifer survival and productivity, and affect the economic value and welfare of animals (Windeyer et al., 2014). Nutrition is closely associated with disease and welfare. Studies in Kenya have reported on disease and mortality in dairy calves on SDFs (Gitau et al., 1994; 2001), but there is limited recent information on factors, including disease, associated with weight gain in dairy calves/heifers on SDFs.

Average daily weight gain (ADG), body condition score (BCS), age at first calving (AFC) and body weight (BW) are some of the indices used to monitor and predict the potential of weaned calves and heifers in dairy farms (Krpálková et al., 2014). The rate of calf growth, as indicated by ADG is commensurate with the quality of feeding and subsequently determines BCS and BW, which subsequently influence onset of puberty and hence AFC (Moran, 2005). Age at first calving can be regarded as an indicator of the quality of nutritional management of heifer calves. Heifers subjected to poor nutrition and with low BW at 6 months of age (therefore a slow growth rate) calved at more than 25 months of age compared to well-nourished heifers that calved at an earlier age (Cooke et al., 2013).

Maximum milk productivity per day of life has been observed in heifers/calves that achieve a prepubertal ADG of 850g day $^{-1}$ and AFC of 24-27 months (Krpálková et al., 2014). In a study to identify the effects of these indices on milk production, a group of Holstein calves had an ADG of between 0.850 kg day $^{-1}$ and 0.949kg day $^{-1}$ during the ages of 5 to 14 months with a mean body weight of 412.5 kg at first calving (Krpálková et al., 2014). This group had the highest milk production in their first lactation. However, the highest lifetime milk production was from heifers that had pre-pubertal ADG $\geq$ 0.949

kg day $^{-1}$. A difference of 1000 kg for a 305-day lactation cow $^{-1}$ was observed between cows that had pre-pubertal ADG ≤ 0.850kg day $^{-1}$ and those with ≥ 0.949 kg day $^{-1}$ (Krpálková et al., 2014).

Calves on SDFs in Kenya, like other East African countries, face the same nutritional challenges as the cows; poor nutrition and feed shortage in the dry season that result in low protein diets (Smith & Chase, 2000). The impact of inadequate nutrition is most evident in the dry season when forage quantity decreases (Njarui et al., 2011) and other high quality feeds, such as hay, are either expensive and/or unavailable to Kenyan SDFs (Bii, 2017). Due to these challenges, a reasonable ADG benchmark for SDFs in the East African region has been estimated at 400-700 g day $^{-1}$ (Lukuyu et al., 2012). Calves achieving this ADG on SDFs in the first 5 months are able to experience their first calving at 27 months or less (Lukuyu et al., 2012).

To maintain a good growth rate, the average nutritional requirements for heifers in Kenya are recommended to be feeds with 12-19% CP (Lukuyu et al., 2012). In calves and heifers, the dietary CP content is positively associated with weight gain (Moran, 2005). Weight gain is highly dependent on, and correlated with, level of protein in the diet. The maximum weight gain was observed in calves weaned onto calf starter with 19.6% CP. The increase in body weight was linearly associated with an increase in protein content in diet fed to calves after weaning. However, there was no significant difference between weight gains in calves fed diets with CP of 19.6% and those fed higher protein levels such as 22% CP (Akayezu et al., 1994).

Different forages have unique nutritional values (Maina, 2008). Maina (2008) recommended that several forages be combined for synergistic benefits to the animals' growth and productivity. Leguminous fodder plants, such as C*alliandra*, can be used as protein source supplements in diets for calves to boost and sustain production and weight gain (Gusha et al., 2013). In Australia, yearling heifers grazed on a mixed pasture of *Sesbania* and signal grass (*Brachiaria decumbens*), and gained an average of 0.70 kg head $^{-1}$ day $^{-1}$ over a 15-month period (Cook et al., 2005b). In Bangladesh, *Sesbania* leaves were identified as a good forage for feeding goats due to the significant increase in body weight in goats (Shahjalal & Topps, 2000). *Calliandra* foliage as fresh or dried fodder contains about 24-30% CP, which is similar to the CP level in some dairy concentrate feeds such as sunflower cake. As a result it can be estimated that replacing dairy concentrate with *Calliandra* will can provide adequate CP to maintain optimum growth rates in calves at weaning (Richards et al., 2015). In a study in Kenya, calves and heifers whose diets were supplemented with C*alliandra* and S*esbania* at 1-1.5 kg DM day^{-1} were observed to maintain a growth rate of >600g day $^{-1}$ when the basal diet was composed of poor quality feed (dry seasonal feeding) (Kaitho & Kariuki, 1998). However, there is a paucity of knowledge about ADG and calf growth benefits from leguminous fodder shrubs. Documented research is primarily focused on medium or large-scale or research farms, and therefore these studies do not demonstrate the shrubs' benefits on livelihoods of semi-commercial SDFs in Kenya.

1.6 The role of cellphones in training for better production on smallholder dairy farms

Education and training have been observed to have a positive impact on farm management and profitability. Training sessions provide avenues for farmers to interact with each other and with experts, hence transforming their perspective and values towards new ideas (Kilpatrick, 2000). A study in central Kenya revealed that the main constraints to adoption and maximization of different technologies (such as fodder trees) were inadequate knowledge on management and unavailability of the technology (Mwangi & Wambugu, 2003).

Participatory education and training of farmers in Kenya has potential to improve adoption and benefit actualization of fodder crop use in SDFs (Mwangi & Wambugu, 2003). Dietary supplementation using high protein forage (such as C*alliandra / Sesbania*), coupled with bi-weekly training on management, was observed to result in significantly increased daily milk production in SDFs in Kenya (Richards et al., 2016). In Zimbabwe (similar context to Kenya), the main economic losses in SDFs were a result of low milk production, long inter-calving periods, low calving rates and late age at first calving. These economic losses were largely attributed to inadequate knowledge on nutrition and poor nutritional management (Ngongoni et al., 2006).

For optimum cattle nutrition and the derived benefits, farmers need proper knowledge and skill. A lack of this knowledge and skill has been one of the main constraints for uptake of best management practices (Smith, 2000; Franzel et al., 2013). For example, poor communication of research findings to farmers was identified as a major stumbling block to optimization of fodder tree technologies in nutritional programs on smallholder farms in Malawi (Ngwira, 2003). Despite a 15-fold increase in the number of farmers planting fodder trees in a period of 5 years in Zimbabwe, small-scale dairy production did not improve. Inadequate tree or calf management knowledge and over-browsing of the fodder trees resulted in low economic returns on those farms (Hove et al., 2003). This low uptake and optimization of technologies due to inadequate management knowledge is mirrored in other East African countries such as Kenya (Lukuyu et al., 2011).

To increase farmer knowledge, attitudes and practices on best management procedures, dairy cooperatives, nongovernmental organizations (NGOs) and farmer groups in Kenya often organize for seminar/extension sessions and farmer field schools (FFS). These sessions are held in partnership with government and industry representatives with specific management expertise and allows farmers to share their challenges and to learn better approaches to dairy management (Wambugu et al., 2011; Ettema, 2012). However, the degree to which farmers understand and retain the knowledge from these educational activities is fairly low since farmers tend to forget over time or do not master complex content depending on the mode of training or delivery (Oakley & Garforth, 1993; Mvena et al., 2013).

Cellphones in Kenya, like the rest of Africa, have been used for dissemination of different kinds of information. Cellphones have been used for the following activities: disease monitoring, weather monitoring, advertising, marketing, financial transactions, business promotion, credit facility, access to advice and many more (The World Bank, 2012). With adequate investment, cellphone technology could be used for effective dissemination of dairy management information to SDFs (Rathod et al., 2016). While this technology has so much potential, there has not been adequate research on its effectiveness for extension purposes in Kenya among SDFs (Smollo et al., 2016).

A randomized controlled trial on human nutrition best practices among women in Kenya concluded that use of cellphones as a complement to face-to-face training was beneficial. In that trial,the intervention group attended one face-to-face training session and cellphone messages were sent twice a week for 5 weeks as reminders, while the control group only attended the face-to-face training. Post-intervention evaluation revealed that knowledge attitudes and practice scores were significantly higher ($p < 0.05$) in the intervention group than the comparison group (Wanjohi, 2018). There is no research to our knowledge that examined the effectiveness of the sole use of cellphone-mediated training for dairy management capacity building for SDFs.

1.7 Research rationale and objectives

The challenges facing semi-commercial SDFs in Kenya have been highlighted by many researchers (Nkya et al., 2007; Lukuyu et al., 2011; Muia et al., 2011; Odero-Waitituh, 2017; Njonge, 2017). However, most of these studies focus on dairy cows and literature on challenges facing calf rearing is scarce. Moreover, there is limited research on semi-commercial SDFs in Kenya from field trials. Consequently, there is need for trial-based research on semi-commercial SDFs to examine leguminous shrub protocols and the impacts of these feeding protocols on milk production and calf ADG. There is a need for effective and efficient training on calf rearing and fodder tree use. Similarly, there is limited randomized controlled trial research documented on the use of cellphones for extension purposes in semi-commercial SDFs. Finally, there is a paucity of research on how adoption of agroforestry contributes to sustainable farmer incomes and livelihoods.

Therefore, the objectives of this thesis research in Kenya were:

1. To determine the factors associated with young-stock weight gain on semi-commercial smallholder dairy farms (SDFs) in Meru County, Kenya. This objective will be addressed in Chapter 2.
2. To determine the effects of nutritional advice and diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban* on ADG in dairy calves on semi-commercial SDFs based on an agroforestry land management model in Kenya. This objective will be addressed in Chapter 3
3. To determine the effectiveness of using cellphone technology as a dairy management training tool on knowledge of semi-commercial SDFs in rural parts of Kenya. This objective will be addressed in Chapter 4.
4. To determine the association between daily milk production and diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban* along with in-person nutrition training, in lactating dairy cattle on semi-commercial SDFs. This objective will be addressed in Chapter 5.
5. To assess the impact of using *Calliandra* and *Sesbania* as feed supplements for dairy cattle on family income and livelihoods during a 16-month trial period on semi-commercial SDFs based on an agroforestry land management model. This objective will be addressed in Chapter 6.

The following hypotheses are behind the objectives of this thesis research.

1. Weight gain in dairy calves/heifers on SDFs in Meru is lower than desired and is a function of a number of calf and management factors.

2. Smallholder dairy farms in Kenya face serious feeding challenges in the dry season and feeding drought-tolerant leguminous shrubs, *Calliandra calothyrsus* and *Sesbania sesban*, can improve/enhance the growth rates of dairy calves.
3. Knowledge dissemination and capacity building by providing electronic reference material through cellphone-mediated training can improve knowledge on good dairy management practices.
4. Smallholder dairy farms in Kenya face serious feeding challenges in the dry season and feeding drought-tolerant leguminous shrubs, *Calliandra calothyrsus* and *Sesbania sesban*, can improve/enhance the milk production of dairy cows.
5. These interventions using leguminous shrubs, *Calliandra calothyrsus* and *Sesbania sesban*, can result in better milk production with lower feed costs for improved profits, and result in better household incomes and livelihoods.

Improvement of nutrition in the study population (dairy cows) was also expected to result in better reproductive performance in the cows. However, reproductive performance was not within the scope of this thesis. The associations between nutritional intervention and reproduction in the dairy cows were described in detail in another Ph.D. thesis.

1.8 Study location and context

This study was carried out in Naari sub-location of Meru County, Kenya, at 0°6'0" N and 37°35'0" E. Meru County is located on the eastern slopes of Mount Kenya and is about 270 kilometers north of Nairobi, the capital city of Kenya. The Naari sub-location is located in the high agricultural potential region within an altitude of approximately 2,000 meters above sea level. The main agricultural activities include dairying, horticulture and lumbering. Farmers grow food crops such as maize, beans and Irish potatoes. The study area was purposively selected since this research was part of a larger study involving dairy farmers in the area. A non-governmental organization, Farmers Helping Farmers, and the University of Prince Edward Island had an existing developmental partnership with the Naari Dairy Cooperative Society, which provided a strong foundation for the work and the entry point to the community.

1.9 References

Abdullahi Alhaji Magaji , Oboegbulem, S. I., Daneji, A. I., Garba, H. S., Salihu, M. D., Junaidu, A. U., Mohammed, A. A., … Mamuda, A. (2011). Incidence of Hydatid cyst disease in food animals slaughtered at. *Veterinary World*, *4*(5), 197–200.

Akayezu, J. M., Linn, J. G., Otterby, D. E., Hansen, W. P., & Johnson, D. G. (1994). Evaluation of calf starters containing different amounts of crude protein for growth of Holstein calves. *Journal of Dairy Science*, *77*(7), 1882–1889. https://doi.org/10.3168/jds.S0022-0302(94)77130-7

Amalie, M., Jein, R., Naukkarinen, M., & Rasmussen, Trine, Q. (2015). *Smallholder Dairy Farmers Challenges in Milk Production and Marketing in Bathi*. Nairobi, Kenya. Retrieved from https://sluse.dk/courses/ilunrm/project/Kenya_Livestock_FinalReport.pdf

Andae, G. (2018, January). New KCC cuts milk prices again, but consumers yet to benefit. *Daily Nation*. Retrieved from https://www.nation.co.ke/business/New-KCC-cuts-milk-prices-again--but-consumers-yet-to-benefit/996-4266398-15j3dd8/index.html

Behnke, R., & Muthami, D. (2011). *The Contribution of Livestock to the Kenyan Economy* (IGAD Livestock Policy Initiative No. 3–11). Nairobi, Kenya.

Bii, B. (2017). Dairy farmers face high cost of feeds as drought bites - Daily Nation. Retrieved August 11, 2017, from http://www.nation.co.ke/business/Dairy-farmers-face-high-cost-of-feeds/996-3800550-ckwc4oz/index.html

Bingi, S., & Tondel, F. (2015). *Recent developments in the dairy sector in Eastern Africa*. *European Centre for Development Policy Management*. Maastricht, Netherlands. Retrieved from http://ecdpm.org/wp-content/uploads/BN-on-dairy-sector-in-EA_final1.pdf

Blake, R. W. (2003). Dairy cattle response in difficult environments. In *7th World Bruna Conference, Fieragricola* (pp. 125–131). Viena, Italy: 7th World Bruna Conference.

Blein, R., Bwalya, M., Chimatiro, S., Faivre-Dupaigre, B., Kisira, S., & Leturque, Henri Yamdjeu, A. W. (2013). *African agriculture, transformation and outlook*. *NEPAD (New Partnership for African Development)*. Johannesburg , South Africa. Retrieved from http://www.un.org/en/africa/osaa/pdf/pubs/2013africanagricultures.pdf

Boor, E. I. (2012). *The Role of Milk Processors in Poverty Reduction among Small Scale Dairy Farmers: Case Study of NKCC Ltd Eldoret Suppliers*. University of Nairobi. Retrieved from http://erepository.uonbi.ac.ke/bitstream/handle/11295/9691/Boor_ The Role Of Milk Processors In Poverty Reduction Among Small Scale Dairy Farmers Case Study Of NKCC Ltd Eldoret Suppliers.pdf?sequence=1&isAllowed=y

Broderick, G. A. (2003). Effects of Varying Dietary Protein and Energy Levels on the Production of Lactating Dairy Cows. *Journal of Dairy Science*, *86*(4), 1370–1381.

https://doi.org/10.3168/jds.S0022-0302(03)73721-7

Bunglavan, S. J. and, & Dutta, N. (2013). Use of Tannins as Organic Protectants of Proteins in Digestion of Ruminants. *Journal of Livestock Science*, *4*, 67–77.

Changwony, K., & Kitilit, J. K. (2014). *Dairy Cattle Feed Types , Quantity Fed and Their Effects on Milk Density within Bomet , Bureti and Nyamira Districts* . Nairobi, Kenya. Retrieved from https://www.yumpu.com/en/document/view/27313276/dairy-cattle-feed-types

Cook, B., Pengelly, B., Brown, S., Donnelly, J., Eagles, D., Franco, A., … Schultze-Kraft, R. (2005a). Calliandra calothyrsus. Retrieved June 25, 2018, from http://www.tropicalforages.info/key/forages/Media/Html/entities/calliandra_calothyrsus.htm

Cook, B., Pengelly, B., Brown, S., Donnelly, J., Eagles, D., Franco, A., … Schultze-Kraft, R. (2005b). Sesbania sesban. Retrieved June 25, 2018, from http://www.tropicalforages.info/key/forages/Media/Html/entities/sesbania_sesban.htm

Cooke, J. S., Cheng, Z., Bourne, N. E., & Wathes, D. C. (2013). Association between growth rates, age at first calving and subsequent fertility, milk production and survival in Holstein-Friesian heifers. *Open Journal of Animal Sciences*, *03*(01), 1–12. https://doi.org/10.4236/ojas.2013.31001

Department for International Development. (1999). Sustainable Livelihoods Guidance Sheets. Retrieved January 9, 2019, from https://www.ennonline.net/dfidsustainableliving

Eghwa, B. (2016, June 28). Kenya Dairy Board commissions milk production survey. *Citizen Digital*. Retrieved from https://citizentv.co.ke/business/dairy-board-commissions-milk-production-survey-131894/

Elijah, K. N. (2017). Dairy farmer households farm gate milk price heterogeneity in Kericho County, Kenya. Journal of Development and Agricultural Economics, 9(7), 168–177. https://doi.org/10.5897/JDAE2017.0813

Elsadani, H. A. (2016). *Investing in rural people in Kenya*. Rome, Italy. Retrieved from https://www.ifad.org/documents/10180/bf67bad8-a182-4c79-a919-433af31eba02

Ettema, B. F. (2012). Dairy Development in Kenya. Retrieved May 11, 2018, from http://www.dairyfarmer.net/fileadmin/user_upload/40_downloads/kenya-dairying-ETTEMA.pdf

Food and Agriculture Organization. (2005, December). Dairy Development Newsletter. *Dairy Development Newsletter*, (9), 1–12. Retrieved from http://www.fao.org/ag/againfo/themes/documents/milk/IDFNewsletterBW.pdf

Food and Agriculture Organization. (2018). Kenya at a glance. Retrieved November 24, 2018, from http://www.fao.org/kenya/fao-in-kenya/kenya-at-a-glance/en/

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J., & Wambugu, C. (2013). Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. *Current Opinion in Environmental Sustainability*, *6*(1), 98–103. https://doi.org/10.1016/j.cosust.2013.11.008

Gitau, G. K., McDermott, J. J., McDermott, B., & Perry, B. D. (2001). The impact of Theileria parva infections and other factors on calf mean daily weight gains in smallholder dairy farms in Murang'a district, Kenya. *Preventive Veterinary Medicine*. https://doi.org/10.1016/S0167-5877(01)00243-4

Gitau, G. K., McDermott, J. J., Waltner-Toews, D., Lissemore, K. D., Osumo, J. M., & Muriuki, D. (1994). Factors influencing calf growth and daily weight gain on smallholder dairy farms in Kiambu District of Kenya. *Preventive Veterinary Medicine*, *21*(2), 179–190.

Government of Alberta. (2018). How Much Feed Will My Cow Eat. Retrieved June 24, 2018, from http://www1.agric.gov.ab.ca/$department/deptdocs.nsf/all/faq7811

Government of Kenya. (2007). Kenya Vision 2030. Retrieved June 24, 2018, from http://www.fao.org/fileadmin/user_upload/drought/docs/Vision 2030- Popular Version.pdf

Gusha, J., Ngongoni, N. T., & Halimani, T. E. (2013). Nutritional composition and effective degradability of four forage trees grown for protein supplementation. *Online Journal of Animal and Feed Research*, *3*(4), 170–175.

Hove, L., Franzel, S., & Moyo, P. S. (2003). Farmer experiences in the production and utilisation of fodder trees in Zimbabwe: Constraints and opportunities for increased adoption. *Tropical Grasslands*, *37*, 279–283. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-1642476784&partnerID=40&md5=d6c022fd216f380eece0e3e2b53bf225

Hummel, J., Südekum, K. H., Streich, W. J., & Clauss, M. (2006). Forage fermentation patterns and their implications for herbivore ingesta retention times. *Functional Ecology*, *20*(6), 989–1002. https://doi.org/10.1111/j.1365-2435.2006.01206.x

IndexMundi. (2018). Kenya demographics profile. Retrieved November 24, 2018, from http://www.indexmundi.com/kenya/demographics_profile.html

Ishler, V., & Varga, G. (2001). Carbohydrate nutrition for lactating dairy cattle. Retrieved June 24, 2018, from https://extension.psu.edu/carbohydrate-nutrition-for-lactating-dairy-cattle

Kaitho, R., & Kariuki, J. (1998). Effects of Desmodiam,Sessbania and Calliandra fed on dairy heifers.pdf. *Asian-Australasian Journal of Animal Sciences*, *11*(6), 680–684. https://doi.org/http://dx.doi.org/10.5713/ajas.1998.680

Kariuki, J. (2017, September 7). Local milk production dropped 17 per cent, says KNBS - Business Daily. *Business Daily*. Retrieved from https://www.businessdailyafrica.com/markets/marketnews/Local-milk-production-dropped-17-per-cent/3815534-4086822-e8buouz/index.html

Kilpatrick, S. (2000). Education and training: impacts on farm management practice. *The Journal of Agricultural Education and Extension*, *7*(2), 105–116. https://doi.org/10.1080/13892240008438811

Krantz, L. (2001). *The sustainable livelihood approach to poverty reduction*. *Division for Policy and Socio-Economic Analysis*. Stockholm, Sweden. Retrieved from https://www.sida.se/contentassets/bd474c210163447c9a7963d77c64148a/the-sustainable-livelihood-approach-to-poverty-reduction_2656.pdf

Kristjanson, P., Krishna, A., Radeny, M., & Nindo, W. (2004). *Pathways out of poverty in Western Kenya and the role of livestock* (Pro-Poor Livestock Policy Initiative No. 14). Nairobi, Kenya. Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/1212/Pathways out of poverty.pdf?sequence=1&isAllowed=y

Krpálková, L., Cabrera, V. E., Vacek, M., Stípková, M., Stádník, L., & Crump, P. (2014). Effect of prepubertal and postpubertal growth and age at first calving on production and reproduction traits during the first 3 lactations in Holstein dairy cattle. *Journal of Dairy Science*, *97*(5), 3017–3027. https://doi.org/10.3168/jds.2013-7419

Lanyasunya, T. P., Musa, H. H., Yang, Z. P., Mekki, D. M., & Mukisira, E. A. (2005). Effects of Poor Nutrition on Reproduction of Dairy Stock on Smallholder Farms in the Tropics. *Pakistan Journal of Nutrition*, *4*(2), 117–122. https://doi.org/10.3923/pjn.2005.117.122

Li, H. Y., Xu, L., Liu, W. J., Fang, M. Q., & Wang, N. (2014). Assessment of the nutritive value of whole corn stover and its morphological fractions. *Asian-Australasian Journal of Animal Sciences*, *27*(2), 194–200. https://doi.org/10.5713/ajas.2013.13446

Lukuyu, B Gacwiri ,C Agili ,S Leon-Verlade, C and Kirui, J, . (2012). Making High Quality Sweet Potato Silage. (J. Low, Ed.). Nairobi: International Potato Center. Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/21584/SweetpotatoBrochure.pdf?sequence=1

Lukuyu, B., Franzel, S., Ongadi, P. M., & Duncan, A. J. (2011). Livestock feed resources: Current production and management practices in central and northern rift valley provinces of Kenya. *Livestock Research for Rural Development.*, *23*(5), 112.

Lukuyu, B., Gachuiri, C. K., Lukuyu, M. N., Lusweti, C., & Mwendia, S. (2012). *Feeding dairy cattle in East Africa*. (B. Lukuyu & C. Gachuir, Eds.), *Feeding dairy cattle in East Africa* (First). Nairobi, Kenya: East Africa Dairy Devleopment Project. Retrieved from https://cgspace.cgiar.org/bitstream/handle/.../EADDDairyManual.pdf

Lukuyu, B., Kugonza, J., Wabwire, R., & Baltenweck, I. (2011). Characterisation of the livestock production system and potential for enhancing productivity through improved feeding at Namayumba , Wakiso district of Uganda , March 2011 Farming system. In

East African Dairy Development Project (EADD) (pp. 1–6).

Maina, S. (2008). Dairy cattle management. Retrieved June 26, 2018, from http://elewa.org/animalmanagement/Dairycattlemanagement.pdf

Makau, D. (2014). *A study of factors associated with the prevalence of coccidia infection in cattle and its spatial epidemiology in Busia, Bungoma and Siaya counties, Kenya*. University of Nairobi. Retrieved from https://cgspace.cgiar.org/handle/10568/56880

Mapiye, C., Foti, R., Chikumba, N., Poshiwa, X., Mwale, M., Chivuraise, C., & Mupangwa, J. F. (2006). Constraints to adoption of forage and browse legumes by smallholder dairy farmers in Zimbabwe. *Livestock Research for Rural Development, 18*(12), 1–12.

Mikkelsen, P. (2014). *Dairy Markets in Africa*. *Dairy Markets in Africa – the Region of Opportunities in the Future*. Højbjerg, Denmark. Retrieved from http://www.pmfood.dk/upl/9730/AFRICAINFORMATION1.pdf

Ministry of Livestock Developement. (2014). Republic of Kenya ministry of livestock development the feeding of the dairy cow. Retrieved January 24, 2016, from http://www.sdcp.or.ke/documents and publications.htm

Moran, J. (2005). Nutrition and young stock. In Peter Storer Editoral Services (Ed.), *Tropical Dairy Farming: Feeding Management for Small Dairy Farmers in the Humid Tropics* (First, pp. 183–190). Collingwood,Australia: CISRO Publishing. Retrieved from http://samples.sainsburysebooks.co.uk/9780643107892_sample_295356.pdf

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. *Livestock Research for Rural Development*, *23*(5). Retrieved from http://www.lrrd.org/lrrd23/5/njar23111.htm

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. FAO Prevention of Food Losses Programme*. Rome, Italy. Retrieved from http://www.fao.org/fileadmin/templates/ags/docs/dairy/P1assessmentkenya.pdf

Muriuki, H. G. (2011). *Dairy development in Kenya*. *FAO-Dairy Reports*. Rome. Retrieved from http://www.fao.org/3/a-al745e.pdf

Muriuki, H., Mwangi, D., & Thorpe, W. (2001). How Smallholder Dairy Systems in Kenya Contribute to Food Security and Poverty Alleviation: results of recent collaborative studies. In *Contribution of Livestock to Food Security and Poverty Alleviation* (pp. 1–9). Morogoro, Tanzania: Tanzania Society of Animal Production Conference. Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/1725/Muriuki et al-2001-Smallholder dairy %26 food security-TSAP.pdf?sequence=1

Muraya, J., Vanleeuwen, J. A., Gitau, G. K., Wichtel, J. J., Makau, D. N., Crane, M. B., … Tsuma, V. T. (2018). Cross-sectional study of productive and reproductive traits of dairy cattle in smallholder farms in Meru, Kenya. Livestock Research for Rural Development, 30(10)

Mvena, Z. S. K., Mattee, A. Z., Wambura, R. M., Mwaseba, D. L., Lazaro, E. A., Kiranga, E. D., & Kilave, D. M. (2013). Farmer Field Schools as a Springboard for Enhanced Uptake of New Agricultural Technologies : Lessons for Tanzania. *International Journal of Basic and Applied Research*, *12*(1), 43–51.

Mwangi, D. M., & Wambugu, C. (2003). Adoption of forage legumes : the case of Desmodium intortum and Calliandra calothyrsus in central Kenya. *Tropical Grasslands*, *37*, 227–238.

Mwebaze, S. (2002). *Pasture improvement technologies based on an on-farm study in Uganda*. *Animal Production*. Uganda. Retrieved from http://www.fao.org/fileadmin/user_upload/drought/docs/Pasture Improvement Technologies.pdf

National Research Council. (2001). *Nutrient Requirements of Dairy Cattle*. (National Research Council, Ed.), *Nutrient Requirements of Dairy Cattle* (7 th). Washington D.C., USA: National Academy Press. https://doi.org/10.1016/j.bbamcr.2011.06.003

Ngigi, M. (2005). The Case of Smallholder Dairying in Eastern Africa (No. 131). Environment and Production Technology Division. Washington D.C., USA. https://doi.org/10.2139/ssrn.695481

Ngongoni, N. T., Mapiye, C., Mwale, M., & Mupeta, B. (2006). Factors affecting milk production in the smallholder dairy sector of Zimbabwe. *Livestock Research for Rural Development*, *18*(6), 89. Retrieved from http://www.lrrd.org/lrrd18/6/ngon18089.htm

Ngwira, A. (2003). Forage demand and constraints to adoption of forage technologies by livestock keepers in Malawi. *Tropical Grasslands*, *37*, 274–278.

Njarui, D. M. G., Gatheru, M., Wambua, J. M., Nguluu, S. N., Mwangi, D. M., & Keya, G. A. (2011). Feeding management for dairy cattle in smallholder farming systems of semi-arid tropical Kenya. *Livestock Research for Rural Development*, *23*(5), 111. Retrieved from http://www.lrrd.org/lrrd23/5/njar23111.htm

Njonge, F. K. (2017). Challenges faced by smallholder dairy farmers in Kirinyaga County , Kenya. *Journal of Agriculture and Veterinary Science*, *10*(8), 71–75. https://doi.org/10.9790/2380-1008017175

Nkya, R., Kessy, B. M., Lyimo, Z. C., Msangi, B. S. J., Turuka, F., & Mtenga, K. (2007). Constraints on smallholder market oriented dairy systems in the north eastern coastal region of Tanzania. *Tropical Animal Health and Production*, *39*, 627–636. https://doi.org/10.1007/s11250-007-9059-4

Oakley, P., & Garforth, C. (1993). *Guide to extension training*. (University of Reading, Ed.) (1st ed.). Rome, Italy: Food and Agriculture Organization of The United Nations. https://doi.org/10.1016/0269-7475(88)90032-3

Ochieng, J., Kirimi, L., & Mathenge, M. (2016). Effects of climate variability and change on agricultural production: The case of small scale farmers in Kenya. NJAS - Wageningen Journal of Life Sciences, 77, 71–78. https://doi.org/10.1016/j.njas.2016.03.005

Odero-Waitituh, J. A. (2017). Smallholder dairy production in Kenya; a review. *Livestock Research for Rural Development*, *29*(139). Retrieved from http://www.fao.org/docrep/W2650T/W2650t07.html

Office of Auditor General-Kenya. (2016). *Kenya dairy board annual report and financial statements*. Nairobi, Kenya. Retrieved from www.oagkenya.go.ke/index.php/reports/doc_download/1643-kenya-dairy-board

Okoth, D. (2009, August 20). Standard Digital News - Kenya Fodder shrubs boost for dairy farmers. *Standard Digital*. Retrieved from https://www.standardmedia.co.ke/article/1144021994/fodder-shrubs-boost-for-dairy-farmers

Orwa, C., Mutua, A., Kindt, R., Jamnadass, R., & Anthon, S. (2009). Sesbania sesban. Retrieved June 25, 2018, from http://www.worldagroforestry.org/sites/treedbs/treedatabases.asp

Otieno, D. (2017, June 11). Before you vote: The truth about milk prices. *Daily Nation*. Retrieved from https://www.nation.co.ke/newsplex/milk-prices-Raila-Odinga/2718262-3965126-5f46xcz/index.html

Oyugi, Z. (2018). Why dairy production in Kenya is 60 per cent more expensive than in the neighboring countries. Retrieved November 6, 2018, from http://farmbizafrica.com/markets/2168-why-dairy-production-in-kenya-is-60-per-cent-more-expensive-than-in-the-neighboring-countries

Phelan, J. (2007). Reflections on Dairy Developement Experiences in different continents. *Indian Dairyman*, *59*(2), 7–16. https://doi.org/10.1017/CBO9781107415324.004

Place, F., Roothaert, R., Maina, L., Franzel, S., Sinja, J., & Wanjiku, J. (2009). *The Impact of Fodder Shrubs on Milk Production and Income Among Smallholder Dairy Farmers in East Africa and the Role of Research Undertaken by the World Agroforestry Centre*. (P. Fredenburg, Ed.), *Ocassional Paper* (Ist, Vol. 12). Nairobi, Kenya: World Agroforestry Centre. Retrieved from http://impact.cgiar.org/pdf/217.pdf

Rathod, P., Chander, M., & Bardhan, D. (2016). Adoption Status and Influencing Factors of Mobile Telephony in Dairy Sector : A Study in Four States of India §. *Agricultural Economics Research Review*, *29*(1), 15–26. https://doi.org/10.5958/0974-0279.2016.00015.X

REGLAP Secretariat. (2012). *Key statistics on the drylands of Kenya, Uganda and Ethiopia*. Nairobi, Kenya. https://doi.org/10.1026/0012-1924.53.2.97

Rengman S. Johansson B. & Murphy M. (2014). Dietary nutrient density and effects on intake and production. In P. Udén (Ed.), *5th Nordic Feed Science Conference* (Vol. 290, pp. 83–87). Upsala: Organising committee of the 5th Nordic Feed Science Conference Department of Animal Nutrition and Management Swedish University of Agricultural Sciences (SLU) SE- 753 23 Uppsala, Sweden. Retrieved from http://www.slu.se/Documents/externwebben/vh-fak/husdjurens-utfodring-och-vard/Publikationer/NFSC 2014 Proceedings2014-06-04.pdf

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G. K., Kamunde, C., Uehlinger, F., & Wichtel, J. (2015). Associations of farm management practices with annual milk sales on smallholder dairy farms in Kenya. *Veterinary World*, *8*(1), 88–96. https://doi.org/10.14202/vetworld.2015.88-96

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G. K., Wichtel, J., Kamunde, C., & Uehlinger, F. (2016). Randomized controlled trial on impacts of dairy meal feeding interventions on early lactation milk production in smallholder dairy farms of Central Kenya. *Preventive Veterinary Medicine*, *3954*, 1–8. https://doi.org/doi:10.1016/j.prevetmed.2016.01.006

Santos, J. E. (2001). Dietary Ingredients and Nutritional Management Impact Fertility. In U.-D. School of Veterinary Medicine (Ed.), *36th Pacific Nortwest Animal Nutrition Conference* (pp. 189–219). Davis, California: University of California - Davis. Retrieved from http://www.nupel.uem.br/pos-ppz/eduardo-nutrional.pdf

Santos, J. E. P. (2008). Impact of Nutrition on Dairy Cattle Reproduction. In 5m Publishing (Ed.), *High Plains Dairy Conference* (pp. 25–36). Amarillo,Texas: 5m Publishing. Retrieved from http://www.thecattlesite.com/articles/1568/impact-of-nutrition-on-dairy-cattle-reproduction/

Santos, J. E. P., Bisinotto, R. S., Ribeiro, E. S., Lima, F. S., Greco, L. F., Staples, C. R., & Thatcher, W. W. (2010). Applying nutrition and physiology to improve reproduction in dairy cattle. *Society of Reproduction and Fertility Supplement*, *67*, 387–403. https://doi.org/10.5661/RDR-VII-387

Serrat, O. (2017). The Sustainable Livelihoods Approach. In *Knowledge Solutions: Tools, Methods, and Approaches to Drive Organizational Performance* (pp. 21–25). Springer, Singapore. https://doi.org/10.1007/978-981-10-0983-9

Schroeder, J. W. (2017). Use Caution When Feeding Dairy Cattle High Levels of Concentrate. Retrieved June 25, 2018, from https://www.ag.ndsu.edu/drought/feeds-and-feeding/use-caution-when-feeding-dairy-cattle-high-levels-of-concentrate

Shahjalal, M., & Topps, J. . (2000). Feeding sesbania leaves to goats. *Asian-Aus. J. Anim. Sci.*, *13*(4), 487–489. Retrieved from https://www.ajas.info/journal/view.php?number=19605

Smith, J., Sones, K., Grace, D., MacMillan, S., Tarawali, S., & Herrero, M. (2013). Beyond milk, meat, and eggs: Role of livestock in food and nutrition security. *Animal Frontiers*, *3*(1), 6–13. https://doi.org/10.2527/af.2013-0002

Smith, R. D., & Chase, L. E. (2000). Nutrition and Reproduction. Retrieved October 14, 2016, from https://www.wvu.edu/~agexten/forglvst/Dairy/dirm14.pdf

Smith, T. (2000). Some Tools To Combat Dry Season Nutritional Stress in Ruminants Under African Conditions. In *Development and Evaluation of Feed Supplementation Packages* (pp. 145–152). Reading, United Kingdom: International Atomic Energy Agency. Retrieved from http://www-naweb.iaea.org/nafa/aph/public/reports-13.pdf

Smollo, J. W., Ali-Olubandwa, A. M., & Ng'endo, C. M. (2016). Influence of Utilizing Animal Husbandry Information from Mobile Phones on Milk Yield Among Smallholder Dairy Farmers In Njoro Sub- County, Kenya. *International Journal of Agricultural Extension*, *04*(01), 41–47.

Tanyanyiwa, F. K. (2016). An assessment of entrepreneurial attributes determining the potential of smallholder dairy farmers progressing to commercial farming. University of KwaZulu-Natal. Retrieved from https://researchspace.ukzn.ac.za/handle/10413/14018

TechnoServe Kenya. (2008). *The Dairy Value Chain in Kenya*. *East Africa Dairy Development Program*. Nairobi, Kenya. Retrieved from http://cgspace.cgiar.org/bitstream/handle/10568/2406/Dairy Value Chain Uganda Report.pdf?sequence=1

The Dairy Policy Forum. (2004). *Policies to Support Smallhoder Dairy for Sustainable Employment and incomes in Kenya Kenya*. Nairobi, Kenya. Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/52337/Policies to support smallhoder dairy in Kenya.pdf?sequence=1

The World Bank. (2012). Using ICT to enable Agricultural Innovation Systems for Smallholders ICT innovations. Retrieved May 14, 2018, from http://www.fao.org/docrep/018/ar130e/ar130e.pdf

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*, 231–238. https://doi.org/10.1007/s11250-011-0003-2

Veras, O. (2017). Agriculture in Africa: Potential versus reality. Retrieved July 29, 2018, from https://ntusbfcas.com/african-business-insights/content/agriculture-in-africa-potential-versus-reality

Wambugu, S., Kirimi, L., & Opiyo, J. (2011). *Productivity trends and performance of dairy farming in Kenya* (WPS 43/2011). *Tegemeo Institute of Agricultural Policy and Development* (Vol. WPS 43/201). Nairobi, Kenya.

Wanjohi, G. W. (2018). *Effectiveness of enhancing face-to-face peer-led nutrition education methods with an intervention of nutrition-related cell phone messaging on Kenyan women's knowledge, attitudes, and practices*. University of Prince Edward Island.

Wathes, D. C., Pollott, G. E., Johnson, K. F., Richardson, H., & Cooke, J. S. (2014). Heifer fertility and carry over consequences for life time production in dairy and beef cattle. *Animal*, *8*(S1), 91–104. https://doi.org/10.1017/S1751731114000755

Windeyer, M. C., Leslie, K. E., Godden, S. M., Hodgins, D. C., Lissemore, K. D., & LeBlanc, S. J. (2014). Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. *Preventive Veterinary Medicine*, *113*(2), 231–240. https://doi.org/10.1016/j.prevetmed.2013.10.019

World Agroforestry Center. (2011). *Fodder trees and milk production in East Africa*. *Policy Brief* (Vol. 12). Nairobi, Kenya. https://doi.org/BR09326

World Bank Group. (2013). Agricultural land (% of land area). Retrieved June 20, 2018, from http://data.worldbank.org/indicator/AG.LND.AGRI.ZS?year_high_desc=false

Yohannes, H. (2015). A Review on Relationship between Climate Change and Agriculture. *Journal of Earth Science & Climatic Change*, *07*(02), 335. https://doi.org/10.4172/2157-7617.1000335

Zhumanova, M., Issahaku, Z. A., & Maharjan, K. L. (2013). Effects of Seasonal Changes and Forage Availability on Milk Yield of Cows among Smallholder Households in Ala-Buka , Kyrgyzstan. *Journal of International Development and Cooperation*, *19*(4), 29–36.

Chapter 2 Animal and management factors associated with weight gain in dairy calves and heifers on smallholder dairy farms in Kenya [1]

2.1 Abstract

Calf growth is an important determinant of dairy herd productivity, particularly in countries where the dairy industry is expanding, such as Kenya. Our objective was to determine factors associated with weight gain in randomly selected dairy calves and heifers in semi-commercial smallholder dairy farms (SDFs) in Kenya.

A cross-sectional study on a census of 321 calves and heifers (dairy calves and heifers up to 36 months of age), sampled from 200 randomly selected semi-commercial SDFs in Naari, Kenya, formed the study population. Youngstock management was recorded using a questionnaire. Biodata were obtained through subsequent physical examination and heart girth measurement. Descriptive statistical analyses were conducted, and mixed model regression was used for identification of factors associated ($p < 0.05$) with the natural log transformation of estimated average daily weight gain (ADG).

Median and mean ADG of the youngstock were 360 and 443 (s.d.=375) g day $^{-1}$, respectively. In the final model, ADG was highest in pre-weaned calves and declined with age. Supplementing with quality hay during the dry season at least weekly was associated with increased ADG. There was an interaction between breed and historical

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[1] **Makau DN,** VanLeeuwen JA, Gitau G K, Muraya J, McKenna SL, Walton C, Wichtel JJ 2018. Animal and management factors associated with weight gain in dairy calves and heifers on smallholder dairy farms in Kenya. *Preventive Veterinary Medicine Vol 161, pp 60-68, ISSN 0167-5877.* https://doi.org/10.1016/j.prevetmed.2018.10.017

disease on ADG such that disease was associated with decreased ADG in *Bos taurus* breeds, while ADG in *Bos indicus* breeds was not affected by disease. There was a significant interaction between education levels of the husband and wife caretakers; when the man's education was low (having less than or equal to primary school), ADG was highest when the woman had not completed primary school, but was lower when the woman had completed primary, secondary or tertiary education, possibly because such women worked off-farm more often.

General growth performance of animals on these farms was lower than benchmarked standards recommended for optimum dairy production but within previously reported ranges for the East African region. Supplementation of diets (with hay and/or concentrates) is recommended for optimum growth in calves and heifers, especially in the dry season. If nutritional management of *Bos taurus* youngstock is not improved, crosses of *Bos indicus* could be better suited for the current nutritional management systems in SDFs in Meru having calf disease problems. Interventions to support educating women (the primary caretakers of the cattle) and men in the community on calf management should be initiated, preferably with shared on-farm responsibilities. Training in better management, even for learned farmers, would be critical to better calf growth.

Key words: smallholder dairy farms; calves; heifers; average daily weight gain; Kenya

2.2 Introduction

Good calf management is the cornerstone of dairy cattle productivity, particularly in countries where the dairy industry is expanding, such as Kenya (Odero-Waitituh, 2017). Milk production in Kenya in 2011 was estimated at 4.8 million tons of milk, 4.6 million tons from cows (Dairy Farming in Kenya, 2011). This volume was produced by approximately 3.5 million cows with exotic blood lines (Friesian, Ayrshire, Jersey and Guernsey breeds and their crosses), and 9.3 million indigenous cows (Muriuki, 2011). Approximately 80% of the milk produced in Kenya comes from 2 million smallholder dairy farms (SDFs) concentrated in the moderately productive areas of Kenya (Dairy Farming in Kenya, 2011).

One very important constraint to expansion of production in SDFs in Africa is suboptimal feeding (Steven et al., 2014). It has been documented that most nutritional problems occur during the dry seasons in Africa (Smith, 2000). The most common constraints on optimal nutrition include insufficient water, inadequate knowledge and technology on feed conservation, and deficient quantities and quality of forages used in nutritional management of dairy animals (Lukuyu et al., 2011). Although feed conservation is practiced to some extent in Kenya, Napier grass and crop residues are often of very poor nutritional quality due to late harvesting, and the quantities are frequently inadequate (Njarui et al., 2011). Kenyan farmers often resort to buying feed from neighboring farms or renting grazing land during the dry season (Njarui et al., 2011). Other high quality feeds, such as hay, can be either expensive and/or unavailable to the Kenyan SDFs (Bii, 2017).

A reasonable growth benchmark for weight gain in calves on SDFs is 400 g day^{-1} (Lukuyu et al., 2012). For bigger breeds, such as Holstein-Friesian, the ideal age at weaning is 12 weeks, or when the animal reaches 80kg body weight (Lukuyu et al., 2012). In the early stages of life (1-2 months), nutritional management is aimed at ensuring proper ruminal development through papillae and increase in size (Ueno et al., 2014). Post-weaning, when the rumen is well-developed, provision of high quality feed is key to maintaining healthy growth rates, and therefore poor quality feed in the dry season can affect skeletal growth and weight gain (Lukuyu et al., 2012). The optimum weight gain for heifers to achieve first calving before the age of 27 months was estimated to be 500-700 g day $^{-1}$ (Lukuyu et al., 2012). Krpálková et al., (2014) reported that a group of Holstein calves that had ADG between 850 g day $^{-1}$ and 949g day $^{-1}$ between the ages of 5 to 14 months had the highest milk production in their first lactation.

Nutrition is closely associated with disease. Calf-hood diseases impact subsequent heifer survival and productivity, and affect the economic value and welfare of animals in a production unit (Windeyer et al., 2014). Studies in Kenya have reported on disease and mortality in dairy calves on SDFs (Gitau et al., 1994a), but there is limited recent information on factors, including disease, associated with weight gain in dairy calves/heifers in SDFs.

In this cross-sectional study, we examined a random sample of young-stock (dairy calves and heifers up to 36 months of age) to identify factors associated with young-stock weight gain in smallholder dairy farms (SDFs) in Meru County, Kenya.

2.3 Materials and methods

2.3.1 Ethical approval

This study was approved by the Research Ethics Board and the Animal Care Committee of the University of Prince Edward Island, NDFCS, and Farmers Helping Farmers, a partner nongovernmental organization. Signed consent of all participants was obtained after the study was fully explained.

2.3.2 Description of study area

This cross-sectional study was carried out in Naari sub-location of Meru County, Kenya, at 0°6'0" N and 37°35'0" E. Meru County is located on the eastern slopes of Mount Kenya and is about 270 kilometers north of Nairobi, the capital city of Kenya. The Naari sub-location is located in the high agricultural potential region within an altitude of approximately 2,000m above sea level. The main agricultural activities include dairying, horticulture and lumbering. Farmers grow food crops such as maize, beans and Irish potatoes. The study area was purposively selected since this research was part of a larger study involving dairy farmers in the area (Figure 2.1a). A non-governmental organization, Farmers Helping Farmers (FHF), and the University of Prince Edward Island (UPEI) had an existing developmental partnership with the Naari Dairy Farmers Cooperative Society (NDFCS), which provided a strong foundation for the work and the entry point to the community.

2.3.3 Sample population and data collection

The farmers included in the study were from NDFCS, a dairy group with an active membership of about 550 farmers who regularly deliver milk to the dairy. A sample size of 200 farms (Figure 2.1b) was randomly selected from the registry of active members between January and May 2015 using software-based random number generation. The sample size was determined based on a need to identify 80 farms with specific characteristics for a related intervention study. Farm-level inclusion criteria included active membership with the Naari Dairy, zero-grazing, and <4 milking cows.

Principal farmers consenting to participate in the study were visited in May-August 2015, and they answered a questionnaire (Appendix 8.2) covering various management factors on their farms. The questionnaire had 58 questions with three main sections covering farm management, youngstock health and productivity, and farmer training and demographic information.

Calves & heifers were included in the study if they were male or female animals less than or equal to 15 months of age, or female and more than 15 months but less than 36 months of age and had not given birth or had a miscarriage/abortion. None of the young stock was excluded because of having had a history of abortion/miscarriage. A total of about 300 eligible calves and heifers were targeted from the 200 participating farms. Additional information on the health of each eligible calf/heifer on each participating farm was collected from a physical examination of the calves/heifers, and the weight was estimated using a heart girth tape.

2.3.4 Data management and analysis

For each calf/heifer, the ADG was calculated as the difference between weights observed in the study at examination and average recorded weights of calves less than three days old in the area divided by the age at examination. For breeds where this information was not available, birth weights from published studies were used (Hickson et al., 2015).

Statistical analyses were done using Stata13.0 software. Descriptive statistics included means, medians, distributions, and proportions, where applicable. Data collected were analyzed using both univariable and multivariable regression analysis as detailed below, with ADG as the outcome of interest. Tests for normality of ADG, using the Shapiro-Wilk test, and Box-Cox analysis for suitable transformations were explored. These tests showed that ADG was right-skewed and a natural logarithm of ADG was normally distributed.

A univariable mixed linear regression model was built for each of the variables to ascertain associations with natural logarithm of ADG at $p \leq 0.4$ in order to determine eligible variables for the multivariable model-building process. Farm identification was utilized as a random effect in the models, to account for possible clustering of calves/heifers within farms.

Multivariable linear regression was later performed using a mixed model with natural logarithm of ADG as the outcome. Farm identification was utilized as a random effect in the models, to account for possible clustering. The p-value was set at 0.05, and interactions between significant parameters were explored. Tests for collinearity (Pearson correlation coefficient) among all parameters meeting the regression modeling cut-off ($p < 0.4$) were determined to aid decision-making on collinear variables to be included in the model building, with decisions based on p-values and biological plausibility. Wald test was used to test overall significance of categorical parameters with more than 2 categories. Assessment of linearity between ADG and continuous variables was done using a lowess plot. Model building used a backward elimination technique and models were compared using likelihood ratio tests for significance of dropped parameters. Testing for confounding by age and other possible confounders was done in the final model by comparing changes in coefficient estimates (>20%) with and without the suspected confounder. Identification of extreme and influential observations was done by sorting and graphing the standardized residuals and comparing changes in coefficient estimates and their significance when modeling with and without influential observations. All observations were retained in the model.

Model evaluation was done to confirm that normality and homoscedasticity assumptions on both random and fixed effects were met. Tests for normality of residuals were done using the Shapiro-Wilk test. Predictions of ADG were performed using the margins command on natural logarithm of ADG and subsequently back-transformed to the original scale of g day $^{-1}$ for ease of interpretation.

2.4 Results

From the 200 sampled farms, a total of 321 calves and weaned heifers were examined. Twenty animals were excluded from the analysis for not meeting the inclusion criteria; eight were male cattle over 15 months old, 12 were heifers over 36 months old. None of the heifers under 36 months had a calf/abortion/miscarriage. There were 41 farms that did not have an eligible calf or heifer, and therefore the final dataset consisted of 301 animals from 159 farms. The mean ADG of the 301 animals was 0.443 kg day $^{-1}$ (s.d. = 0.375) with a median of 0.360 kg day $^{-1}$. The calves under 15 months of age had a mean ADG of 0.482 kg day $^{-1}$ (s.d. = 0.441), while the heifers over 15 months of age had a mean ADG of 0.364 kg day $^{-1}$ (s.d. = 0.151).

2.4.1 Descriptive statistics and univariable analyses between natural logarithm of ADG and various factors

The mean age of calves and heifers combined was 12.5 months (s.d. = 9.5), with a median of 12 months. The population was comprised of 202 calves and 99 heifers over

15 months of age. There were 123 female calves and 79 male calves. Animal-level variables that met the $p < 0.40$ univariable analysis cut-off are presented in Table 2.1.

Age was a highly significant factor of ADG, as expected, in the univariable analyses. Sex of the calf was however not associated with ADG at $p < 0.40$. A total of six cattle breeds were kept on these farms (Table 2.1) with more than half of the dairy cattle population comprised of Friesian crosses.

Most of the calves and heifers had no history of disease, with only a quarter of them having suffered from navel ill, diarrhea or pneumonia. Among this population of 79 calves and heifers with history of disease, pneumonia was the most common disease affecting 63.3% of them. Farmer demographic variables that met the $p < 0.40$ univariable analysis cut-off are in Table 2.1. Women were more often the principal farmer than men. Higher levels of formal education (university/college) were not common among both women and men. More than half (60.4% of women, 57.2% of men) of participating farmers had only obtained a primary school education, or less.

A number of farmer demographic variables were included in the questionnaire but did not meet the ADG univariable analysis cut-off of $p < 0.40$. The mean age of women and men in dairy farming in the area was 47.1 years (s.d. = 13.6) and 51.7 years (s.d. = 14.3), respectively. The mean land size owned in this area was 2.3 acres (s.d. = 2.9) and, on average, 40.3% (95% CI: 39.5 - 44.2%) of land owned was used for dairy production. Household sizes were, on average, 4 people with a s.d. of 2 people.

The following farm management variables met the $p < 0.40$ univariable analysis cut-off (Table 2.1). Most of the farms housed their young animals in a dirt-floored pen, whereas

10.1% had wooden floors, while few (2.5%) had concrete floors. Most farmers dewormed their young cattle 3 months after the last deworming. Feed changes among young-stock were common on two-thirds of farms, especially when the season changed. At the time of this study, feed shortage was a problem in this area. Only one-third of farmers had adequate feed for their young cattle within the 12 months prior to the commencement of the project.

Nearly all, 98.1%, of the farms fed calves and heifers on Napier grass. Twenty-two farms fed calves and heifers on silage, with 90.9% (20/22) of these animals being fed on maize silage, while the others were given grass silage. Farms feeding maize and grass silage were combined for regression analysis and met the $p < 0.40$ univariable analysis cut-off (Table 2.1).

Other significant farm management factors included supplementation with concentrates for heifers and calves at least once a week; with half of the farms having some form of concentrate feed in their calf/heifer diets. The three most commonly used concentrate supplements on the 82 farms were dairy meal - 64.6%, maize germ - 20.7%, and calf pellets - 14.6%. A quarter of the farmers fed hay as a daily supplement during the dry season. A third of the farmers occasionally fed calves and heifers on banana leaves and non-leguminous tree foliage. Slightly more than half of the population of calves and heifers in these farms always had access to clean drinking water.

In summary, factors associated with ADG ($p <0.4$) included calf age, breed, and history of disease, gender of principal farmer, education level of both farmers, and the following management factors: deworming frequency, feed adequacy in last 12 months, feed changes, feeding of silage, hay, tree and banana foliage, concentrates and access to clean drinking water.

Other farm-level management variables were included in the questionnaire but did not meet the univariable analysis cut-off of $p < 0.4$. Few farmers fed high protein forages (Desmodium/Lucerne) and leguminous trees/shrubs (*Calliandra*/*Sesbania*/mulberry) to calves and heifers, at 4.4% and 8.2%, respectively. The use of sweet potato vines as fodder was practiced, among 25% of the farmers, feeding them to calves and heifers at least once a week. Although 74.8% of farmers had received some form of training on dairy management, most (70%) farmers incorrectly indicated that the calves consumed at least 4 liters of first colostrum only after 24 hours. However, free suckling of colostrum by newly born calves was practiced by nearly two-thirds of farms, making it difficult to know exactly how much colostrum calves consumed within the first 12 or 24 hours. Vitamin and mineral supplementation was common, with 74.2% of these SDFs providing some form of mineral and vitamin supplementation to calves and heifers on the farms, but there was no difference in ADG between farms supplementing vitamins and minerals versus those farms who did not supplement.

2.4.2 Multivariable analysis between ln ADG and various factors

The highest correlation observed between variables meeting the cut-off p-value was 0.3, between weekly hay feeding and weekly concentrate feeding. Of the 83 calves supplemented with hay at least weekly, 62 (74.7%) were also supplemented with concentrates at least weekly. Of the 151 calves supplemented with concentrate at least weekly, 62 (41%) were also supplemented with hay at least weekly. Therefore, weekly concentrate feeding was not retained in the final model in favor of weekly hay feeding, since both correlated variables could not remain in the final model and be statistically significant.

In the final multivariable linear mixed model, age, breed and history of disease were animal-level variables that were significantly associated with ADG (Table 2.2). Since the relationship between ADG and age appeared curvilinear, a quadratic form was used for age as a continuous predictor. Weekly supplemental feeding of hay, education level of both the man and the woman, and gender of the principal farmer were farm-level variables that were significantly associated with ADG. There was a significant interaction between breed and disease, and a significant interaction between man's education level and woman's education level, and thus the final model used for this analysis was:

Ln of ADG= hay + age + age squared + breed + disease history + breed*disease history + gender of principal farmer + man's education level + woman's education level + man's * woman's education level

The intra-class correlation of ADG estimated among farms was 0.25 with 95%CI = 0.14 to 0.42. About 36.6% of the total variation observed in ADG was at the farm level.

Figure 2.2 provides a lowess plot of the relationship between age and ADG, since it is hard to understand the curvilinear relationship from the coefficients in Table 2.2. There was a general decrease in predicted ADG from about 750g day $^{-1}$ at 2 weeks of age to about 600g day $^{-1}$ at weaning. The predicted ADG in a preweaning calf from the final model ranged from 711 - 798 g day $^{-1}$ at 1 month of age, depending on the breed. There was a subsequent decrease in ADG in older animals, dropping to approximately 350 g day $^{-1}$ for heifers between 10 and 30 months of age.

Since there was a significant interaction between breed and disease history (p <0.0005), we cannot interpret the coefficients of the main effects of breed and disease history in isolation because they depend on the level of the other variable within the interaction (Table 2.2, Figure 2.3). While controlling for age in the model, the effect of disease on ADG was most observed in the predominantly Guernsey breed among all exotic cross breeds, presenting with an ADG of about 259.1 g day $^{-1}$ (95% CI: 214.9 to 303.3 g day $^{-1}$), which is substantially lower than the overall mean ADG of 443 g day $^{-1}$. Local and dual-purpose crosses (Others in Figure 2.3) were estimated to have the highest ADG of about 676 g day $^{-1}$ when subjected to similar management conditions as the other breeds and when disease was present (Figure 2.3).

For the farm-level variable “supplemented hay”, when we exponentiated the coefficient, there was a 1.23 times effect, meaning that there was a 23% increase in ADG compared to calves not supplemented weekly with hay. For the principal farmer variable, ADG was lower by 20.7% when the principal farmer was female, compared to the baseline of both males and females identified as the principal farmers, whereas there was no statistically significant difference between males identifying as the principal farmer versus the baseline.

Since there was also a significant interaction between the education levels of the husband and wife with respect to ADG, their associations with ADG depend on each other (Table 2.2, Figure 2.4). When women’s education was low (having less than primary school), ADG was highest when the man had not completed primary school, but ADG was lower when the man had completed primary school, and substantially lower when the man had completed secondary school. When the women’s education was high (completed college/university), the ADG was significantly lower when the men finished primary school compared to lower or higher levels of education. There were no differences in ADG, by men's education level, when women finished primary or secondary school.

The model assumptions on normality and homescedasticity were well met. Scatter plots of fitted values and standardized residuals did not depict distinct patterns in the distribution of residuals, with only 4 observations that were outside 2 standard deviations, and these 4 observations were not outliers. The standardized residuals had a good fit on the normality plot, with only the 2 extreme observations mentioned earlier. A model fit with and without these observations had no difference from a model with all observations. Therefore, all observations were retained in the final model with 301 observations from 159 farms.

2.5 Discussion, Conclusion and Recommendations

The descriptive findings for ADG for this study were generally in agreement with similar studies conducted in Kenya. Gitau et al., (1994a) estimated that the overall median daily weight gain in similar farming systems in Kenya was 210 g day $^{-1}$ with a range of -400 to 900 g day $^{-1}$. The observed mean ADG of calves and heifers in SDF in Naari was 443 ± 375 g day $^{-1}$ with a median of 360 g day $^{-1}$. This weight gain was within the benchmarked performance achievement for dairy farms of between 400 to 500 g day $^{-1}$ (Lukuyu et al., 2012). However, the optimum ADG for calves and heifers within the first 5 months in dairy farms is estimated at 500 g day $^{-1}$ to 700 g day $^{-1}$ for heifers to achieve first calving at age 27 months or less (Lukuyu et al., 2012). The general performance (ADG) of calves in SDFs in this area was within range but with a large standard deviation. The effects of low ADG on heifers only becomes quantifiably evident post-puberty i.e. age at first calving and milk production per lactation (Abeni et al., 2000). For calves that were at the onset of puberty (12 months), estimated ADG in these Naari production systems suggest that it is unlikely that heifers and calves included in this study would achieve the primary target of first calving at about 27 months. Krpálková et al., (2014) observed that a higher lactation productivity per lifetime had been observed in heifers/calves that had a prepubertal (12-15 months) ADG of about 850g day^{-1} suggesting that calves in this study would have limited lifetime milk-production potential.

Our study was able to identify a number of interesting animal- and farm-level variables associated with ADG, while identifying important interactions and controlling for confounding and within-herd clustering. Age was observed to be significantly associated with ADG ($p < 0.0005$) in the study farms in a curvilinear manner (Figure 2.2). Within the first 4 months of life, the predicted ADG appeared to constantly decrease in a fairly linear manner (section A Figure 2.2). This trend was similar to the one observed by (Gitau et al., 1994b) in SDFs in Kiambu district, Kenya. This decrease could be due to reduced milk consumption resulting from the sale of milk soon after the designated colostrum period of lactation (milk sales are banned for the first 2 weeks post-calving in Kenya). Therefore, the calf should be introduced to good quality solid feeds such as hay and concentrate early to allow proper rumen development and hence good absorption of any consumed feeds. In our study, for calves 6 to 12 months of age, there was a slower overall rate of decline in the ADG in the calves (section B Figure 2.2). After 12 months of age, growth stabilized at about 300 g day^{-1} before a decrease in trend to <300 g day^{-1} after 27 months of age. However, due to possible survivor bias affecting this study population, these ADG estimates may overestimate the true ADG because calves/heifers with very poor growth due to chronic diseases or very poor management likely did not survive to become part of this study.

Given that this was not a cohort study, it was difficult to ascertain at what point slow growth actually occurred in older heifers, but from the cross-sectional data, it is clear that older calves and heifers have lower cumulative ADG than younger calves and heifers. It could be that the older heifers had poor growth as calves and better growth as heifers, or vice versa, or even steady modest growth throughout their lives. Additionally, the farmers in this study had no standardized feeding regimes for calves or heifers according to respective ages. Therefore, it was not possible to completely ascertain the actual effects of different feeding methods used on the farms, unless a cohort study of calves and heifers were conducted.

According to most literature, calves reach puberty at 9 months of age, are considered breeding heifers at 15-16 months, and become lactating cows at about 24-27 months (Lukuyu et al., 2012). In our study, the late maturing age of the heifers resulted in our nulliparous heifer age bracket being wide (up to 36 months of age). This wide range in age adds variability to our data since the long period of growth prior to first parturition likely includes several additional environmental and management changes in the life of the animals, such as seasonal feeds and changes in housing.

Two other animal-level variables were associated with ADG in the final model, and their interpretation in the final model is dependent on each other since they were involved in an interaction: breed and history of disease (Table 2.2). Calf diseases are documented to negatively affect calf and heifer survival, growth, welfare and productivity (Windeyer et al., 2014). Although disease resulted in a decreased ADG in most predominantly *Bos taurus* breeds in our study, especially in Guernsey, weight gain in other breeds was not severely affected. In general, animals that had no history of disease had higher ADG in *Bos taurus* breeds compared to those with disease, but the opposite was seen in predominantly *Bos indicus* breeds (Figure 2.3). Dual purpose breeds, *Bos indicus,* and their crosses, tend to be more resilient in response to diseases in Africa (Mwai et al., 2015). However, the history of disease on our participating farms was unlikely to be completely accurate due to inaccurate memory recall, and these errors may have led to misclassification bias of these results, particularly the unexpected *Bos indicus* results that were based on a relatively small number (n=19) of calves in this category.

Various nutritional and management factors were associated with ADG in our study (Table 2.2). Supplementation of diets with hay at least weekly was observed to result in increased weight gain in calves and heifers. The average nutritional requirements for heifers are 12-19% crude protein (CP), inversely depending on age, to maintain a good growth rate (Lukuyu et al., 2012). In calves and heifers, the CP content in the diet is generally positively associated with weight gain (Moran, 2005). However, in our study, there was no significant association between ADG and supplementing diets with concentrates, although weekly concentrate feeding, and hay feeding were correlated, therefore retaining weekly hay feeding in the model likely prevented weekly concentrate feeding from being retained in the model. The concentrates commonly found in this study were dairy meal or calf pellets that have an estimated CP of 14 to 18% (BLGG - Wageningen University, 2013). In a controlled trial (Ueno et al., 2014) found that feeding hay during the suckling phase resulted in a significant increase in daily dry matter intake

(DMI), of about 318 g, and at least 0.23% increase in live body weight in the post-weaning phase. This increased DMI was postulated to stimulate growth of ruminal papillae and development of rumen-reticulum muscles, thus increasing capacity and digestive ability. This physiological maturation then translated into better nutritional gain from the feed consumed, as well as increased volume of feed intake (Ueno et al., 2014). Our study, based on a regression model, agrees with the postulated and observed effect of hay in the SDFs in Naari, Meru, with estimated weight gain of 456.7 g day $^{-1}$ when hay is supplemented at least weekly, compared to 371.4 g day $^{-1}$ in calves not feeding hay. Our results suggest that it is important to provide supplements to youngstock, either hay or concentrates, although feeding both may help ADG when quality forages are in short supply.

The management arrangement of the farm in our study was associated with the ADG of the animals on a particular farm (p=0.002). The estimated ADG in farms managed/run by female farmers was only slightly lower than that on farms where the principal farmer was male (427.2 g day $^{-1}$ vs 430.4 g day $^{-1}$ respectively. However, a synergistic effect was observed when both male and female farmers were involved in management of the farm, with an ADG of 510.5 g day $^{-1}$ (95% CI: 388.3 to 632.6g day $^{-1}$). These findings were in agreement with a study done (Richards et al., 2015) in Nyeri county , Kenya, where it was observed that overall milk production of farms run by women was lower than those farms run by their male counterparts. However, there was a significant interaction between feed availability and gender on milk production in that study; farms run by men did not have decreased milk production as a result of feed shortage, but those farms run by women did experience decreased milk production, likely because women were busy with other household chores, leaving less time to search for additional cattle feed compared to men. On farms where both male and female farmers were equally involved in management, shared responsibility for searching out high quality feeds for calves, even in times of scarcity, is more likely to be successful.

The level of formal education/training of both the man and woman on the farm was significantly associated with ADG ($p < 0.0054$ and $p < 0.0001$, respectively), and there was also a significant interaction between the education level of the man and that of the woman ($p < 0.0005$). When women's education was low (having less than primary school), ADG was highest when the man had not completed primary school but was lower when the man had completed primary school, and substantially lower when the man had completed secondary school. This finding might suggest he is employed off the farm and the woman's access to critical inputs is restricted due to lower involvement of the man and his ability to access resources (Doss et al., 2011). When the women's education was high (completed college/university), the ADG was significantly lower when the men finished primary school compared to lower or higher levels of education. There were no differences in ADG, by men's education level, when women finished primary or secondary school (Figure 2.4). The interaction could be a result of the farmer (man or woman) with better education levels preferring to get off-farm jobs, thus spending less time on farm management. This interaction could possibly be a result of more hired labor that was unsupervised on the farm, thus leading to underfeeding of animals in those farms, but these factors were not examined as part of our study.

Our selection criteria were meant to exclude any animals that had either miscarried or aborted for one reason or the other. This could be influenced by the fact that the animals were either poorly fed or of low productivity. However, although there was a risk of survival bias, none of the animals sampled were excluded on this basis. The current study was cross-sectional in nature, which normally means that identified factors associated with the outcome may not have occurred prior to the outcome. However, with the outcome being ADG, which is a function of management throughout the rearing period, this temporality issue for our study is unlikely to be a major concern. It would be helpful to carry out a cohort study to better monitor growth of calves and heifers in these smallholder dairy farms, and identify significant factors associated with superior growth. An alternative study for quantifying the benefits of certain growth factors related to management and nutrition would be a field trial, with random allocation and controlled management to reduce the effects of confounding variables.

In conclusion, growth in calves and heifers in smallholder dairy farms in Meru, Kenya, was low compared to internationally expected performance targets (post weaning and at puberty). However, compared to other SDFs in Kenya, the ADG in the study area was within previously reported ranges. ADG was found to be significantly associated with age, breed, history of disease, supplementing with hay at least weekly during the dry season, gender of the principal farmer, and education levels of the farmers. Since 26% of youngstock were reported to have had at least one of the three common calf-hood diseases (navel ill, diarrhea, and pneumonia), farmers should be encouraged to feed 4 liters of colostrum within the first 6 hours of life to enhance passive immunity against these diseases. Supplementation of diets (with hay and/or concentrates) with additional protein and energy is recommended for optimum growth in calves and heifers. If nutritional management of *Bos taurus* youngstock is not improved, crosses of *Bos indicus* could be better suited for the current nutritional management systems in SDFs in Meru due to their growth performance in the face of disease. With the highest ADG occurring when both genders were heavily involved in managing the farm, efforts to encourage shared responsibility of farm work could be helpful. Since secondary education was associated with higher ADG, efforts to improve secondary education attainment may be a route to greater dairy animal productivity. As higher education of the man and the woman running the farm was associated with lower ADG, perhaps due to them being heavily involved in off-farm activities, these farmers should be reminded that neglected calf management will lead to poor calf welfare and ADG and ultimately lost potential for the animals' long-term productivity. Additionally, training and capacity-building for hired help could minimize the farm impact of absences of principal farmers. Farmers and animal health professionals could use these conclusions and recommendations to advise farmers better on calf management and growth.

2.6 References

Abeni, F., Calamari, L., Stefanini, L., & Pirlo, G. (2000). Effects of daily gain in pre- and postpubertal replacement dairy heifers on body condition score, body size, metabolic profile, and future milk production. *Journal of Dairy Science*, *83*(7), 1468–1478. https://doi.org/10.3168/jds.S0022-0302(00)75019-3

Bii, B. (2017). Dairy farmers face high cost of feeds as drought bites - Daily Nation. Retrieved August 11, 2017, from http://www.nation.co.ke/business/Dairy-farmers-face-high-cost-of-feeds/996-3800550-ckwc4oz/index.html

BLGG -Wageningen University. (2013). *Study on the Kenyan Animal Feed and Fodder Sub - sectors. Quality Analysis of animal feedstuffs and fodders in Kenya (Sub-report V). pp 57*. Wageningen.

Dairy Farming in Kenya | Farming in Kenya. (2011). Retrieved October 9, 2015, from http://softkenya.com/farming/dairy-farming-in-kenya/

Doss, C., Raney, T., Anríquez, G., Croppenstedt, A., Gerosa, S., Lowde, S., … Matuscke, I. (2011). The role of women in agriculture. *Food and Agriculture Organization of the United NAtions*, (11), 1–48. https://doi.org/10.1002/2014GB005021

Gitau, G. K., McDermott, J. J., Waltner-Toews, D., Lissemore, K. D., Osumo, J. M., & Muriuki, D. (1994a). Factors influencing calf growth and daily weight gain on smallholder dairy farms in Kiambu District of Kenya. *Preventive Veterinary Medicine*, *21*(2), 179–190.

Gitau, G. K., McDermott, J. J., Waltner-Toews, D., Lissemore, K. D., Osumo, J. M., & Muriuki, D. (1994b). Factors influencing calf morbidity and mortality in smallholder dairy farms in Kiambu District of Kenya. *Preventive Veterinary Medicine*, *21*(2), 167–177. https://doi.org/10.1016/0167-5877(94)90005-1

Hickson, R., Zhang, I., & Mcnaughton, L. (2015). Brief communication: Birth weight of calves born to dairy cows in New Zealand. *Proceedings of the New Zealand Society of Animal Production*, *75*, 257–259.

Krpálková, L., Cabrera, V. E., Vacek, M., Stípková, M., Stádník, L., & Crump, P. (2014). Effect of prepubertal and postpubertal growth and age at first calving on production and reproduction traits during the first 3 lactations in Holstein dairy cattle. *Journal of Dairy Science*, *97*(5), 3017–3027. https://doi.org/10.3168/jds.2013-7419

Lukuyu, B., Franzel, S., Ongadi, P. M., & Duncan, A. J. (2011). Livestock feed resources: Current production and management practices in central and northern rift valley provinces of Kenya. *Livestock Research for Rural Development.*, *23*(5), 112.

Lukuyu, B., Gachuiri, C. K., Lukuyu, M. N., Lusweti, C., & Mwendia, S. (2012). *Feeding dairy cattle in East Africa*. (B. Lukuyu & C. Gachuir, Eds.), *Feeding dairy cattle in East Africa* (First). Nairobi, Kenya: East Africa Dairy Devleopment Project. Retrieved from https://cgspace.cgiar.org/bitstream/handle/.../EADDDairyManual.pdf

Moran, J. (2005). Nutrition and young stock. In Peter Storer Editoral Services (Ed.), *Tropical Dairy Farming: Feeding Management for Small Dairy Farmers in the Humid Tropics* (First, pp. 183–190). Collingwood,Australia: CISRO Publishing. Retrieved from http://samples.sainsburysebooks.co.uk/9780643107892_sample_295356.pdf

Muriuki, H. G. (2011). *Dairy development in Kenya*. *FAO-Dairy Reports*. Rome. Retrieved from http://www.fao.org/3/a-al745e.pdf

Mwai, O., Hanotte, O., Kwon, Y.-J., & Cho, S. (2015). African Indigenous Cattle: Unique Genetic Resources in a Rapidly Changing World. *Asian-Australasian Journal of Animal Sciences*, *28*(7), 911–921. https://doi.org/10.5713/ajas.15.0002R

Njarui, D. M. G., Gatheru, M., Wambua, J. M., Nguluu, S. N., Mwangi, D. M., & Keya, G. A. (2011). Feeding management for dairy cattle in smallholder farming systems of semi-arid tropical Kenya. *Livestock Research for Rural Development*, *23*(5), 111. Retrieved from http://www.lrrd.org/lrrd23/5/njar23111.htm

Odero-Waitituh, J. A. (2017). Smallholder dairy production in Kenya; a review. *Livestock Research for Rural Development*, *29*(139). Retrieved from http://www.fao.org/docrep/W2650T/W2650t07.htm#P0_0from http://www.lrrd.org/lrrd29/7/atiw29139.html

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G. K., Kamunde, C., Uehlinger, F., & Wichtel, J. (2015). Associations of farm management practices with annual milk sales on smallholder dairy farms in Kenya. *Veterinary World*, *8*(1), 88–96. https://doi.org/10.14202/vetworld.2015.88-96

Smith, T. (2000). Some Tools To Combat Dry Season Nutritional Stress in Ruminants Under African Conditions. In *Development and Evaluation of Feed Supplementation Packages* (pp. 145–152). Reading, United Kingdom: International Atomic Energy Agency. Retrieved from http://www-naweb.iaea.org/nafa/aph/public/reports-13.pdf

Ueno, R. K., Neumann, M., Marafon, F., Ambrogi, M., Daros, B. A., & Pletz, E. (2014). Effect of hay on performance of Holstein calves at suckling and post-weaning. *Revista Ceres*, *61*(5), 668–674. https://doi.org/10.1590/0034-737X201461050010

Windeyer, M. C., Leslie, K. E., Godden, S. M., Hodgins, D. C., Lissemore, K. D., & LeBlanc, S. J. (2014). Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. *Preventive Veterinary Medicine*, *113*(2), 231–240. https://doi.org/10.1016/j.prevetmed.2013.10.019

Figure 2.1a: Study area showing Naari sub-location in Meru County, Kenya

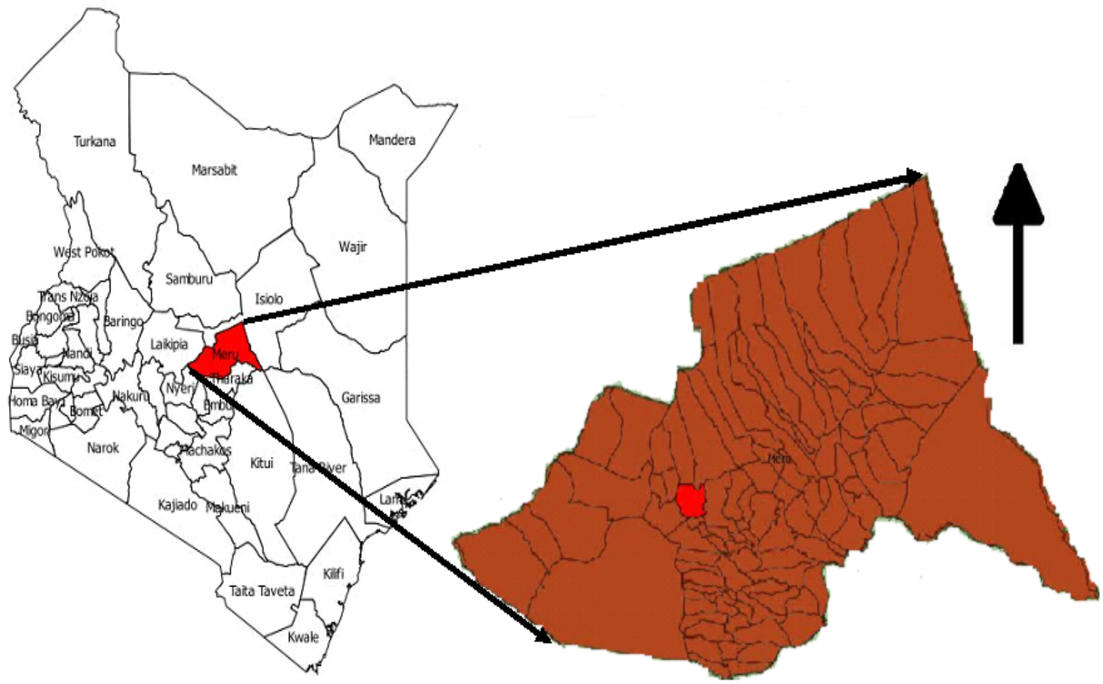


Figure 2.1b: Study households in the Naari Dairy Farmers Cooperative Society region

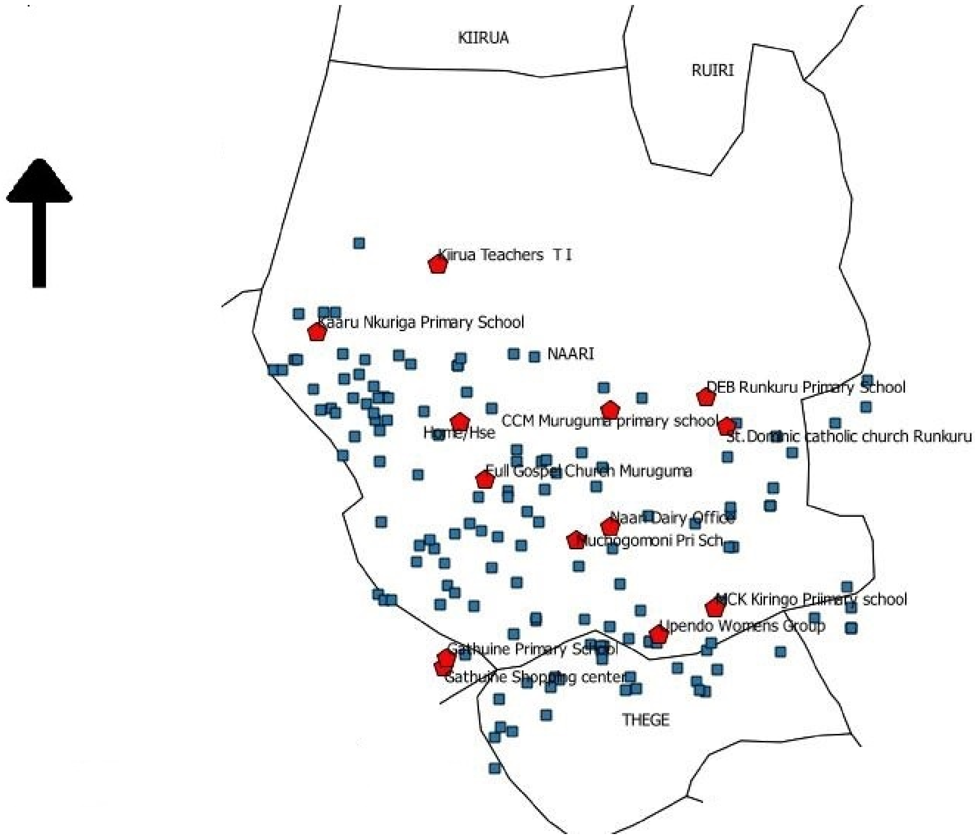


Table 2.1: Descriptive statistics and p-values for unconditional mixed linear regressions for variables marginally (P<0.40) associated with ln of Average Daily Gain for 301 calves and heifers among 159 smallholder dairy farms near Meru, Kenya in 2015

Variable Names and Categories	Percentage (Numerator / Denominator)	Geometric mean Average Daily Gain (grams)	p-value
Animal Factors:			
Age (months)	n/a [b]	n/a [b]	<0.001
Breed			0.278 [a]
Ayrshire	9.3 (28/301)	356.1	reference
Friesian	58.8 (177/301)	369.0	0.806
Guernsey	25.6 (77/301)	354.1	0.742
Others	6.3 (19/301)	491.9	0.085
History of disease			
No	73.8 (222/301)	381.6	reference
Yes	26.1 (79/301)	341.4	0.191
Farmer Demographic Factors:			
Principal farmer/ manager			0.066 [a]
Both (shared)	17.9 (28/159)	418.3	reference
Female	52.8 (85/159)	353.7	0.041
Male	29.2 (46/159)	374.5	0.560
Woman's education level			0.001 [a]
None	13.2 (21/159)	446.2	reference
Primary	47.2 (75/159)	329.8	0.002
Secondary	32.1 (51/159)	413.6	0.618
College/university	7.6 (12/159)	359.3	0.189
Man's education level			0.012 [a]
None	15.7 (25/159)	431.2	reference
Primary	41.5 (66/159)	333.9	0.004
Secondary	35.9 (57/159)	387.5	0.348
College/university	6.9 (11/159)	394.8	0.466
Farm Management Factors:			
Type of barn floor			
Wooden/concrete	12.6 (20/159)	409.2	reference
Dirt	87.4 (139/159)	363.7	0.281
Deworming frequency			
> 3 months	6.3 (10/159)	318.9	reference
≤ 3months	93.7 (149/159)	375.5	0.266

Farm had adequate feed in the last 12 months			
No	67.9 (108/159)	379.5	reference
Yes	32.1 (51/159)	352.4	0.179
Feed changes within 1 year			0.035[a]
Never	30.8 (49/159)	341.7	reference
At least once a month	3.2 (5/159)	574.5	0.012
Seasonally	66 (105/159)	376.2	0.210
Fed on silage			
No	86.2 (137/159)	364.7	reference
Yes	13.8 (22/159)	405.9	0.367
Supplemented with concentrates			
No	48.4 (77/159	341.4	reference
Yes	51.6 (82/159)	402.1	0.034
Supplemented with hay			
No	74.2 (118/159)	348.9	reference
Yes	25.8 (41/159)	434.3	0.004
Fed on tree & banana foliage			
No	68.6 (109/159)	381.8	reference
Yes	31.5(50/159)	348.8	0.249
Always access to clean drinking water			
No	49.1 (78/159)	349.0	reference
Yes	50.9 (81/159)	391.1	0.154

[a] Overall p-values for categorical variables with >2 categories.

[b] Continuous variable, therefore, proportions and ADG by group not applicable

Table 2.2: Final mixed regression model for ln Average Daily Gain in 301 calves or heifers in 159 dairy farms in Meru County, Kenya, in 2015

Variables and their categories	Coefficient	Coefficient. Conf. [95% Interval]		p-value
Animal Factors:				
Age in months	-0.057[@]	-0.074[@]	-0.039[@]	<0.0005
Age in months squared	0.001[@]	0.001[@]	0.002[@]	<0.0005
Breed				0.3799[!]
Ayrshire	reference			
Friesian [a,]	0.079[#]	-0.116[#]	0.274[#]	0.429[#]
Guernsey [b]	0.160[#]	-0.049[#]	0.369[#]	0.134[#]
Others [c]	0.012[#]	-0.271[#]	0.295[#]	0.932[#]
History of disease (no disease is reference)	-0.036[#]	-0.414[#]	0.341[#]	0.850[#]
Breed & History of disease interaction				<0.0005[!]
Ayrshire * no disease	reference			
Friesian * disease [a]	0.035 [$]	-0.371[$]	0.442 [$]	0.864
Guernsey * disease [b]	-0.484[$]	-0.910 [$]	-0.058 [$]	0.026
Others * disease [c]	0.577 [$]	0.009 [$]	1.146 [$]	0.047
Farm Management Factors:				
Supplemented hay	0.207	0.080	0.334	0.001
Farmer Demographic Factors				
Principal farmer/manager gender				0.0021[!]
Both (shared)	reference			
Female [a]	-0.232	-0.368	-0.095	0.001
Male [b]	-0.088	-0.235	0.058	0.237
Man's education level				0.0054[!]
Did not complete primary school	reference			
Completed primary school [a]	-0.575[#]	-0.915[#]	-0.235[#]	0.001[#]
Completed secondary school [b]	-1.099[#]	-1.466[#]	-0.732[#]	<0.0005[#]
Completed college/university [a]	-0.120[#]	-0.506[#]	0.265[#]	0.541[#]
Woman's education level				0.0001[!]
Did not complete primary school	reference			
Completed primary school [a]	-0.739[#]	-1.055[#]	-0.423[#]	0.000[#]
Completed secondary school [a]	-0.574[#]	-0.944[#]	-0.203[#]	0.002[#]
Completed college/university [a]	-0.516[#]	-1.026[#]	-0.005[#]	0.048[#]
Man's education * Woman's education				<0.0005[!]
Man (Did not complete primary) *Woman (Did not complete primary)	reference			
Man (Primary education) *Woman (Primary education) [a]	0.391 [$]	0.007[$]	0.775[$]	0.046
Man (Primary education) *Woman (Secondary education) [a, b, d, e]	0.403[$]	-0.051 [$]	0.856 [$]	0.082
Man (Primary education)	-0.851[$]	-1.799 [$]	0.096 [$]	0.078

*Woman (College/university education) [c]				
Man (Secondary education) *Woman (Primary education) [d, e]	1.116 [$]	0.692 [$]	1.540 [$]	<0.0005
Man (Secondary education) *Woman (Secondary education) [e]	1.087 [$]	0.632 [$]	1.543 [$]	<0.0005
Man (Secondary education) *Woman (College/university education) [a, b, d, e]	0.844 [$]	0.232 [$]	1.456 [$]	0.007
Man (College/university education) *Woman (Primary education)	[α]	[α]	[α]	[α]
Man (College/university education) *Woman (Secondary education)	[α]	[α]	[α]	[α]
Man (College/university education) *Woman (College/university education)	[α]	[α]	[α]	[α]
Constant	0.093	-0.268	0.455	0.613

[!] Overall P-values for categorical variables with >2 categories.

[@] Variable is part of a curvilinear relationship, and therefore coefficients cannot be interpreted in isolation but rather in combination with the other relevant coefficients for the curvilinear variable, and these combinations are best reported using a graph (Figure 2.2)

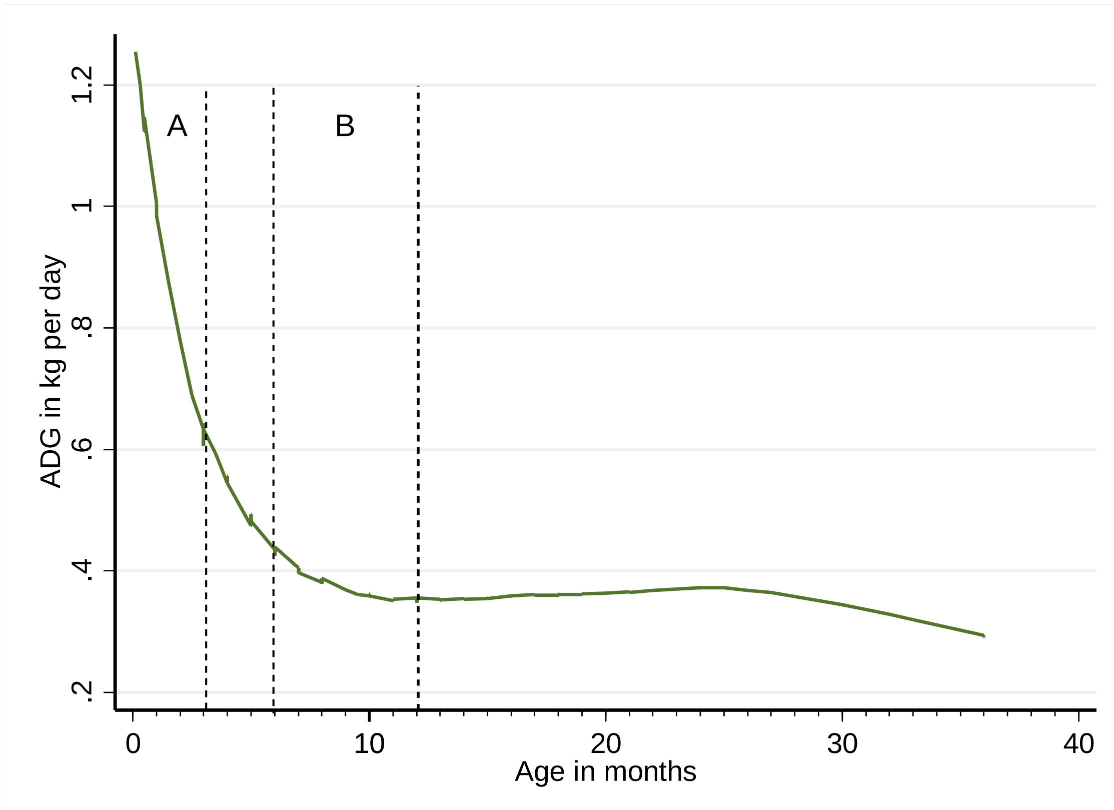
[#] Variable is part of an interaction variable; therefore, coefficients and P values should be interpreted with caution, in combination with the other relevant variable of the interaction, and these variables are best reported using a graph (Figure 2.3 & 2.4)

[$] Levels are part of an interaction variable with many cross-tabulated categories from the main effect variables, and therefore coefficients should be interpreted with caution relative to the other variable in the interaction, and these results are best reported using a graph (Figure 2.3 & 2.4)

[α] Interactions and pairwise comparisons for this level could not be estimated from the model.

[a-e] Different letter superscripts represent significant differences between coefficients of different levels (other than the reference level which use the category p-values) for interaction variables and categorical variables not involved in interactions when they have more than 2 levels.

Figure 2.2: Lowess plot indicating a curvilinear relationship between ADG kilograms day^{-1} and age of a calf/ heifer based on individual weights of 301 calves and heifers among 159 smallholder dairy farms near Meru, Kenya in 2015



(A-preweaning period, B- Period between 6 months and onset of puberty).

Figure 2.3: Predicted median ADG (g day^{-1}) and 95% confidence interval bars for average aged calf/heifer of various breeds when kept under basic management in farms managed by both genders with no education when affected by disease, based on the final model of 301 calves and heifers among 159 smallholder dairy farms near Meru, Kenya in 2015

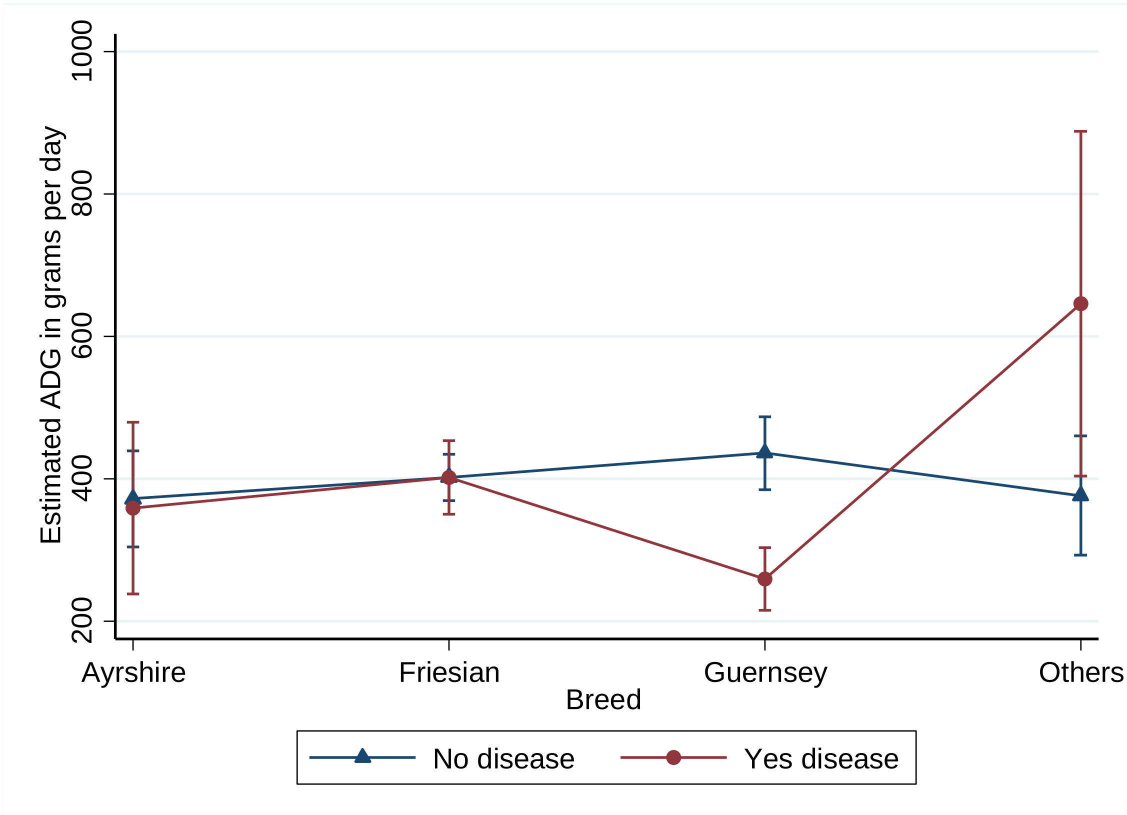
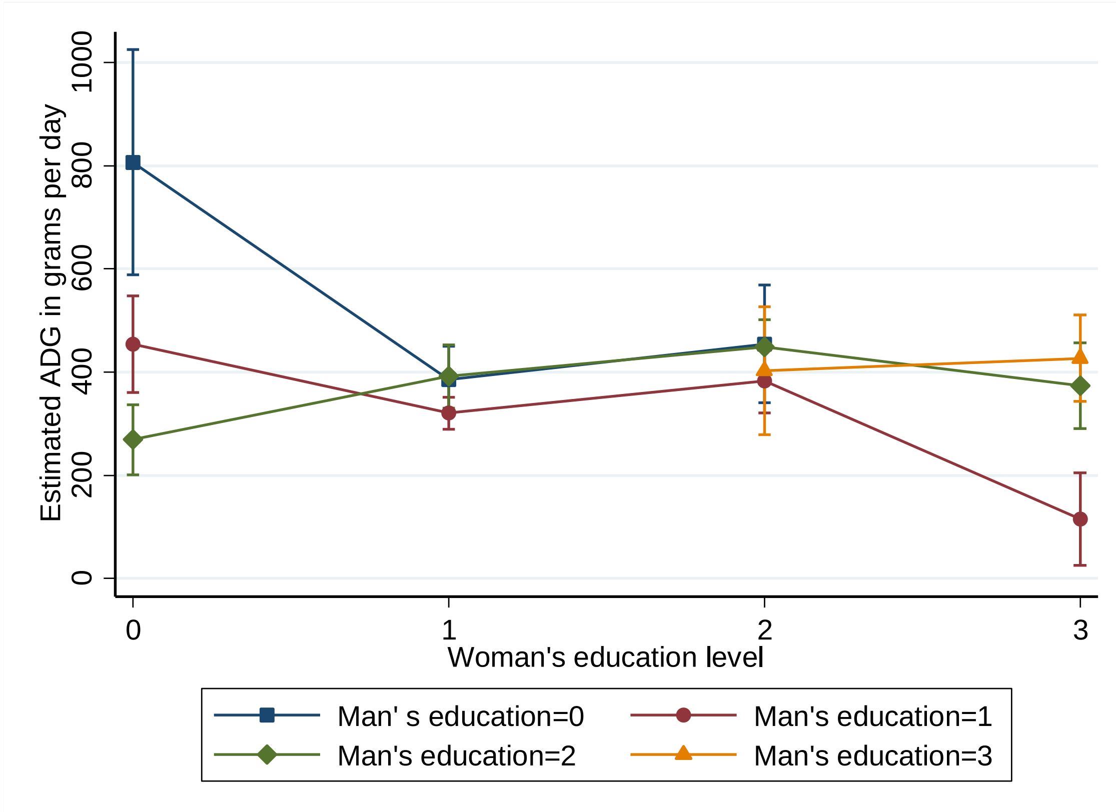


Figure 2.4: Results of the interaction between male and female education levels on the predicted ADG and 95% confidence interval bars for 301 calves and heifers among 159 smallholder dairy farms near Meru, Kenya in 2015



NB: 0- Primary education not complete, 1- Primary education complete, 2- Secondary education complete, 3- University/college education complete.

Chapter 3 Randomized controlled trial to determine the effects of *Calliandra* and *Sesbania* supplementation on growth of dairy calves in smallholder farms in Kenya

3.1 Abstract

The growth rate of female calves in dairy farms is a crucial factor that influences age at first calving, hence affecting lifetime lactation productivity of a dairy cow. Diets with adequate crude protein are necessary to support calf growth. The study objective was to ascertain the association between diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban* shrubs and average daily weight gain (ADG) of dairy calves in semi-commercial smallholder farms.

This trial involved 155 calves from 73 randomly selected semi-commercial smallholder dairy farms (SDFs) randomly allocated to either the intervention or comparison groups in Naari, Meru County, Kenya. The intervention group received nutritional advice and seedlings of *Calliandra calothyrsus* and *Sesbania sesban*. Every 1-2 months for 16 months, data on farm nutritional practices and management were collected in a questionnaire, and physical examinations were done to monitor weight and health status. Descriptive and univariable statistical analyses were conducted, and multivariable mixed linear regression models were used for identification of factors associated ($p < 0.05$) with the natural log transformation of ADG of calves on a given farm, controlling for clustering of visits within calves.

For calves < 6 months old, feeding at least 0.2kg (wet weight) of *Calliandra / Sesbania* to a calf day $^{-1}$ would result in 33.2% increase in ADG, while controlling for confounding by breed and sex of the calf. For calves ≥ 6 months, there was a significant interaction

between amount of hay fed and if calves were also fed on *Calliandra / Sesbania.* When no *Calliandra / Sesbania* supplementation was provided, the mean ADG was low and relatively constant even with increasing amounts of hay, but when C*alliandra / Sesbania* supplement was added to the diet, the mean ADG increased from 0.17kg to 0.48kg when hay was fed at 1 and 5 kg, respectively, while controlling for confounding by amount of maize silage fed and the prevailing season.

In conclusion, supplementation of young calf diets (<6 months old) with at least 0.2kg *Calliandra / Sesbania* calf $^{-1}$ day $^{-1}$ should achieve a 33% increase in ADG. Supplementation of older calf diets (6-12 months old) fed on hay would also result in a substantial increase in ADG. Smallholder dairy farms in Kenya could adopt agroforestry land use systems to cope with feed shortages and low protein in farm-available feeds for their calves.

Key words: Kenya; supplementation; smallholder; *Calliandra*; *Sesbania*; calf growth.

3.2 Introduction

Good calf nutritional management is the cornerstone of dairy cattle productivity, health and welfare (Windeyer et al., 2014), particularly in countries where the dairy industry is expanding, such as Kenya (Odero-Waitituh, 2017). Average daily weight gain (ADG) is correlated with the quality of feeding and subsequently determines body condition score (BCS) and body weight (BW), which influence onset of puberty, age at first calving (AFC), and ultimately lifetime milk production (Akayezu et al., 1994; Lukuyu et al., 2012; Cooke et al., 2013; Krpálková et al., 2014). The optimum expected ADG for Kenyan dairy calves and heifers (with a mixture of local and exotic breeding) to achieve first calving at age 27 months or less is about 500 – 700 g day $^{-1}$ (Lukuyu et al., 2012). Krpálková et al., (2014) observed that calves that had a prepubertal ADG of 850g day $^{-1}$ were able to calve at 24-25 months, and had a higher lactation productivity per lifetime.

The impact of inadequate calf nutrition in Kenya is most evident in the dry season due to limited access to high quality feeds (Njarui et al., 2011; Bii, 2017). This dry season challenge is exacerbated by inadequate knowledge and technology on feed conservation, and deficient quantity and quality of home-grown forages used to feed dairy animals (Lukuyu et al., 2011). Coping mechanisms for feed shortages that have been adopted by SDFs in Kenya, include: buying feed from neighboring farms, renting grazing land, and feeding low quality fodder during the dry season (Njarui et al., 2011). Since most farmers prefer to provide home-grown feeds to reduce feeding costs, use of crop residues is the most common coping strategy (Lukuyu et al., 2011). The crop residue used as the main feed at the peak of the dry seasons for more than 80% of smallholder dairy farms (SDFs) is dry maize stover, a poor quality fodder with an estimated average crude protein (CP) of 2.5% and neutral detergent fiber (NDF) of 70% (Njarui et al., 2011).

Leguminous fodder shrubs, such as *Calliandra,* can be used as protein supplements in diets for cattle to improve production and weight gain in calves during the dry season (Gusha et al., 2013). The main advantage of these fodder shrubs is the ability to tolerate harsh climatic conditions, such as drought, while providing reasonable amounts of good quality nutrients (Franzel et al.,2013). Therefore, supplementation with leguminous tree fodder can be used to mitigate effects of poor quality feed on growth and production in the dry season (Sibanda & Ndlovu, 1992).

Agroforestry is a land management system which combines trees and or shrubs with crops and/or livestock in the same piece of land (University of Missouri , 2013). Prioritization of integrated farming systems with fodder trees and food crops is considered a key step towards sustainable dairy production in Rwanda (Kamanzi and Mapiye , 2012), and perhaps in Kenya as well (Afande & Wachira, 2015). The propagation and utilization of high-yielding and good-quality forages could play a significant role in strengthening smallholder dairy production in densely populated areas (Muriuki, 2003; Gillah et al., 2012) with farmland constraints in the East African region (Kamanzi and Mapiye, 2012). Some of the agroforestry approaches used by farmers include: intercropping the fodder trees /shrubs with other crops, or planting them as a hedge during the rainy season and then harvesting them in the dry season (Cuddeford, 1999).

Some of the fodder shrubs promoted in the highlands of the East African region include *Calliandra*, *Leucaena*, *Chamecytisus* and *Sesbania* (Franzel et al., 2013). However, research on calf weight gain benefits from leguminous fodder shrubs is scarce and primarily found within large-scale or research farms; therefore, these studies do not demonstrate the shrub's benefits on semi-commercial SDFs in Kenya. In this randomized controlled field trial, we examined a random sample of calves to determine the effects of nutritional advice and diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban* on ADG in dairy calves on semi-commercial SDFs based on an agroforestry land management system.

3.3 Materials and methods

3.3.1 Ethical approval

This study was approved by the Research Ethics Board and the Animal Care Committee of UPEI, NDFCS, and FHF, a partner nongovernmental organization. Signed consent of all participants was obtained after the study was fully explained.

3.3.2 Description of study area

This randomized controlled field trial was carried out in Naari sub-location of Meru County, Kenya (0°6'0" N and 37°35'0" E). Meru County is located on the eastern slopes of Mount Kenya and is 270 kilometers north of Nairobi, the capital city of Kenya. Naari sub-location is in the high agricultural potential region with an altitude of approximately 2,000 m above sea level. The main agricultural activities include: dairying, subsistence crop farming, horticulture and lumbering. Farmers grow food crops such as maize, beans and Irish potatoes and forages for dairy cows. The study area was purposively selected since this research was part of a larger study involving dairy farmers in the area (Muraya et al., 2018; Makau et al., 2018). A non-governmental organization, FHF, and UPEI had an existing developmental partnership with the NDFCS. This rapport provided a strong foundation for the work and the entry point to the community.

3.3.3 Sample population and data collection

This trial was done concurrent to another trial on the effect of *Calliandra* and *Sesbania* supplementation on milk production of dairy cows (see Chapter 5). Therefore, the study sampling frame at the farm level for this trial was based on the same sampling frame as the milk production trial since the same farms were used for both trials. The farmers included in the study were from NDFCS, a dairy group with an active membership of approximately 550 farmers (an active member is defined as one who regularly sold milk to the NDFCS at the time of the study). A sampling frame of 200 randomly selected farms previously used in a bigger cross-sectional study (umbrella study) in 2015 was used. From this sampling frame of 200 farms, 80 farms were selected using the following inclusion criteria: active membership with the NDFCS, zero-grazing, and <4 milking cows to ensure selection of smallholder farms.

For the milk production trial, the 80 farms were blocked and randomly allocated to different intervention groups in the randomized controlled field trial, with days in milk (DIM) as a blocking variable (see Chapter 5). Since changes in milk production due to enhanced feeding are likely to be greater in early lactation, DIM was deemed a very important variable for block randomization when assessing effects of *Calliandra* and *Sesbania* on milk production.

The four intervention groups included nutrition intervention only, reproduction intervention only, nutrition-reproduction (combined) interventions, and a comparison group that received neither intervention. Farmers in the nutrition and combined groups were issued with at least 150 *Calliandra* and 150 *Sesbania* seedlings to plant on their farms 7 months prior to the commencement of the monitoring visits of the trial. It was expected that the shrubs would be grown enough to start feeding at commencement of the study. Two types of leguminous shrubs were used since there was a large difference in altitude among the farms in the study area, and it was unclear which type of shrub would be best on the farms. *Sesbania* is known to be hardier at higher altitudes than *Calliandra* but has slightly lower protein content than *Calliandra* (Franzel et al., 2013). Nutrition groups also received monthly advice on how to feed their cattle better with the feeds and resources available on the farm. Farmers in the reproduction intervention group were provided with monthly advice on better reproductive management and free intrauterine antibiotics (if warranted due to an intrauterine infection recorded) and/or free hormonal injections of prostaglandin F2α and/or gonadotropin releasing hormone (if warranted due to an intrauterine infection recorded, ovarian cyst recorded, or heat synchronization desired for breeding purposes due to poor heat detection).

For this trial involving calves on the same 80 farms, male and female calves 1 to 12 months of age were eligible to be part of the trial. All calves included in the study were dewormed routinely using albendazole-10% every 3 months during the study period. When a calf became older than 12 months, it was no longer part of the study and therefore no more observations were recorded. At most, 3 calves per farm were eligible to be included in this study to lower the bias that larger farms may have on the overall study results.

Principal farmers consenting to participate in the study were visited monthly (intervention groups) or bimonthly (comparison group) from May 2016 to October 2017. At these visits, they responded to a questionnaire (Appendices 8.2 & 8.3) covering various management factors on their farms since the last visit. The questionnaire had three main sections related to farmer training and demographic information, nutritional and other management, and calf health and growth. Physical exams were also carried out at each visit on all study calves, including heart girth measurements for weight estimation.

On commencement of the project, farmers were trained on how to weigh feed quantities fed to the calves once a week, and how to record these feed weight measurements in a provided logbook. All farmers were issued with standard spring weighing scales and large plastic bags for holding quantities of forages while weighing. Measurements and records of all high protein forages were the focus of the scale use on the farms, although weights of other forages were also recorded. Amounts of concentrate fed to calves were determined by weighing the filled containers used to measure concentrates on the farms and recording the number of containers provided daily. These feed provision entries for each calf were averaged for the month at the next visit to give 1 entry per calf per visit. From anecdotal information obtained from a different study elsewhere the feeding regime for each calf was generally consistent, at least at the weekly level. Budget and logistical constraints did not allow for laboratory feed analyses. Therefore, questions were asked at each visit to categorize the quality of the feed (e.g. height of the Napier grass, which correlates well with feed quality (Lukuyu et al., 2012). It was recorded if feeding of calves was complemented with grazing, which did occur on some farms initially classified as zero-grazing, especially in the dry season.

For farmers who had forgotten to record the feeding details in the logbook for any given visit, feed weights were assessed based on the current portions being fed to the calves on the day of the visit. The farmers were asked if the feed measurements recorded in the logbooks and on the day of visit were representative of the normal feeding since the last visit. In a clear majority of cases (81% - 416/512), the farmers confirmed that there were no differences between what was currently fed and what was fed during the time since the last visit. Therefore, data collected in the logbooks and on the date of the visit were assumed to be representative of the monthly nutritional management. For the 19% of visits when there were discrepancies between what was reported as normal feeding and the measured feeding, average measurements between logbook recordings and current measurements were used to minimize reporting bias; because farmers have been known to report practices according to what the research team wanted to hear (Richards, 2017).

3.3.4 Data management and analysis

Field data were entered into MS Excel 2010 (Microsoft, Sacramento, California, USA). Statistical analyses were done using Stata13.0 software (StataCorp LLC, College station, Texas, USA). There was a hierarchical nature to the data, with visits clustered within calves, and this clustering was considered during the statistical analyses. There was also a small amount of clustering of calves within farms, but there were only 1.6 calves/farm, on average, during the trial period, making this clustering negligible.

For each calf, the ADG for the first month into the study was calculated as the difference between the current weight and the average birthweight (by breed) observed in the study (for calves less than 1 week old), and then divided by the age in days at first examination. For breeds where this information was not available, birth weights from published studies were used (Hickson et al., 2015). For subsequent visits (observations), ADG was calculated as the difference between the previous weight measurement and current weight measurement, divided by the difference between visits in days. For descriptive purposes, the mean ADG was calculated for 3 groups: for all calves irrespective of age (1-12 months); for calves < 6 months; and for calves ≥ 6 but ≤ 12 months old. All ADG observations within each of these time periods were averaged for the overall average ADG for each period.

Descriptive statistics for the other variables included means, medians, distributions, and proportions, where applicable. For inferential statistical analyses, data were analyzed using both univariable and multivariable linear regression analysis, as detailed below, with ADG in kilograms (kg) as the outcome of interest. The outcome in its original scale was right-skewed (1.4), and the Shapiro-Wilk test was used for normality testing of ADG ($p < 0.05$), and therefore suitable transformations for the ADG outcome were explored. To correct for this skewed distribution, the outcome was transformed to the natural log scale for purposes of fitting a linear model.

The primary study objective was to determine if the nutrition intervention contributed to higher ADG in calves on those farms receiving the intervention. Two of the four group allocations of 20 farms which received the nutrition intervention of advice and *Calliandra/Sesbania* shrubs, the nutrition and combined groups, were combined into one collapsed intervention group. The comparison and reproduction groups were also combined into one collapsed comparison group since they did not receive any direct nutrition-related interventions for their calves.

The initial statistical analyses were based on these 2 collapsed study groups. Significant differences in mean natural log of ADG between the two groups were assessed using one-way ANOVA, adjusting for clustering of visits within calves. These analyses would assume that the random allocation to groups balanced out potential confounders to ADG in calves between the groups. Some farmers appeared to pay less attention to nutrition when calves were more than 6 months old. These farmers kept the calves in the same stalls as the adult cows, with partitions for a separate sleeping and supplementation area, but being fed the same forages as the cows. Therefore, the observations were split into two age groups: less than 6 months old and more than 6 months old. It was assumed that this split analysis would control for any differences attributed to changes in intensity of management between young calves on milk and older weaned calves. Therefore, ANOVAs were conducted for the whole sample population, and for each age group separately.

A second set of statistical analyses, multivariable mixed linear regression models, were conducted for isolating the specific impact of the use of the *Calliandra* and *Sesbania* shrubs in the nutritional management of the calves in both age groups. For modeling purposes, because control farms were visited bimonthly (for logistical reasons), monthly observations from the nutrition, combined and reproduction groups were adjusted to a bimonthly format by averaging measurements of ADG and other continuous variables from 2 consecutive months to have entries representing every other month visit. For categorical predictor variables (which were all binary), if a predictor was positive for both or one of the two visits, it was considered positive, but if it was negative for both months, it was considered negative for the visit.

For each age group, a univariable mixed linear regression model with natural log of ADG as the outcome, was built for each of the independent variables. Univariable associations with natural log of ADG at $p \leq 0.4$ were eligible for mixed multivariable linear regression model-building processes. For both models, clustering of visits within calves was accounted for by a random effect.

Model 1 (<6-month-old calves), and model 2 (≥6-month-old calves) were both fitted with an autoregressive (ar) correlation structure assuming that the correlation between 2 contiguous visits would be exponentially greater than 2 non-contiguous visits (Kincaid, 2005; Dohoo et al., 2009). The ar1 correlation structure was suitable for both models. The p-value for variables to remain in both models was set at 0.05, and interactions between significant model fixed effects were explored. Tests for correlation (Pearson correlation coefficient) among all parameters meeting the regression modeling cut-off ($p \leq 0.4$) was done to aid decision-making on collinear variables to be included in the model-building, with decisions based on p-values and biological plausibility. Models were fitted using the manual backward stepwise elimination technique, and p values were used to determine fixed parameters to keep in the model. Assessment of linearity between natural log of ADG and continuous variables was done using lowess plots for visualization. Terms that had a nonlinear relationship with natural log of ADG were fitted as curvilinear terms in the models, where applicable. Wald's test was used to test for overall significance of categorical parameters with more than 2 categories. Testing for confounding of model variables was done by comparing changes in coefficient estimates (>20%) with and without the suspected confounders.

Model evaluation was done to confirm that normality and homoscedasticity assumptions on both random and fixed effects were met. Identification of extreme and influential observations was done by sorting and graphing the standardized residuals and comparing changes in coefficient estimates and their significance when modeling with and without influential observations. For ease of interpretation of effects of different predictors, coefficients were exponentiated to back-transform them to the original scale of kg gained day $^{-1}$.

3.4 Results

In total, 155 calves aged 1-12 months old were visited on 73 farms during the 16-month study period, generating a total of 512 observations. Seven of the 80 farms were excluded from the study since calves on these farms only had data points when they were less than 1 month old during the study period, making them inappropriate for determining the benefits of feeding *Calliandra calothyrsus* and *Sesbania sesban* to calves 1 to 12 months old.

In addition to ineligible farms, some calves on eligible farms provided fewer observation points than expected, for a variety of reasons. Farmers mostly had 1 or 2 calves under 12 months on a given visit. However, some calves on these farms didn't stay long in the study, either dying or being sold off before completion of the study. Furthermore, some calves were sent out for grazing in a community pasture in a local forest, especially in the dry season which was the larger part of the study period, leading to fewer observations for these calves.

The geometric mean ADG for the study population was 0.275 kg (geometric s.d. 1.0). In the age group <6 months (n=119), the geometric mean ADG was 0.361 kg (geometric s.d. 1.2), which was significantly higher (ANOVA $p < 0.05$ using natural log of ADG) than the ADG in the age group ≥6 months (n=92) of 0.230 kg (geometric s.d. 1.1). However, the geometric mean ADG in the collapsed intervention group <6 months old was 0.345 kg (geometric s.d. 1.5) which was not significantly higher (ANOVA $p > 0.05$

using natural log of ADG) than the collapsed comparison group which had a geometric mean ADG of 0.307 kg (geometric s.d. 1.6 kg). Similarly, when looking at the calves 6-12 months of age, the geometric mean ADG was only slightly higher (ANOVA $p > 0.05$ using natural log of ADG) in the collapsed intervention group with 0.225 kg (geometric s.d. 1.4) versus the collapsed comparison group with 0.202 kg (geometric s.d. 1.4). There was no significant difference in natural log of ADG between collapsed study groups when the whole study population was used, regardless of age, where the collapsed intervention group was 0.290 kg (geometric s.d. 1.1 kg) while the collapsed comparison group was 0.254 kg (geometric s.d. 1.1). Because there was no significant difference in natural log of ADG between the collapsed intervention and comparison groups in either of the age categories (<6 months or ≥6 months); the results from the second set of statistical analyses were essential for isolating the specific impact of the use of the *Calliandra* and *Sesbania* shrubs in the nutritional management of the calves in both age groups.

3.4.1 Descriptive statistics and univariable analyses between natural log of ADG (kg) and various factors

Table 3.1 includes the variables that met the p-value ≤ 0.4 eligibility criterion for multivariable linear regression modeling of natural log of ADG for calves <6 months of age and/or were part of the final model of natural log of ADG for calves <6 months of age. The descriptive results in Table 3.1 are presented by collapsed intervention and comparison groups (with a p-value for differences between groups) to demonstrate the similarity of the two groups to the reader, achieved by the random allocation of farms to the groups. Summarizing results from Table 3.1, we can see that the calves kept on the study farms were all exotic crosses (i.e. Friesian, Ayrshire, Jersey and Guernsey), with Friesians comprising over 75% of the calves. Nearly 75% of the visits for these calves occurred during the dry season. For most of the study period, farmers in both groups did not graze their calves and maintained a consistent feeding regimen for their calves. Over 60% of the calves were female. Skin parasites, such as ticks, were a common occurrence on the calves in both study groups (over 79%). On average, farmers fed maize silage at 0.6-1.12 kg calf $^{-1}$ day $^{-1}$, and more than 1.7 kg of maize stover calf $^{-1}$ day $^{-1}$ in both groups. All of the above variables were similar for the collapsed intervention and comparison groups ($p>0.05$).

The mean amount of concentrate supplement (dairy meal or calf pellets) fed to a calf day $^{-1}$ (0.136 kg) in the collapsed intervention group (Table 3.1) was significantly more than the amount fed to calves in the collapsed comparison group. Similarly, the calves in the collapsed intervention group were fed significantly more (0.037kg) *Calliandra and Sesbania* calf $^{-1}$ day^{-1} than those in the collapsed comparison group (0kg). However, amounts of *Calliandra and Sesbania* fed to calves on the collapsed intervention farms were low because we observed the shrubs growing well on some farms but not so well on other farms, and some farmers reported routinely feeding most or all of the C*alliandra/Sesbania* to the milking cows, leading to low amounts remaining for calf-feeding.

Table 3.2 includes the variables that met the p-value $\leq$ 0.4 eligibility criterion for multivariable linear regression modeling of calves $\geq$6 months of age and/or were part of the final model for calves $\geq$6 months of age. The calves kept on the study farms were all exotic crosses (i.e. Friesian, Ayrshire, Jersey and Guernsey), with Friesians comprising approximately 75% of the calves. Generally, management for calves in the $\geq$6-month-old age group was similar to the management of <6-month-old-age group. Most (72%) of the visits for these calves were done in the dry season, with 75% of the farmers reporting that they didn't graze them during the period since the last visit. Calves mostly (90%) had normal appetites, and like the <6-month-old age group, occurrence of skin parasites was common (over 87%) in both groups during most of the visits. The diets (and mean daily amounts) for the older calves included Napier grass (2.39 kg), hay (0.254kg), and maize stover (2.38 kg) (Table 3.2). All the above variables were similar for the intervention and comparison groups ($p > 0.05$).

Unlike the <6-month-old age group, supplementation with concentrates was not significantly higher in the collapsed intervention group than the collapsed comparison group and averaged around 0.19kg calf $^{-1}$ day $^{-1}$. However, as expected, the collapsed intervention group supplemented calf diets with significantly more C*alliandra / Sesbania* than the collapsed comparison group (which fed none), with a mean of 0.030 kg calf $^{-1}$ day^{-1} over the study period. Due to variable shrub growth rates and some farmers feeding most or all the C*alliandra / Sesbania* to the milking cows, low amounts remained for calf-feeding.

3.4.2 Multivariable analysis of natural log of ADG (kg) for calves <6 months

The first mixed multivariable linear regression model with natural log of ADG as the outcome variable (for calves <6 months old) was based on 194 observations, after converting observations from monthly to bi-monthly format in the intervention groups, which came from 119 calves on 68 study farms. Evaluation of correlation among eligible ($p \leq 0.4$) model parameters was assessed before fitting all parameters significant from the univariable analysis. For calves <6 months old, being fed milk was highly correlated with age of the calf (0.6), but since both were strongly associated with natural log of ADG in the model, both predictors were kept in the final model.

Model 1: ***Ln of ADG= Constant + At least 0.20(kg) Calliandra/Sesbania fed + Fed milk + Amount of concentrate (kg) – Age in months + Amount of maize silage (kg) – Grazing + Breed – Sex(female) – Skin parasites***

Factors positively associated with natural log of ADG at a given visit were: amount of *Calliandra / Sesbania* fed, amount of concentrate fed, amount of maize silage fed and when the calf was fed milk. Factors negatively associated with natural log of ADG of a calf at a given visit were: the age of the calf in months, if the calf was grazed, and presence of skin parasites. Breed and sex of the calf were confounding the effect of *Calliandra / Sesbania* feeding and therefore were retained in the model even though they were far from significant (Table 3.3a).

To identify the least amount of C*alliandra / Sesbania* needed to produce some level of significant effect on ADG, different levels were explored. The optimum amount of C*alliandra / Sesbania* was obtained by adding 2 standard deviations to the mean amount of C*alliandra / Sesbania* fed to calves in this age group, hence 0.2 kg was used as the cut-off.

When all factors were held constant, and when accounting for clustering of visits within calves, feeding at least 0.2kg (wet weight) of *Calliandra / Sesbania* to a calf day $^{-1}$ would result in 33.2% increase in ADG, while controlling for confounding by breed and sex of the calf, and other variables in the final model (Table 3.3a). This positive association between C*alliandra / Sesbania* supplementation and ADG was only marginally statistically significant (p =0.085) but was forced into the model because it was the predictor of interest in the relatively small study. Calves on milk had significantly higher ADG (39.4% more) compared to weaned calves. Supplementation of calf diets with whole plant maize silage (including the cobs and kernels) was nearly significantly associated with an increase in natural log of ADG (p = 0.054), and therefore was retained in the final model. For every kg of maize silage fed to a calf day $^{-1}$, it was estimated that the mean ADG would increase by 4.2%. The mean ADG significantly decreased by 18.9% with every month the calf grew older. When skin parasites (primarily ticks) were present, mean ADG was estimated to significantly (p <0.0005) decrease by 31% compared to when calves had no observable skin parasites (Table 3.3a).

Scatter plots of fitted values and standardized residuals did not depict distinct patterns in the distribution of standardized residuals in the model. The model assumption for homescedasticity was met, but the normality assumption was not met (using Shapiro Wilk's test) for the visit random effect of this model. Four observations in model 1 were observed to have standardized residual values >2.0, and they were examined to check if they were outliers. There was no evidence of these observations being outliers but when modeled without these observations, the significance and effects of concentrate feeding, *Calliandra/Sesbania* supplementation and amount of silage fed were affected. Since these observations were considered influential but not true outliers, they were retained in the final model.

3.4.3 Multivariable analysis of natural log of ADG (kg) for calves ≥6 months

The second mixed multivariable linear regression model with natural log of ADG as the outcome variable (for calves ≥ 6 months) was based on 150 observations from 92 calves on 60 study farms. Evaluation of correlation among eligible ($p \leq 0.4$) model parameters was assessed before fitting all parameters significant from the univariable analysis. The highest correlation was 0.2 between presence of skin parasites and suffering from a disease.

Model 2: ***Ln of ADG= Constant + Fed on Calliandra/Sesbania – Amount of hay fed (kg) + Fed on calliandra/sesbania * Amount of hay (kg) + Normal appetite– Skin parasites – Season (wet) + Amount of maize silage fed (kg)***

Factors positively associated with natural log of ADG of a calf ≥6 months old at a given visit were: if calves were fed on *Calliandra / Sesbania*, and if the calf had a normal appetite. Factors negatively associated with natural log of ADG of a calf ≥6 months old at a given visit were: amount of hay fed and presence of skin parasites. There was also a significant interaction variable between amount of hay fed and if calves were also fed on *Calliandra / Sesbania.* Amount of maize silage fed, and the prevailing season were confounding the effect of *Calliandra / Sesbania* feeding and therefore were retained in the model even though they were far from significant (Table 3.3b).

For this older age group, amounts of *Calliandra / Sesbania* fed were similar to the amounts fed to the younger group. However, unlike the <6-month-old group, the animals in this group were larger, and they would require a larger amount of *Calliandra / Sesbania* to produce the same ADG effect as that achieved in the smaller calves. Without this larger amount being available, less was fed, and therefore, for this age group, *Calliandra / Sesbania* was simply dichotomized based on whether calves were fed any amount of *Calliandra / Sesbania*. Feeding *Calliandra / Sesbania* to the calves was beneficial for better ADG but the amount of benefit depended on the amount of hay being fed to the calf (interaction shown in Table 3.3b and Figure 3.1). When no *Calliandra / Sesbania* supplementation was provided, the mean ADG was low and relatively constant with increasing amounts of hay, but when C*alliandra / Sesbania* supplement was added to the diet, the mean ADG increased from 0.17kg to 0.48kg when hay was fed at 1 and 5 kg, respectively (Figure 3.1).

When calves had a normal appetite, ADG was 51.7% higher than when calves had a poor appetite. When skin parasites were present (primarily ticks), mean ADG was estimated to decrease by 49.3% compared to when they had no observable skin parasites (Table 3.3b). Prevailing season and amount of maize silage fed had no significant effect on ADG in this age group but were confounding the effect of C*alliandra / Sesbania* on ADG, and therefore were included in the final model.

Scatter plots of fitted values and standardized residuals did not depict distinct patterns in the distribution of standardized residuals. Model assumptions on normality and homescedasticity were met on all levels in model 2.

3.5 Discussion, Conclusion and Recommendations

This study is the first field-based randomized controlled trial to determine the benefits of feeding leguminous shrubs, such as *Calliandra / Sesbania,* to calves on semi-commercial SDFs. The geometric mean ADG for this study population was 0.275 kg for calves 1-12 months of age. This ADG was lower than what had earlier been observed among a random sample of farms in this area (Makau et al., 2018), probably due to the prolonged dry season experienced during the study period and the current study included only smallholder farmers with < 4 milking cows. In both age groups (< 6 months and ≥ 6 months) of our study, supplementation of calf diets with *Calliandra / Sesbania* was associated with an increase in calf ADG on these smallholder farms. The observed increase in ADG was likely attributable to an increase in CP consumed by the calves through their *Calliandra / Sesbania* supplemented feed (Akayezu et al., 1994; Kaitho & Kariuki, 1998; Cook et al., 2005; Franzel et al., 2013).

The effective level of *Calliandra / Sesbania* supplementation differed between the two age groups; the younger calves required a higher minimum amount of supplementation (0.2 kg calf $^{-1}$day $^{-1}$) compared to the older calves where any amount of *Calliandra / Sesbania* was better than not feeding *Calliandra / Sesbania* at all. This difference in response in the two age groups could be attributed to the difference in ruminal development and efficiency of ruminal microbial digestion to extract nitrogen from the plant foliage. The rumens of older calves were likely better developed, and ruminal microbes were more efficiently transforming non-protein nitrogen to synthesize their own true protein (Moran, 2005b) and thus even small amounts of *Calliandra / Sesbania* resulted in better ADG.

The study results confirm that both quantity and quality of forage were important for good ADG in the study calves, particularly the calves ≥6 months old because of the significant interaction between *Calliandra/Sesbania* feeding and amount of hay fed (Table 3.3b and Figure 3.1). Just giving lots of low protein forage is not very helpful (bottom line of Figure 3.1), and just giving some high protein forage without sufficient low protein forage is not very helpful (left side of Figure 3.1) but giving some high protein forage and lots of low protein forage can really help ADG, with ADG approaching 0.5 kg day $^{-1}$. A combination of the two feed probably availed a good balance of fiber (energy source) and CP increasing DMI and digestion (Ishler & Varga, 2001). While there were some challenges with growing the shrubs on some farms, most farms receiving the shrubs were able to grow them well, providing an inexpensive source of high protein forage for the calves.

Calves fed on milk had higher ADG than when they had been weaned (Table 3.3a). This could be attributed to the reduction in readily available dietary true protein when calves switched from a primarily milk diet to a diet with no milk, as the rumen environment may not have adapted yet to effectively digest plant protein (Moran, 2005b). Similarly, ADG was observed to decrease with age which was expected in these SDFs' management systems. This inverse association between age and ADG was similar to growth trends associated with milk-feeding and age observed in other studies (Gitau et al., 1994; London et al., 2012).

An increase in the amount of concentrate (dairy meal/calf pellets) fed was associated with an increase in ADG in the younger calves (Table 3.3a). Dairy meal or calf pellets are formulated to provide easily metabolizable CP in diet. An increase in the amount of concentrate availed more CP to the calves necessary for increased ADG (Lukuyu et al., 2012). Although the CP in good dairy meal is essentially lower (~ 16%) than that of good quality calf pellets (18 - 20%) (Moran, 2005a), the subsistence farmers in this study population used dairy meal as a cheaper alternative to calf pellets since they understood the need for concentrate feeding to calves before and after weaning (Makau et al., 2018). However, since farmers in this study population were not as meticulous in management of older calves (≥ 6 months) as they were with the younger calves (< 6 months), there was no statistical evidence of association between concentrate feeding and ADG in the older calves.

Farmers chose to mitigate the effects of feed shortages by taking out the calves to graze, which was a significant model variable for the young calves (Table 3.3a). Grazing was however associated with a decrease in ADG among these calves, although there was no evidence of interaction between season and grazing. Most of the forage grazed was dried up grasses of low quality and calves spent energy walking off to grazing fields mostly far from the homes, which would potentially result in reduced ADG.

Presence of skin parasites, especially ticks, was associated with a decrease in ADG in both age groups (Table 3.3a and 3.3b). This decreased ADG could be because of blood loss from the ticks, or from tick-borne infections, such as East Coast Fever (ECF) and anaplasmosis, which were endemic in the area, and thus calves with skin parasites were more likely to fall ill and loose body condition (Food and Agriculture Organization, 1993). Poor appetite was also associated with reduced ADG in the final model, in addition to the skin parasite variable, because calves can develop poor appetite from illnesses other than those associated with tick-borne diseases. Calves with poor appetite were clearly not able to consume adequate amounts of CP and energy to support optimal growth.

In this trial, an increase in the amount of maize silage was somewhat associated with an increase in ADG (p=0.054 and 0.11 for young and old calves, respectively (Table 3.3a and 3.3b). Although this effect of maize silage was marginally significant for younger calves (< 6 months) and not statistically significant for calves ≥ 6 months, the positive effect of maize silage on ADG was similar to that observed elsewhere (Nazli et al., 2018). For the older group, the amount of maize silage fed confounded the effect of *Calliandra / Sesbania* on ADG. Generally, farmers in this study population prepared silage using the whole maize plant harvested at the 'milk' stage (when the kernels contain a whitish fluid (Nielsen, 2018)). Other additives included in the silage during preparation were wheat bran, molasses or urea, depending on the preference, accessibility and availability of these products to the study farmers. It was therefore expected that when farmers added maize silage to the daily calf ration, it would provide additional CP and energy necessary for increased ADG. Similar additive practices aimed at improving the available protein (Yitbarek & Tamir, 2014), metabolizable energy content (Kordi & Naserian, 2012) and supporting the fermentation process (Meng-zhen & Yi-xin, 2013) in silage have been documented in countries such as Zambia (Smith, 2010). More maize silage fed would directly enhance ADG on its own but would also potentially enhance ADG through *Calliandra / Sesbania* intake since the functional rumens in these older calves would combine the energy in the maize silage with the protein in the *Calliandra / Sesbania* for improved ADG. Therefore, it was important to control for the confounding effect of silage intake on the relationship between *Calliandra / Sesbania* and ADG.

Common confounders to various production attributes in livestock include breed and sex of the animal and the case was no different in this trial. Although breed and sex were not significantly associated with ADG, they influenced the effect of the intervention of interest (*Calliandra / Sesbania*) on ADG among the younger calves. Friesians are a genetically big breed capable of eating more fodder, such as *Calliandra / Sesbania*, than other breeds, and therefore some of the association between *Calliandra / Sesbania* and ADG could have been due to differences in breed. Therefore, it was not surprising that breed confounded the relationship between *Calliandra / Sesbania* and ADG. Regarding sex, we know that the testosterone in males usually promotes faster growth, but only if they are fed well. However, farmers in this study preferred female calves to male calves as they were potential future milking cows. Consequently, female calves were usually fed better (more nutritious feed). The effect of this management difference was manifested as a confounding effect of sex on the effect of *Calliandra / Sesbania* ADG. Without controlling for the confounding effects of sex on the relationship between *Calliandra / Sesbania* and ADG, we would potentially over-estimate the relationship between *Calliandra / Sesbania* and ADG. Sex and breed were not confounders among the older calves, likely because of less variability in growth and feeding in this age group. There was no significant interaction between amount of *Calliandra / Sesbania* being fed and breed or sex, however, the small sample size may have made it difficult to find these additional interactions.

Although the *Calliandra / Sesbania* shrubs are known to be tolerant to harsh climatic conditions, the prevailing season was a confounding factor to their effect on ADG in the older calves. This confounding effect of season could have been because of changes in other management practices adopted by the farmers to cope with changes in feed availability during the dry season. There was no significant interaction between

Calliandra / Sesbania being fed and season, however, the small sample size may have made it difficult to find these additional interactions.

Although our field trial was designed to control for selection bias and confounding by various factors, through random selection of farms, random allocation of farms to the intervention groups, and multivariable linear regression modeling, the study period was long to maximize the monitoring period possible during the graduate program of the lead author, and therefore the sample population changed with time. New calves were introduced into the farms and added to the study through on-farm calves and purchases, and this dynamic situation could have contributed to some selection bias and uncontrolled confounding.

In terms of a second limitation to the study, in some cases, farmers and calves withdrew from the project and this may have contributed to some loss to follow-up bias. However, their withdrawals from the study were deemed to be not for study-related reasons but personal reasons such as cattle sales or death, change in farm priorities, and family issues, leading to minimal bias to the study results.

We do not report results of models for clustering of calves within farms because we ascertained that there was less clustering of calves within farms (1.6 calves/farm on average) than clustering of visits within calves (3.3 visits/calf on average). We conducted similar multivariable linear regression analyses controlling for clustering of calves within farms. However, the results of those models, controlling for clustering of calves within farms, were similar to the reported models for both age groups, and therefore they were not included in the study methods or results.

In conclusion, supplementation of calf diets (<6 months old) with at least 0.2kg *Calliandra / Sesbania* calf $^{-1}$ day $^{-1}$ would achieve an increase in ADG. Supplementation of calf diets (≥6 months old) fed on ample hay would result in a substantial increase in ADG. Use of *Calliandra* and *Sesbania* through agroforestry can be used to improve growth rate of calves in SDFs in Kenya and should be promoted. Agroforestry land use systems can be adopted as a way for dairy farmers to cope with causes of feed shortage and low CP in farm-available feeds for their calves.

Feeding weaned calves some form of concentrate (dairy meal/ calf pellets) results in an increase in ADG especially for calves <6 months old. Smallholder dairy farms are therefore advised to include calf pellets in calf diets, especially for the 1-2 months before and after weaning time to ensure proper rumen formation and transition from a pre-ruminant to a ruminant, leading to faster calf growth. However, in absence of conventional calf pellets, dairy meal in smaller quantities can be used as feed supplement to calf diets.

Although grazing is a widely practiced coping mechanism for SDFs when there is feed shortage, it has a negative impact on calf ADG. Farmers should institute better feed conservation methods, such as making hay and silage, and maintain zero-grazing calf management to achieve better growth rates of their calves. Ticks affect the rate of growth of calves at all ages, and good tick control management (such as spraying and zero-grazing) for calves on SDFs would support other feeding initiatives for faster weight gain.

3.6 References

Afande, F. O., & Wachira, I. J. (2015). Constraints to Profitability of Smallholder Dairy Farmers in Nyeri South Sub-County, Kenya. *Developing Country Studies*, *5*(7), 11–43. Retrieved from www.iiste.org

Akayezu, J. M., Linn, J. G., Otterby, D. E., Hansen, W. P., & Johnson, D. G. (1994). Evaluation of calf starters containing different amounts of crude protein for growth of Holstein calves. *Journal of Dairy Science*, *77*(7), 1882–1889. https://doi.org/10.3168/jds.S0022-0302(94)77130-7

Bii, B. (2017). Dairy farmers face high cost of feeds as drought bites - Daily Nation. Retrieved August 11, 2017, from http://www.nation.co.ke/business/Dairy-farmers-face-high-cost-of-feeds/996-3800550-ckwc4oz/index.html

Cook, B., Pengelly, B., Brown, S., Donnelly, J., Eagles, D., Franco, A., … Schultze-Kraft, R. (2005). Calliandra calothyrsus. Retrieved June 25, 2018, from http://www.tropicalforages.info/key/forages/Media/Html/entities/calliandra_calothyrsus.htm

Cuddeford, V. (1999). A Fodder Hedge Provides Feed for Cattle in the Dry Season - Barza Scripts. Retrieved June 5, 2018, from http://scripts.farmradio.fm/radio-resource-packs/package-51-raising-livestock-and-poultry/a-fodder-hedge-provides-feed-for-cattle-in-the-dry-season/

Dohoo, I. R., Martin, S. W., & Stryhn, H. (2009). *Repeated Measures data*. (S. M. McPike, Ed.), *Veterinary Epidemiologic Research* (2nd ed.). Charlottetown, Prince Edward Island: VER Inc.

Food and Agriculture Organization. (1993). Parasites in dairy cattle and buffalo. In *Small Scale Dairy Farming Manual* (5th ed., pp. 143–172). Chiangmai, Thailand: Regional Dairy Development and Training Team for Asia and Pacific. Retrieved from http://www.fao.org/AG/againfo/themes/documents/Dairyman/Dairy/V5U10_6.htm

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J., & Wambugu, C. (2013). Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. *Current Opinion in Environmental Sustainability*, *6*(1), 98–103. https://doi.org/10.1016/j.cosust.2013.11.008

GCSA. (2014). Guernsey. Retrieved September 30, 2018, from https://lbcentre.com.au/Guernsey.php

Gillah, K. A., Kifaro, G. C., & Madsen, J. (2012). Urban and peri urban dairy farming in East Africa: A review on production levels, constraints and opportunities. *Livestock Research for Rural Development*, *24*(11).

Gitau, G. K., McDermott, J. J., Waltner-Toews, D., Lissemore, K. D., Osumo, J. M., & Muriuki, D. (1994). Factors influencing calf growth and daily weight gain on smallholder dairy farms in Kiambu District of Kenya. *Preventive Veterinary Medicine*, *21*(2), 179–190.

Gusha, J., Ngongoni, N. T., & Halimani, T. E. (2013). Nutritional composition and effective degradability of four forage trees grown for protein supplementation. *Online*

Journal of Animal and Feed Research, *3*(4), 170–175.

Hickson, R., Zhang, I., & Mcnaughton, L. (2015). Brief communication: Birth weight of calves born to dairy cows in New Zealand. *Proceedings of the New Zealand Society of Animal Production*, *75*, 257–259.

Ishler, V., & Varga, G. (2001). Carbohydrate nutrition for lactating dairy cattle. Retrieved June 24, 2018, from https://extension.psu.edu/carbohydrate-nutrition-for-lactating-dairy-cattle

Kaitho, R., & Kariuki, J. (1998). Effects of Desmodiam,Sessbania and Calliandra fed on dairy heifers.pdf. *Asian-Australasian Journal of Animal Sciences*, *11*(6), 680–684. https://doi.org/http://dx.doi.org/10.5713/ajas.1998.680

Kamanzi M and Mapiye C. (2012). Feed inventory and smallholder farmers' perceived causes of feed shortage for dairy cattle in Gisagara District, Rwanda. *Trop Anim Health Prod*, *44*(7), :1459-68. https://doi.org/doi: 10.1007/s11250-012-0087-3

Kincaid, C. (2005). Guidelines for Selecting the Covariance Structure in Mixed Model Analysis. In G. S. Nelson (Ed.), *Statistics and Data Analysis* (pp. 1–8). Philadelphia, Pennsylvania: SAS Institute Inc. Retrieved from http://www2.sas.com/proceedings/sugi30/198-30.pdf

Kordi, M., & Naserian, A. A. (2012). Influence of wheat bran as a silage additive on chemical composition , in situ degradability and in vitro gas production of citrus pulp silage. *African Journal of Biotechnology*, *11*(63), 12669–12674. https://doi.org/10.5897/AJB12.767

Krpálková, L., Cabrera, V. E., Vacek, M., Stípková, M., Stádník, L., & Crump, P. (2014). Effect of prepubertal and postpubertal growth and age at first calving on production and reproduction traits during the first 3 lactations in Holstein dairy cattle. *Journal of Dairy Science*, *97*(5), 3017–3027. https://doi.org/10.3168/jds.2013-7419

London, M. L., Bernard, J. K., Froetschel, M. A., Bertrand, J. K., & Graves, W. M. (2012). The relationship between weight, age, and average daily gain to show performance of Georgia 4-H and Future Farmers of America (FFA) commercial dairy heifers. *Journal of Dairy Science*, *95*(2), 986–996. https://doi.org/10.3168/jds.2011-4599

Lukuyu, B., Franzel, S., Ongadi, P. M., & Duncan, A. J. (2011). Livestock feed resources: Current production and management practices in central and northern rift valley provinces of Kenya. *Livestock Research for Rural Development.*, *23*(5), 112.

Lukuyu, B., Gachuiri, C. K., Lukuyu, M. N., Lusweti, C., & Mwendia, S. (2012). *Feeding dairy cattle in East Africa*. (B. Lukuyu & C. Gachuir, Eds.), *Feeding dairy cattle in East Africa* (First). Nairobi, Kenya: East Africa Dairy Devleopment Project. Retrieved from https://cgspace.cgiar.org/bitstream/handle/.../EADDDairyManual.pdf

Lukuyu, B., Kugonza, J., Wabwire, R., & Baltenweck, I. (2011). Characterisation of the livestock production system and potential for enhancing productivity through improved feeding at Namayumba , Wakiso district of Uganda , March 2011 Farming system. In *East African Dairy Development Project (EADD)* (pp. 1–6).

Makau, D. N., VanLeeuwen, J. A., Gitau, G. K., Muraya, J., McKenna, S. L., Walton, C., & Wichtel, J. J. (2018a). Animal and management factors associated with weight gain.

Preventive Veterinary Medicine, (Accepted).

Meng-zhen, Q. I. N., & Yi-xin, S. (2013). Effect of Application of a Bacteria Inoculant and Wheat Bran on Fermentation Quality of Peanut Vine Ensiled Alone or with Corn Stover. *Journal of Integrative Agriculture*, *12*(3), 556–560. https://doi.org/10.1016/S2095-3119(13)60257-9

Moran, J. (2005a). Nutrition and young stock. In Peter Storer Editoral Services (Ed.), *Tropical Dairy Farming: Feeding Management for Small Dairy Farmers in the Humid Tropics* (First, pp. 183–190). Collingwood,Australia: CISRO Publishing. Retrieved from http://samples.sainsburysebooks.co.uk/9780643107892_sample_295356.pdf

Moran, J. (2005b). The nutrient requirements of calves. In Peter Storer Editoral Services (Ed.), *Rearing Young Stock on Tropical Farms in Asia* (First, pp. 31–39). Collingwood,Australia: CISRO Publishing. Retrieved from http://www.publish.csiro.au/ebook/chapter/9780643107427_Chapter4

Muraya, J., VanLeeuwen, J. A., Gitau, G. K., Wichtel, J. J., Makau, D. N., Crane, M. B., … Tsuma, V. T. (2018). Cross-sectional study of productive and reproductive traits of dairy cattle in smallholder farms in Meru, Kenya. *Livestock Research for Rural Development*, *30*(in press).

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. FAO Prevention of Food Losses Programme*. Rome, Italy. Retrieved from http://www.fao.org/fileadmin/templates/ags/docs/dairy/P1assessmentkenya.pdf

Nazli, M. H., Halim, R. A., Abdullah, A. M., Hussin, G., & Samsudin, A. A. (2018). Potential of feeding beef cattle with whole corn crop silage and rice straw in Malaysia. *Tropical Animal Health and Production*, *50*(5), 1119–1124. https://doi.org/10.1007/s11250-018-1538-2

Nielsen, R. L. B. (2018). Kernel Development Stages in Corn. Retrieved December 4, 2018, from https://www.agry.purdue.edu/ext/corn/pubs/corn-03.htm

Njarui, D. M. G., Gatheru, M., Wambua, J. M., Nguluu, S. N., Mwangi, D. M., & Keya, G. A. (2011). Feeding management for dairy cattle in smallholder farming systems of semi-arid tropical Kenya. *Livestock Research for Rural Development*, *23*(5), 111. Retrieved from http://www.lrrd.org/lrrd23/5/njar23111.htm

Odero-Waitituh, J. A. (2017). Smallholder dairy production in Kenya; a review. *Livestock Research for Rural Development*, *29*(139). Retrieved from http://www.fao.org/docrep/W2650T/W2650t07.htm#P0_0from http://www.lrrd.org/lrrd29/7/atiw29139.html

Richards, S. M. (2017). *Productivity and welfare of cows on smallholder dairy farms in Kenya*. University of Prince Edward Island. Retrieved from https://www.islandscholar.ca/islandora/object/ir%3A21369/datastream/PDF/download

Sibanda, H. M., & Ndlovu, N. R. (1992). The value of indigenous browseable tree species in livestock production in semi-arid communal grazing areas of Zimbabwe. In J. E. C. Stares, A. N. Said, & J. A. Kategile (Eds.), *Proceedings of the joint feed resources network workshop held in Gaborone, Botswana* (p. 430). Addis Ababa: African Feeds

Research Network. ILCA (International Livestock Centre for Africa). Retrieved from http://www.fao.org/wairdocs/ilri/x5519b/x5519b0c.htm

Smith, T. (2010). Some Tools To Combat Dry Season Nutritional Stress in Ruminants Under African Conditions. In *Development and field evaluation of animal feed supplementation packages* (pp. 145–152). Austria: Internatonal Atomic Energy Agency. Retrieved from https://www.researchgate.net/publication/237254680

University of Missouri Center. (2013). Chapter 1 : Defining Agroforestry. In *Training Manual for Applied Agroforestry Practices* (2013 Editi, pp. 9–15). University of Missouri Center for Agroforestry. Retrieved from http://www.centerforagroforestry.org/pubs/training/chap1.pdf

Windeyer, M. C., Leslie, K. E., Godden, S. M., Hodgins, D. C., Lissemore, K. D., & LeBlanc, S. J. (2014). Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. *Preventive Veterinary Medicine*, *113*(2), 231–240. https://doi.org/10.1016/j.prevetmed.2013.10.019

Yitbarek, M. B., & Tamir, B. (2014). Silage Additives : Review. *Open Journal of Applied Sciences*, (April), 258–274. https://doi.org/10.4236/ojapps.2014.4502

Table 3.1: Descriptive statistics for variables with P≤0.4 associations from unconditional mixed linear regressions on natural log of ADG (kg) for 262 visits on 119 calves (<6 months old) in 68 smallholder dairy farms near Meru, Kenya, in 2016-2017

Variable and Categories	Percentage for collapsed Comparison group (n=97 visits)	Geometric mean ADG (Kg) for collapsed Comparison group (n=97 visits)	Percentage for collapsed Intervention group (n=165 visits)	Geometric mean ADG (Kg) for collapsed Intervention group (n=165 visits)	p-value for differences in ADG
Breed					<0.0005
Friesian	72.2% (70)	0.281	80.0% (132)	0.339	
Ayrshire	23.7% (23)	0.356	12.1% (20)	0.353	
Guernsey	4.1% (4)	0.279	7.3% (12)	0.449[2]	
Jersey	0.0%		0.6% (1)	0.412[2]	
Season					0.002
Dry	74.3% (72)	0.315	73.9% (122)	0.362	
Wet	25.7% (25)	0.254	26.1% (43)	0.316	
Grazing					0.057
Yes	19.6% (19)	0.222	15.8% (26)	0.333	
No	80.4% (78)	0.318	84.2% (139)	0.351	
Feed changes					0.152
Yes	20.6% (20)	0.299	18.8% (31)	0.306	
No	79.4% (77)	0.295	81.2% (134)	0.357	

Sex					0.068
Male	41.2% (40)	0.294	38.2% (63)	0.320	
Female	58.8% (57)	0.296	61.8% (102)	0.367	
Skin parasites					0.002
Yes	81.4% (79)	0. 247	78.2% (129)	0.329	
No	18.6% (18)	0. 304	21.8% (36)	0.431	
Amount of maize silage fed to calves daily (kilograms)	1.174 (0.294)	n/a	0.639 (0.226)	n/a	0.192
Amount of maize stover fed to calves daily (kilograms)	1.927 (0.458)	n/a	1.697 (0.367)	n/a	0.342
Amount of dairy meal fed to calves daily (kilograms)	0.060 (0.02)	n/a	0.196 (0.022)	n/a	0.062
Amount of calliandra/sesbania fed to calves daily (kilograms) [1]	0	n/a	.037(.008)	n/a	0.666

[1] Variable added to the table as a predictor of interest

[2] Literature values were used for birth weights for the first ADG estimates, which could have biased these mean ADG values.

Table 3.2: Descriptive statistics for variables with P≤0.4 associations from unconditional mixed linear regressions on natural log of ADG (kg) for 203 visits to 92 calves (≥ 6 months old) on 60 smallholder dairy farms near Meru, Kenya, in 2016-2017

Variable and Categories	Percentage for collapsed Comparison group (n=85 visits)	Geometric mean ADG (Kg) for collapsed Comparison group (n=85 visits)	Percentage for collapsed Intervention group (n=118 visits)	Geometric mean ADG (Kg) for collapsed Intervention group (n=118 visits	p-value for differences in ADG
Breed					0.159
Friesian	63.5% (54)	0.193	86.4% (102)	0.225	
Ayrshire	27.1% (23)	0.222	7.6% (9)	0.225	
Guernsey	9.4% (8)	0.218	5.9% (7)	0.279	
Season					0.496
Dry	75.3% (64)	0.202	68.6% (81)	0.220	
Wet	24.7% (21)	0.202	31.4% (37)	0.243	
Grazing					0.126
Yes	21.2% (18)	0.180	25.4% (30)	0.220	
No	78.8% (67)	0.209	74.6% (88)	0.230	
Normal appetite					0.396
Yes	87.1% (74)	0.207	93.2% (110)	0.228	
No	12.9 % (11)	0.176	6.8% (8)	0.227	
Skin parasites					<0.0005
Yes	85.9% (73)	0.195	89.0% (105)	0.225	
No	14.1% (12)	0.258	11.0% (13)	0.253	
Amount of Napier fed to calves daily (kilograms)	2.191 (0.260)	n/a	2.589 (0.385)	n/a	0.120

Amount of hay fed to calves daily (kilograms)	0.213 (0.115)	n/a	0.295 (0.110)	n/a	0.280
Amount of maize stover fed to calves daily (kilograms)	2.46 (0.513)	n/a	2.302 (0.298)	n/a	0.353
Amount of dairy meal fed to calves daily (kilograms)	0.163 (0.04)	n/a	0.225 (0.034)	n/a	0.083
Amount of *Calliandra/Sesbania* fed to calves daily (kilograms)[1]	0 (0)	n/a	0.03 (0.011)	n/a	0.90

[1] Variable added to the table as a predictor of interest

Table 3.3a: Final generalized linear mixed linear regression model for ln of ADG for 119 calves <6 months old in 68 smallholder dairy farms near Meru, Kenya 2016-2017, adjusting for clustering of visits within calves

Variables and their categories	Coefficient	[95% Conf. Interval]		p- value
Amount of *Calliandra/Sesbania* fed				
Less than 0.2 kg	reference			
At least 0.2 kg	0.284	-0.040	0.607	0.085
On milk				
No	reference			
Yes	0.332	0.010	0.585	0.010
Amount of concentrate (dairy meal/pellets)	0.287	0.007	0.566	0.044
Age in months	-0.210	-0.302	-0.118	<0.0005
Amount of maize silage (kg)	0.042	-0.001	0.086	0.054
Grazing				
No	reference			
Yes	-0.311	-0.523	-0.099	0.004
Breed				0.335[!]
Friesian	reference			
Ayrshire [a]	0.172	-0.032	0.375	0.098
Guernsey [a]	-0.072	-0.392	0.248	0.660
Jersey [a]	0.328	-0.803	1.459	0.569
Sex				
Male	reference			
Female	-0.043	-0.211	0.126	0.621
Skin parasites				
No	reference			
Yes	-0.370	-0.576	-0.164	<0.0005
Constant	-0.534	-0.974	-0.095	0.017

[!] Overall P-values for categorical variables with >2 categories.

[a] Letter superscript represent significant differences between coefficients of different levels (other than the reference level which use the category p-values) for categorical variables with more than 2 levels.

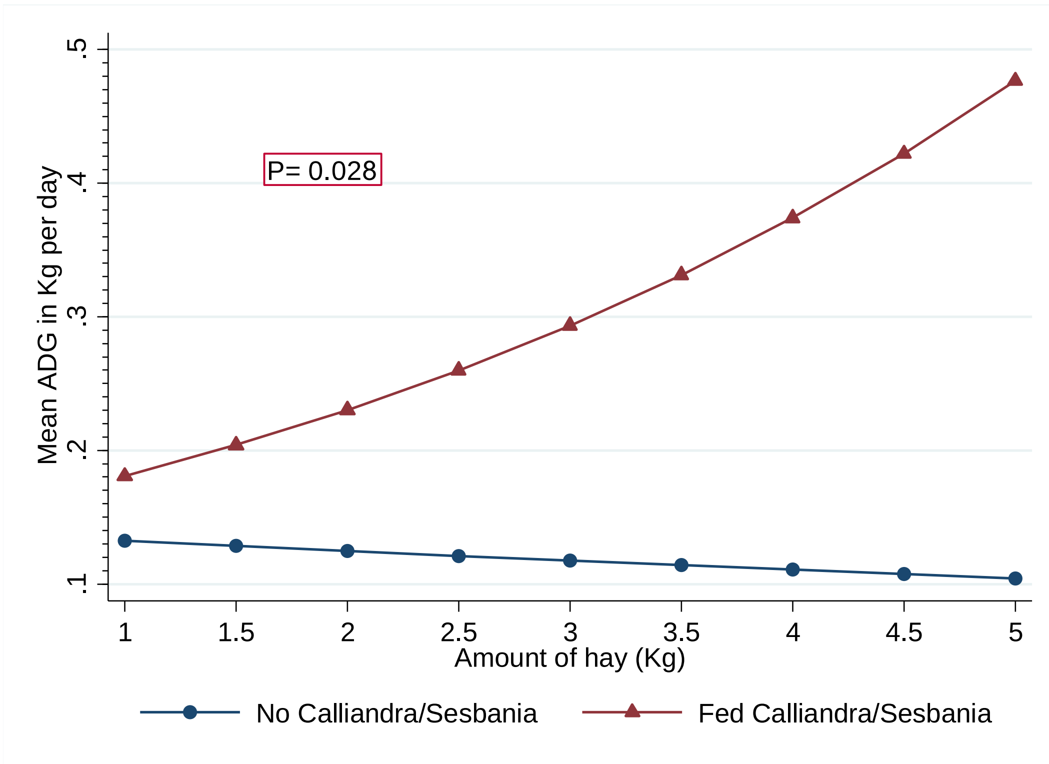
Table 3.3b: Final generalized linear mixed linear regression model for ln of ADG for 92 calves ≥ 6 months old in 60 smallholder dairy farms near Meru, Kenya 2016-2017, adjusting for clustering of visits within calves

Variables and their categories	Coefficient	[95% Conf. Interval]		p- value
Fed on *Calliandra/Sesbania*				
No	reference			
Yes	0.112[α]	-0.305[α]	0.529[α]	0.599[α]
Amount of hay (kg)	-0.044[α]	-0.156[α]	0.068[α]	0.441[α]
Amount of hay (kg) * Fed on *Calliandra/Sesbania*	0.290[β]	0.315[β]	0.549[β]	0.028[β]
Normal appetite				
No	reference			
Yes	0.417	0.097	0.737	0.011
Skin parasites				
No	reference			
Yes	-0.680	-1.019	-0.340	<0.0005
Season				
Dry	reference			
Wet	-0.195	-0.452	0.062	0.137
Amount of maize silage (kg)	0.036	-0.008	0.079	0.110
Constant	-1.792	-2.224	-1.359	<0.0005

[α] Variable is part of an interaction variable; therefore, coefficients and P values should be interpreted with caution, in combination with the other relevant variable of the interaction, and these variables are best reported using a graph (Figure 3.1).

[β] Values are part of an interaction variable with several cross-tabulated categories from the main effect variables, and therefore coefficients should be interpreted with caution relative to the other variable in the interaction, and these results are best reported using a graph (Figure 3.1).

Figure 3.1: Margins plot indicating effect of interaction between amount of hay fed and *calliandra/sesbania* supplementation on the mean ADG of 92 calves more than 6 months old (all factors held constant) when accounting for clustering of visits within calves in smallholder dairy farms near Meru, Kenya during monthly visits in 2016-2017



Chapter 4 Effectiveness of using cellphone technology as a dairy management training tool for smallholder dairy farms in Kenya [2]

4.1 Abstract

There is increasing need for knowledge on the utility of information and communication technology (ICT) for improved agricultural productivity and enhanced income in smallholder production enterprises. The objective of this study was to determine the effectiveness of using cellphone technology as a training tool on smallholder dairy farms (SDFs) in Kenya.

This field trial was carried out between June and September 2017 on 40 farms randomly selected from members of the Naari Dairy Farmers Cooperative Society in Naari sub-location of Meru County, Kenya. An abridged dairy management handbook, developed by Farmers Helping Farmers and the University of Prince Edward Island, was translated into the local dialect, and disseminated as short message text. After pre-intervention knowledge assessments on dairy management, farms were randomly allocated into intervention and comparison groups. Using an online short message service interface (because the study population all had cell phones but only 1.7% had smart phones), short messages on management practices were sent daily, for 3 months, to the phones owned by the farmers in the intervention group. Post-intervention assessment of dairy management knowledge related to the messages was done 3 weeks post-intervention.

[2] Makau D N, VanLeeuwen J A, Gitau G K, Muraya J, McKenna S L, Walton C and Wichtel J J 2018. Effectiveness of using cellphone technology as a dairy management training tool for smallholder dairy farms in Kenya. *Livestock Research for Rural Development. Volume 30 (11), Article #195*. http://www.lrrd.org/lrrd30/11/dennm30195.html

Within and between group comparisons and net changes were determined using t-tests, Chi-squared tests where applicable.

There were no significant demographic or knowledge differences between the two groups pre-intervention. Compared to pre-intervention, trained farmers in the intervention group were significantly more informed on: mastitis prevention, disease (calf diarrhea) prevention, stall management, the role of a balanced nutritious diet on immunity and the resolution of some health conditions post-intervention. Translation of message content to the local language and using easily understandable terminology were reported to be helpful for better understanding and motivation of farmers to implement recommendations.

Cellphone technology with a short message service interface can be an effective training tool for SDFs in remote areas of Kenya located far from where seminars are conducted for dairy farmers.

Keywords: developing country; economic; education; information communication technology; livelihoods; rural farmers

4.2 Introduction

Like other developing countries, optimal production of the smallholder dairy industry in Kenya is constrained by various challenges including: inadequate feed quality and quantity, poor storage facilities for feed conservation, high cost of feed inputs and inadequate information on production approaches and technologies (Lukuyu et al., 2011). Poor communication of research findings to farmers has been identified as a major stumbling block to uptake of best management practices and existing technologies for better cattle nutrition and production on SDFs (Ngwira, 2003; Mwangi & Wambugu, 2003; Hove et al., 2003; Franzel et al., 2014; World Bank Group, 2017). Participatory education and training of farmers could enhance adoption of improved fodder crop use and establishment and efficient use of pastures in SDFs in Kenya (Mwangi & Wambugu, 2003; Lukuyu et al., 2011).

Cellphones have been used in different parts of Africa by farmers and fishermen to support their businesses with numerous benefits and challenges alike. In Ghana, cocoa farmers were able to save on various transaction costs, such as transportation and operational costs (arranging for inputs and contacting purchasing clerks), through the use of cellphones (Ofosu-asare, 2011). A study on the fishing industry (Ghana) observed that fishermen who had cellphones were able to expand their markets using cellphone communication with clients. In addition, the fishermen were able to make decisions based on current information received through their cellphones (Salia et al., 2011). Other benefits highlighted by farmers in northern Ghana included improved communication with farm input suppliers, resulting in increased efficiency in farming (Alhassan & Kwakwa, 2012). However, there has been limited research on the use of cellphones for agricultural education purposes in Africa.

A study to assess the use of cellphones for dissemination of agricultural information in India concluded that farmers mostly used their phones for meeting social needs and receiving extension messages was incidental (Sahota & Kameswari, 2014). However, a more recent study, in the same area of India, concluded that farmers had used cellphones for communication with universities and veterinary institutions on animal husbandry for more than 3 years prior to the 2014 study (Rathod et al., 2016). The authors recommended that adequate measures be undertaken to promote adoption of cellphone technology for effective dissemination and use of livestock-related information (Rathod et al., 2016). There has been further innovation in agriculture to increase the impact of human communication and social connections on agricultural productivity and smallholder incomes. These social connections have been achieved through specialized applications that act as conduits of information dissemination in the United Kingdom (The World Bank, 2012). These innovations are needed in Africa as well.

Over the last decade, cellphone technology has become largely accessible in even the remotest parts of Kenya (Karlsen et al., 2010). Like the rest of Africa, cellphones in Kenya are used for exchange and dissemination of information such as: disease monitoring, weather monitoring, advertising, marketing, financial transactions, business promotion, credit facility, access to advice and much more (The World Bank, 2012).

A study done on SDFs in Nakuru county, Kenya, documented significant positive association between increased milk yields and use of cellphones for provision of extension services (Smollo et al., 2016). However, although use of cellphones has a huge potential for improving smallholder productivity, various factors influence the gains. These factors include: timeliness, quality and trustworthiness of the information disseminated, type of agricultural practices, skills and knowledge levels of the farmers, institutional policies and regulations (Mittal & Tripathi, 2009). As a consequence of these factors, under-utilization of animal husbandry information via cellphones has affected milk production in SDFs in Kenya (Smollo et al., 2016). There is increasing need for knowledge on the utility of information and communication technology (ICT) for enhanced agricultural productivity, and potentially improved income in smallholder production enterprises (The World Bank, 2012). However, research on the effectiveness and use of cellphones, as one method of ICT, in training farmers or disseminating extension-related information in the East African region, especially Kenya, is minimal.

The objective of this study was to determine the effectiveness of using cellphone technology as a dairy management training tool on knowledge of smallholder dairy farmers in rural parts of Kenya.

4.3 Materials and methods

4.3.1 Ethical approval

This study was approved by the Research Ethics Board and the Animal Care Committee of UPEI, NDFCS, and FHF, a partner nongovernmental organization. Signed consent of all participants was obtained after the study was fully explained.

4.3.2 Description of study area

This randomized controlled field trial was carried out in Naari sub-location of Meru County, Kenya (0°6'0" N and 37°35'0" E). Meru County is located on the eastern slopes of Mount Kenya and is 270 kilometers north of Nairobi, the capital city of Kenya. Naari sub-location is in the high agricultural potential region with an altitude of approximately 2,000 m above sea level. The main agricultural activities include: dairying, subsistence crop farming, horticulture and lumbering. Farmers grow food crops such as maize, beans and Irish potatoes and forages for dairy cows. This study area was predetermined since this trial was part of a larger study involving dairy farmers in the area (Makau et al., 2018; Muraya et al., 2018). A non-governmental organization, FHF, and UPEI had an existing developmental partnership with the NDFCS. This rapport provided a strong foundation for the work and the entry point to the community.

4.3.3 Sample population and data collection

The farmers included in the study were from NDFCS, a dairy group with an active membership of 550 farmers (active member is defined as one who regularly sold milk to the NDFCS at the time of the trial). In May 2015, 200 SDFs were randomly selected from the NDFCS registry for a related cross-sectional study using software-based random number generation. One hundred of the 200 SDFs were involved in another related intervention study, and therefore were not eligible for this trial to preserve the integrity of the intervention study. Of the remaining 100 SDFs, participants were selected if they met the eligibility criteria of: active membership with the NDFCS, possession of a cellphone, and subscription to the Safaricom carrier as the cellphone service provider. A total of 95 of the 100 SDFs met the inclusion criteria. Sixty farms were selected for this study through random number generation. Phone interviews were conducted to confirm compliance with the criteria and interest in participating in the study. When a farmer declined to participate in the study, the farm corresponding to the next random number was invited to participate as a replacement. The sample size was determined based on a need to demonstrate differences in knowledge levels between two groups of 30 farmers with respect to the cellphone training intervention, 95% confidence and 80% power.

The 60 farmers were randomly allocated into either a comparison (30) or intervention (30) group. The principal farmers for each group were invited to attend an initial meeting for their group orientation. The meeting for the intervention group was held one day before that of the comparison group. Both meetings were followed by administration of a questionnaire (Appendix 8.4) for collection of baseline data (pre-intervention) on knowledge on dairy management. The questionnaire implementation was facilitated by a local farmer who served as a translator from English to 'Kimeru' (local language) where necessary.

Some sections of the questionnaire were borrowed from a questionnaire used in the 2015 study. The questionnaire had 37 questions with sections on farm household demographics and principal farmer's knowledge related to: mastitis prevention and management, teat blockages, nutritional management, stall design, and neonatal calf management practices. After these two initial meetings, held on two consecutive days in June 2017, the 60 selected farmers subsequently began participating in the study (Figure 4.1).

The farmers in the intervention group were registered in a database management system using MySQL (Structured Query Language) and content dissemination was managed through an Apache platform. Only 1.7% of the farmers in the study population owned smart phones.

4.3.4 Intervention

An abridged version of a dairy management handbook developed by FHF and UPEI was used to develop the content used for training the intervention group. The abridged handbook was translated into the local language (Kimeru) and compressed into short text messages of 160-200 characters. Using a XAMP server and an online integrated SMS interface, 'Africa's Talking' provided by Safaricom, the short text messages were sent daily to the cellphones owned by the farmers in the intervention group. One message was sent per day, 5 days a week for 3 months between June and September 2017.

Post-intervention data were collected during a follow-up meeting 3 weeks after completion of the intervention. These meetings were held separately for each of the groups (intervention and comparison), at different times on the same day. A local farmer (translator) facilitated the filling of a self-administered questionnaire and subsequent focus group discussions (FGD) for both groups. During these meetings data on knowledge of the farmers on dairy management were collected. The FGD for the intervention group was aimed at assessing the overall experience and impact of the cellphone intervention and clarify any issues emanating from the training messages. The FGD for the comparison group served as an avenue to address some challenges the farmers faced on their farms related to feeding and mastitis. The themes for discussion were centered around nutrition and mastitis management questions in the questionnaire. At these meetings, participants in both groups received one-liter of cooking oil and one kilogram of dairy cow mineral supplements as appreciation for their participation. All farmers in the comparison group were subsequently provided with detailed education seminars to address some of the farm management challenges they faced.

4.3.4 Data management and analysis

Data from the questionnaires were keyed into MS Excel 2010 (Microsoft, Sacramento, California, USA) and checked for errors. Data were then transferred to STATA software 13.0 (StataCorp LLC, College station, Texas, USA) for statistical analysis. Descriptive statistical analysis (summarizing distributions, means, and medians) was done for continuous variables. Categorical variables were also summarized using frequencies and percentages.

Knowledge scores were calculated based on responses provided to groups of questions on feeding (3) and mastitis prevention (7). Each right answer given was allocated a value of 1 while each wrong answer was 0. Responses to all questions within a group were then summed up to provide a score for each individual respondent for that group of questions. There were no missing responses to these questions.

For continuous variables (e.g. size of land used for dairy production and knowledge scores), pairwise comparisons were carried out using two sample t-tests for between-group comparisons, and one-sample paired t-tests for before and after comparisons of the same group. For categorical variables, Pearson's Chi-square and Fisher's exact tests (if cells had fewer than 5 farmers) were used. The net change was calculated by comparing differences in scores on questions pre- and post-intervention within and between groups. For proportions, confidence intervals were used to identify significant differences between groups and within groups (Barr, 2018). Results were considered significant if p value ≤ 0.05 or confidence interval were not overlapping. Farmers agreed to the use of the data for research purposes as long as confidentiality was maintained.

4.4 Results

A total of 40 farmers participated up to the completion of the study, 20 farmers withdrew from the study (Figure 4.1). Their reasons for withdrawing included: ineligibility because they were no longer selling their milk to NDFCS; getting a job off the farm (making the training irrelevant and not being available for post-intervention assessment); and having a change of farming priorities (resulting in sale of animals, hence no motivation to continue to participate in the project). These reasons were not perceived to be related to the study or its objectives and therefore selection bias was expected to be minimal.

4.4.1 Demographics of and farm characteristics of participating SDFs

Out of the 40 farmers who completed the study, most were male, with no significant difference in gender between the intervention and comparison groups (p = 0.34) (Table 4.1). Most of the women (78.6%) had only studied up to primary level education, while most of the men (61.5%) had studied up to secondary school level. The difference in education levels between the two genders in the study population was statistically significant (p = 0.02). However, there was no statistically significant difference between the education levels of the principal farmers between the two study groups (Table 4.1).

More than two-thirds of farmers reported that a substantial (50-75%) proportion of their total household income was earned through dairy farming (Table 4.1). On average, farmers had 3.4 acres (s.d.= 2.4 acres) of land available for dairy and crop production. Most farmers (55.0%) allocated at least 50.0% of their available land to dairy production (Table 4.1).

4.4.2 Pre-intervention knowledge analysis and comparison between groups

Farmers were keen to increase their knowledge in dairy farming, with 62.5% of them having attended some form of training on dairy farming. The proportion of farmers that had attended some training (through seminars and or educational/experiential trips) on dairy production in the last one year prior to the field trial was not significantly different between the two groups (p > 0.05) (Table 4.1). However, slightly more farmers in the comparison group reported having attended training than the intervention group. A high proportion of principal farmers in both groups were not able to recall the subject of training sessions they had attended. Although not significantly different between groups, the proportion that could not remember was modestly higher among intervention group members (Table 4.1).

General knowledge on mastitis prevention was fairly good in the study population pre-intervention. Washing the udder prior to milking was a commonly known practice (82.5% - 33/40), but only a handful knew about using some cleaning agent in the wash water (15.0% - 6/40). Few farmers knew about post-milking teat dip (25.0% - 10/40) and dry cow therapy (30.0% - 12/40). There were no significant differences in mastitis prevention knowledge scores between the two groups pre-intervention (Table 4.2).

Feeding knowledge (and its application) was similar between the two study groups pre-intervention. One-third of farmers (13/40) knew that it was good to supplement calf diets with some concentrate and thought dairy meal would suffice, while 80.0% (32/40) of farmers knew that they needed to supplement the diet of dairy cows with dairy meal for steaming up pre-calving. There were no significant differences in nutrition knowledge score between farmers in the two groups pre-intervention (Table 4.2).

4.4.3 Intervention summary and feedback

All farmers in the intervention group received cellphone training messages during the 3-month intervention period. Most (70.8% - 17/24) of these farmers did not keep track of the number of messages sent to them and mentioned that they received many messages. Although a message was sent out daily for 5 days a week, the mean number of messages reported to be received by farmers was 4.4 messages per week, with a s.d. = 2.0 messages per week. Some farmers (29.2% - 7/24) estimated they had received between 4-7 messages during the entire training period, lowering the average. Most farmers reported that they always read 100% of the message (the entire message) (Figure 4.2-1).

From the post-intervention meeting with the intervention group, farmers generally found the content of the message understandable, except for one farmer who had some difficulty understanding the messages (Figure 4.2-2). On a scale of 1 (very easy to understand), 2 (easy to understand), 3 (somewhat easy to understand), 4 (difficult to understand), and 5 (very difficult to understand), the mean, s.d. and median scores for content understandability were 2.3, 0.9, and 3.0, respectively.

On a scale of 1 (very informative), 2 (informative), 3 (somewhat informative), 4 (not very informative), and 5 (not informative at all), the mean, s.d. and median scores regarding how informative the messages were comprised of 2.3, 1.0, and 3.0, respectively. More than a third of farmers reported that the messages were very informative (Figure 4.2-3). Over half of the farmers felt extremely or very motivated (Figure 4.2- 4) to practically implement the dairy cow management practices from messages such as those covering mastitis prevention and Napier grass feeding and other cow nutrition practices. Additionally, most farmers felt that the messages received (such as management of cases of retained placenta) were very effective for their dairy management systems (Figure 4.2-5).

Since the messaging was one-way (farmers could not ask questions for clarification), the extent of the challenge faced by the farmers regarding not being able to call back to inquire about the messages was assessed on a scale of 1 (not challenging at all), 2 (slightly challenging), 3 (challenging), 4 (very challenging), and 5 (extremely challenging). Eleven of the 24 intervention farmers were indifferent and so didn't respond to the question. The challenge of not knowing who to call back about the messages was not largely experienced among the farmers except for those who found this a big challenge (Figure 4.2-6), with mean, s.d. and median scores of 2.0, 1.5 and 1.0, respectively.

A third of the farmers (8/24) had some questions and concerns about some messages received in the 3-month intervention period. A few of these farmers with concerns (37.5% - 3/8) thought that the messages were not very clear and orderly for thematic continuity in each message, while 25.0% (2/8) of these farmers had concerns that some of the translations from English to the local (Kimeru) language were difficult to contextualize on their farms. However, 37.5% (3/8) of farmers with concerns chose not to articulate their concerns altogether. Some of the 8 farmers (25.0% - 2/8) that had concerns chose to ask for help from veterinarians, veterinary technicians or their neighbors to read and better understand the knowledge, while the rest chose to ignore the concerns and understand the messages as they had read them.

From the FGD, some farmers expressed a challenge not previously envisioned. Since the screen of the feature phones was small, scrolling through to read a full 160-character message took some time.

4.4.3 Post-intervention comparison between and within groups

Knowledge on the different practices taught as beneficial methods of mastitis control (using a different wash cloth for each milking cow, drying udder before milking with a clean cloth or paper towel, using a different drying cloth for each milking cow, using a teat dip post-milking, giving fresh feed soon after milking, using dry-cow treatment when drying cows off prior to calving, and not leaving milk in the udder to allow calves to suckle) was again assessed for the two groups post-intervention.

The mean mastitis prevention knowledge score on comparison farms decreased, but in the intervention group, there was an increase in mean score on knowledge of mastitis prevention practices, producing a net change in knowledge on mastitis prevention of 3.4 between the 2 groups, which was significant ($p < 0.01$) (Table 4.2). From FGD, it was evident that, although farmers in the intervention group were more knowledgeable about some of these practices post-intervention, the rationale was not always clear to them. Clarification was provided on how each of the practices was relevant in reducing mastitis occurrence on farms.

There was also a difference between groups in knowledge level on diarrhea prevention post-intervention ($p < 0.01$). Most of the intervention group (87.5% - 21/24) and (25.0% - 4/16) of the comparison group - knew that housing the calf in a clean and dry place would help reduce occurrence of calf diarrhea cases. Similarly, post-intervention, more farmers in the intervention group (66.7% - 16/24) knew that always providing dry bedding and removing manure from the stall daily was helpful in preventing diarrhea in calves compared to the comparison group at 0% ($p < 0.01$). There were no differences in diarrhea prevention knowledge between groups pre-intervention. From the FGD, it was apparent that although farmers had calves on their farms, most of them did not have conventional stalls/pens for their calves. Because of this farming practice, bedding in calf pens was not a major consideration for them.

On causes of teat blockage, there was a significant difference ($p = 0.02$) in the understanding that udder infection was a risk factor for teat blockage between the comparison (62.5%, 10/16) and intervention (91.7%, 22/24) groups post-intervention. Similarly, more farmers in the intervention group (58.3%, 14/24) than the comparison group (18.8%, 3/16) knew (post-intervention) that improper milking techniques (pulling hard on the teats during daily routine milking) was associated with teat blockage ($p = 0.01$). Compared to the comparison group, post-intervention, the intervention group was also more aware that teat blockage problems could be an inherited problem (0% - 0/16 vs 25.0% - 6/24, respectively) ($p = 0.03$). There were no differences in teat blockage knowledge between groups pre-intervention.

From the FGD, farmers indicated that pulling the teat during milking was necessary for some cows because they had small teats due to cross breeding of *Bos taurus* breeds with *Bos indicus* breeds, with the latter mostly having small teats. With this cross-breeding being common in the area, most farmers had habituated to this pulling technique of milking, even when the cows had standard size teats that could be milked easily using the squeezing technique.

The mean knowledge score on feeding practices was assessed based on the understanding of ideal height for harvesting Napier, need for dairy meal for steaming up cows pre-calving, and colostrum feeding times for newborn calves. Although there was a 0.4 increase and a 0.1 decrease in the mean knowledge score in the comparison and intervention groups respectively, these changes were not significant. There was no significant difference between the two groups post-intervention. However, the net change of 0.5 in scores on knowledge about recommended feeding practices was significant

(Table 4.2). When asked about the benefits of good nutrition post-intervention, 58.3% (14/24) of the intervention farmers were knowledgeable ($p = 0.04$) on the role of a balanced nutritious diet in supporting the resolution of rain scald compared to 25.0% (4/16) in the comparison group. During the FGD, farmers from both groups mentioned that feeding cows on short Napier grass and steaming up were not very novel concepts to them since they had been trained about them in other seminars as well. However, the physiological rationale behind these practices were not clear to them.

4.5 Discussion, Conclusion and Recommendations

Analyses in this trial ultimately involved 40 farms randomly selected and allocated into intervention and comparison groups. Training the intervention group through SMS on smallholder dairy management best practices for 3 months resulted in significant increases in dairy management knowledge scores on various husbandry aspects in the intervention group. Farmers in the intervention group were more knowledgeable on mastitis prevention practices, associations between stall hygiene and calf disease, as well as some beneficial nutritional management practices post-intervention; indicative of the improvement of knowledge for better production, irrespective of previous training and formal education levels. This improvement in knowledge could be attributed to the fact that by using cellphones as a training tool, farmers could keep the information with them at their fingertips for potentially long periods of time (Martin & Hall, 2011). Moreover, the cellphone messaging as a training tool was well-received by the farmers, who read the messages and were largely motivated to implement the recommendations. In addition, the farmers considered a frequency of one message a day as a suitable and effective way of delivering training content to them.

These trial findings had some resemblance to findings in other SDFs in Kenya; a study by (Staal et al., 2003) highlighted a positive effect on milk production (not evaluated in this study) when farmers in Njoro sub-county used husbandry information received through mobile phones. However, that study was not expressly designed to evaluate effectiveness of using cellphones as a training tool towards improved knowledge, which was the focus of this study.

This study population was generally representative of other SDFs in Kenya. Most of the principal farmers were female, which has been observed in other studies (Gallina, 2016). However, in the current training and research sessions, more men (65.0%) than women participated, which is likely a result of women being busy with chores at home and the patriarchal culture. Men are more frequently involved in off-farm activities, such as attending training and research sessions, than women. Some of the men attending the sessions indicated that they were representing their wives. Comparative pre-intervention analysis between the two groups showed that the groups were generally alike.

Similarly, on dairy management practices, such as feeding and mastitis prevention, there was no significant difference between the groups prior to intervention. The random allocation assisted in mitigating possible selection bias (Kahan et al., 2015).

Analogous to other findings in other areas in Kenya (Richards et al., 2015), dairy production was the main source of income for most (55.0%) farmers. The land acreages in this study population were small, with an average of 3.4 acres available for dairy and crop farming. The average land size of these SDFs was slightly higher than the average (2

- 2.8 acres) documented in the region (Mugambi et al., 2015) but within the range documented by other studies in Kenya (Omiti et al., 2006; Vanleeuwen et al., 2012).

Most farmers in this study were keen on dairy production and thus had attended some form of training on dairy management. This is a common happening in dairy cooperatives in Kenya where the dairy cooperative organizes seminar/extension sessions for farmers to increase knowledge and improve production (Wambugu et al., 2011; Ettema, 2012). However, a short-coming of this form of farmer training has been that the knowledge retention can be relatively low among session attendants. Less than a half of the farmers in this study were able to recall details of the trainings they had attended within the last year pre-intervention.

Use of cellphone messaging for information dissemination in Kenya has increased in the last decade; in the agricultural sector, this dissemination has played a great role in enhancing information transfer between farmers, researchers and industry representatives (Kiptum, 2016). In recent years, cellphone technology has been adopted and is now used for some agricultural purposes in Kenya. Most of the innovations being prioritized include using SMS on cellphones for information access to farmers (The World Bank, 2012). Using one-way messaging in this study was done through MySQL on an Apache-based SMS gateway server which allows for transmission of uniform messages from a server to many individuals as a promotional item (Hussain, 2016). MySQL is essentially a common language for accessing databases (Oracle Corporation, 2013). Apache is one of the most widely used software for database interaction, visualization and management (Balkhi, 2009).

Overall, the farmers reported that the message reception was good. On assessing how the farmers felt about the information in the messages, the general feeling was that the messages were informative, and hence more than half of the farmers were extremely or very motivated to implement dairy management advice in the messages. This messaging encouraged discussions between farmers, as well as consultations with veterinary service providers, especially when some components were unclear. The use of cellphone messaging as a form of information dissemination has been shown to increase farmer-to-farmer training and uptake of various technologies (The World Bank, 2012). Unfortunately, most feature phones have small storage capacities and thus farmers sometimes need to delete older messages when the phone memory is full. However, farmers mentioned that they read most of the messages sent to their phones at any one moment and could retain the messages that provided new information to them and they preferred not to delete them. For this reason, receiving the messages made them happier compared to one-day farmer seminar trainings. Similar findings in relation to content retention were observed in another study (Farm Africa, 2015).

The main message-related challenge highlighted by the farmers in the FGD was that parts of the message were not easily readable on the small screen of the feature phone. For example, some farmers reported that some messages were longer than the phone screen display could handle at one time and took a long time to scroll through it at the time of receiving the message. Farmers in the FGD said they sometimes took a break in reading one long message, and then they sometimes forgot to read the rest of the message later. However, the farmers indicated that translation of messages into the local language was a welcome idea. Although some farmers had a challenge in understanding some translated words, the messages were still considered by most farmers to be easy to understand. Cellphone training has been considered a sustainable approach to support the use of media technologies for training purposes (World Bank Group, 2017).

The mastitis prevention knowledge scores in the comparison group appeared to decrease significantly, while the intervention group scores increased slightly. The relatively high pre-intervention knowledge scores for the comparison group (compared to post-intervention) may have been a result of the pre-intervention meeting for the intervention group being held a day before that of the comparison group. Farmers in the intervention and comparison groups may have discussed the contents of the questionnaires and the meeting since they were all within the same relatively small community, resulting in higher comparison group scores. This unintended dissemination was mitigated post-intervention where both groups were interviewed at different times of the same day. It is therefore recommended that reducing the interval between assessments of the study groups would reduce probability of information transfer between the comparison and intervention groups.

Knowledge scores on feeding practices, such as the amount and time of colostrum given to calves, and ideal height of Napier grass harvesting for optimum milk production, also had significant net changes between the two groups. The comparison group appeared to have increased their knowledge scores while the intervention group didn't change much. This unexpected net change in knowledge score could be attributed to the fact that such information was also communicated to the farmers by another NGO in the area and in other training forums. However, knowledge on other nutritional information (such as for some skin conditions (rain scald) which could quickly resolve when cows are fed a well-balanced diet) (Roberson et al., 2012) was significantly higher in the intervention group than comparison group. Similarly, more farmers in the intervention group were knowledgeable on the benefits of hygiene in calf diarrhea management post-intervention.

A limitation was loss to follow-up in both the intervention and comparison groups, reducing the final sample size and power of this study. The reasons for farmers not completing the trial were unlikely to be related to the study objectives, minimizing any bias from this attenuated sample size. However, a smaller sample size leads to reduced power to detect significant differences between groups. Fortunately, we were still able to find significant differences in knowledge between the groups, even with the smaller sample size.

Another limitation of the study was the unintended dissemination of knowledge during the trial, leading to farmers in the comparison group improving in their knowledge scores. A change in study design to have different populations farther apart and a shorter period between evaluation of study groups would help reduce unintended information diffusion between the groups and 'contamination' of the comparison group.

We hypothesize that, the improvement in knowledge of the farmers in this study would most likely translate into better dairy management, production and improved incomes to the farmers. This effect of training was observed by (Richards et al., 2016) where good use of high protein forages coupled with continuous on-farm education and training on best management practices, significantly increased daily milk production in SDFs in Kenya. While a significant difference was observed on knowledge levels of trainees, further investigation on effectiveness of this form of training on actual milk production and practices is needed.

A cost-benefit analysis would likely show that use of cellphones for training is a cost-effective approach for knowledge transfer from the farmer's perspective, given that in Kenya, most farmers already have a cell phone and do not pay anything to receive messages. Therefore, a subscription fee would likely be the only real cost to the farmer, along with a slight increase in charging costs if the phone was used more. Benefits to the farmer could be substantial, depending on the improvements made on the farm. A comparative investigation of effectiveness of seminar training vs cellphone training would be informative on the impact and sustainability for such alternative farmer training methods.

With this study population, interventions implemented needed to be based on a feature phone interface. Evaluation of a smartphone application that allows a more interactive interface between the farmer and messages on smartphones could be explored in the future when smartphones become more common among rural farmers. Furthermore, a trial to compare the differences in cost and impact of training using the feature phone and smartphone would be more informative on the best cellphone interventions for SDFs in Kenya.

The results of the current study indicate that SMS technology for feature phones can be an effective training tool for farmers on SDFs in Kenya. Furthermore, the technology can be applied in remote areas located far from where regular seminars are conducted for dairy farmers (for farmers with cellphones). The bulk educational messaging to farmers can effectively supplement other forms of farmer education.

There is demand for knowledge on good husbandry practices on SDFs in Kenya as exemplified by the high level of motivation, value of information, and willingness to implement the recommendations expressed by the farmers in this trial. Translation of message content to the local language and using easily understandable terminology were reported to be helpful for better understanding and motivation of farmers to implement recommendations.

Dairy production accounts for a sizable portion of the income in SDFs in Kenya. Therefore, use of cellphone-based interventions to improve production could be a way to improve livelihoods and economic power of farmers in SDFs in Kenya.

4.6 References

Alhassan, H., & Kwakwa, P. A. (2012). The Use of Mobile Phones by Small Scale Farmers in Northern Ghana : Benefits and Challenges. *Journal of Entrepreneurship and Management*, *1*(3), 40–45. Retrieved from http://www.publishingindia.com/GetBrochure.aspx?query=UERGQnJvY2h1cmVzfC8xMzg1LnBkZnwvMTM4NS5wZGY=

Balkhi, S. (2009). What is Apache? - What is a Web Server? Retrieved June 16, 2018, from http://www.wpbeginner.com/glossary/apache/

Barr, D. R. (2018). Using Confidence Intervals to Test Hypotheses. *Journal of Quality Technology*, *1*(4), 256–258. https://doi.org/10.1080/00224065.1969.11980385

Ettema, B. F. (2012). Dairy Development in Kenya. Retrieved May 11, 2018, from http://www.dairyfarmer.net/fileadmin/user_upload/40_downloads/kenya-dairying-ETTEMA.pdf

Farm Africa. (2015). Testing the Use of Mobile Technology To Improve Smallholder Sesame Cultivation. Retrieved May 14, 2018, from https://www.farmafrica.org/downloads/resources/ict244lowres.pdf

Gallina, A. (2016). *Gender dynamics in dairy production in Kenya: A literature review* (No. 182). Copenhagen, Denmark. Retrieved from www.ccafs.cgiar.org

Hove, L., Franzel, S., & Moyo, P. S. (2003). Farmer experiences in the production and utilisation of fodder trees in Zimbabwe: Constraints and opportunities for increased adoption. *Tropical Grasslands*, *37*, 279–283. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-1642476784&partnerID=40&md5=d6c022fd216f380eece0e3e2b53bf225

Hussain, S. N. (2016). SMS Requirements & Highlevel Design. Retrieved June 16, 2018, from https://cwiki.apache.org/confluence/pages/viewpage.action?pageId=65865302

Kahan, B. C., Rehal, S., & Cro, S. (2015). Risk of selection bias in randomised trials. *Trials*, *16*(1), 1–7. https://doi.org/10.1186/s13063-015-0920-x

Karlsen, C., David, A., & Hopmann, N. (2010). *Kenya Connected : Mobile Technology is linking Journalists to Local Sources*. *Journalism*. University of Southern Denmark. Retrieved from https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=3&ved=0ahUKEwjxjpv9_5nbAhWBy1MKHfYqAfQQFgg7MAI&url=https://www.sdu.dk/-/media/files/om_sdu/centre/journalistik/specialer/2010/kenya_connected_camilla_karlsen.pdf&usg=AOvVaw3DBhypGQnmI-5bB8swjPP

Kiptum J C 2016. *Ict Framework For Adoption In The Dissemination Of Agricultural Information In Kenya :(Case Study Of Agricultural Development Corporation)*. University of Nairobi. Retrieved from http://erepository.uonbi.ac.ke/handle/11295/97618

Lukuyu, B., Franzel, S., Ongadi, P. M., & Duncan, A. J. (2011). Livestock feed resources: Current production and management practices in central and northern rift valley provinces of Kenya. *Livestock Research for Rural Development.*, *23*(5), 112.

Makau, D., VanLeeuwen, J., Gitau, G., Muraya, J., McKenna, S., Walton, C., & Wichtel, J. (2018). Animal and management factors associated with weight gain. *Preventive Veterinary Medicine*, 161, 6-68. https://doi.org/10.1016/j.prevetmed.2018.10.017

Martin, B. L., & Hall, H. (2011). *Mobile Phones and Rural Livelihoods : Diffusion , Uses , and Perceived Impacts Among Farmers in Rural Uganda* (7 No. 4) (Vol. 7). Annenberg.

Mittal, S., & Tripathi, G. (2009). Role of Mobile Phone Technology in Improving. In *Agricultural Economics Research Review* (Vol. 22, pp. 451–459). Indian Council for Research on International Economic Relations (ICRIER).

Mugambi, D. K., Mwangi, M., Kairu, S., & Gitunu, A. M. (2015). Assessment of performance of smallholder dairy farms in Kenya : an econometric approach. *Journal of Applied Biosciences*, *82*, 7891–7899. https://doi.org/10.4314/jab.v85i1.13

Muraya, J., VanLeeuwen, J. A., Gitau, G. K., Wichtel, J. J., Makau, D. N., Crane, M. B., … Tsuma, V. T. (2018). Cross-sectional study of productive and reproductive traits of dairy cattle in smallholder farms in Meru, Kenya. *Livestock Research for Rural Development*, *30*(171). Retrieved from http://www.lrrd.org/lrrd30/10/jmura30171.html

Mutunga, I. M., & Waema, T. M. (2016). Context of mobile phone use and its effects on smallholder farmer ' s livelihood outcomes in Kenya. *International Journal of Scientific Research and Innovative Technology*, *3*(4), 121–136.

Mwangi, D. M., & Wambugu, C. (2003). Adoption of forage legumes : the case of Desmodium intortum and Calliandra calothyrsus in central Kenya. *Tropical Grasslands*, *37*, 227–238. Retrieved from http://www.tropicalgrasslands.asn.au/Tropical Grasslands Journal

Ngwira, A. (2003). Forage demand and constraints to adoption of forage technologies by livestock keepers in Malawi. *Tropical Grasslands*, *37*, 274–278.

Ofosu-asare, K. (2011). *Trade Liberalisation , Globalisation and the Cocoa Industry in Ghana : The Case of the Smallholder Cocoa Farmers Kwaku Ofosu-Asare*. University of Westminster. Retrieved from http://westminsterresearch.wmin.ac.uk/10484/1/Kwaku_OFOSU-ASARE.pdf

Omiti, J., Wanyoike, F., Staal, S., & Delgado, C. (2006). Will Small-Scale Dairy Producers in Kenya Disappear Due to Economies of Scale in Production ? Retrieved July 22, 2018, from https://ageconsearch.umn.edu/bitstream/25674/1/cp060516.pdf

Oracle Corporation. (2013). What is MySQL? Retrieved June 12, 2018, from https://dev.mysql.com/doc/refman/8.0/en/what-is-mysql.html

Rathod, P., Chander, M., & Bardhan, D. (2016). Adoption Status and Influencing Factors of Mobile Telephony in Dairy Sector : A Study in Four States of India §. *Agricultural*

Economics Research Review, *29*(1), 15–26. https://doi.org/10.5958/0974-0279.2016.00015.X

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G. K., Kamunde, C., Uehlinger, F., & Wichtel, J. (2015). Associations of farm management practices with annual milk sales on smallholder dairy farms in Kenya. *Veterinary World*, *8*(1), 88–96. https://doi.org/10.14202/vetworld.2015.88-96

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G. K., Wichtel, J., Kamunde, C., & Uehlinger, F. (2016). Randomized controlled trial on impacts of dairy meal feeding interventions on early lactation milk production in smallholder dairy farms of Central Kenya. *Preventive Veterinary Medicine*, *3954*, 1–8. https://doi.org/doi:10.1016/j.prevetmed.2016.01.006

Roberson, J. R., Baird, A. N., & Pugh, D. G. (2012). Diseases of the Integumentary System. In D. G. Pugh & A. N. Baird (Eds.), *Sheep and Goat Medicine* (Second Edi, pp. 256–290). W.B. Saunders. https://doi.org/http://dx.doi.org/10.1016/B978-1-4377-2353-3.10010-1

Sahota, C., & Kameswari, V. L. V. (2014). M obile P hones A gricultural E xtension. *Jurnal Pengajian Media Malaysia*, *16*(1), 1–11.

Salia, M., Nsowah-Nuamah, N. N. N., & Steel, W. F. (2011). Effects of Mobile Phone Use on Artisanal Fishing Market Efficiency and Livelihoods in Ghana. *The Electronic Journal of Information Systems in Developing Countries*, *47*(1), 1–26. https://doi.org/10.1002/j.1681-4835.2011.tb00334.x

Smollo, J. W., Ali-Olubandwa, A. M., & Ng'endo, C. M. (2016). Influence of Utilizing Animal Husbandry Information from Mobile Phones on Milk Yield Among Smallholder Dairy Farmers In Njoro Sub- County, Kenya. *International Journal of Agricultural Extension*, *04*(01), 41–47. Retrieved from http://www.escijournals.net/IJAE

Staal, S. J., Waithaka, M., Njoroge, L., D M Mwangi, Njubi, D., & Wokabi, A. (2003). *Costs of milk production in Kenya: Estimates from Kiambu, Nakuru and Nyandarua Districts*. Nairobi, Kenya. https://doi.org/10.13140/2.1.2945.9206

The World Bank. (2012). Using ICT to enable Agricultural Innovation Systems for Smallholders ICT innovations. Retrieved May 14, 2018, from http://www.fao.org/docrep/018/ar130e/ar130e.pdf

Vanleeuwen, J. A., Mellish, T., Walton, C., Kaniaru, A., & Gitau, R. (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*, 231–238. https://doi.org/10.1007/s11250-011-0003-2

Wambugu, S., Kirimi, L., & Opiyo, J. (2011). *Productivity trends and performance of dairy farming in Kenya* (WPS 43/2011). *Tegemeo Institute of Agricultural Policy and Development* (Vol. WPS 43/201). Nairobi, Kenya. https://doi.org/WPS 43/2011

World Bank Group. (2017). Agriculture ICT Extension Services. Retrieved May 15, 2018, from https://www.innovationpolicyplatform.org/system/files/4_Agri ICT Extension_Agri_Nov20.pdf

Figure 4.1: Flow diagram of participants for a cellphone training intervention trial on dairy management in Kenya in 2017

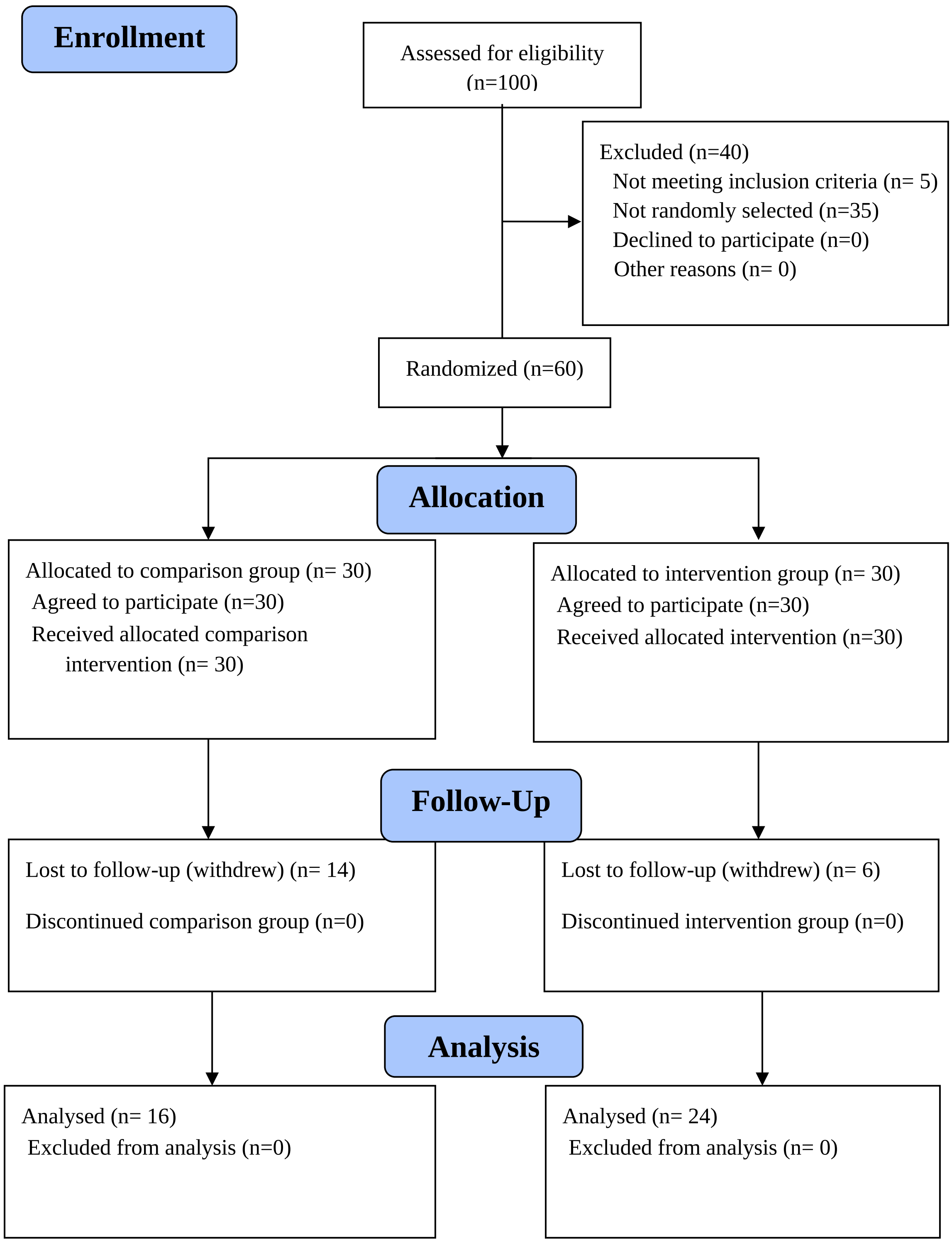


Table 4.1: Demographic and other characteristics of 40 smallholder dairy farms participating in a cellphone training trial on dairy management in Kenya in 2017

Variable Names and Categories	Intervention Group (n=24)	Comparison Group (n=16)	p-value	Total Population (n=40)
Gender			0.343	
Male	70.8% (17)	56.3% (9)		65.0%
Female	29.2% (7)	43.8% (7)		35.0%
Marital status			0.056	
Married	87.5% (21)	93.8% (15)		90.0%
Divorced or widowed	4.2% (1)	6.2% (1)		5.0%
Single	8.3% (2)	0.0%		5.0%
Education attained by principal farmer			1.000	
Primary	50.0% (12)	50.0% (8)		50.0%
Secondary	45.8% (11)	50.0% (8)		47.5%
University/college	4.2% (1)	0.0%		2.5%
Proportion of total income from dairy			0.129	
Less than 50%	8.3% (2)	31.25% (5)		17.5%
50 – 75 %	83.3% (20)	68.75% (11)		77.5%
More than 75 %	8.3% (2)	0.0%		5.0%
Proportion of land used for			0.893	

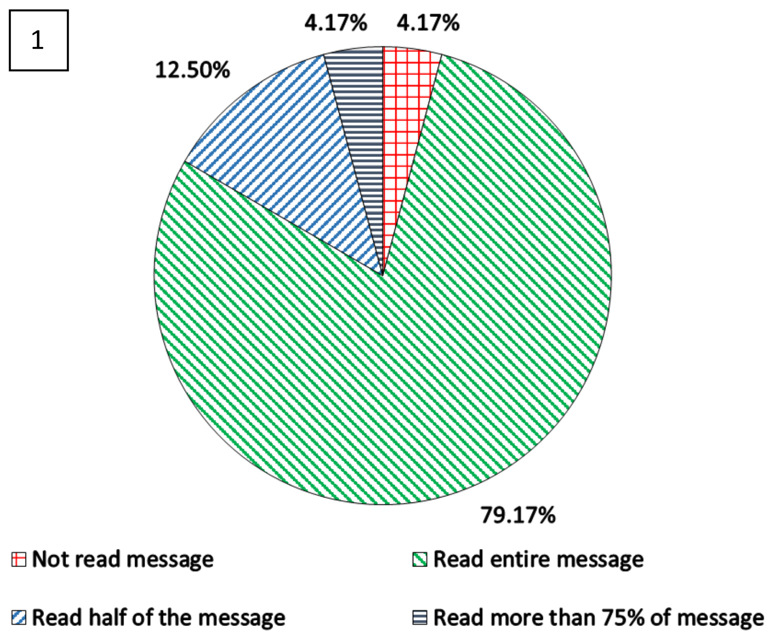
dairy				
25% or less	33.3% (8)	25.0% (4)		30.0%
50 – 75	50% (12)	62.5% (10)		55.0%
More than 75%	16.7% (4)	12.5% (2)		15.0%
Attended any training within the last year			0.056	
Yes	50.0% (12)	81.2% (13)		62.5%
No	50.0% (12)	18.8% (3)		37.5%
Subject of training if attended training within the last year			0.271	
Can't remember	75.0% (9) *	46.2% (6) *		60.0% *
General husbandry and feeding	16.7% (2) *	15.4% (2) *		16.0% *
Silage making	8.3% (1) *	38.4% (5) *		24.0% *

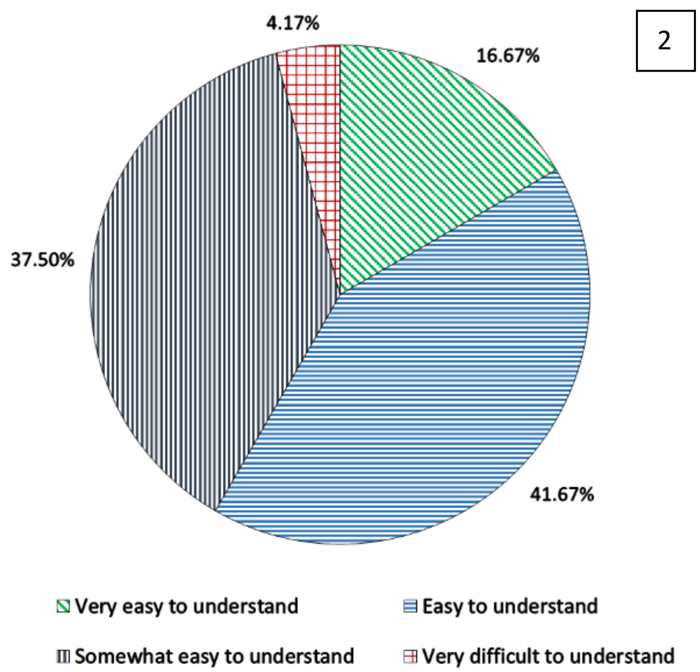
** Based on n= 12 and 13 in the two groups, respectively (those who attended some training)*

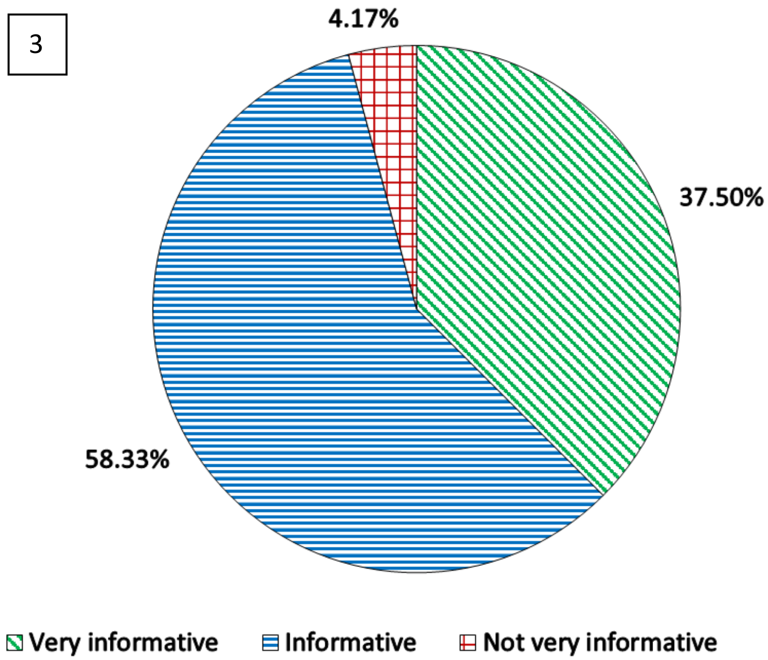
Table 4.2: Mean knowledge scores on mastitis prevention and feeding for 40 smallholder dairy farmers participating in a cellphone training trial on dairy management in Kenya in 2017

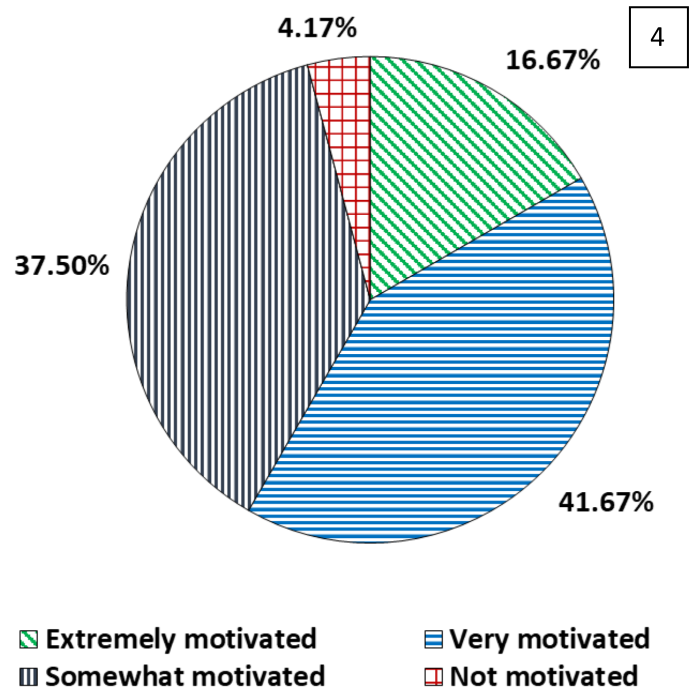
	Mean knowledge scores	**Intervention (n=24)**	**Comparison (n=16)**	***p-value***
Pre-intervention	Mastitis prevention	3.8 (s.d. 1.9)	4.7 (s.d. 1.1)	0.07
	Feeding	2.2 (s.d. 0.5)	2.0 (s.d. 1.0)	0.48
Post-intervention	Mastitis prevention	4.3 (s.d. 1.4)	1.8 (s.d. 0.8)	<0.001
	Feeding	2.3 (s.d. 0.7)	2.4 (s.d. 0.8)	0.69
Net change	Mastitis prevention	0.5 (s.e. 0.4)	- 2.9 (s.e. 0.3)	<0.001
	Feeding	-0.1(s.e. 0.2)	0.4 (s.e. 0.3)	<0.001

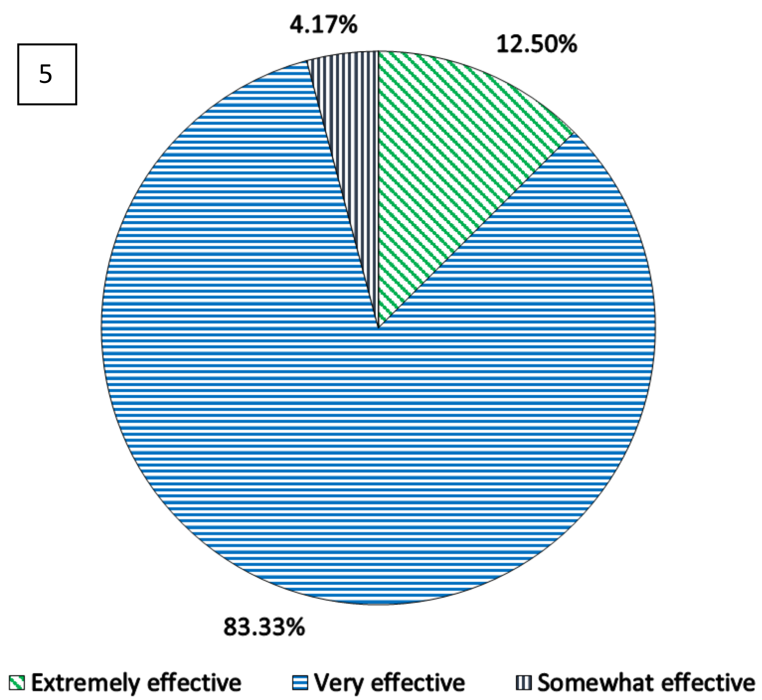
Figure 4.2: Descriptive analysis of perspectives and experiences of 24 farmers in the intervention group on the cellphone messaging intervention in Kenya in 2017

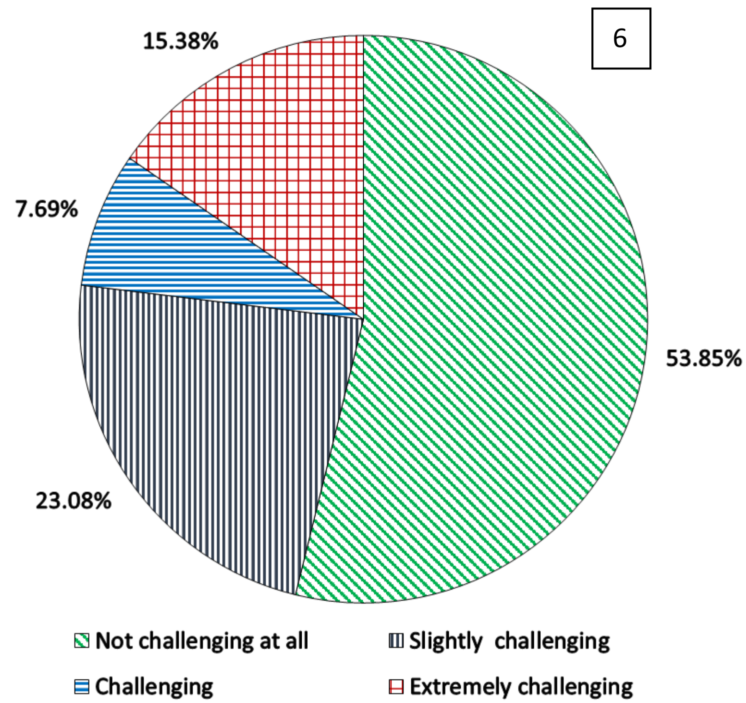





3
4.17%
37.50%
58.33%
Very informative
Informative
Not very informative


4
4.17%
16.67%
37.50%
41.67%
Extremely motivated
Very motivated
Somewhat motivated
Not motivated





1-Proportion of message read by the farmer, 2- Degree and ease of understandability of the messages by farmers, 3 – Level of informativeness and importance to the farmer, 4 – Degree of motivation to implement message recommendations, 5 – Farmers perception on level of effectiveness of received messages, 6 – Degree to which not being able to call back challenged the farmers

Chapter 5 Effects of *Calliandra* and *Sesbania* supplementation on milk production in dairy cattle on smallholder farms in Meru County, Kenya

5.1 Abstract

There is a growing interest in protein supplementation of dairy cows using leguminous shrubs in Kenya. The study objective was to ascertain the association between diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban* and milk production in dairy cattle on semi-commercial smallholder farms.

This trial involved 235 cows from 80 SDFs randomly allocated to 4 treatment study groups in Kenya; 1) receiving *Calliandra* & *Sesbania* and nutritional advice; 2) receiving reproductive medicines and advice; 3) receiving both group 1 and 2 interventions; and 4) receiving neither intervention. Farm nutritional practices and management data were collected in a questionnaire, and subsequent physical examinations, mastitis tests and milk production of cows on the farm were monitored for 16 months. Descriptive and univariable statistical analyses were conducted, and multivariable mixed model linear regression was used for identification of factors associated ($p < 0.05$) with the natural log transformed daily milk production of cows on a given farm.

The mean milk production cow $^{-1}$ day $^{-1}$ was 6.39 liters (s.d. 3.5) with a median of 6.0 liters. Feeding *Calliandra / Sesbania* to cows was significantly ($p < 0.0005$) associated with at least one-liter increase in milk produced cow $^{-1}$ day $^{-1}$ with every kg fed. Other variables positively associated with ln of daily milk production in the final model included: feeding of Napier grass, amount of silage and dairy meal fed, body condition and appetite of the cow. Other variables negatively associated with ln of daily milk

production in the final model included: amount of maize germ fed, days in milk, sudden feed changes, pregnancy and subclinical mastitis.

In conclusion, our field trial data confirm that *Calliandra* / *Sesbania* through agroforestry can be used to improve milk production in semi-commercial SDFs in Kenya. Agroforestry land use systems can be adopted as a way for dairy farmers to cope with feed shortages and low crude protein in farm-available feeds for their cows.

Key words: Kenya; agroforestry; smallholder; *Calliandra; Sesbania*; milk production

5.2 Introduction

The average daily milk production per cow in most tropical dairy enterprises in developing countries such as Kenya is estimated to be nearly 70% lower than that of cows in developed countries (Muraya et al., 2018). While genetics explain some of the difference, management and environmental factors largely affect the milk production (Blake, 2003). Moreover, there is a high correlation between lactation length and yield with plane of nutrition (Lanyasunya et al., 2005).

In Kenya, like other east African countries, inadequate nutrition is a major constraint affecting the production and reproduction of dairy cattle (Smith & Chase, 2000). The impact of inadequate nutrition is most evident in the dry season, where production decreases as good quality feeds dwindle and become more expensive (Bii, 2017; Njarui et al., 2011). Therefore, purchase of feeds contributes to high costs of production, limiting growth and profitability of SDFs (Kirui et al., 2010). The impact of feed shortage is exacerbated by inadequate knowledge and technology on feed conservation, (Lukuyu et al., 2011).

Since most farmers prefer to provide home-grown feeds to reduce feed costs, use of crop residues is the most common coping strategy (Lukuyu et al., 2011). The main crop residue used as the main feed at the peak of the dry seasons for more than 80% of SDFs is dry maize stover. This feed was of low protein and energy level. Dry maize stover is estimated to have an average crude protein (CP) of 2.5% and neutral detergent fiber (NDF) of 70% (Njarui et al., 2011).

Due to increasing human population and climate change, there has been a decrease in land available for dairy production (Muriuki, 2003). Therefore, there is need to devise more sustainable land use systems to support growth in smallholder dairy production systems (Afande & Wachira, 2015). Agroforestry is a land management system where trees and/or shrubs are combined with crops and/or livestock in the same piece of land (University of Missouri, 2013). Some of the agroforestry approaches used by farmers include: intercropping the fodder trees or shrubs with other crops, or planting them as a hedge during the rainy season and then harvesting in the dry season (Cuddeford, 1999). Fodder trees can therefore play an important role as a feed source to sustain production in livestock and mitigate effects of poor quality feed on milk production especially in dry season (Sibanda & Ndlovu, 1992). In Mexico, an increase in milk production of up to 80% was reported when cows had high-protein legume forage supplementation in their first lactation (Absalón-Medina et al., 2012).

Some of the fodder shrubs promoted in the highlands of the East African region include *Calliandra, Leucaena, Chamecytisus* and *Sesbania* (Franzel et al., 2013). Their main advantage (in agroforestry) is the ability to tolerate harsh climatic conditions, such as drought, while providing fairly reasonable amounts of good quality nutrients (Franzel et al., 2013). On average, one kilogram of *Calliandra* foliage fed to a dairy cow has been reported to increase daily milk production by approximately 0.6 to 0.8 kg after controlling for breed, season and other feeds (Place et al., 2009). Prioritization of integrated farming systems with fodder trees and food crops is considered a key step towards sustainable dairy production in Rwanda (Kamanzi and Mapiye , 2012), and perhaps in densely populated rural areas of Kenya as well where there are severe farmland constraints. However, the research on production benefits from leguminous fodder shrubs is primarily found within large-scale or research farms, and therefore these studies do not demonstrate the shrubs' benefits on semi-commercial SDFs in Kenya.

In this randomized controlled field trial, we monitored a random sample of dairy cows to ascertain the association between daily milk production and diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban* along with in-person nutrition training, in lactating dairy cattle on smallholder farms.

5.3 Materials and methods

5.3.1 Ethical approval

This study was approved by the Research Ethics Board and the Animal Care Committee of UPEI, NDFCS, and FHF, a partner nongovernmental organization. Signed consent of all participants was obtained after the study was fully explained.

5.3.2 Description of study area

This randomized controlled field trial was carried out in Naari sub-location of Meru County, Kenya (0°6'0" N and 37°35'0" E). Meru County is located on the eastern slopes of Mount Kenya and is 270 kilometers north of Nairobi, the capital city of Kenya. The

Naari sub-location is in the high agricultural potential region with an altitude of approximately 2,000m above sea level. The main agricultural activities include dairying, subsistence crop farming, horticulture and lumbering. Farmers grow food crops, such as maize, beans and Irish potatoes, and forages for dairy cows. The study area was purposively selected since this research was part of a larger study involving dairy farmers in the area (Makau et al., 2018; Muraya et al., 2018). A non-governmental organization, FHF, and UPEI had an existing developmental partnership with the NDFCS. This rapport provided a strong foundation for the work and the entry point to the community.

5.3.3 Sample population and data collection

The farmers included in the study were from NDFCS, a dairy group with an active membership of approximately 550 farmers (an active member is defined as one who regularly sold milk to the NDFCS at the time of the study). For this trial, the same farms selected for the calf randomized controlled trial (Chapter 3) were used. The 80 farms were randomly selected if they met the inclusion criteria of: active membership with the NDFCS, zero-grazing, and <4 milking cows.

The 80 farms were blocked based on days in milk (DIM) and randomly allocated to four intervention groups in the randomized controlled field trial. Since changes in milk production due to enhanced feeding are likely to be greater in early lactation, DIM was deemed a very important variable for block randomization. The four study groups included: nutrition intervention only, reproduction intervention only, nutrition & reproduction (combined) interventions, and a comparison group that received neither intervention. Farmers in the nutrition and combined groups were issued with 150 *Calliandra* and 150 *Sesbania* seedlings to plant on their farms prior to the commencement of the monitoring visits. It was expected that the shrubs would be mature enough to start feeding them to cows at the study commencement. Two types of leguminous shrubs were used since there was a difference in altitude among the farms in the study area, and it was unclear which type of shrub would be best on the farms. *Sesbania* is known to be hardier at higher altitudes than *Calliandra* but has slightly lower protein content than *Calliandra* (Devendra, 1992). Farmers receiving nutritional interventions also received monthly advice on how to feed their cattle better with the feeds and resources available on the farm. Farmers receiving reproduction interventions were provided with monthly advice on better reproductive management and free intrauterine antibiotics (if warranted due to an intrauterine infection recorded) and/or free hormonal injections of prostaglandin F2α and/or gonadotropin releasing hormone (if warranted due to an intrauterine infection recorded, ovarian cyst recorded, or heat synchronization desired for breeding purposes due to poor heat detection).

Principal farmers consenting to participate in the study were visited monthly (intervention groups) and bimonthly (comparison group) from May 2016 to October 2017. During these visits, they responded to a questionnaire (Appendices 8.2 & 8.3) covering various management factors on their farms since the previous visit. The questionnaire had sections related to farmer training and demographic information, farm and nutritional management, and cow health and milk productivity. At these farm visits, physical examinations, including body condition score (BCS – using a 1-5 point scale (Klopčič et al., 2011)) and California Mastitis Tests (CMT), were conducted.

Cow comfort was assessed since it can have a substantial impact on milk production. Overall stall comfort was formulated as a composite 'Comfort Score' (with a maximum of 6), which was a function of: 1) Stall Length; 2) Stall Width; 3) Stall Lunge Space; 4) Stall Shade; 5) Stall Softness; and 6) Stall Hygiene. For comfort score components 1-4, parameters based on cow size were utilized (Cook et al., 2005) . For comfort score components 5 and 6, knee tests for impact and wetness were utilized, respectively (McFarland & Graves, 1995). These knee tests have been used to assess floor conditions for cattle elsewhere (Richards, 2017; Kathambi et al., 2018). We included a marginal category to adapt the knee tests to the highly variable stall conditions in Kenya where crop waste and dirt (not sand) are commonly used for floor surfaces. A score of 1, ½ or 0 was given for each of these 6 individual comfort score components for each of the following categorizations: good (equal or surpassed minimum requirement for measurements 1 – 4; clearly passing knee tests for 5 – 6), fair (within 10% of the minimum requirement for measurements 1 – 4; equivocal for 5 – 6) or poor (not within 10% of the minimum requirement for measurement 1 – 4; clearly failing knee tests for 5 – 6).

On commencement of the study, farmers were trained on how to weigh quantities of feed fed to the animals once a week, and how to record in a provided logbook the feed weights and the daily milk production on the following day after the feed weight measurements were taken. All farmers were issued with standard spring weighing scales and used large plastic bags for holding quantities of forages for measurement. Measurements and records of all high protein forages were the focus of the scale use on the farms; weights of other forages were also recorded. The amount of concentrate fed was determined by weighing the filled containers used to measure concentrates when feeding cows on the farms. These entries for each individual cow were averaged at the time of visit to give 1 entry per cow per visit. From anecdotal information obtained during the pilot phase of the study in 2015, the feeding regime for each cow was generally quite consistent, at least at the weekly level. Budget and logistical constraints did not allow for laboratory feed analyses; therefore, questions were asked at each visit to categorize the quality of the feed. For example, the height of the Napier grass fed was recorded, since tall Napier grass is known to have low protein content compared to short Napier grass (Lukuyu et al., 2012).

For farmers who had forgotten to record the milk and feeding details in the logbook, milk production for the visit was assessed based on the previous day's total milk production for the cow. Feed weights were also assessed based on the current portions being fed to the cow on the day prior to the visit. The farmers were asked if the production and feeding on the day prior to the visit were representative of the production and feeding since the last visit. In most cases, 83.3% of the time (1214/1458), the farmers confirmed that production and feeding were representative. Therefore, data collected on the date of the visit were assumed to be representative of the monthly management and production. For the 16.7% of visits when there were discrepancies, average measurements between available logbook recordings and current measurements were used to minimize reporting bias because owners have been known to report practices according to what the research team wanted to hear (Richards, 2017).

5.3.4 Data management and analysis

Field data were entered into MS Excel 2010 (Microsoft, Sacramento, California, USA). Statistical analyses were done using Stata13.0 software (StataCorp LLC, College Station, Texas, USA). There was a hierarchical nature to the data, with visits clustered within cows, and cows clustered within farms.

Descriptive statistics included means, medians, distributions, and proportions, where applicable. Data collected were analyzed using both univariable and multivariable linear regression analysis, with daily milk production in liters as the outcome of interest. A histogram of the outcome in its original scale had a positive skew of 1.3. Shapiro-Wilk test, used for normality testing, of daily milk production was significant ($p < 0.05$) and therefore suitable transformations for the daily milk production outcome were explored. To correct for this skewed distribution, the outcome was transformed to the natural log scale for purposes of fitting a linear model. For ease of interpretation of effects of different predictors, coefficients were exponentiated to back-transform them to the original scale.

The primary study objective was to determine if the nutrition intervention contributed to higher daily milk production on those farms receiving the intervention. Two of the four group allocations of 20 farms received the nutrition intervention of advice and *Calliandra* and *Sesbania* shrubs, the nutrition and combined groups. However, the combined group also received reproductive intervention which could also improve daily milk production if cows calved out more quickly than cows on farms in non-reproduction intervention groups. Therefore, combining the two nutrition intervention groups and two non-nutrition intervention groups together in the statistical analyses was not desired (as done in Chapter 3). As a result, significant differences in natural log of daily milk production between the four intervention groups were assessed using Bonferroni-adjusted one-way ANOVA. These analyses would assume that the random allocation to groups balanced out the other factors that may affect daily milk production between groups. At the start of the study, other known factors that may affect daily milk production (e.g. weight, height, age, body condition score, pregnancy status and parity) were compared by group using ANOVA or Fisher's exact analyses to confirm that groups were not different for these variables. Nonsignificant p-values were confirmatory that the random allocation was successful at balancing these factors among groups.

Performance of the shrubs was largely dependent on the farmers' management practices (weeding, watering, manure use, etc.) and prevailing weather conditions (natural availability of water, sunshine, and temperature). Therefore, farmers in the two nutrition intervention groups did not always feed the recommended portions of the foliage all the time, either due to lack of foliage, poor harvesting technique or lack of compliance. For this reason, descriptive analyses were group-based while subsequent data analysis was based on the actual feeding practices of the farmers as opposed to the different study groups.

In some cases where DIM information was missing (6% of 1458), the farmers had bought cows into the farm and they had not obtained the reproductive history of the cows from the seller. Therefore, DIM data was presumed to be missing completely at random (MCAR) and imputation would be beneficial for modeling purposes. For these missing

DIM data, the overall mean DIM was inserted as an imputation to avoid loss of observations in the models (Heijden et al., 2006).

A univariable mixed linear regression model was fitted for each of the variables to ascertain associations with natural logarithm of daily milk production ($p \leq 0.4$). Factors significant at $p \leq 0.4$ and other suspected confounders were considered for a linear mixed multivariable model-building process. Tests for correlation (Pearson correlation coefficient) among all parameters meeting the regression modeling cut-off ($p \leq 0.4$) were done to aid decision-making on degree of correlation between variables to be included in the model-building.

Multivariable mixed linear regression was subsequently performed with natural logarithm of daily milk production in liters as the outcome. Two models were fitted to account for the two different levels of clustering through the inclusion of random effects. Model 1 controlled for clustering at the visit level, while model 2 controlled for clustering at the cow level. Model 1 was fitted with an autoregressive correlation (ar) structure assuming that the correlation between 2 contiguous visits would be exponentially greater than 2 non-contiguous visits (Kincaid, 2005; Dohoo et al., 2009). The ar1 correlation structure produced the same AIC as ar2 (2044), thus ar1 was used for the final model. Model 2 (AIC 1912) was fitted with an exchangeable correlation structure since it was assumed that the correlation between any two cows within a farm was the same (Kincaid, 2005; Dohoo et al., 2009).

The p-value for variables to remain in both final models was set at 0.05, and interactions between significant model fixed effects were explored. Wald's test was used to test overall significance of categorical parameters with more than 2 categories. Assessment of linearity between daily milk production and continuous variables was done using lowess plots for visualization. Variables with nonlinear relationships with the outcome were fitted as curvilinear terms in the model, where applicable.

Model-building was done through the manual backward stepwise elimination technique, and p-values were used to determine fixed effects to keep in the model. Testing for confounding of model variables by variables not in the final model was done by comparing changes in coefficient estimates (>20%) with and without the suspected confounders. Model evaluation was done to confirm that normality and homoscedasticity assumptions on both random and fixed effects were met. Identification of extreme and influential observations was done by sorting and graphing the standardized residuals and comparing changes in coefficient estimates and their significance when modeling with and without influential observations. Predictions of daily milk production were performed on a back-transformed scale of milk produced in liters day $^{-1}$.

5.4 Results

In this trial, a total of 607 visits were made to 80 farms on which a total of 235 cows were included in the study, with a portion of these cows milking at any given visit, generating 1458 observations during the study period (16 months). Observations when cows were dry were excluded from the analysis. The mean milk production cow $^{-1}$ day $^{-1}$ was 6.4 liters (s.d. 3.5) with a median of 6.0 liters and a range of 0.25 – 27.5 liters. Most of the cows kept on the trial farms were predominantly exotic (i.e. Friesian, Ayrshire, Jersey and Guernsey) crosses. In the comparison group, 95.2% (60/63) were predominantly exotic, producing an average of 5.9 liters cow $^{-1}$ day $^{-1}$. In the nutrition group 98.3% (61/62) were predominantly exotic, with mean milk production of 6.5 liters of milk cow $^{-1}$ day $^{-1}$. The combined and reproduction groups had 98.2% (53/54) and 92.8% (52/56) predominantly exotic cows producing 6.4 liters cow $^{-1}$ day $^{-1}$, and 5.6 liters cow $^{-1}$ day $^{-1}$ respectively. There was no effect of breed on daily milk production ($p > 0.05$). The natural log transformed daily milk production had a mean of 1.7 (s.d. 0.6) and a median of 1.8.

For the primary study objective, to determine if the nutrition intervention contributed to higher daily milk production on those farms receiving the intervention, there were no significant ($p > 0.05$) differences in natural logarithm of daily milk production between the four intervention groups using the Bonferroni-adjusted one-way ANOVA. Through random allocation, potential confounders were controlled for, as depicted in Table 5.1. Therefore, the results from the second set of statistical analyses were essential for determining the impact of the use of the *Calliandra* and *Sesbania* shrubs in the nutritional management of the cows.

5.4.1 Descriptive statistics and univariable analyses between natural log of milk production and various factors

Several variables met the $p \leq 0.4$ cut-off on univariable mixed linear regression analyses for associations with natural logarithm of daily milk production when accounting for clustering of visits within cows. Differences in natural log of daily milk production for these variables among the 4 study groups are shown in Tables 5.2a,5.2b and 5.3, as described.

Concentrate feeding was less commonly practiced in the control group (70.5%), than it was in the intervention groups (Table 5.2a) although not significantly different ($p > 0.05$). Farmers mostly used dairy meal as the concentrate feed, and only seldom used maize germ. Farmers occasionally changed the amounts of concentrate fed to cows on their farms across all groups. These changes were most frequent among farmers in the nutrition group ($p < 0.05$), where feed changes of the amount of concentrate fed to cows were made 18.7% of the time during the study period (Table 5.2a).

Napier grass was fed for most of the study period, and farmers preferred to feed available Napier grass at any height rather than not feed any Napier grass at all. This practice was most observed in the comparison group (85.3% of the time) although this was not significantly ($p > 0.05$) different from the other groups (Table 5.2a). Proportions of cows undergoing sudden changes in feed were similar among the groups. Most of the study period was characterized by dry weather and so more than 2/3 of the visits (> 64%) were in the dry season (Table 5.2a). Milk production cow $^{-1}$ day $^{-1}$ was higher in the dry season than the wet season for the nutrition group (6.6 liters cow $^{-1}$ day $^{-1}$) compared to the other groups ($p = 0.013$).

For most of the visits, animals in all groups were healthy and physiological parameters were within normal range; cows had normal appetite more than 98% of the time across all groups. However, skin parasites (ticks) were a problem in the animals in these farms for most of the study period. There were significant differences in proportions of examined animals affected by parasites during the visits, with more infestation observed in the reproduction group than the other groups (Table 5.2b). Subclinical mastitis occurrence was most common in the nutrition group (21.9%) and lowest in the reproduction group (11.2%) (Table 5.2b) ($p = 0.043$). Pregnancy risks were relatively low and similar across all groups ($p > 0.05$).

The mean amount of dairy meal fed was highest in the combined intervention group of farmers who fed, on average, 1.8 kg cow $^{-1}$ day $^{-1}$. Maize germ was only fed in much smaller quantities in the control and combined groups (Table 5.3). These differences between the groups were not significantly different $p > 0.05$. Farmers in the 2 intervention groups were also providing significantly more mineral/vitamin supplements than the comparison and reproduction groups (Table 5.3).

Of the two intervention groups (nutrition and combined), the nutrition group fed 0.1 kg more *Calliandra* and *Sesbania* than the combined interventions group (Table 5.3), with both groups feeding significantly more than the other two groups. Farmers also used other kinds of fodder (bean pods, vegetables, kitchen by-products, wheat straw, etc.) as a coping strategy to supplement diets of cows when there were feed shortages. The level of this stop-gap feeding practice was significantly higher in the comparison group (0.6 kg cow $^{-1}$ day $^{-1}$) than the other 3 groups (Table 5.3).

Use of maize silage was also common among some farmers to support milk production. The reproduction group fed the most maize silage at 3.3 kg cow $^{-1}$ day $^{-1}$, while the combined, nutrition, and comparison groups fed less than 60% of this amount (Table 5.3), although differences were not statistically significant.

The mean BCS of cows was quite similar among groups (Table 5.3). The mean DIM for cows in the nutrition and combined groups was 299.3 (s.d. 10.8) days and 249.4 (s.d.10.5) days, respectively, which were not significantly different from the other groups. Pen comfort score was better in the reproduction (3.5/6) and nutrition (3/6) groups compared to the other groups; differences in milk production among these groups were not significant (Table 5.3).

5.4.2 Multivariable analysis between natural log daily milk production (liters) and various factors

The multivariable mixed linear regression model with the natural log of daily milk production as the outcome variable was based on 1458 total observations from 607 visits to 80 farms; with 235 cows for an average of 6.2 visits per cow *(maximum 16 visits/cow* and an average of 1.6 cows per farm per visit *(maximum 3 cows/farm/visit)*.

In the evaluation of correlation between eligible model variables, there were various predictors with correlation of more than 0.4 but none of the correlated variables remained significant in the final multivariable model.

Model 1 ***(random effect of visits clustered within cows)***: ***Ln of milk = Constant + Amount of dairy meal fed (kg) + Amount of maize silage (kg) + Amount of Calliandra/Sesbania fed (kg) – Amount of Calliandra/Sesbania fed squared (kg) – Amount of maize germ fed (kg) + BCS – BCS squared – DIM + DIM squared + Normal appetite – Pregnant status – Subclinical mastitis – Sudden feed changes***

In the final multivariable linear mixed model controlling for clustering of visits within cows, normal appetite of the animal, BCS, dairy meal, *Calliandra / Sesbania*, and maize silage fed to cows were significantly positively associated with amount of milk produced on the natural log scale. Factors negatively associated with natural log of daily milk production were the amount of maize germ fed, DIM, pregnancy status of the animal, whether the animals had subclinical mastitis and sudden changes in their feeding. Amount of *Calliandra / Sesbania* fed (Figure 5.1), DIM (Figure 5.2), and BCS (Figure 5.3) were all curvilinearly associated with natural log of daily milk production. Feeding about 2 kg (wet weight) of *Calliandra / Sesbania* appeared to have the optimum effect of increasing milk production (Figure 5.1). However, on occasion, a few farmers with lower milk production were able to feed ≥ 2.5 kg of foliage to their cows per day, affecting the shape of the graph. Milk production was estimated to peak within the first 100 DIM, as expected, before consistently decreasing for the rest of the lactation period, with a small number of cows in late lactation (500-900 DIM) with slightly increased milk production on farms with more abundant higher quality feed being fed to the cows. Optimum milk production was observed when BCS was 3.5 (Figure 5.3). However, on rare occasions, cows had BCS more than 3.5, but they were not accompanied with better milk production (Figure 5.3) because their DIM was high (>275 days).

When all factors were held constant and accounting for clustering of visits within cows, a kg increase in the amount of dairy meal (between 0-7kg) fed was estimated to result in a 3.9% increase ($p < 0.0005$) in mean amount of milk produced day $^{-1}$ (Table 5.4a). Mean milk production for cows increased by 0.8% cow $^{-1}$ day $^{-1}$ with every kg increase in maize silage fed (between 0-30 kg). However, feeding maize germ to cows significantly resulted in reduced mean milk production day $^{-1}$ (i.e. with every kg increase of maize germ there was a 27.1% decrease in milk production cow $^{-1}$ day $^{-1}$ (Table 5.4a). BCS, DIM and the amount of *Calliandra / Sesbania* foliage fed per day had curvilinear relationships with ln milk day $^{-1}$, as shown in Figures 5.1-5.3, with ln milk day $^{-1}$ increasing and then decreasing as each of these increased.

When abrupt changes were made to the cow's diet, the mean milk production day $^{-1}$ was estimated to decrease by 9.9%. When cows had a normal appetite, mean daily milk production was two times higher ($p < 0.0005$) compared to when appetite was poor. When a cow was pregnant or with sub-clinical mastitis, mean milk production day $^{-1}$ for the cow at that time was reduced by 23.4% and 6.0%, respectively (Table 5a). The estimated within-group correlation for observations in this model was 0.38.

Model 2 ***(random effect of cows clustered within farms)***: ***Ln of milk = Constant + Visit number + Amount of dairy meal fed + Amount of Calliandra/Sesbania fed – Amount of maize germ fed + Amount of maize silage + Feeding Napier grass + BCS – BCS squared – DIM + DIM squared + Normal appetite – Pregnant status – Sudden feed changes***

In the final multivariable linear mixed model controlling for clustering of cows within farms, the natural log of milk production of a cow day $^{-1}$ was observed to be higher by 0.9% in every subsequent visit after the first visit (Table 5.4b). When feeding cows on *Calliandra / Sesbania*, 1 kg increase of *Calliandra / Sesbania* foliage was estimated to result in a 9.4% increase in mean milk production cow $^{-1}$ day $^{-1}$. The quadratic form of *Calliandra / Sesbania* was not significant and so was not used in this final model.

One kg increase in the amount of dairy meal (between 0-7kg) was estimated to result in 4.7% increase in mean milk produced cow $^{-1}$ day $^{-1}$. There was a 0.8% increase in mean milk production cow $^{-1}$ day $^{-1}$ when farmers increased amount of maize silage fed (between 0-30kg) to their cows by 1 kg. However, every kg of maize germ fed to cows was associated with drop in mean daily milk production by 18.9% (Table 5.4b).

Use of Napier grass to feed cows was estimated to significantly increase mean milk production cow $^{-1}$ day $^{-1}$ by 7.6% compared to when no Napier grass was fed to cows (Table 5.4b).

Sudden feed changes to the cows' diets negatively affected milk production by 10.0% cow $^{-1}$ day $^{-1}$ compared to when changes were not abrupt (Table 5.4b). Every unit increase in BCS was estimated to result in a 2-liter increase in mean milk production day $^{-1}$, although this association was not linear (similar to Figure 5.3) showing that this association plateaued for cows with BCS above 2.5. When cows had a normal appetite, mean daily milk production was 37.7% higher compared to when appetite was poor. When pregnant, the mean milk production cow $^{-1}$ day $^{-1}$ for these animals reduced by 25.8% (Table 5.3a). In this model, the estimated within-group correlation for the observations was 0.464.

For both models, the model assumptions on normality and homoscedasticity were met on the farm, cow and visit levels. Scatter plots of fitted values and standardized residuals also did not depict distinct patterns in the distribution of standardized residuals at all levels of the model. About 17% (model 1: 242/1458 and model 2: 245/1458) of observations had standardized residuals greater than 2 standard deviations. However, after evaluation, these observations were found not to be true outliers. The standardized residuals had a good fit on the normality plot. Removal of these observations had no effect on significance and coefficients of the predictors with one exception; there was an 8% decrease in the effect of subclinical mastitis on natural log of milk without affecting its significance in model 1, and a 12% decrease in the effect of sudden feed changes on natural log of milk without affecting the variable significance in model 2. These observations were influential but not true outliers; therefore, all observations were retained in both final models.

5.5 Discussion, Conclusion and Recommendations

Our field trial data confirm that feeding *Calliandra* / *Sesbania* along with nutritional advice can be used to improve daily milk production on semi-commercial SDFs in Meru county, Kenya (Table 5.4a & 5.4b). Agroforestry land use systems can be adopted as a way for dairy farmers to cope with feed shortages and low crude protein in farm-available feeds for their cows. Daily milk production on the study SDFs improved even when no direct nutritional interventions were used on the farms (i.e. the farmers themselves were the ones that grew the shrubs, harvested them when ready, and fed them to the cows).

These leguminous shrubs are high in protein, and thus, supplement the CP necessary for good milk production in dairy cows feeding on poor quality feed (Paterson et al., 1999; Cook et al., 2005; Franzel et al., 2013). This trial result was similar to findings observed elsewhere (Richards et al., 2016) in SDFs in Kenya where milk production was observed to increase by 0.4kg day $^{-1}$ when *Calliandra / Sesbania* was fed to a cow.

The negative effect of feeding maize germ on daily milk production was unexpected (Table 5.4a & 5.4b). Very few farmers were using maize germ as a concentrate supplement, leading to very small amounts being fed, on average (Table 5.3). Some farmers who used maize germ chose to formulate their homemade concentrate mix by combining some maize germ with dairy meal, bran or other available grains. This mixture was then used to feed the dairy cows as the daily feed ration of concentrate supplement. Consequently, farmers feeding maize germ (especially in comparison group) reduced the amounts of high protein supplements in the cow's diet (e.g. dairy meal), resulting in a negative effect of maize germ in the final model. This situation could have resulted from a diluting effect when nutrients were not balanced and proportional due to unavailability or due to inadequate skill by the farmer to formulate feed (Changwony & Kitilit, 2014).

While the shrubs provide an excellent source of crude protein, we know that an adequate balance of energy and proteins are necessary for milk production (Delaby et al., 2010). Irrespective of which level of clustering was controlled in the present study, daily milk production increased when more dairy meal was used to supplement the animals' diets (Table 5.4a & 5.4b). The dairy concentrate findings of this study were in agreement (although lower) to several other studies (Romney et al., 2000; Oetzel, 2015; Richards et al., 2016; Bii, 2017). The small increase in milk production was likely a function of the poor BCS of study cows and small amount of dairy concentrate being fed in the study area (Table 5.3).

In this trial, an increase of mean milk production cow $^{-1}$ day $^{-1}$ was observed with an increase in amount of silage fed (Table 5.4a & 5.4b). Maize silage in this area was mostly made of whole maize plants harvested at the 'milk' stage. Other additives included during silage preparation were wheat bran / molasses / urea, depending on the preference, accessibility and availability of these products to farmers. Similar practices, such as those aimed at improving the available protein (Yitbarek & Tamir, 2014) and metabolizable energy (ME) content (Kordi & Naserian, 2012) and supporting the fermentation process (Meng-zhen & Yi-xin, 2013) in silage, have been documented in countries such as Zambia (Smith, 2010). It was therefore expected that when farmers added a good amount of maize silage to the daily cow ration, this would provide additional CP and energy necessary for better milk production. Well-prepared whole maize silage also has a low NDF proportion, leading to increased digestibility and higher dry matter intake (DMI), which would support an increase in milk production (Rengman et al., 2014).

Feeding Napier grass to cows in this study population was associated with higher daily milk production (Table 5.4b). Irrespective of what height the Napier grass was fed, feeding Napier grass was significantly better (7.6 % increase in mean milk production day $^{-1}$) than not feeding any Napier grass. Napier grass provides some rumen degradable CP and energy (Moran, 2005b) to the cows over and above what was received through other diets fed to the cows, thus improving milk production. These findings were in agreement with another study (Karuga, 2011). The effect of feeding Napier grass was however not significant in model 1 (when accounting for clustering of visits within cows), perhaps because other factors influenced the direct effect of Napier grass fed on milk production at given times of the study. There was no evidence of confounding in the final model, so these other factors could have been practices or factors that were not consistent throughout the study period. Therefore, by having visit as a random effect, some monthly variability in daily milk production attributed to Napier grass was accounted for in the random part of the model and was insignificant in the fixed part of the model.

An increase in BCS was significantly associated with better daily milk production in these cows (Table 5.4a & 5.4b), which was in agreement with other studies (Domecq et al., 1997; Roche et al., 2007; Richards et al., 2016) . Poor body condition is indicative of a current or previous negative energy balance in a cow (Moran, 2005a), which affects milk production, milk composition and reproduction of dairy cows (Vries & Veerkamp, 2000). This imbalance is a common occurrence in SDFs in developing countries during the dry season when readily available feed is often of poor quality (Smith & Chase, 2000; Njarui et al., 2011).

Cows in this study had relatively long inter-calving periods which meant high DIM (Table 5.4a & 5.4b). The relationship between daily milk production and DIM in this study was not linear; daily milk production increased between 1-100 DIM, followed by a consistent decline up to 300 days. There were only a few animals producing milk with DIM greater than 500. The unexpected shape of the graph (Figure 5.2) depicting an increase in daily milk production for very high DIM is specific to those few cows and their cow- and farm-level characteristics. This production curve was similar to other studies that depicted the physiological norm of daily milk production in dairy cows with peak production experienced about 2 months postpartum (Silvestre et al., 2009; Macciotta et al., 2011).

Higher daily milk production was observed when animals had good appetite (Table 5.4a & 5.4b). This finding is similar to other studies where higher DMI was associated with better milk production since such animals would have the necessary CP and ME for higher milk production (Johnson et al., 2003; Smith & Brouk, 2014).

Being pregnant was associated with a reduction in mean daily milk production in this study population (Table 5.4a & 5.4b). Pregnant cows spend more of their energy to support pregnancy and consequently reduce the amount of milk produced (Olori et al., 1997; Bohmanova et al., 2006; Penasa et al., 2016). In Kenya, in some cases, farmers said they even chose to reduce frequency of milking when pregnant cows seemed to lose body condition too much, which would also lead to lower daily milk production. This decision was subjective and was made independently by the farmer.

Subclinical mastitis was significant in model 1 when accounting for clustering of visits within cows but was not significant in model 2 when accounting for clustering of cows within farms. When controlling for cow-related predisposition to mastitis (e.g. genetics and udder conformation) with cow random effects, the effect of mastitis on daily milk production was also reduced in the fixed part of the model. However, controlling for visit allowed for the effects of new cases in cows to be accounted for in the fixed part of the model. Subclinical mastitis was associated with up to a 6% decrease in daily milk production compared to when there was no mastitis. Findings of our study were similar to another study in SDFs in Kenya (Richards et al., 2016). Damage of mammary tissue, due to infection, especially milk secretory epithelia, affects milk yield (Gonçalves et al., 2016) and composition (Batavani et al., 2007).

When farmers abruptly changed diets of dairy cows, daily milk production decreased significantly (Table 5.4a & 5.4b). This reduction was likely as a result of reduced feed intake and overall digestibility as the cows' rumens adapted to the new diet introduced.

Although our study design was aimed at controlling for confounding by various factors through multivariable linear regression analyses, the study period was long (16 months) and so the study population changed with time. New cows were introduced into the farms (purchased) and added to the study, while other cows left the study (open population), and this could have contributed to some selection bias for the make-up of the four groups, impacting whether or not the group variable would be significantly associated with the outcome in the first set of analyses. However, in the second set of analyses conducted irrespective of group identity, the open population would only affect the numbers of cow observations in each group.

There was substantial loss to follow-up in the study, which may also have affected our study results, since some farmers replaced dead cows with new ones, and in some cases, farmers withdrew from the study altogether. However, the withdrawals from the study were not for study-related reasons. The reasons included: death of the cow or changes in farmer priorities, among other family issues. Therefore, it is unlikely that these withdrawals led to biased results.

The allocation of 20 farms to four groups was based on the intended intervention of *Calliandra / Sesbania* foliage being fed to cows in the 2 intervention groups (nutrition and combined), with the hypothesis that the combined group would experience a synergistic positive effect on conception (Muraya, 2019) . Performance of these shrubs was variable and largely dependent on management, prevailing weather conditions and availability of water for the shrubs. Due to the practical challenges associated with growing the shrubs, farmers in the intervention groups did not all feed equal amounts of the shrub foliage all the time, either due to lack of foliage, poor harvesting technique or lack of compliance. For this reason, data analysis was based on the actual feeding practices of the farmers as opposed to the different study groups.

An evaluation of the different homemade concentrate mixes that farmers used on their farms and their nutritional content, would be helpful in quantifying the effect of this farm practice. Investigations on the financial implications of using agroforestry system to feed

Calliandra and *Sesbania* to cows compared to their productivity would also elucidate the sustainability and possible wider adoptability of this intervention by SDFs in Kenya. An assessment of the effects of long-term use of *Calliandra* and *Sesbania* on soil structure and properties would also be beneficial to farmers, since some literature (Desaeger & Rao, 1999) positively associated *Sesbania* shrubs with some species of soil nematodes, which may affect other food crops on the farms in the long-term.

In conclusion, the authors established that C*alliandra* and S*esbania* can be used to improve daily milk production in semi-commercial SDFs in Kenya. Agroforestry land use systems can be adopted as a way for dairy farmers to cope with shortages and poor quality in farm-available feeds for their cows. Concentrate feeding (dairy meal) to dairy cows was shown to improve daily milk production and should be fed optimally. However, improper homemade mixes of different concentrates, such as maize germ, may result in lower daily milk production. Therefore, advice on homemade mixes should be sought from skilled personnel. Although shorter Napier grass is more nutritious than tall mature Napier grass, feeding Napier grass at any height is better than not feeding any at all, and so farmers should continue feeding Napier grass when available. Smooth transition when changing feed for dairy cows would be a better way to ensure consistent daily milk production rather than abrupt changes, hence inventory management and better feed delivery planning is required on these farms. Better BCS and shorter DIM would be more profitable to the farmers since cows would produce more milk, therefore attention is needed to improve feeding and reproduction. Subclinical mastitis affects daily milk production and thus farmers should utilize CMT for early detection and treatment of mastitis cases while employing preventive management practices that reduce occurrences of new cases of mastitis on their farms. Overall, this project had a positive impact on the semi-commercial SDFs in this study area given the improved daily milk production observed over the different farm visits compared to the baseline.

5.6 References

Absalón-Medina, V. A., Nicholson, C. F., Blake, R. W., Fox, D. G., Juárez-Lagunes, F. I., Canudas-Lara, E. G., & Rueda-Maldonado, B. L. (2012). Economic analysis of alternative nutritional management of dual-purpose cow herds in central coastal Veracruz, Mexico. *Tropical Animal Health and Production*, *44*(6), 1143–1150. https://doi.org/10.1007/s11250-011-0050-8

Afande, F. O., & Wachira, I. J. (2015). Constraints to Profitability of Smallholder Dairy Farmers in Nyeri South Sub-County, Kenya. *Developing Country Studies*, *5*(7), 11–43. Retrieved from www.iiste.org

Batavani, R. A., Asri, S., & Naebzadeh, H. (2007). The effect of subclinical mastitis on milk composition in dairy cows. *Iranian Journal of Veterinary Research*, *8*(3), 205–211. Retrieved from http://ijvr.shirazu.ac.ir/article_925_8c286f02d8fb54b4bf530539cc1f950c.pdf

Bii, B. (2017). Dairy farmers face high cost of feeds as drought bites - Daily Nation. Retrieved August 11, 2017, from http://www.nation.co.ke/business/Dairy-farmers-face-high-cost-of-feeds/996-3800550-ckwc4oz/index.html

Blake, R. W. (2003). Dairy cattle response in difficult environments. In *7th World Bruna Conference, Fieragricola* (pp. 125–131). Viena, Italy: 7th World Bruna Conference.

Bohmanova, J., Miglior, F., Kelly, M., Kistemaker, G., & Loker, S. (2006). Effect of pregnancy on milk yi eld of Canadian dairy cattle. Retrieved July 18, 2018, from https://www.cdn.ca/Articles/GEBSEPT2006/Effect_of_Pregnancy_on_Milk_Yield.pdf

Changwony, K., & Kitilit, J. K. (2014). *Dairy Cattle Feed Types , Quantity Fed and Their Effects on Milk Density within Bomet , Bureti and Nyamira Districts* . Nairobi, Kenya. Retrieved from https://www.yumpu.com/en/document/view/27313276/dairy-cattle-feed-types

Cook, B., Pengelly, B., Brown, S., Donnelly, J., Eagles, D., Franco, A., … Schultze-Kraft, R. (2005). Calliandra calothyrsus. Retrieved June 25, 2018, from http://www.tropicalforages.info/key/forages/Media/Html/entities/calliandra_calothyrsus.htm

Cook, N. B., Bennett, T. B., & Nordlund, K. V. (2005). Monitoring Indices of Cow Comfort in Free-Stall-Housed Dairy Herds. *Journal of Dairy Science*, *88*(11), 3876–3885. https://doi.org/10.3168/jds.S0022-0302(05)73073-3

Cuddeford, V. (1999). A Fodder Hedge Provides Feed for Cattle in the Dry Season - Barza Scripts. Retrieved June 5, 2018, from http://scripts.farmradio.fm/radio-resource-packs/package-51-raising-livestock-and-poultry/a-fodder-hedge-provides-feed-for-cattle-in-the-dry-season/

Delaby, L., Husson, F., & Faverdin, P. (2010). Predicting energy × protein interaction on milk yield and milk composition in dairy cows. *Journal of Dairy Science*, *93*(9), 4128–4143. https://doi.org/10.3168/jds.2009-2669

Desaeger, J., & Rao, M. R. (1999). The root-knot nematode problem in sesbania fallows and scope for managing it in western Kenya. *Agroforestry Systems*, *47*, 273–288. Retrieved from http://www.scopus.com/inward/record.url?eid=2-s2.0-0033450930&partnerID=40&md5=7191d57a80fe65b67d9af4196a636cc1

Devendra, C. (1992). Legume trees and other fodder trees as protein sources for livestock. Retrieved September 21, 2018, from http://www.fao.org/docrep/003/T0632E/T0632E07.htm

Dohoo, I. R., Martin, S. W., & Stryhn, H. (2009). *Repeated Measures data*. (S. M. McPike, Ed.), *Veterinary Epidemiologic Research* (2nd ed.). Charlottetown, Prince Edward Island: VER Inc.

Domecq, J. J., Skidmore, A. L., Lloyd, J. W., & Kaneene, J. B. (1997). Relationship Between Body Condition Scores and Milk Yield in a Large Dairy Herd of High Yielding Holstein Cows. *Journal of Dairy Science*, *80*(1), 101–112. https://doi.org/10.3168/jds.S0022-0302(97)75917-4

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J., & Wambugu, C. (2013). Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. *Current Opinion in Environmental Sustainability*, *6*(1), 98–103. https://doi.org/10.1016/j.cosust.2013.11.008

Gonçalves, J. L., Martins, C. M. D. M. R., Barreiro, J. R., Tomazi, T., Gameiro, A. H., Kamphuis, C., … Santos, M. V. (2016). Effect of bovine subclinical mastitis on milk yield and composition. Retrieved July 18, 2018, from http://nmconline.omnibooksonline.com/nmc-annual-meetings

Heijden, G. J. M. G. Van Der, Donders, A. R. T., Stijnen, T., & Moons, K. G. M. (2006). Imputation of missing values is superior to complete case analysis and the missing-indicator method in multivariable diagnostic research : A clinical example. *Journal of Clinical Epidemiology*, *59*, 1102–1109. https://doi.org/10.1016/j.jclinepi.2006.01.015

Johnson, C. R., Lalman, D. L., Brown, M. A., Appeddu, L. A., Buchanan, D. S., & Wettemann, R. P. (2003). Influence of milk production potential on forage dry matter intake by multiparous and primiparous Brangus females. *J. Anim. Sci.*, *81*, 1837–1846.

Kamanzi M and Mapiye C. (2012). Feed inventory and smallholder farmers’ perceived causes of feed shortage for dairy cattle in Gisagara District, Rwanda. *Trop Anim Health Prod*, *44*(7), :1459-68. https://doi.org/doi: 10.1007/s11250-012-0087-3

Karuga, J. (2011, May 10). Napier grass farming method promises higher milk yield. *Business Daily*. Retrieved from https://www.businessdailyafrica.com/magazines/1248928-1159188-ekbw32z/index.html

Kathambi, E. K., VanLeeuwen, J. A., Gitau, G. K., & Mckenna, S. L. (2018). A cross-sectional study of the welfare of calves raised in smallholder dairy farms in Meru, Kenya, 2017. *Veterinary World*, *11*(8), 1094–1101. https://doi.org/10.14202/vetworld.2018.1094-1101

Kincaid, C. (2005). Guidelines for Selecting the Covariance Structure in Mixed Model Analysis. In G. S. Nelson (Ed.), *Statistics and Data Analysis* (pp. 1–8). Philadelphia, Pennsylvania: SAS Institute Inc. Retrieved from http://www2.sas.com/proceedings/sugi30/198-30.pdf

Kirui, O.K.; Okello, J.J. and Nyikal, R. . (2010). Awareness and use of m-banking services in agriculture: The case of smallholder farmers in Kenya. In O. K. Kirui (Ed.), *Paper presented at African Association of Agricultural Economists Confernce* (pp. 1–18). Cape Town, South Africa. https://doi.org/10.4018/978-1-60566-820-8.ch001

Klopčič, M., Hamoen, A., & Bewley, J. (2011). *Body condition scoring of dairy cows*. (M. Klopčič & A. Kuipers, Eds.) (First). Arnhem, Netherlands: University of Ljubljana Biotechnical Faculty Department of Animal Science. Retrieved from https://rodica.bf.uni-lj.si/web/gov/pub/2011_Klopcic_et_al_Body_condition_of_dairy_cows.pdf

Kordi, M., & Naserian, A. A. (2012). Influence of wheat bran as a silage additive on chemical composition , in situ degradability and in vitro gas production of citrus pulp silage. *African Journal of Biotechnology*, *11*(63), 12669–12674. https://doi.org/10.5897/AJB12.767

Lanyasunya, T. P., Musa, H. H., Yang, Z. P., Mekki, D. M., & Mukisira, E. A. (2005). Effects of Poor Nutrition on Reproduction of Dairy Stock on Smallholder Farms in the Tropics. *Pakistan Journal of Nutrition*, *4*(2), 117–122. https://doi.org/10.3923/pjn.2005.117.122

Lukuyu, B., Franzel, S., Ongadi, P. M., & Duncan, A. J. (2011). Livestock feed resources: Current production and management practices in central and northern rift valley provinces of Kenya. *Livestock Research for Rural Development.*, *23*(5), 112.

Lukuyu, B., Gachuiri, C. K., Lukuyu, M. N., Lusweti, C., & Mwendia, S. (2012). *Feeding dairy cattle in East Africa*. (B. Lukuyu & C. Gachuir, Eds.), *Feeding dairy cattle in East Africa* (First). Nairobi, Kenya: East Africa Dairy Devleopment Project. Retrieved from https://cgspace.cgiar.org/bitstream/handle/.../EADDDairyManual.pdf

Lukuyu, B., Kugonza, J., Wabwire, R., & Baltenweck, I. (2011). Characterisation of the livestock production system and potential for enhancing productivity through improved feeding at Namayumba , Wakiso district of Uganda , March 2011 Farming system. In *East African Dairy Development Project (EADD)* (pp. 1–6).

Macciotta, N. P. P., Dimauro, C., Rassu, S. P. G., Steri, R., & Giuseppe, P. (2011). The mathematical description of lactation curves in dairy cattle The mathematical curves in dairy cattle. *Italian Journal of Animal Science*, *10*(4). https://doi.org/10.4081/ijas.2011.e51

Makau, D. N., VanLeeuwen, J. A., Gitau, G. K., Muraya, J., McKenna, S. L., Walton, C., & Wichtel, J. J. (2018). Animal and management factors associated with weight gain in dairy calves and heifers on smallholder dairy farms in Kenya. *Preventive Veterinary Medicine*, *161*, 60–68. https://doi.org/https://doi.org/10.1016/j.prevetmed.2018.10.017

McFarland, D. F., & Graves, R. E. (1995). A case study with dairy cattle: free stalls. Animal behavior and the design of livestock and poultry systems. *Northeast Regional Agricultural Engineering Service*, *84*, 277–295.

Meng-zhen, Q. I. N., & Yi-xin, S. (2013). Effect of Application of a Bacteria Inoculant and Wheat Bran on Fermentation Quality of Peanut Vine Ensiled Alone or with Corn Stover. *Journal of Integrative Agriculture*, *12*(3), 556–560. https://doi.org/10.1016/S2095-3119(13)60257-9

Moran, J. (2005a). Problems with unbalanced diets. In Department of Primary Industries (Ed.), *Tropical Dairy Farming: Feeding Management for Small Dairy Farmers in the Humid Tropics* (pp. 147–158). Melbourne,Australia: CISRO Publishing. Retrieved from http://www.publish.csiro.au/issue/3363.htm

Moran, J. (2005b). Supplements for milking cows. In Department of Primary Industries (Ed.), *Tropical dairy farming : feeding management for small holder dairy farmers in the humid tropics* (pp. 99–112). Melbourne,Australia: CSIRO Publishing.

Muraya, J., VanLeeuwen, J. A., Gitau, G. K., Wichtel, J. J., Makau, D. N., Crane, M. B., … Tsuma, V. T. (2018a). Cross-sectional study of productive and reproductive traits of dairy cattle in smallholder farms in Meru, Kenya. *Livestock Research for Rural Development*, *30*(171). https://doi.org/http://www.lrrd.org/lrrd30/10/jmura30171.html

Muraya, J. (2019). Improving reproductive efficiency in cows to improve livelihoods of smallholder dairy farmers in Kenya. University of Prince Edward Island.

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. FAO Prevention of Food Losses Programme*. Rome, Italy. Retrieved from http://www.fao.org/fileadmin/templates/ags/docs/dairy/P1assessmentkenya.pdf

Njarui, D. M. G., Gatheru, M., Wambua, J. M., Nguluu, S. N., Mwangi, D. M., & Keya, G. A. (2011). Feeding management for dairy cattle in smallholder farming systems of semi-arid tropical Kenya. *Livestock Research for Rural Development*, *23*(5), 111. Retrieved from http://www.lrrd.org/lrrd23/5/njar23111.htm

Oetzel, G. R. (2015). Subacute Ruminal Acidosis in Dairy Herds : Physiology , Pathophysiology , Milk Fat Responses , and Nutritional Management. In University of Wisconsin School of Veterinary Medicine (Ed.), *Preconference Seminar 7A: Dairy Herd Problem Investigation Strategies: Lameness, Cow Comfort, and Ruminal Acidosis* (pp. 89–119). Vancouver, BC, Canada: American Association of Bovine Practitioners. Retrieved from https://www.vetmed.wisc.edu/dms/fapm/fapmtools/2nutr/sara1aabp.pdf

Olori, V., Brotherstone, S., Hill, G. W., & McGuirk, B. J. (1997). Effect of gestation stage on milk yield and composition in Holstein Friesian dairy cattle. *Livestock Production Science*, *52*, 167–176. https://doi.org/10.1016/S0301-6226(97)00126-7

Paterson, R. T., Kiruiro, E., & Arimi, H. K. (1999). Calliandra calothyrsus as a supplement for milk production in the Kenya highlands. *Tropical Animal Health and Production*, *31*(2), 115–126. https://doi.org/10.1023/A:1005119808090

Penasa, M., Marchi, M. De, & Cassandro, M. (2016). Short communication : Effects of pregnancy on milk yield , composition traits , and coagulation properties of Holstein cows. *Journal of Dairy Science*, *99*, 4864–4869. https://doi.org/10.3168/jds.2015-10168

Place, F., Roothaert, R., Maina, L., Franzel, S., Sinja, J., & Wanjiku, J. (2009). *The Impact of Fodder Shrubs on Milk Production and Income Among Smallholder Dairy Farmers in East Africa and the Role of Research Undertaken by the World Agroforestry Centre*. (P. Fredenburg, Ed.), *Ocassional Paper* (Ist, Vol. 12). Nairobi, Kenya: World Agroforestry Centre. Retrieved from http://impact.cgiar.org/pdf/217.pdf

Rengman S. Johansson B. & Murphy M. (2014). Dietary nutrient density and effects on intake and production. In P. Udén (Ed.), *5th Nordic Feed Science Conference* (Vol. 290, pp. 83–87). Upsala: Organising committee of the 5th Nordic Feed Science Conference Department of Animal Nutrition and Management Swedish University of Agricultural Sciences (SLU) SE- 753 23 Uppsala, Sweden. Retrieved from http://www.slu.se/Documents/externwebben/vh-fak/husdjurens-utfodring-och-vard/Publikationer/NFSC 2014 Proceedings2014-06-04.pdf

Richards, S. M. (2017). *Productivity and welfare of cows on smallholder dairy farms in Kenya*. University of Prince Edward Island. Retrieved from https://www.islandscholar.ca/islandora/object/ir%3A21369/datastream/PDF/download

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G. K., Wichtel, J., Kamunde, C., & Uehlinger, F. (2016). Randomized controlled trial on impacts of dairy meal feeding interventions on early lactation milk production in smallholder dairy farms of Central Kenya. *Preventive Veterinary Medicine*, *3954*, 1–8. https://doi.org/doi:10.1016/j.prevetmed.2016.01.006

Roche, J. R., Lee, J. M., Macdonald, K. A., & Berry, D. P. (2007). Relationships Among Body Condition Score , Body Weight , and Milk Production Variables in Pasture-Based Dairy Cows. *Journal of Dairy Science*, *90*(8), 3802–3815. https://doi.org/10.3168/jds.2006-740

Romney, D., Kaitho, R., Biwott, J., Wambugu, M., Chege, L., Omore, A., … Thorpe, W. (2000). Technology development and field testing: access to credit to allow smallholder dairy farmers in Central Kenya to reallocate concentrates during lactation,. In *3rd All Africa Conference on Animal Agriculture.* (pp. 1–7). Alexandria, Egypt: Egyptian Society of Animal Production. Retrieved from https://cgspace.cgiar.org/handle/10568/1588

Sibanda, H. M., & Ndlovu, N. R. (1992). The value of indigenous browseable tree species in livestock production in semi-arid communal grazing areas of Zimbabwe. In J. E. C. Stares, A. N. Said, & J. A. Kategile (Eds.), *Proceedings of the joint feed resources* *network workshop held in Gaborone, Botswana* (p. 430). Addis Ababa: African Feeds Research Network. ILCA (International Livestock Centre for Africa). Retrieved from http://www.fao.org/wairdocs/ilri/x5519b/x5519b0c.htm

Silvestre, A. M., Martins, A. M., Santos, V. A., Ginja, M. M., & Colaço, J. A. (2009). Lactation curves for milk , fat and protein in dairy cows : A full approach. *Livestock Science*, *122*(2–3), 308–313. https://doi.org/10.1016/j.livsci.2008.09.017

Smith, J. F., & Brouk, M. J. (2014). Factors affecting dry matter intake by lactating dairy cows. *Kansas Agricultural Experiment Station Research Reports*, *0*(2), 52–58. https://doi.org/10.4148/2378-5977.319

Smith, R. D., & Chase, L. E. (2000). Nutrition and Reproduction. Retrieved October 14, 2016, from https://www.wvu.edu/~agexten/forglvst/Dairy/dirm14.pdf

Smith, T. (2010). Some Tools To Combat Dry Season Nutritional Stress in Ruminants Under African Conditions. In *Development and field evaluation of animal feed supplementation packages* (pp. 145–152). Austria: Internatonal Atomic Energy Agency. Retrieved from https://www.researchgate.net/publication/237254680

University of Missouri Center. (2013). Chapter 1 : Defining Agroforestry. In *Training Manual for Applied Agroforestry Practices* (2013th ed., pp. 9–15). University of Missouri Center for Agroforestry. Retrieved from http://www.centerforagroforestry.org/academy/2015/chp1-DefiningAgroforestry_2015.pdf

Vries, M. J. De, & Veerkamp, R. F. (2000). Energy Balance of Dairy Cattle in Relation to Milk Production Variables and Fertility. *Journal of Dairy Science*, *83*(1), 62–69. https://doi.org/10.3168/jds.S0022-0302(00)74856-9

Yitbarek, M. B., & Tamir, B. (2014). Silage Additives : Review. *Open Journal of Applied Sciences*, (April), 258–274. https://doi.org/10.4236/ojapps.2014.4502

Table 5.1: Distribution of animal parameters among different groups prior to the intervention for 80 smallholder dairy farms near Meru, Kenya in 2016

Parameter	Comparison group (s.d.)	Nutrition group (s.d.)	Combined group (s.d.)	Reproduction group (s.d.)	ANOVA p value
Average body weight (kg)	387.8 (77.3)	383.7 (71.6)	391.9 (60.1)	395.6 (59.5)	0.922
Average body condition score	2.2 (0.5)	2.1 (0.5)	2.2 (0.5)	2.2 (0.6)	0.625
Average height (cm)	124.3 (19.7)	115.9 (7.0)	119.0 (7.3)	118.6 (6.7)	0.165
Average age (years)	5.8 (2.0)	5.5 (2.0)	5.5 (2.2)	5.8 (2.5)	0.949
Average parity	2.5 (1.3)	2.5 (1.6)	2.7 (1.5)	2.7 (1.5)	0.932
Pregnant (%)	38.7% (12/31)	40.6% (13/32)	25.0% (8/32)	38.9% (14/36)	0.848$^{\alpha}$

$^{\alpha}$ *p-value from Fisher's exact test*

Table 5.2a: Descriptive statistics for farm-visit level categorical variables for unconditional mixed linear regressions for variables with P ≤ 0.40 associations with natural log of daily milk production from 607 farm visits to 80 smallholder dairy farms near Meru, Kenya in 2016-2017

Variable and Categories	Percentage in comparison group (n=95 farm visits)	Arithmetic mean daily milk production (liters)	Percentage in nutrition group (n=219 farm visits)	Arithmetic mean daily milk production (liters)	Percentage in combined group (n=199 farm visits)	Arithmetic mean daily milk production (liters)	Percentage in reproduction group (n=94 farm visits)	Arithmetic mean daily milk production (liters)	P-value for difference in milk production
Concentrate supplementation									0.184
Yes	70.5% (67)	6.0	76.7% (168)	6.7	77.4% (154)	6.5	71.3% (67)	5.8	
No	29.5% (28)	5.8	23.3% (51)	5.9	22.6% (45)	5.9	28.7% (27)	4.9	
Changes in concentrate amounts									0.091
Yes	6.4% (6)	8.6	18.7% (41)	7.0	16.1% (32)	6.1	11.7% (11)	6.2	
No	93.6% (89)	5.7	81.3% (178)	6.4	83.9% (167)	6.4	88.3% (83)	5.4	
Napier grass fed									0.002
Yes	85.3% (81)	6.2	82.2% (180)	6.4	82.4% (164)	6.5	70.2% (66)	5.8	
No	14.7% (14)	4.5	17.8% (39)	6.8	17.6% (35)	5.9	29.8% (28)	5.1	
Sudden change in feed									0.002
Yes	13.8% (13)	5.9	18.7% (41)	6.4	19.1% (38)	6.4	13.8% (13)	4.7	
No	86.2% (82)	5.9	81.3% (178)	6.5	80.9% (161)	6.4	86.2% (81)	5.7	
Season									0.033
Dry	78.9% (75)	5.8	74.9% (164)	6.6	75.4% (150)	6.4	62.8% (59)	5.7	
Wet	21.1% (20)	6.6	25.1% (55)	6.1	24.6% (49)	6.5	37.2% (35)	5.4	

Table 5.2b: Descriptive statistics for cow-observation level categorical variables for unconditional mixed linear regressions for variables with P ≤ 0.40 associations with natural log of daily milk production for 1458 cow observations in 235 cows on 80 smallholder dairy farms near Meru, Kenya in 2016-2017.

Variable Categories	Percentage in comparison group (n=227 cow observations)	Arithmetic mean daily milk production (liters)	Percentage in nutrition group (n=434 cow observations)	Arithmetic mean daily milk production (liters)	Percentage in combined group (n=432 cow observations)	Arithmetic mean daily milk production (liters)	Percentage in reproduction group (n=365 cow observations)	Arithmetic mean daily milk production (liters)	P-value for difference in milk production
Normal appetite									0.069
Yes	98.7% (224)	6.0	99.5% (432)	6.5	99.0% (428)	6.4	99.5% (363)	5.6	
No	1.3% (3)	5.5	0.5% (2)	0.0	1.0% (4)	1.0	0.5% (2)	2.0	
Skin parasites present									0.128
Yes	90.7% (206)	5.4	84.8% (368)	6.4	84.0% (363)	6.4	96.7% (353)	5.6	
No	9.3% (21)	9.3	15.2% (66)	7.1	16.0% (69)	5.6	3.3 % (12)	5.5	
Subclinical mastitis									0.131
Yes	20.3% (46)	6.1	21.9% (95)	5.6	14.8% (64)	8.0	11.2% (41)	4.1	
No	79.7% (181)	5.9	78.1 % (339)	6.8	85.2% (368)	6.1	88.8% (324)	5.7	
Pregnant									<0.0005
Yes	26.0% (59)	5.2	27.6% (120)	5.2	24.1% (104)	5.6	26.3% (96)	4.9	
No	74.0% (168)	6.2	72.4% (314)	7.0	75.9% (328)	6.6	73.7% (269)	5.8	

Table 5.3: Descriptive statistics for continuous variables for unconditional mixed linear regressions for variables with P ≤ 0.40 associations with natural log of daily milk production 1458 cow observations from 607 farm visits for 235 cows on 80 smallholder dairy farms near Meru, Kenya in 2016-2017

Variable Names	Mean (s.d.) in comparison group (n=227 cow observations)	Mean (s.d.) in nutrition group (n=434 cow observations)	Mean (s.d.) in combined group (n=432 cow observations)	Mean (s.d.) in reproduction group (n=365 cow observations)	P-value for difference in milk production
Amount of daily dairy meal (kg)	1.4 (0.1)	1.6 (0.1)	1.8 (0.1)	1.6 (0.1)	<0.0005
Amount of daily maize germ (kg)	0.04 (0.01)	0.0 (0.0)	0.03 (0.01)	0.01 (0.01)	0.010
Amount of daily mineral/vitamin (g)	38.6 (1.2)	39.8 (0.7)	40.6 (0.6)	30.0 (1.6)	<0.0005
Amount of daily *Calliandra/Sesbania* (kg)	0.00 (0.0)	0.2 (0.02)	0.1 (0.02)	0.01 (0.003)	0.002
Amount of other supplementary feed (kg)	0.6 (0.5)	0.4 (0.4)	0.3 (0.3)	0.1 (0.03)	0.071
Amount of daily maize silage (kg)	1.9 (0.4)	1.6 (0.3)	1.3 (0.2)	3.3 (0.4)	<0.0005
Body condition score	2.2 (0.03)	2.2 (0.02)	2.3 (0.02)	2.3 (0.03)	<0.007
Days in milk	313.0 (14.6)	299.3 (9.7)	248.3 (8.7)	291.6 (12.0)	<0.0005
Pen comfort score*	2.7 (0.5)	3.0 (0.4)	2.9 (0.3)	3.5 (0.1)	0.102

** Farm-visit level variable based on farm visit numbers by group: comparison group n= 95 farm visits, nutrition group n= 219 farm visits, combined group n=199 farm visits and reproduction group n=94 farm visits.*

Table 5.4a: Final generalized linear mixed linear regression model for natural log of daily milk production for 1458 cow observations from 607 farm visits of 235 cows on 80 smallholder dairy farms near Meru, Kenya in 2016-2017, adjusting for clustering of visits within cows

Variables and their categories	Exponentiated Coefficient	Coefficient	[95% Conf. Interval]		P- value
Amount of daily *Calliandra/Sesbania* (kg)	1.376[β]	0.319[β]	0.174[β]	0.464[β]	<0.0005[β]
Amount of daily *Calliandra/Sesbania* squared (kg squared)	0.927[β]	-0.076[β]	-0.127[β]	-0.025[β]	0.003[β]
Amount of daily dairy meal (kg)	1.039	0.038	0.018	0.057	<0.0005
Amount of daily maize silage (kg)	1.008	0.008	0.004	0.013	<0.0005
Amount of daily maize germ (kg)	0.729	-0.316	-0.480	-0.153	<0.0005
Sudden feed changes					
No	reference	reference			
Yes	0.901	-0.104	-0.172	-0.036	0.003
Body condition score	2.151[β]	0.766[β]	0.426[β]	1.106[β]	<0.0005[β]
Body condition score squared	0.878[β]	-0.130[β]	-0.203[β]	-0.057[β]	0.001[β]
Days in milk	0.998[β]	-0.002[β]	-0.002[β]	-0.001[β]	<0.0005[β]
Days in milk squared	1.000[β]	1.50^{-06}[β]	1.06^{-06}[β]	1.93^{-06}[β]	<0.0005[β]
Normal appetite					
No	reference	reference			
Yes	2.018	0.702	0.433	0.971	< 0.0005
Pregnant					
No	reference	reference			
Yes	0.766	-0.267	-0.323	-0.211	< 0.0005
Subclinical mastitis					
Negative	reference	reference			
Positive	0.940	-0.062	-0.126	0.001	0.055
Constant	1.289	0.254	-0.199	0.706	0.272

[β] Variable is part of a curvilinear relationship, and therefore coefficients cannot be interpreted in isolation but rather in combination with the other relevant coefficients for the curvilinear variable, and these combinations are best reported using a graph (Figure 5.1, 5.2 & 5.3)

Table 5.4b: Final generalized linear mixed linear regression model for natural log of daily milk production for 1458 cow observations from 607 visits of 235 cows on 80 smallholder dairy farms near Meru, Kenya in 2016-2017, adjusting for clustering of cows within farms

Variables and their categories	**Exponentiated Coefficient**	**Coefficient**	**[95% Conf. Interval]**		**P- value**
Amount of daily *Calliandra /Sesbania* (kg)	1.094	0.090	0.012	0.168	0.024
Visit number [α]	1.009 [α]	0.009 [α]	0.003 [α]	0.015 [α]	0.002[α]
Amount of daily dairy meal (kg)	1.047	0.046	0.027	0.065	<0.0005
Amount of daily maize germ (kg)	0.811	-0.210	-0.363	-0.058	0.007
Amount of daily maize silage (kg)	1.008	0.008	0.004	0.012	<0.0005
Napier grass fed					
No Napier grass fed	reference	reference			
Fed at any height	1.076	0.073	0.016	0.130	0.012
Sudden feed changes					
No	reference	reference			
Yes	0.901	-0.104	-0.162	-0.046	<0.0005
Body condition score	2.038 [β]	0.712 [β]	0.378 [β]	1.045 [β]	<0.0005 [β]
Body condition score squared	0.886 [β]	-0.121 [β]	-0.193 [β]	-0.050 [β]	0.001 [β]
Days in milk	0.998 [β]	-0.002 [β]	-0.002 [β]	-0.001 [β]	<0.0005 [β]
Days in milk squared	1.000 [β]	1.59^{-06} [β]	1.15^{-06} [β]	2.02^{-06} [β]	<0.0005 [β]
Normal appetite					
No	reference	reference			
Yes	1.377	0.320	0.097	0.542	0.005
Pregnant					
No	reference	reference			
Yes	0.742	-0.299	-0.353	-0.245	<0.0005
Constant	1.730	0.548	0.120	0.975	0.012

[α] Ordinal variable: time of farm visit modeled as a continuous variable.

[β] Variable is part of a curvilinear relationship, and therefore coefficients cannot be interpreted in isolation but rather in combination with the other relevant coefficients for the curvilinear variable, and these combinations are best reported using a graph (Figure 5.2 & 5.3).

Figure 5.1: Lowess plot indicating a curvilinear relationship between amounts of *Calliandra/Sesbania* fed and natural log of milk production day $^{-1}$ for 1458 observations from 607 visits of 235 cows on 80 smallholder dairy farms near Meru, Kenya in 2016-2017

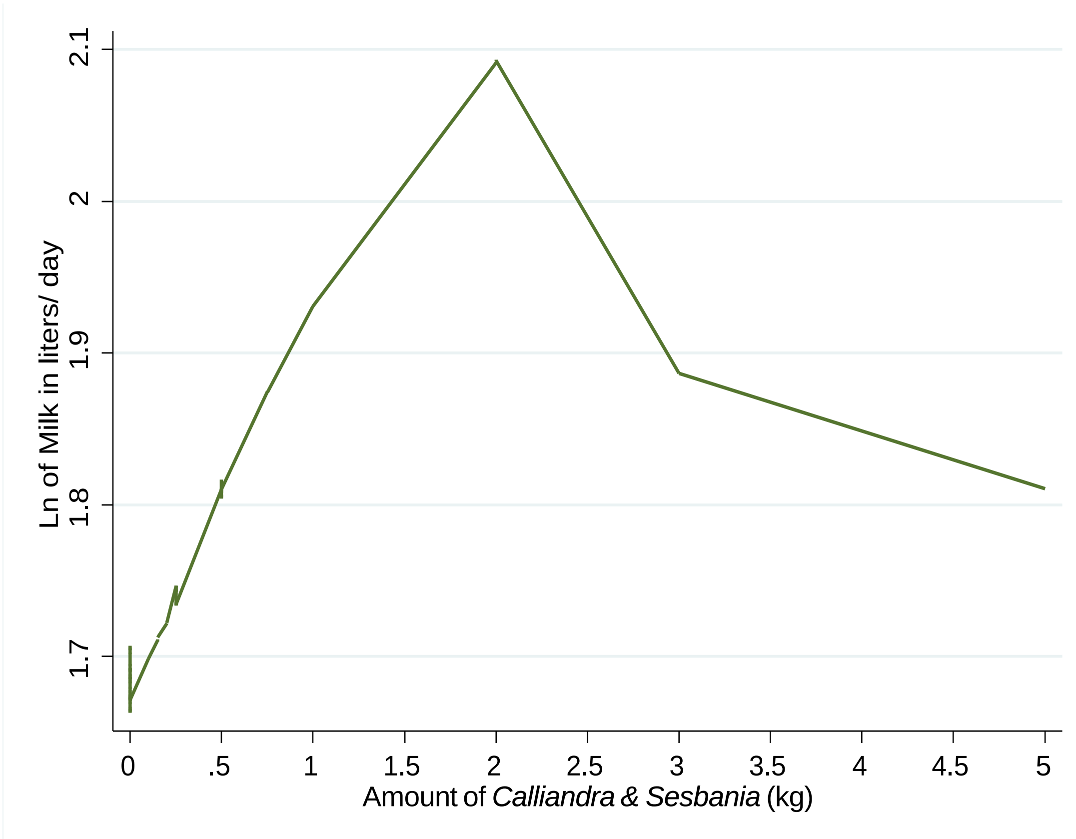


Figure 5.2: Lowess plot indicating a curvilinear relationship between days in milk and natural log of milk production day $^{-1}$ for 1458 observations from 607 visits of 235 cows on 80 smallholder dairy farms near Meru, Kenya in 2016-2017

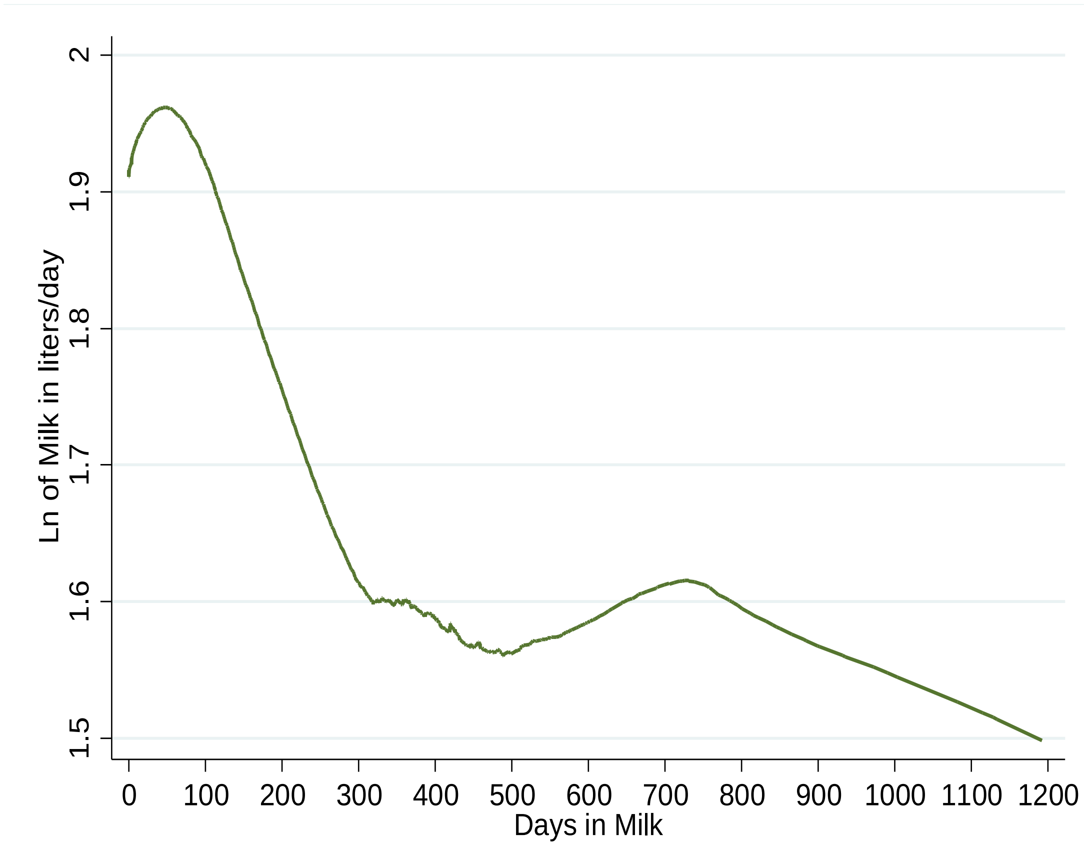
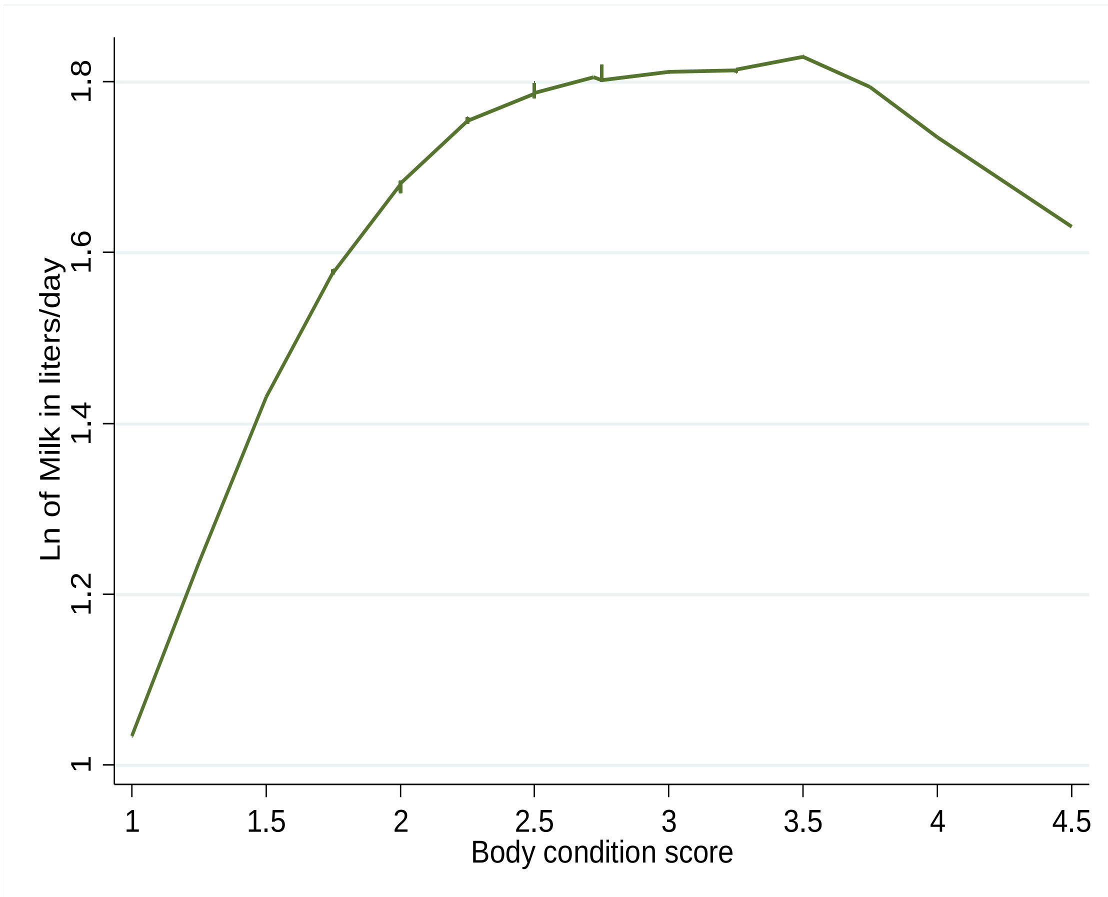


Figure 5.3: Lowess plot indicating a curvilinear relationship between body condition and natural log of milk production day $^{-1}$ for 1458 observations from 607 visits of 235 cows on 80 smallholder dairy farms near Meru, Kenya in 2016-2017



Chapter 6 Impact of supplementing *Calliandra* and *Sesbania* as cattle feed on family livelihoods in smallholder dairy farms

6.1 Abstract

An agroforestry land use system aimed at improving production of smallholder dairy farms (SDFs) using *Calliandra / Sesbania* shrubs was introduced to semi-commercial SDFs in Meru, Kenya. The objective of this study was to assess the impact of using *Calliandra* and *Sesbania* as feed supplements for dairy cattle on family income and livelihoods during a 16-month trial period on semi-commercial SDFs based on an agroforestry land management model.

Eighty farmers randomly allocated to four groups (nutrition, reproduction, combined nutrition and reproduction, and a comparison group) were enrolled in this study. The nutrition intervention included nutritional management advice and 150 *Calliandra* seedlings and 150 *Sesbania* seedlings to each farm. Farms were visited every 1-2 months during the trial to collect data on milk production and feeding practices during the previous day. Seventy of these farms completed the trial and were interviewed post-intervention. Partial budget analysis of their farms was done by comparing change in average monthly profits (from milk) and feeding costs cow $^{-1}$ for the first and last 6 months of the intervention. Focus group discussions were used to collect qualitative information on livelihood effects from the trial.

There was a KES 2,380.3 (USD 23.5) increase in average monthly profit cow $^{-1}$ in the nutrition group comparing the first and last 6 months of the trial, representing a 68.8% improvement ($p = 0.02$). Average feeding costs significantly decreased across all groups over the trial period. Knowledge on dairy cow nutrition, level of confidence on calf management, and feeling of empowerment to raise calves/heifers to achieve first calving

at 27 months were higher among farmers in the nutrition and combined groups than farmers in the other groups.

There were positive direct and indirect impacts on the income and livelihoods of farmers in the two groups receiving nutritional interventions. Agroforestry, using *Calliandra / Sesbania* shrubs, can improve household livelihoods if adopted by SDFs in Kenya.

Key words: livelihoods, Kenya, smallholder dairy, agroforestry, *Calliandra* and *Sesbania*.

6.2 Introduction

Smallholder dairy production plays a major role in food security and poverty alleviation in Kenya (Muriuki, et al., 2001; VanLeeuwen et al., 2012). In Kenya about 40-45% of daily milk production on smallholder farms (SDFs) is not sold but used for household nutrition (~35%) and calf nutrition (~10%) (Muriuki, 2011). The role of livestock in human health and nutrition in developing countries is significant and vast, and is influenced by various factors (Randolph et al., 2007; Makau, 2014). In Kenya, the dairy value chain is one of the largest avenues for job creation and employment in the informal sector, with every 1000 liters of daily milk produced estimated to generate approximately 77 jobs (Muriuki, 2011).

Smallholder dairy farming complements crop production through daily/monthly income generation, creation of employment, stimulation of infrastructural developments; and is considered a pathway out of poverty (Muriuki, 2003; VanLeeuwen et al., 2012). Both economic recovery and wealth creation in many rural communities in Kenya are directly related to the production level of the dairy sector (The Dairy Policy Forum, 2004). There is a positive association between poverty and food insecurity; households that sell the lowest volumes of milk to collection and processing centers in Kenya are poorer and more food insecure than households selling more milk (Muriuki et al., 2001; Boor, 2012).

In this study, livelihoods were defined as the means of living as constituted by various capabilities, assets and activities (Serrat, 2017). Therefore, livelihoods would be considered sustainable based on their ability to withstand and recover from stresses and threats to the means of living. Such livelihoods are capable of enhancing interventions that mitigate vulnerability to stressful situations (Krantz, 2001). Level of income/economic capital is one of the indicators used to gauge a sustainable livelihood (Department for International Development, 1999).

Agroforestry has been used in agricultural production to reduce the effects of harsh climatic changes on farmers' incomes and livelihoods and is a promising pathway out of poverty (Rahman et al., 2012; Thorlakson & Neufeldt, 2012). The quality of life and household living standards of farmers practicing some level of agroforestry in parts of Kenya was observed to improve as a result of better farm productivity, mitigated farm losses, increased off-farm income generation and improved general environmental conditions (micro-environment) of their farms (Thorlakson & Neufeldt, 2012).

Incorporation of diet supplementation with good quality grass and legume fodder in Mexico resulted in increased lactation performance of cows from an average of USD 866-1,311 marginal profits per three lactation lifetime of a cow (Absalón-Medina et al., 2012). Although SDFs in Uganda adopted growing of Napier grass for fodder, there was a general decrease in family incomes observed in the dry season because of reduced dairy production (a consequence of inadequate feed) coupled with reduced food produced for the family due to small land acreage (Kabirizi et al., 2007). Intercropping of food crops and leguminous forages was subsequently identified as an alternative production technique to mitigate the effects of dry seasons. This integrated farming method was a better production system with additional benefits, including better quality of food crop yields and preservation of soil integrity (Kabirizi et al., 2007) .

In Tanzania, SDFs who supplemented their cattle diets with fodder trees saved an average of USD 310 cow $^{-1}$ year $^{-1}$ in production costs (Chakeredza et al., 2007). These savings would have been extra cost incurred for the purchase of commercial concentrate feed for the cows (Chakeredza et al., 2007). In Kenya, it is estimated that the cumulative net returns to smallholder farms that had adopted fodder tree technologies between 1993-2008 was between 18.7 - 29.6 million USD (World Agroforestry Center, 2011). However, there is a paucity of current research on benefits (to family livelihoods) of using *Calliandra / Sesbania* agroforestry on semi-commercial SDFs in Kenya. The objective of this study was to assess the impact of using *Calliandra* and *Sesbania* as feed supplements for dairy cattle on family income and livelihoods on semi-commercial SDFs based on an agroforestry land management model. This assessment was done using dairy production generated income.

6.3 Materials and methods

6.3.1 Ethical approval

This study was approved by the Research Ethics Board and the Animal Care Committee of UPEI, NDFCS, and FHF, a partner nongovernmental organization. Signed consent of all participants was obtained after the study was fully explained.

6.3.2 Description of study area

This randomized controlled field trial was carried out in Naari sub-location of Meru County, Kenya (0°6'0" N and 37°35'0" E). Meru County is located on the eastern slopes of Mount Kenya and is 270 kilometers north of Nairobi, the capital city of Kenya. Naari sub-location is in the high agricultural potential region with an altitude of approximately 2,000m above sea level. The main agricultural activities include: dairying, subsistence crop farming, horticulture and lumbering. Farmers grow food crops such as maize, beans and Irish potatoes and forages for dairy cows. The study area was purposively selected since this research was part of a larger study involving dairy farmers in the area. A non-governmental organization, FHF, and UPEI had an existing developmental partnership with NDFCS. This rapport provided a strong foundation for the work and the entry point to the community.

6.3.3 Sample population and data collection

The farmers included in the study were those involved in the randomized controlled nutrition trial in Chapter 3 & 5. Eighty farms had been randomly selected based on the inclusion criteria of: active membership with the NDFCS, zero-grazing, and <4 milking cows.

The 80 farms were randomly block-allocated into four different groups in the randomized controlled field trials, with average days in milk (DIM) as a blocking variable. Since changes in milk production due to enhanced feeding are likely to be greater in early lactation, DIM was deemed a very important variable for block randomization. The four intervention groups included nutrition interventions only, reproduction interventions only, nutrition-reproduction (combined) interventions, and a comparison group that received neither intervention. Farmers in the nutrition and combined groups were issued with at least 150 *Calliandra* seedlings and 150 *Sesbania* seedlings (in early 2016) to plant on their farms prior to the commencement of the monitoring visits (July 2016-October 2017) of the project. The nutrition and combined groups also received monthly advice on how to feed their cattle better with the feeds and resources available on the farm. Farmers in the reproduction intervention group were provided with monthly advice on better reproductive management and treatments as described in Chapter 5. Seventy of the 80 farms completed the trial from July 2016 to October 2017.

Farms in the 3 intervention groups were visited monthly during the trial to trouble-shoot any issues with the tending or harvesting of the *Calliandra* and *Sesbania* shrubs, or the reproduction intervention, and to collect data on milk production and feeding practices during the previous day. Data were recorded in a questionnaire adapted and modified from the 2015 baseline study (Makau et al., 2018). Farms in the comparison group were visited bi-monthly to collect similar milk and nutrition data.

A post-intervention questionnaire was administered to assess the knowledge, attitudes and practices (KAP) of the farmers on use of leguminous shrubs and dairy cow management at the end of the trial period, and whether farmers' KAP was different by intervention group. The analysis in this paper will focus on some indicators of livelihood impact assessment which include: feeling of empowerment in dairy management, knowledge and awareness of general nutrition and use of *Calliandra / Sesbania* shrubs on their farms, and confidence in management of dairy cows & calves. The level of confidence on dairy cow nutrition was assessed on a scale of 1 (Not confident), 2 (Somewhat confident), 3 (Confident), and 4 (Very confident).

Focus group discussions (FGDs) were used to collect qualitative information on livelihood effects from the trial. Discussions were classified into four themes relevant to the intervention (i.e. milk production and feeding practices, importance of dairy production to the households, the project intervention and its effect on household livelihoods (economies) and knowledge dissemination to and by the farmers). Farmers in the nutrition and combined groups were invited to the FGD on the same day, while a separate meeting was held for the reproduction and comparison groups. Proceedings of the FGDs were facilitated by the researcher and were recorded for reference to inform the quantitative data.

6.3.4 Data management and analysis

Data from the questionnaires were entered into MS Excel 2010 (Microsoft, Sacramento, California, USA) and checked for errors. Data were then transferred to STATA software 13.0 (StataCorp LLC, College station, Texas, USA) for statistical analysis. Descriptive statistical analysis (summarizing distributions, means, and medians) was done for continuous variables. Categorical variables were also summarized using frequencies and percentages.

Partial budget analysis was used to assess marginal changes in revenues in Kenya shillings (KES) by comparing farms receiving nutritional interventions with those not receiving nutrition interventions. A comparison of milk production revenue and feeding costs was done for the baseline (i.e. first 6 months – July to December 2016) and the end-line (i.e. last 6 months of the trial – May to October 2017) for each farm. The comparative period included both dry and wet seasons. Average monthly milk income and feeding costs cow $^{-1}$ were calculated by: 1) calculating daily average milk production and purchased feed volumes fed from the data obtained during the baseline and end-line periods; 2) multiplying by 30 (to represent days per month) the volumes of milk produced (liters) and feed (kg) fed cow $^{-1}$; 3) averaging prices of feeds (per g or kg) and milk liter $^{-1}$ during the 6-month comparison periods; and 4) multiplying the average prices with the average monthly feed amounts and milk amounts, respectively. Profit was calculated as the difference between average monthly income cow $^{-1}$ and average monthly feeding cost cow $^{-1}$. The profit was used for analysis of net change in monthly profit cow $^{-1}$ between the first six months and last six months within groups, for each intervention group.

This partial budget was focused on the milk production revenue and typical purchased feed costs and assumed that all other costs (e.g. labor associated with tending and harvesting fodder crops) were constant. Purchased feeds of interest for the analyses were dairy meal, maize germ, wheat bran and mineral supplementation. Maize silage was also included in the cost of production for three reasons: 1) there is a substantial amount of energy in maize silage, having a substantial impact on milk production; 2) some farmers fed maize silage while others did not; and 3) there are costs associated with the proper storage of the maize silage from the harvested maize plants (e.g. chopping, mixing in molasses or some other product to assist fermentation, packing and plastic), which should be reflected in the feed costs. The cost of the *Calliandra* and *Sesbania* seedlings was a one-time small cost, and therefore wasn't included in the partial budget but is factored in at the end.

Bonferroni adjusted one-way ANOVA was used to evaluate statistically significant differences in average monthly production costs and profits among study groups. Significant differences in net change in profit was calculated within the intervention groups using paired t-tests, comparing average monthly profit at the baseline 6 months and at end-line 6 months.

For dichotomous variables from the post-intervention interview data, Pearson's Chi-square and Fisher's exact tests (if cells had fewer than 5 farmers) were used to check for differences between the different groups. Focus group discussion data were recorded and transcribed for qualitative analysis to provide contextual information. Results were considered significant when p value ≤ 0.05. Farmers agreed to the use of the data for research purposes as long as confidentiality was maintained.

6.4 Results

During the 16-month study period, 10 farms were lost to follow-up at different times of the study (3 from each of the nutrition, combined and comparison groups and 1 from reproduction group). Reasons for the losses to follow-up included cessation of membership to NDFCS, cattle sales or death, change in farm priorities, and family issues. These reasons were not related to the objective of the study and so minimal bias on the results was expected. For the 70 farms that completed the trial, the mean land size was

2.1 acres with a mean of 1.8 milking cows per farm. The average farmland size and number of milking cows was similar among the 80 farms starting the trial and the 70 farms completing the trial (Table 6.1 and 6.2).

6.4.1 Demographic data and changes

Despite the random allocation of herds, some of the herd demographics, animal characteristics (days in milk, breed, and pregnancy status), prevalence of subclinical mastitis and number of cow observations during the different seasons were different among the four trial groups at baseline (Table 6.1). In particular, the nutrition group cows had the highest DIM and most subclinical mastitis at baseline. On the other hand, the reproduction group had a higher proportion of Friesian crosses and visits occurring during the wet season compared to the other groups (Table 6.1).

Cases of mastitis decreased significantly ($p<0.05$) in all groups when comparing baseline vs end-line data. The proportion of observations when cows were pregnant in the combined group increased significantly from 16.4% at baseline to 28.2% at end-line (Table 6.2).

6.4.2 Partial budget analysis

The average cost of dairy meal was calculated as the average retail price of all dairy meal brands sold at the NDFCS during the trial period, which was (34.8 KES kg^{-1}). The same approach was used for the other feeds of interest, producing the following average costs: maize germ (18.7 KES kg^{-1}), bran (19.0 KES kg^{-1}), and mineral supplement (0.6 KES g^{-1}). The estimated cost of maize silage was 12.8 KES kg^{-1}, calculated as an average of retail prices for silage and labor costs for silage-making documented between 2015 and 2018 (Sawa, 2015; Caroline, 2016; Nanjinia, 2018; Obi, 2018).

The average monthly milk production among the 70 farms ranged between 161.5 – 204.5 liters cow $^{-1}$ at baseline (Table 6.3) and between 167.9 – 237.2 liters cow $^{-1}$ at the end of the study, which was an increase in all groups except the farms in the combined group, who had a 17.6 liter decrease in their average milk production (Table 6.3). The average price of milk, calculated as an average of prices offered to the farmers by NDFCS during the trial period, was KES 37.00 liters $^{-1}$. The changes in milk production were only significant in the nutrition and reproduction groups (Table 6.3)

Mean feeding expenses decreased from baseline to end-line across all groups by 44.1% for maize silage, 40.4% for wheat bran, 32.2% for dairy meal and 31.7% for maize germ. Across the groups, the mean monthly feeding expenditure decreased, from an average of KES 3,325.1 – 4,699.6 (USD 32.9 – 46.4) cow $^{-1}$ at baseline to KES 2,286.9 – 3,597.5 (USD 22.6 – 35.6) cow $^{-1}$ at end-line (Table 6.4). The decrease in feeding expenses was significant in all groups ($p < 0.05$), except the nutrition group (Table 6.4).

The average monthly profits cow $^{-1}$ significantly increased from the baseline to the end-line for all groups except the combined group (Table 6.5). The change in average monthly profits cow $^{-1}$ in the nutrition group was a 68.8% increase ($p < 0.02$). There were significant net changes in average monthly profits cow $^{-1}$ across all groups except between the nutrition and reproduction groups (Table 6.6).

6.4.3 KAP Questionnaire responses

Compared to the comparison and reproduction groups, all the farmers in the nutrition group and most of the combined group (88.2%) felt they were more empowered in dairy management. For example, at the end of the trial, these farmers felt that they were able to raise calves and heifers optimally to achieve age at first calving (AFC) of about 27 months of age (Table 6.7). As well, significantly more farmers in the nutrition and combined group than the comparison group correctly indicated that main benefit of colostrum was to provide the calf with immunity (Figure 6.1). Also, more farmers in the combined group than in the other groups knew that there was a different mineral for dry cows from milking cows (Table 6.7). More farmers in both the nutrition and combined groups than the comparison and reproduction groups reported that agroforestry could be a sustainable land use system (Table 6.7).

More farmers in the nutrition and combined group felt confident and informed on matters of dairy farming and nutrition, compared to the comparison and reproduction groups (Figure 6.2). The mean, s.d. and median scores of confidence levels were 1.9, 0.7, 2 for the comparison group, 3.5, 0.6, 4 for the nutrition group, 3.1, 0.7, 3 for the combined group, and 2.1, 0.8, 2 for the reproduction group. These scores were significantly higher for the nutrition and combined groups compared to the comparison and reproduction groups ($p < 0.001$) while there was no significant difference in scores between the nutrition vs combined groups and between the comparison vs reproduction groups ($p > 0.05$).

6.4.4 *Focus group discussions*

From the intervention and comparison groups, 20 farmers (67% women) participated in the discussions. Farmers unanimously reported that dairy production was the main source of livelihood in the area and indicated that they would not substitute it with any other form of farming. Some farmers said, “Dairy farming is the backbone of our households”. Some of the benefits farmers reported to have accrued from dairy production, especially with improved milk production, included: better nutrition through drinking fresh milk/yoghurt; a source of family income through milk sales, and thus it was a major pathway from poverty; collateral for credit acquisition; a source of school fees for the children through milk sales; cattle as a form of savings for future liquidation, if necessary; livelihoods security that allowed farmers to diversify into other kinds of farming; a source of manure for sale and use on farms for better crop yields and animal feed production; beverages (milk/tea) for hosting social functions for visitors; and use of cows/heifers for dowry payment. Given the extent of the role of dairy production, farmers were positive that any improvement in the productivity of their enterprises would be of great benefit to their households.

The intervention groups (those who received shrubs and education) unanimously reported that they had seen some improvement in returns from their dairy enterprises since they began participating in this trial. The comparison groups (those who didn’t receive shrubs) indicated that they had seen slight improvement but would wish to have made more improvement. Although the comparison group didn’t receive any direct intervention, farmers cited the informal advice offered during the farm visits and from other farmers to have contributed to the improvements observed. Some farmers (women) within the comparison group reported that their friends in the nutrition-related intervention groups had shared seeds of the *Calliandra/Sesbania* shrubs with them and they had started some nurseries of their own on their farms.

The most important challenge raised by the farmers in both the intervention and comparison groups was low milk production during the dry season and early rainy season due to inadequate feed. This low milk production was more of a problem in the comparison group than it was in the intervention groups who reported, “Milk production has not reduced much in the last dry season like it has been in other years”. Some farmers said that since they started using the shrubs, they no longer used dairy meal on their farms and instead used the shrub foliage with wheat bran, and that milk production was still good. Although farmers in both groups knew about silage-making, the largest hinderance for this form of feed conservation was the costs involved.

Farmers in the intervention groups unanimously reported that they would recommend these shrubs to other farmers, saying “Because they increase milk production!” As a result, the women reported they had shared this information in different women’s groups, and some women had been requested to supply seeds to the women’s groups while others had managed to convince new members to join NDFCS to benefit from such interventions in the future. Male farmers indicated that although they did not share the knowledge about the shrubs in groups, they had shared their knowledge with neighbors and managed to convince their neighbors to attempt using these shrubs on their farms.

6.5 Discussion, Conclusion and Recommendations

From the partial budget analysis, it was evident that there were significant changes in monthly milk production and profit cow $^{-1}$ between the first and last 6 months of the trial. These time periods were selected purposively because it was expected that at the beginning of the trial, the shrubs were not evenly mature to provide constant foliage to the cows enough to significantly affect milk production. Additionally, replacement of dead seedlings was also done during the middle of the trial period. During the last six months of the trial, it was assumed that all shrubs in the nutrition and combined farms were evenly mature and were optimally being used in all the farms, providing a basis for comparison between farms that had shrubs and those who hadn't received any shrubs.

The 68.8% increase in monthly profits cow $^{-1}$ in the nutrition group (Table 6.5) was associated with a significant improvement in average monthly milk production cow $^{-1}$ (Table 6.3). This increase in milk production would be largely attributed to the nutritional interventions (feeding shrubs and farmer education) implemented on farms in these groups. Better nutritional management and feeding of higher amounts of CP to cows would lead to an increase in amount of milk produced by lactating cows. Farmers feeding these shrubs to cows could also reduce the amount of dairy meal fed and still maintain a good level of production. Similar observations have been made after adoption of different feeding interventions in SDFs in Kenya and other African countries (Omore et al., 2004; VanLeeuwen et al., 2012). With an average of more than 50% of household income in SDFs attributed to dairy production, this increase would undoubtedly translate to better livelihoods (VanLeeuwen et al., 2012).

The cost for *Calliandra* and *Sesbania* seedlings at the time of publication in Kenya was approximately KES 25, therefore 300 seedlings would total KES 7,500. Assuming the seedlings were purchased at this price, with the nutrition group having increased its monthly profit by over KES 2,300, the return on the investment would only take 3.5 months, after which time, the additional profit would be available for other expenditures.

The average monthly feeding expenses decreased for farms in all groups. The decrease was significant for all groups except the nutrition group; probably because they had already started feeding the shrubs around the baseline period and already made some adjustments to their feeding practices. These farmers may also have felt that with the additional CP from shrubs, they needed to maintain energy to enhance milk production and reproduction. Some of the decrease in feeding expenses attributable to maize silage could be because farmers were running low on amounts of silage. However, there were no significant changes in monthly profits for SDFs in the combined group, primarily due to a decrease in milk production (Table 6.3 and 6.5). This milk production level could be attributed to farmers in the combined and reproduction groups focusing more on getting their cows pregnant (primary objective of reproduction interventions). For example, in the reproduction group, farmers were observed to reduce their milking frequency when cows seemed to be losing body condition and taking a long time to come in heat, especially when there were feed shortages. The rationale was that reduced milk production would counter the negative energy balance experienced during suboptimal feeding.

Farmers in the nutrition and combined groups were significantly more knowledgeable and aware of good dairy nutrition practices compared to the comparison and reproduction groups (Figure 6.1 and Table 6.7), which demonstrates a benefit of the nutrition intervention. Better knowledge of dairy nutrition would promote better on-farm and off-farm decision-making, thus resulting in more efficient farm management and increased profits, leading to improved livelihoods (Chapman et al., 2003). Moreover, farmers in the nutrition and combined groups reported that agroforestry could be a sustainable land use system (Table 6.7). Generally, SDFs in this area, as is common in other parts of Kenya, are on relatively small acreages (Richards, 2017; Maina et al., 2018). Adoption of agroforestry would reduce vulnerability to, and effects of, feed shortages on household income and economies, translating to improved and sustainable livelihoods (Kiptot et al., 2014; General Secretariat of the Organization of American States, 2015). Franzel et al., (2013) cited similar impacts and benefits on farmer livelihoods in Zimbabwe, Ethiopia and Uganda after planting and using fodder trees on their farms.

Farmers in the nutrition and combined group felt more empowered and were significantly more confident about general dairy nutrition and raising calf and heifer for earlier age at first calving (Table 6.7 and Figure 6.2). The average AFC of heifers in SDFs in Kenya (as it was in the study area) was estimated at 34 months but could be up to 40 months (Menjo et al., 2009). A reduction in AFC would subsequently translate to high returns resulting from higher lactation per lifetime (Krpálková et al., 2014) which would lead to improved livelihoods. Moreover, increased empowerment and confidence observed among farmers in the nutrition and combined groups was indicative of intangible impacts of the interventions towards improved livelihoods (Ashley & Hussein, 2000). These farmers would most likely be able to make effective decisions on farm management, leading to more efficient production and increased returns.

It was encouraging to get positive responses from the farmers during the FGDs regarding the agroforestry systems offered in the trial and how the leguminous shrubs helped mitigate the effects of feed shortage in milk production. Given the central role of dairy farming in this community, it was clear that any benefits in productivity and profit observed on the farms translated to better livelihoods for the household. Similar findings were observed in a longer study that integrated more interventions to improve SDFs production in rural Kenya (VanLeeuwen et al., 2012). Farmers who fed cows on leguminous shrubs in Ethiopia, Zimbabwe, Uganda and Kenya also reported benefits through increased milk production and reduction in feeding costs (reduced dairy meal use) (Cook et al., 2005; Franzel et al., 2013; Richards, 2017).

Farmers in the study had participated in different knowledge transfer activities within their circle of friends and neighbors, resulting in increased membership to the NDFCS. Such indirect benefits of the intervention are encouraging. Growth in NDFCS would translate into other socioeconomic benefits to the Naari area since the Dairy also supplied basic foods and household amenities to the community, and availed a credit facility to active members who shipped milk to the NDFCS, as was observed in Nyeri County, Kenya (VanLeeuwen et al., 2012).

Among the limitations of this study, farmers in this trial were not able to accurately indicate how much time they used to plant and manage the shrubs. There were no reports of any additional hired labor since most of the farms were generally worked by household members whose primary occupation was farming. Lack of that additional information limited the quantification of indirect costs and opportunity costs of having the shrubs on the farm. These potential costs were not factored into the partial budget. However, the labor to manage the shrubs beyond the first few months when the shrubs were establishing their roots would be minimal and would be similar to the management of other forage crops in terms of tending, fertilizing, and harvesting the forage crops.

Another limitation to the study was that the random allocation did not lead to completely equal farm and animal demographics and management, due to the small size of the farms and that there being just 20 farms in each group. For example, breed, DIM, prevalence of subclinical mastitis, and pregnancy status were not significantly different between groups, and the number of cow observations during the wet season was not the same among the four trial groups at baseline (Table 6.1 and 6.2). Some of these factors could have also had an impact on the changes in milk production and feed costs, and therefore changes in profit. However, factors, such as pregnancy and DIM, would be less likely to affect profit since farmers would likely reduce purchased feeds provided to pregnant cows and those with high DIM, coinciding with their lower milk production.

Notwithstanding these possible confounding factors on the milk production and profit, the estimates of improvements to these outcomes from the nutritional interventions are likely conservative for a couple of reasons. The initial 6 months was a quasi-baseline in the sense that there were already nutritional interventions in the form of nutritional advice provided to the farmers during this time. However, a monitoring period prior to this time frame was not possible for logistical reasons. Secondly, the research team noticed that on a minority of farms with leguminous shrubs, the shrubs were already being harvested and fed to the cows during this first six months of baseline. Both of these circumstances likely led to a baseline level of milk production that was potentially higher than if neither of these situations happened; suggesting that the impacts on milk production and dairy net income were possibly underestimated.

As a third limitation, due to the close geographical placement of the intervention and comparison farms, it was likely that some level of unintentional information transfer to the comparison farmers from the intervention farmers occurred. This information transfer could bias the responses and practices of those comparison group farmers and the measurements of their cows. However, the farmers in the comparison group did not have leguminous shrubs on their farms, except perhaps at the very end of the study, reducing this possible bias. If anything, this bias would only make the estimates in the differences in profits between groups more conservative than they really are. However, from a livelihood development perspective, this spread of leguminous shrubs would be a 'good problem' to have. The natural spread of this land management model could have extensive benefits to the incomes and livelihoods of the community and SDFs.

Use of *Calliandra / Sesbania* in an agroforestry land management system has many intricate benefits (tangible and intangible) not only to the farmer, but to the environment as well. A more detailed study on the impact of intercropping these shrubs with food crops and using them in the long-term sustainability of agricultural ecosystems would elucidate other benefits not explored in these analyses.

Increasing human population and land fragmentation is constantly leading to shrinking land available for dairy farming. Smallholder dairy farms should adopt an agroforestry land management model for more sustainable production and more stable incomes from their dairy cows. Stable household incomes, prevailing weather notwithstanding, would contribute to less vulnerable household economies and more sustainable livelihoods.

In conclusion, the nutritional interventions (education and *Calliandra / Sesbania* shrubs) with and without reproductive interventions had positive financial, knowledge, practices impact on the livelihoods of farmers. Agroforestry, using *Calliandra / Sesbania*, with supportive education / training, can improve dairy farm household incomes and livelihoods if adopted by SDFs in Kenya, where agroecologically appropriate.

6.6 References

Absalón-Medina, V. A., Nicholson, C. F., Blake, R. W., Fox, D. G., Juárez-Lagunes, F. I., Canudas-Lara, E. G., & Rueda-Maldonado, B. L. (2012). Economic analysis of alternative nutritional management of dual-purpose cow herds in central coastal Veracruz, Mexico. *Tropical Animal Health and Production*, *44*(6), 1143–1150. https://doi.org/10.1007/s11250-011-0050-8

Ashley, C., & Hussein, K. (2000). *Developing methodologies for livelihood impact assessment: Experiences of the African Wildlife Foundation in East Africa*. *Sustainable Livelihoods*. London, United Kingdom. https://doi.org/10.3390/su7054850

Boor, E. I. (2012). *The Role of Milk Processors in Poverty Reduction among Small Scale Dairy Farmers: Case Study of NKCC Ltd Eldoret Suppliers*. University of Nairobi. Retrieved from http://erepository.uonbi.ac.ke/bitstream/handle/11295/9691/Boor_ The Role Of Milk Processors In Poverty Reduction Among Small Scale Dairy Farmers Case Study Of NKCC Ltd Eldoret Suppliers.pdf?sequence=1&isAllowed=y

Caroline, W. (2016, April 22). Youth chama turns silage into a money-maker. *Daily Nation*. Retrieved from https://www.nation.co.ke/business/seedsofgold/Youth-group-making-money-from-preparing-silage/2301238-3170310-5hrrfp/index.html

Chakeredza, S., Hove, L., Akinnifesi, F. K., Franzel, S., Ajayi, O. C., & Sileshi, G. (2007). Managing fodder trees as a solution to human-livestock food conflicts and their contribution to income generation for smallholder farmers in southern Africa. *Natural Resources Forum*, *31*, 286–296. https://doi.org/10.1111/j.1477-8947.2007.00160.x

Chapman, R., Slaymaker, T., & Young, J. (2003). *Livelihoods Approaches to Information and Communication in Support of Rural Poverty Elimination and Food Security*. *Bridging Reasearch and Policy*. London, United Kingdom. Retrieved from http://www.odi.org.uk/resources/details.asp?id=164&title=livelihoods-approaches-information-communication-support-rural-poverty-elimination-food-security

Cook, B., Pengelly, B., Brown, S., Donnelly, J., Eagles, D., Franco, A., … Schultze-Kraft, R. (2005). Calliandra calothyrsus. Retrieved June 25, 2018, from http://www.tropicalforages.info/key/forages/Media/Html/entities/calliandra_calothyrsus.htm

Department for International Development. (1999). Sustainable Livelihoods Guidance Sheets. Retrieved January 9, 2019, from https://www.ennonline.net/dfidsustainableliving

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J., & Wambugu, C. (2013). Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. *Current Opinion in Environmental Sustainability*, *6*(1), 98–103.

https://doi.org/10.1016/j.cosust.2013.11.008

General Secretariat of the Organization of American States. (2015). How to rapidly assess the effects of the application of CITES decisions on livelihoods in poor rural communities. In F. A. F. Ochoa (Ed.), *Handbook on CITES and livelihoods* (pp. 1–44). Washington D.C., USA: Department of Sustainable Development.

Kabirizi, J., Mpairwe, D., and Mutetikka, D. (2007). The Effect of Integrating Forage Legumes in Smallholder Crop/Livestock Farming System on Food, Fodder and Animal performance. In *Conference on International Agricultural Research for Development* (pp. 1–7). Kampala: University of Kassel-Witzenhausen and University of Gottingen,. Retrieved from http://www.tropentag.de/2007/abstracts/full/44.pdf

Kiptot, E., Franzel, S., & Degrande, A. (2014). Gender, agroforestry and food security in Africa. *Current Opinion in Environmental Sustainability*, *6*(1), 104–109. https://doi.org/10.1016/j.cosust.2013.10.019

Krantz, L. (2001). The sustainable livelihood approach to poverty reduction. Division for Policy and Socio-Economic Analysis. Stockholm, Sweden. Retrieved from https://www.sida.se/contentassets/bd474c210163447c9a7963d77c64148a/the-sustainable-livelihood-approach-to-poverty-reduction_2656.pdf

Krpálková, L., Cabrera, V. E., Vacek, M., Stípková, M., Stádník, L., & Crump, P. (2014). Effect of prepubertal and postpubertal growth and age at first calving on production and reproduction traits during the first 3 lactations in Holstein dairy cattle. *Journal of Dairy Science*, *97*(5), 3017–3027. https://doi.org/10.3168/jds.2013-7419

Maina, F., Mburu, J., Gitau, G., VanLeeuwen, J., & Negusse, Y. (2018). Economic efficiency of milk production among small-scale dairy farmers in Mukurweini, Nyeri County, kenya. *Journal of Development and Agricultural Economics*, *10*(5), 152–158. https://doi.org/10.5897/JDAE2017.0915

Makau, D. (2014). *A study of factors associated with the prevalence of coccidia infection in cattle and its spatial epidemiology in Busia, Bungoma and Siaya counties, Kenya*. University of Nairobi. Retrieved from https://cgspace.cgiar.org/handle/10568/56880

Makau, D. N., VanLeeuwen, J. A., Gitau, G. K., Muraya, J., McKenna, S. L., Walton, C., & Wichtel, J. J. (2018a). Animal and management factors associated with weight gain in dairy calves and heifers on smallholder dairy farms in Kenya. *Preventive Veterinary Medicine*, *161*. https://doi.org/10.1016/j.prevetmed.2018.10.017

Menjo, D. K., Bebe, B. O., Okeyo, A. M., & Ojango, J. M. K. (2009). Analysis of early survival of Holstein-Friesian heifers of diverse sire origins on commercial dairy farms in Kenya. *Tropical Animal Health and Production*, *41*(2), 171–181. https://doi.org/10.1007/s11250-008-9172-z

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. *FAO Prevention of Food Losses Programme*. Rome, Italy. Retrieved from http://www.fao.org/fileadmin/templates/ags/docs/dairy/P1assessmentkenya.pdf

Muriuki, H. G. (2011). *Dairy development in Kenya*. *FAO-Dairy Reports*. Rome. Retrieved from http://www.fao.org/3/a-al745e.pdf

Muriuki, H., Mwangi, D., & Thorpe, W. (2001). How Smallholder Dairy Systems in Kenya Contribute to Food Security and Poverty Alleviation: results of recent collaborative studies. In *Contribution of Livestock to Food Security and Poverty Alleviation* (pp. 1–9). Morogoro, Tanzania: Tanzania Society of Animal Production Conference. Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/1725/Muriuki et al-2001-Smallholder dairy %26 food security-TSAP.pdf?sequence=1

Nanjinia, W. (2018, April 7). Silage bale wrapping, new trend in fodder packaging lasts two years. *Standard Digital*. Retrieved from https://www.standardmedia.co.ke/business/article/2001275988/silage-bale-wrapping-new-trend-in-fodder-packaging

Obi, L. (2018, March 31). Storing silage in pits is out of date; savvy farmers now bale it. *Daily Nation*. Retrieved from https://www.nation.co.ke/business/seedsofgold/Introducing-silage-baling/2301238-4365374-90rekvz/index.html

Omore, A., Mulindo, J. C., Islam, S. M. F., Nurah, G., Khan, M. I., Staal, S. J., & Dugdill, B. T. (2004). *Employment generation through smallscale dairy marketing and processing* (FAO Animal and Production Health No. 158). Rome. https://doi.org/ISBN: 9251049807 ISSN: 0254-6019

Rahman, S., Imam, M., Snelder, D., & Sunderland, T. (2012). Agroforestry for livelihood security in agrarian landscapes of the Padma floodplain in Bangladesh. *Small-Scale Forestry*, *11*(4), 529–538. https://doi.org/10.1007/s11842-012-9198-y

Randolph, T. F., Schelling, E., Grace, D., Nicholson, C. F., Leroy, J. L., Cole, D. C., … Ruel, M. (2007). Invited Review: Role of livestock in human nutrition and health for poverty reduction in developing countries. *Journal of Animal Science*, *85*(11), 2788–2800. https://doi.org/10.2527/jas.2007-0467

Richards, S. M. (2017). *Productivity and welfare of cows on smallholder dairy farms in Kenya*. University of Prince Edward Island. Retrieved from https://www.islandscholar.ca/islandora/object/ir%3A21369/datastream/PDF/download

Sawa, P. (2015, December 7). Kenya Dairy farmers make maize silage to maximize profits. *Barzawire*. Retrieved from http://wire.farmradio.fm/en/farmer-stories/2015/12/kenya-dairy-farmers-make-maize-silage-to-maximize-profits-13241

Serrat, O. (2017). The Sustainable Livelihoods Approach. In Knowledge Solutions: Tools, Methods, and Approaches to Drive Organizational Performance (pp. 21–25).

Springer, Singapore. https://doi.org/10.1007/978-981-10-0983-9

The Dairy Policy Forum. (2004). *Policies to Support Smallhoder Dairy for Sustainable Employment and incomes in Kenya Kenya*. Nairobi, Kenya. Retrieved from https://cgspace.cgiar.org/bitstream/handle/10568/52337/Policies to support smallhoder dairy in Kenya.pdf?sequence=1

Thorlakson, T., & Neufeldt, H. (2012). Reducing subsistence farmers' vulnerability to climate change: evaluating the potential contributions of agroforestry in western Kenya. *Agriculture & Food Security*, *1*(1), 15. https://doi.org/10.1186/2048-7010-1-15

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*, 231–238. https://doi.org/10.1007/s11250-011-0003-2

World Agroforestry Center. (2011). *Fodder trees and milk production in East Africa*. *Policy Brief* (Vol. 12). Nairobi, Kenya. https://doi.org/BR09326

Table 6.1: Demographic and other characteristics of 114 cows from 80 Kenyan smallholder dairy farms on 378 visits (606 observations) over 6-month baseline in 2016-2017

Parameter	Overall (n=606)	Comparison group (n=119)	Nutrition group (n=194)	Combined group (n=183)	Reproduction group (n=110)	P- value
Average # of milking cows/farm (s.d.)	1.8 (0.7)	2.1 (0.6) [a]	1.8 (0.7) [bc]	1.7 (0.6) [c]	1.9 (0.8) [b]	0.0002
Average # of acres/farm (s.d.)	2.1 (1.8)	2.1 (1.8) [a]	1.8 (1.5) [a]	1.9 (0.6) [a]	2.8 (2.7) [b]	0.338
Average # of days in milk (s.d.)	242.5 (176)	251.8 (166) [a]	276.9 (73) [ab]	215.6 (182) [ac]	216.2 (176) [ac]	0.002
Breed						<0.001
Zebu or dual purpose (#)	2.6% (16)	5.0% (6) [a]	0% (0) [b]	3.3% (6) [a]	3.6% (4) [a]	
Friesian crosses (#)	56.6% (343)	46.2% (55) [a]	52.6% (102) [a]	57.4% (105) [a]	73.6% (81) [b]	
Ayrshire crosses (#)	15.0% (91)	13.5% (16) [a]	16.4% (32) [ab]	11.5% (21) [ac]	20.0% (22) [ab]	
Guernsey crosses (#)	19.5% (118)	33.6% (40) [a]	21.7% (42) [b]	18.0% (33) [b]	2.7% (3) [c]	
Jersey crosses (#)	6.3% (38)	1.7% (2) [a]	9.3% (18) [b]	9.8% (18) [b]	0% (0) [a]	
Pregnant (#)	23.8% (144)	24.4% (29) [a]	27.3% (53) [a]	16.4% (30) [ab]	29.1% (32) [ac]	0.030
Subclinical mastitis positive (#)	27.1% (164)	26.1% (31) [a]	34.5% (67) [ab]	22.9% (42) [ac]	21.8% (24) [ac]	0.038
Wet Season (#)	24.6% (149)	16.8% (20) [a]	18.0% (35) [a]	19.7% (36) [a]	52.7% (58) [b]	<0.001

[a-c] Different letter superscripts represent significant differences between coefficients of different levels (other than the reference level which use the category p-values) for interaction variables and categorical variables not involved in interactions when they have more than 2 levels.

Table 6.2: Demographic and other characteristics of 121 cows from 70 Kenyan smallholder dairy farms on 326 visits (519 observations) over 6-month end-line in 2016-2017

Parameter	**Overall (n=519)**	**Comparison group (n=71)**	**Nutrition group (n=129)**	**Combined group (n=163)**	**Reproduction group (n=156)**	**P- value**
Average # of milking cows/farm (s.d.)	1.8 (0.8)	1.8 (0.7) [a]	1.6 (0.8) [ab]	2.0 (0.8) [ac]	1.8 (0.7) [ad]	0.002
Average # of acres/farm (s.d.)	2.1 (1.7)	1.6 (1) [a]	1.7 (1.4) [ab]	2.0 (0.6) [c]	2.8 (2.7) [ad]	0.11
Average # of days in milk (s.d.)	330.6 (210)	404.1 (252) [a]	318.8 (174) [bc]	288.8 (171) [d]	350.5 (243) [ac]	0.001
Breed						<0.001
Zebu or dual purpose (#)	3.7% (19)	2.8% (2) [a]	3.1% (4) [a]	0% (0) [b]	8.3% (13) [a]	
Friesian crosses (#)	59.9% (311)	50.7% (36) [a]	58.9% (76) [a]	55.2% (90) [a]	69.9% (109) [b]	
Ayrshire crosses (#)	15.6% (81)	16.9% (12) [a]	18.6% (24) [a]	12.3% (20) [a]	16.0% (25) [a]	
Guernsey crosses (#)	17.0% (88)	25.4% (18) [a]	15.5% (20) [a]	25.2% (41) [ab]	5.8% (9) [c]	
Jersey crosses (#)	3.9% (20)	4.2% (3) [a]	3.9% (5) [a]	7.4% (12) [ab]	0% (0)[c]	
Pregnant (#)	25.6% (133)	29.6% (21) [a]	27.9% (36) [a]	28.2% (46) [a]	19.2% (30) [a]	0.183
Subclinical mastitis positive (#)	7.9% (41)	11.3% (8) [a]	7.0% (9) [a]	9.2% (15) [a]	5.8 (9) [a]	0.45
Wet Season (#)	13.3% (69)	0% (0) [a]	12.4% (16) [b]	11.7% (19) [b]	21.8% (34) [c]	<0.001

[a-c] Different letter superscripts represent significant differences between coefficients of different levels (other than the reference level which use the category p-values) for interaction variables and categorical variables not involved in interactions when they have more than 2 levels.

Table 6.3: Average monthly milk production cow^{-1} at the start of the intervention (6-month baseline) and at the end of the intervention (6-month end-line) for 70 Kenyan smallholder dairy farms from 2016-2017

Group	Average milk production - Baseline (liters)	Average milk production - End-line (liters)	Change in milk production	Paired t-test (p-value)
Comparison (n=17 farms)	161.5	167.9	+6.4	0.80
Nutrition (n=17 farms)	183.3	237.2	+53.9	0.04
Combined (n=17 farms)	204.5	186.9	-17.6	0.40
Reproduction (n=19 farms)	169.2	201.7	+32.5	0.05

Table 6.4: Average monthly feeding cost cow^{-1} per month at the start of the intervention (6-month baseline) and at the end of the intervention (6-month end-line), for 70 Kenyan smallholder dairy farms in 2016-2017 (1 USD=KES 101.2)

Group	Average feeding cost- Baseline in KES (USD)	Average feeding cost - End-line KES (USD)	Change in average feeding cost in KES (USD)	Paired t-test (p-value)
Comparison (n=17)	3,669.3 (36.3)	2,286.9 (22.6)	-1,382.4 (13.7)	0.03
Nutrition (n=17)	3,325.1 (32.9)	2,939.7 (29.1)	-385.4 (3.8)	0.35
Combined (n=17)	3,879.1 (38.3)	2,529.0 (25.0)	-1,350.1(13.3)	0.001
Reproduction (n=19)	4,699.6 (46.4)	3,597.5 (35.6)	-1,102.1(10.8)	0.04

Table 6.5: Average monthly profit cow^{-1} at the start of the intervention (6-month baseline) and at the end of the intervention (6-month end-line), for 70 Kenyan smallholder dairy farms in 2016-2017 (1 USD=KES 101.2)

Group	Average profit – Baseline in KES (USD)	Average profit – End-line in KES (USD)	Change in average profit in KES (USD) (%)	Paired t-test (p-value)
Comparison (n=17)	2,307 (22.8)	3,923.5 (38.8)	+1,616.5 (16.0) (	0.03
Nutrition (n=17)	3,457.6 (34.2)	5,837.9 (57.7)	+2,380.3 (23.5)	0.02
Combined (n=17)	3,688.1 (36.4)	4,387.9 (43.3)	+699.8 (6.9)	0.40
Reproduction (n=19)	1,561.5 (15.4)	3,866.9 (38.2)	+2,305.4 (22.8)	0.002

Table 6.6: Group comparisons of net change in average monthly profit cow $^{-1}$ at the start of the intervention (6-month baseline) and at the end of the intervention (6-month end-line), for 70 Kenyan smallholder dairy farms in 2016-2017 (1 USD=KES 101.2)

Profit change in KES (USD)	Profit change in KES (USD)	Unpaired t-test p-value
Comparison= 1,616.5 (16.0)	Nutrition = 2,380.3 (23.5)	0.01
Comparison= 1,616.5 (16.0)	Combined = 699.8 (6.9)	0.001
Comparison= 1,616.5 (16.0)	Reproduction = 2,305.4 (22.8)	0.004
Reproduction = 2,305.4 (22.8)	Nutrition = 2,380.3 (23.5)	0.78
Reproduction = 2,305.4 (22.8)	Combined = 699.8 (6.9)	<0.001
Combined = 699.8 (6.9)	Nutrition = 2,380.3 (23.5)	<0.001

Profit change = (Average baseline profit) - (Average end-line profit)

Table 6.7: Summary of select questionnaire responses by 70 smallholder dairy farmers in Kenya in 2017 post-intervention

Question	Comparison group (n=17)	Nutrition group (n=17)	Combined group (n=17)	Reproduction group (n=19)	P- value
Feeling of empowerment to raise calves/heifers to achieve first calving at 27 months					<0.001
Yes	17.6% (3)[a]	100% (17)[b]	88.2% (15)[b]	21.1% (4)[a]	
No	82.4% (14)	0% (0)	11.8% (2)	78.9% (15)	
There is special mineral supplement for dry cows					0.007
True	52.9% (9)[a]	82.4% (14)[a]	100% (17)[b]	73.7% (14)[a]	
False	47.1% (8)	17.6% (3)	0% (0)	26.3% (5)	
Agroforestry can be a sustainable land use system					<0.001
Yes	0% (0)[a]	94.1% (16)[b]	64.7% (11)[c]	5.3% (1)[a]	
No	100% (17)	5.9% (1)	35.3% (6)	94.7% (18)	

Figure 6.1: Post-intervention descriptive analysis of the knowledge of 70 farmers on the main reason for feeding first colostrum to calves in Kenyan smallholder farms in 2017

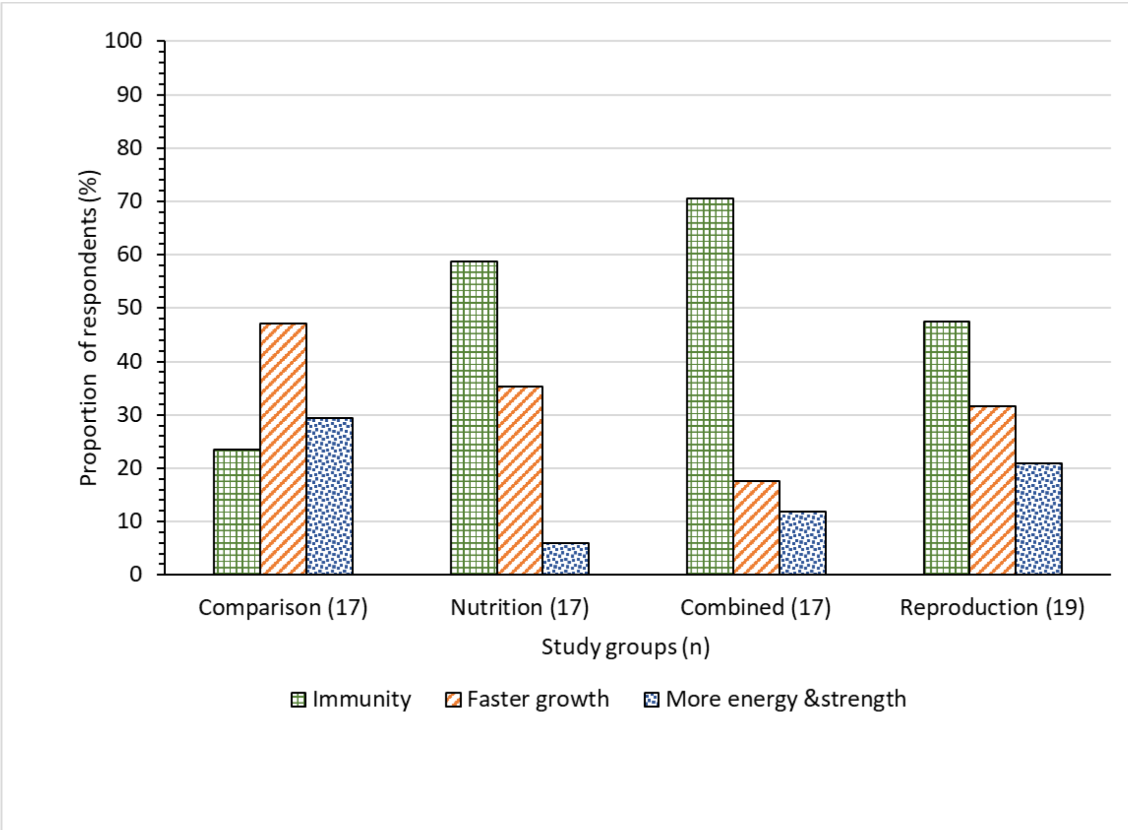
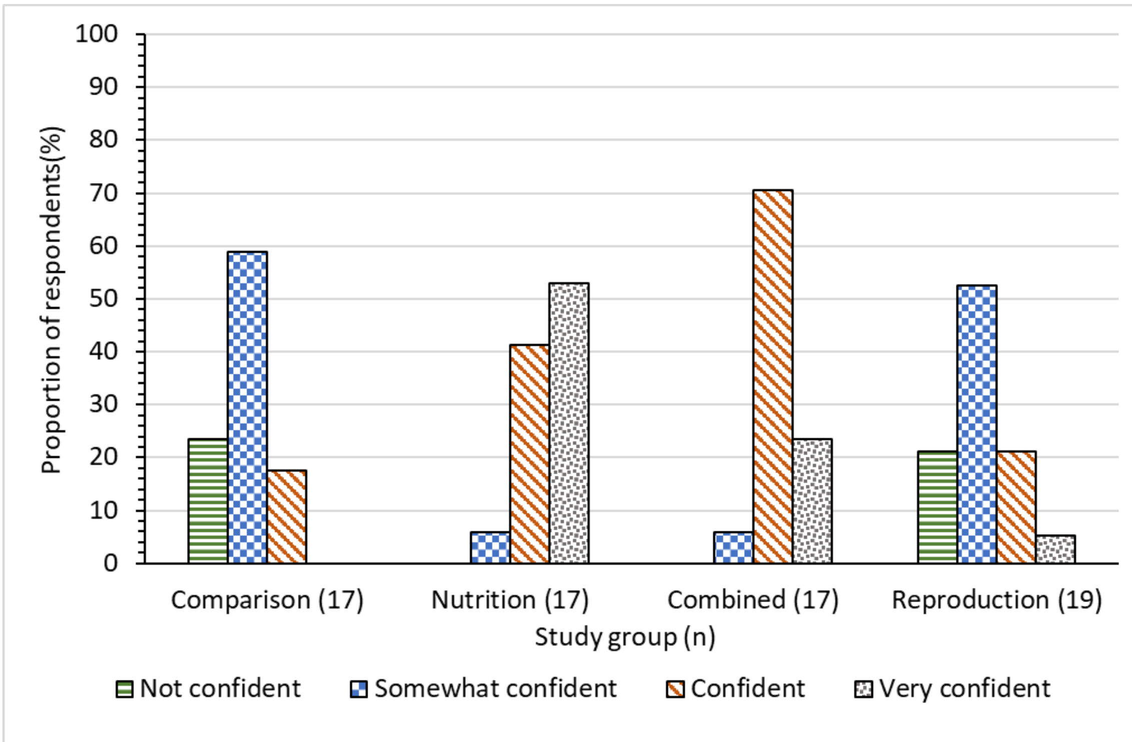


Figure 6.2: Post-intervention descriptive analysis of levels of confidence of 70 farmers on dairy farming and nutrition in Kenyan smallholder farms in 2017



Chapter 7 Conclusion

7.1 Introduction

There is a paucity of knowledge on interactions between smallholder dairy management and farmer livelihoods amidst socioeconomic constraints of rural Kenya. Smallholder dairy farmers play a major role in the dairy value chain in Kenya. However, there is minimal research addressing various challenges faced by the semi-commercial smallholder dairy enterprises. This thesis sought to address this dearth of research, in collaboration with several partners: the Naari Dairy Farmers Cooperative Society (NDFCS), the Upendo Women's Group, Farmers Helping Farmers, the Atlantic Veterinary College – University of Prince Edward Island, University of Nairobi, the Canadian Queen Elizabeth II Diamond Jubilee Scholarships (QES), the Rideau Hall Foundation (RHF), Community Foundations of Canada (CFC), and Canadian universities.

The overall hypotheses of this thesis were: 1) weight gain in dairy calves/heifers on SDFs in Meru is lower than desired and is a function of a number of calf and management factors; 2) smallholder dairy farmers in Kenya faced serious feeding challenges in the dry season, and feeding drought-tolerant leguminous shrubs, *Calliandra calothyrsus* and *Sesbania sesban*, will improve/enhance the growth rates of dairy calves; 3) knowledge dissemination and capacity building by providing electronic reference material through cellphone-mediated training will improve knowledge and attitudes on good dairy management practices; 4) feeding drought-tolerant leguminous shrubs, *Calliandra calothyrsus* and *Sesbania sesban*, will improve/enhance the milk production of dairy cows; 5) these interventions using leguminous shrubs, *Calliandra calothyrsus* and

Sesbania sesban, will result in better milk production with lower feed costs for improved profits, and result in better income and livelihoods.

A cross-sectional study was used to evaluate animal and management factors associated with weight gain in dairy calves and heifers on smallholder dairy farms (Chapter 2). Two randomized controlled trials were used to assess the effect of using *Calliandra* and *Sesbania* as leguminous drought-tolerant feed supplements for dairy animals. The analyses focused on the association between consumption of *Calliandra / Sesbania* and dairy calf weight gain (Chapter 3) and milk production in dairy cows (Chapter 5). A randomized controlled trial was used to evaluate if cellphones could be used as effective tools for training farmers on dairy best management practices (Chapter 4). A partial budget analysis was done using the *Calliandra / Sesbania* intervention cohort to assess whether the interventions contributed to sustainable livelihoods compared to farmers not receiving this intervention (Chapter 6).

7.2 Animal and management factors associated with weight gain in dairy calves/heifers on smallholder dairy farms in Kenya

The specific aim of this study was to determine the factors associated with weight gain in dairy calves and heifers on semi-commercial (SDFs). This investigation was carried out in the form of a cross-sectional study involving 200 members of the Naari Dairy Farmers Cooperative Society (NDFCS) randomly selected from 550 active members in the Dairy in May 2015. This study formed the baseline for the calf trial described later.

A census of calves and heifers (up to 36 months of age), sampled from the 200 randomly selected SDFs in Naari, Kenya, formed the study population. Youngstock management was recorded using a questionnaire administered through farmer interviews between May and August 2015. Calf and heifer biodata were obtained through subsequent physical examination and heart girth measurement. Calves and heifers were included in the study if they were male or female animals less than or equal to 15 months old, or female and more than 15 months but less than 36 months of age and had not given birth or had a miscarriage/abortion. None of the young stock was excluded because of having had an abortion/miscarriage. Additional information on the health of each eligible calf/heifer was collected through a physical examination of the calves/heifers, and the weight was estimated using a heart girth tape. Descriptive statistical analyses were conducted, and univariable and multivariable mixed linear regression was used for identification of factors associated ($p < 0.05$) with the natural log transformation of estimated average daily weight gain (ADG).

There were 41 farms that did not have an eligible calf or heifer, and therefore the final dataset consisted of 301 animals from 159 farms. The mean ADG of the 301 animals was 0.443 kg day $^{-1}$ (s.d. = 0.375) with a median of 0.360 kg day $^{-1}$. The calves under 15 months of age had a mean ADG of 0.482 kg day $^{-1}$ (s.d. = 0.441), dropping from 0.750 kg day $^{-1}$ at 2 weeks of age to about 0.6 kg day $^{-1}$ at 3 months of age and 0.35 kg day $^{-1}$ at 10 months old, while the heifers over 15 months of age had a mean ADG of 0.364 kg day $^{-1}$ (s.d. = 0.151). These findings for ADG in this study were generally in agreement with similar studies conducted in Kenya (Gitau et al., 1994) and within the benchmarked performance achievement for Kenyan dairy farms of between 400 to 500 g day $^{-1}$ (Lukuyu et al., 2012). The mean age of calves and heifers combined was 12.5 months (s.d. = 9.5), with a median of 12 months. The population was comprised of 202 calves under 15 months and 99 heifers over 15 months of age. There were 123 female calves and 79 male calves.

Most of the calves and heifers had no history of disease, with only a quarter of them having suffered from navel ill, diarrhea or pneumonia. Among this population of 79 calves and heifers with history of disease, pneumonia was the most common disease affecting 63.3% of them. Women were more often the principal farmer than men. Higher levels of formal education (university/college) were not common among both women and men. More than half (60.4% of women, 57.2% of men) of participating farmers had only obtained a primary school education, or less. The mean land size owned in this area was 2.3 acres (s.d. = 2.9) and, on average, 40.3% (95% CI:39.5 – 44.2%) of land owned was used for dairy production.

Age of the calf or heifer, breed and history of disease were animal-level variables that were significantly associated with ADG. Since the relationship between ADG and age appeared curvilinear, a quadratic form was used for age as a continuous predictor. Weekly supplemental feeding of hay, education level of both the man and the woman, and gender of the principal farmer were farm-level variables that were significantly associated with ADG. Supplementing with quality hay during the dry season at least weekly was associated with 23% increase in ADG. Similarly, Ueno et al., (2014) found that feeding hay during the suckling phase resulted in a significant increase in daily dry matter intake (DMI) which subsequently resulted to increased weight gain. In calves and heifers, the crude protein content in the diet is generally positively associated with weight gain (Moran, 2005a). In this study, there was no significant association between ADG and supplementing diets with concentrates, although at least weekly concentrate feeding, and at least weekly hay feeding were correlated, and both variables were significantly associated with the natural log transformation of ADG in univariable analyses. The concentrates commonly found in this study were dairy meal or calf pellets that had an estimated CP of 14 – 18% (BLGG -Wageningen University, 2013). Only half of the farmers fed either calf pellets or dairy meal to calves at least weekly, and only a quarter of farmers fed hay at least weekly. Due to the cross-sectional nature of this study, it was not possible to accurately assess the quantities fed, although that would have provided better data for the analyses.

There was a significant interaction between breed and history of disease. History of disease was associated with decreased ADG in *Bos taurus* breeds, while ADG in *Bos indicus* breeds were not affected by disease as much. However, the history of disease on our participating farms was unlikely to be completely accurate due to inaccurate memory recall, and these errors may have led to misclassification bias of these results, particularly the unexpected *Bos indicus* results that were based on a relatively small number (n=19) of calves in this category. Alternatively, it is possible that the indigenous breed provided those calves with better immunity to the strains of diseases found in Kenya compared to the exotic *Bos taurus* breeds that were introduced with colonization. Calf diseases have been reported to negatively affect calf and heifer survival, growth, welfare and productivity (Windeyer et al., 2014).

ADG was lower by 20.7% when the principal farmer was female, compared to the baseline of both males and females identified as the principal farmers, whereas there was no statistically significant difference between males identifying as the principal farmer versus the baseline. There was a significant interaction between man's education level and woman's education level. When women's education was low (having less than primary school), ADG was highest when the man had not completed primary school, but ADG was lower when the man had completed primary school, and substantially lower when the man had completed secondary school. There were no differences in ADG, by men's education level, when women finished primary or secondary school. The interaction could be a result of the farmer (man or woman) with better education levels preferring to get off-farm jobs, thus spending less time on farm management. In such cases, farmers relied more on hired labor that was unsupervised on the farm, leading to underfeeding of animals in those farms, but these factors were not examined as part of our study. The intra-class correlation of ADG estimated among farms was 0.25 with 95%CI = 0.14 to 0.42. About 36.6% of the total variation observed in ADG was at the farm level.

These gender and education findings were similar to a study done (Richards et al., 2015a) in Nyeri County, Kenya, where it was observed that overall milk production of farms run by women was lower than those farms run by their male counterparts. However, there was a significant interaction between cattle fodder availability and gender on milk production in that study; farms run by men did not have decreased milk production as a result of a fodder shortage, but those farms run by women did experience decreased milk production when there was a fodder shortage on these small farms, likely because women were busy with other household chores, leaving less time to search for additional cattle fodder compared to men. In our study, on farms where both male and female farmers were equally involved in management, shared responsibility for searching out high quality fodder for calves, even in times of scarcity, was more likely to be successful than if the farm was run by just one person.

The current study was cross-sectional in nature, which normally means that identified factors associated with the outcome may not have occurred prior to the outcome. It would be helpful to carry out a cohort study to better monitor growth of calves and heifers on these smallholder dairy farms, and identify significant factors associated with superior growth. An alternative study for quantifying the benefits of certain growth factors related to management and nutrition would be a field trial, with random allocation to management groups to reduce the effects of confounding variables.

In conclusion, growth in calves and heifers on semi-commercial SDFs in Meru, Kenya, was low compared to internationally expected performance targets (at weaning and at puberty). However, compared to other SDFs in Kenya, the ADG in the study area was within previously reported ranges. Average daily weight gain was found to be significantly associated with age, breed, history of disease, supplementing with hay at least weekly during the dry season, gender of the principal farmer, and education levels of the farmer. Since 26% of youngstock were reported to have had a history of calf-hood disease, farmers should be encouraged to feed 4 liters of colostrum within the first 6 hours of life to enhance passive immunity against these diseases. Supplementation of diets (with hay and/or concentrates) with additional protein and energy is recommended for optimum growth in calves and heifers. Efforts to encourage shared responsibility of farm work coupled with training and capacity-building would likely improve calf rearing and ADG.

7.3 Effects of *Calliandra* and *Sesbania* supplementation on growth of dairy calves on smallholder farms in Meru County, Kenya

The growth rate of female calves on dairy farms is a crucial factor that influences age at first calving, hence affecting lifetime lactation productivity of a dairy cow (Krpálková et al., 2014). From the cross-sectional study, it was evident that calves in SDFs could perform better with improved nutrition. Diets with adequate crude protein are necessary to support calf growth. The current study objective was to ascertain the association between diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban* shrubs and ADG of dairy calves among 80 farms, based on an agroforestry land management system, through a randomized controlled trial.

The 80 trial farms were randomly selected from the sampling frame of 200 semi-commercial SDFs used in the cross-sectional study if they met the inclusion criteria of: active membership with the NDFCS, zero-grazing, and <4 milking cows. Since there were nutrition trials for both lactating cows and calves on these 80 farms, and changes in milk production due to enhanced feeding are likely to be greater in early lactation, days in milk (DIM) was deemed a very important variable for block random allocation of the 80 farms into four intervention groups. The intervention groups were: 1) receiving *Calliandra* & *Sesbania* and nutritional advice; 2) receiving reproductive medicines and advice; 3) receiving both group 1 and 2 interventions; and 4) receiving neither intervention.

All calves/heifers less than or equal to 12 months old were monitored over the 16-month trial period on the 80 farms. Farm nutritional practices and management data were collected in a questionnaire. All farmers were issued with standard spring weighing scales and used large plastic bags for holding quantities of forages for measurement. Measurements and records of all high protein forages were the focus of the scale use on the farms. Weights of other forages were also recorded. Amounts of concentrate fed to calves were determined by weighing the filled containers used to measure concentrates on the farms and recording the number of containers provided daily.

For farmers who had forgotten to record the feeding details in the logbook, feed weights were assessed based on the current portions being fed to the cow on the day prior to the visit. From anecdotal information obtained during a related study in 2015, the feeding regime for each calf was generally quite consistent, at least at the weekly level (Richards et al., 2016).

Farms in the intervention groups were visited monthly for troubleshooting and collection of feeding data while farms in the comparison group were visited bi-monthly for collection of similar data. These feed provision entries for each nutrition intervention calf were averaged for the 2 months to give 1 entry per calf per 2 months. Budget and logistical constraints did not allow for laboratory feed analyses. It was recorded if feeding of calves was complemented with grazing, which occurred on some farms initially classified as zero-grazing, especially in the dry season. Physical examinations were used to monitor weight and health status, along with history of disease since the last visit, at the farm.

Initial statistical analyses compared ADG by intervention groups. However, performance of the shrubs was largely dependent on the farmers' management practices (weeding, watering, manure use, etc.) and prevailing weather conditions (natural availability of water, sunshine, and temperature). Therefore, farmers in the two nutrition intervention groups did not always feed the recommended portions of the foliage all the time, either due to lack of foliage, poor harvesting technique or lack of compliance. For this reason, subsequent data analysis was based on the actual feeding practices of the farmers as opposed to the different study groups. Descriptive statistics and univariable mixed linear regression analyses were conducted, and multivariable mixed linear regression models were used for identification of factors associated ($p < 0.05$) with the natural log transformation of ADG of calves on a given farm, controlling for clustering of visits within calves.

Some farmers appeared to pay less attention to nutrition when calves were more than 6 months old. These farmers kept the calves in the same stalls as the adult cows, with partitions for a separate sleeping and supplementation area, but being fed the same forages as the cows. Therefore, the observations were split into two age groups: less than 6 months old and 6 months old or more. It was assumed that this split analysis would control for any differences attributed to changes in intensity of management between young calves on milk and older weaned calves.

This trial involved 155 calves from 73 SDFs randomly allocated to either the intervention or comparison groups. Seven of the 80 farms were excluded from the study since calves on these farms only had data points when they were less than 1 month old during the study period, making them inappropriate for determining the benefits of feeding *Calliandra calothyrsus* and *Sesbania sesban* to calves 1 to 12 months old. Farmers mostly had 1 or 2 calves under 12 months on a given visit. However, some calves on these farms didn't stay long in the study, either dying or being sold off before completion of the study, leading to fewer observations for these calves. The statistical analysis involved 119 calves <6 months on 68 study farms, and 92 calves ≥ 6 months on 60 study farms.

With the log transformed data, the geometric mean ADG for the study population was 0.275 kg (geometric s.d. 1.0). In the age group <6 months, the geometric mean ADG was 0.361 kg (geometric s.d. 1.2), which was significantly higher than the ADG in the age group ≥6 months of 0.230 kg (geometric s.d. 1.1). However, the geometric mean ADG in the collapsed intervention group <6 months old was 0.345 kg (geometric s.d. 1.5) which was somewhat but not significantly higher than the collapsed comparison group, which had a geometric mean ADG of 0.307 kg (geometric s.d. 1.6). For calves 6-12 months of age, the geometric mean ADG in the collapsed intervention group was 0.225 kg (geometric s.d. 1.4) while in the collapsed comparison group was 0.202 kg (geometric s.d. 1.4) ($p > 0.05$).

There were no significant differences in ADG between the intervention groups. From the final mixed linear regression model for calves < 6 months old, feeding at least 0.2 kg (wet weight) of *Calliandra / Sesbania* to a calf day $^{-1}$ was associated with a 33.2% increase in ADG, while controlling for confounding by breed and sex of the calf. For calves ≥ 6 months, there was a significant interaction between amount of hay fed and if calves were also fed on *Calliandra / Sesbania.* When no *Calliandra / Sesbania* supplementation was provided, the mean ADG was low and relatively constant, even with increasing amounts of hay fed, but when C*alliandra / Sesbania* supplement was added to the diet, the mean

ADG increased from 0.17 kg to 0.48 kg when hay was fed at 1 and 5 kg day $^{-1}$ respectively, while controlling for confounding by amount of maize silage fed and prevailing season. This difference in response in the two age groups could be attributed to the difference in ruminal development and efficiency of ruminal microbial digestion to extract nitrogen from the plant foliage. The rumens of older calves were likely better developed, and ruminal microbes were more efficiently transforming non-protein nitrogen to synthesize their own true protein (Moran, 2005c), and thus even small amounts of *Calliandra / Sesbania* resulted in better ADG.

The study results confirm that both quantity and quality of forage were important for good ADG in the study calves, particularly the calves ≥6 months old because of the significant interaction between *Calliandra* / *Sesbania* feeding and amount of hay fed. Giving some high protein forage and lots of low protein forage can help ADG, with weight gains approaching 0.5 kg day $^{-1}$. While there were some challenges with growing the shrubs on some farms, most farms receiving the shrubs were able to grow them well, providing an inexpensive source of high protein forage for the calves.

Calves <6 months fed on milk had 39.4% higher ADG than when they had been weaned. This decrease with age could be attributed to the reduction in readily available dietary protein when calves switched from a primarily milk diet to a diet with no milk, as the rumen environment may not have adapted yet to effectively digest plant protein (Moran, 2005c). Similarly, ADG was observed to decrease with age within the 6-month age group, which was expected in these farm management systems. This inverse association between age and ADG was similar to growth trends associated with milk-feeding and age observed in other studies (Gitau et al., 1994; London et al., 2012).

An increase in the amount of concentrate (dairy meal/calf pellets) fed was associated with a 33.2% increase in ADG in the younger calves. Dairy meal or calf pellets are formulated to provide easily metabolizable CP in diet. An increase in the amount of concentrate availed more CP to the calves, leading to increased ADG (Lukuyu et al., 2012). Although the CP in good dairy meal is typically lower (~ 16%) than that of good quality calf pellets (18 - 20%) (Moran, 2005a), the subsistence farmers in this study population used dairy meal as a cheaper alternative to calf pellets since they understood the need for concentrate feeding to calves before and after weaning (Makau et al., 2018). However, since farmers in this study population were not as meticulous in their management of older calves (≥ 6 months) as they were with the younger calves (< 6 months), there was no statistical evidence of association between concentrate feeding and ADG in the older calves.

When skin parasites (primarily ticks) were present, mean ADG was estimated to decrease significantly by 31% for calves <6 months and 49.3% for calves ≥ 6 months compared to when calves had no observable skin parasites. This decreased ADG could be because of blood loss from the ticks, or from tick-borne infections, such as East Coast Fever and anaplasmosis, which were endemic in the area, and thus calves with skin parasites were more likely to fall ill and loose body condition (Food and Agriculture Organization, 1993).

Normal appetite was associated with a 51.7% increase in ADG. Poor appetite was also associated with reduced ADG in the final model, in addition to the skin parasite variable, because calves can develop poor appetite from illnesses other than those associated with tick-borne diseases. Calves with poor appetite were clearly not able to consume adequate amounts of CP and energy to support optimal growth.

In conclusion, supplementation of young calf diets (<6 months old) with at least 0.2kg *Calliandra / Sesbania* calf $^{-1}$ day $^{-1}$ should achieve a 33% increase in ADG. Supplementation of older calf diets (6-12 months old) fed on hay would result in a substantial increase in ADG. Smallholder dairy farms in Kenya could adopt agroforestry land use systems to cope with feed shortages and low protein in farm-available feeds for their calves. Tick management and diet supplementation with some concentrate would complement the benefits of *Calliandra* / *Sesbania* on ADG.

Although the *Calliandra / Sesbania* shrubs are known to be tolerant to harsh climatic conditions, the prevailing season was a confounding factor to their effect on ADG in the older calves. This confounding effect of season could have been because of changes in other management practices adopted by the farmers to cope with changes in feed availability during the dry season. The wet seasons during the study were lighter than normal, leading to more severe fodder shortages than normal, forcing farmers to feed fodders of low quality, such as maize stover, banana leaves, and weeds, likely contributing to the low overall ADG, despite the benefit of *Calliandra / Sesbania* on some farms. There was no significant interaction between *Calliandra / Sesbania* being fed and season, however, the small sample size may have made it difficult to find these additional interactions.

We do not report results of models for clustering of calves within farms because we ascertained that there was less clustering of calves within farms (1.6 calves/farm on average) than clustering of visits within calves (3.3 visits/calf on average). However, results of the models controlling for clustering of calves within farms were similar to the reported model results for both age groups.

7.4 Effectiveness of using cellphone technology as a dairy management training tool for smallholder dairy farms in Kenya

From the previous sections, suboptimal nutrition management, feed shortages from small land sizes, and limited knowledge transfer were major constraints facing semi-commercial SDFs in this area. The objective of this trial sought to explore the effect of cellphones as a supplementary training option for communicating dairy health management information to improve smallholder knowledge, and ultimately production and income, although these latter outcomes were not examined in this study.

The sampling frame for this study was the remainder of the 200 randomly selected semi-commercial SDFs in the cross-sectional study that were not in the nutrition trials. Enrollment was based on eligibility criteria of: 1) active membership with the NDFCS; 2) possession of a cellphone; and 3) subscription to the Safaricom carrier as the cellphone service provider. Ninety-five SDFs met the inclusion criteria. Sixty farmers were selected for this study through random number generation. The 60 farmers were randomly allocated into either a comparison (n=30) or intervention (n=30) group. Pre-intervention data were collected through in-person questionnaires on farm and farmer demographic parameters and various dairy health management aspects contained in the cell phone messages. The intervention group received one message per day, 5 days a week for 3 months between June and September 2017. Post-intervention data were collected from both groups during follow-up meetings 3 weeks after completion of the intervention, which included the same dairy health management questions contained in the pre-intervention questionnaire, along with questions on perceptions of the messaging for the intervention group. Focus group discussions also obtained contextual information on the cell phone training.

Pre- and post-intervention knowledge scores were calculated based on responses provided to groups of questions on feeding (n=3), and mastitis prevention (n=7). Each right answer given was allocated a value of 1, while each wrong answer was 0. Responses to all questions within a group were then summed up to provide a score for each individual respondent for that group of questions. Within and between group comparisons and net changes were determined using unpaired and paired t-tests and Chi-squared tests, where applicable.

A total of 40 farmers completed the study, while 20 farmers withdrew from the study. Reasons for loss to follow-up were not perceived to be related to the study or its objectives (e.g. sold the cattle due to drought). As a result, there were 24 and 16 farmers in the intervention and control groups at the end of the trial, respectively.

There were no significant demographic or knowledge score differences between the two groups pre-intervention. Most of the female farmers (78.6%) had only studied up to primary level education, while most of the male farmers (61.5%) had studied up to secondary school level. Analogous to other findings in other areas in Kenya (Richards et al 2015), dairy production was the main source (50-75%) of household income for most (55.0%) farmers. The land acreages in this study population were small, with an average of 2.4 acres available for dairy and crop farming. The average land size of these SDFs was similar to other study findings documented in the region (Mugambi et al 2015) and within the range documented in other areas in Kenya (Omiti et al 2006; Vanleeuwen et al 2012).

All farmers remaining in the intervention group reported that they had received cellphone training messages during the 3-month intervention period. Most intervention farmers reported that they always read the whole message received. More than a third of farmers reported that the messages were very informative. Over half of the farmers felt extremely or very motivated to practically implement the dairy cow management practices from messages such as those covering mastitis prevention, Napier grass feeding and other cow nutrition practices.

Training the intervention group using cellphone messages resulted in significant increases in dairy management knowledge scores in the intervention group. Knowledge on the mastitis prevention practices included using a different wash cloth for each milking cow, drying udder before milking with a clean cloth or paper towel, using a different drying cloth for each milking cow, using a teat dip post-milking, giving fresh feed soon after milking, using dry-cow treatment when drying cows off prior to calving, and not leaving milk in the udder to allow calves to suckle. The mean mastitis prevention knowledge score on comparison farms decreased over time (from 4.3 to 1.8), but in the intervention group, there was an increase in mean score on knowledge of mastitis prevention practices (from 3.8 to 4.7), producing a net change in knowledge on mastitis prevention of 3.4 between the 2 groups ($p < 0.01$).

The knowledge score on feeding practices was assessed based on the understanding of ideal heights for harvesting Napier, need for dairy meal for steaming up cows with dairy meal pre-calving, and colostrum feeding times for newborn calves. The mean knowledge scores in the intervention group remained almost constant (2.2 – pre-intervention & 2.3 – post- intervention) while the comparison group score increased from 2.0 to 2.4 pre- and post- intervention respectively. There was no significant difference in nutrition knowledge scores pre- and post-intervention within the groups.

When asked about the immunity benefits of good nutrition post-intervention, more farmers (58.3% - 14/24) in the intervention group were knowledgeable ($p = 0.04$) on the role of a balanced nutritious diet in supporting the resolution of rain scald compared to 25.0% (4/16) in the comparison group. During the FGDs, farmers from both groups mentioned that feeding cows on short Napier grass and steaming up cows were not very novel concepts to them since they had been trained about them in other seminars as well.

The use of cellphone messaging as a form of information dissemination has been shown to increase farmer-to-farmer training and uptake of various technologies (The World Bank, 2012). The improvements in knowledge of farmers in the intervention group occurred irrespective of previous training and formal education levels. This improvement in knowledge could be attributed to the fact that by using cellphones as a training tool, farmers could keep the information with them at their fingertips on their phones for potentially long periods of time (Martin & Hall, 2011). Farmers mentioned at the intervention FGD that they read most of the messages sent to their phones at any one moment and could retain the messages that provided new information to them and they preferred not to delete them. Similar findings in relation to content retention were observed in another study (Farm Africa, 2015). The findings of our trial had some resemblance to findings in other SDFs in Kenya; a study by (Staal et al 2003) highlighted a positive effect on milk production when farmers in Njoro Sub-County used husbandry information received through mobile phones.

A limitation of this study was the loss to follow-up in both the intervention and comparison groups. The reasons for farmers not completing the trial were unlikely to be related to the study objectives, minimizing any bias from this attenuated sample size. However, a smaller sample size leads to reduced power to detect significant differences between groups. Fortunately, we were still able to find significant differences in knowledge between the groups, even with the smaller sample size.

The results of the current study indicate that SMS technology for feature phones can be an effective training tool for farmers on SDFs in Kenya. Furthermore, the technology may be applicable in remote areas located far from where regular seminars are conducted for dairy farmers and where cellphone coverage is adequate. The bulk educational messaging to farmers can effectively supplement other forms of farmer education. While a significant difference was observed on knowledge levels of trainees, further investigation on effectiveness of this form of training on actual milk production and practices is needed. When smartphones become more common, training that includes pictures and diagrams would likely augment this teaching modality.

7.5 Effects of *Calliandra* and *Sesbania* supplementation on milk production in dairy cattle on smallholder farms in Meru County, Kenya

From the cross-sectional study, the average land acreage utilized by the 200 farmers in this area was about 2.3 acres and not all of it was used for dairy fodder production. The feed produced did not seem to be adequate for the calves, especially in the dry season. Supplementation of calf diets with *Calliandra* and *Sesbania* resulted in increased ADG when examined in the first nutrition trial involving 80 semi-commercial SDFs. Additionally, from the training trial, it was clear that some education on nutritional management best practices for lactating dairy cow would be beneficial to these SDFs. The objective of this trial was to ascertain the association between daily milk production and diet supplementation with *Calliandra calothyrsus* and *Sesbania sesban*, along with in-person nutrition training, in lactating dairy cattle on smallholder farms.

The same 80 farms in the calf nutrition trial were utilized for this cow nutrition trial. The four study groups included: 1) receiving *Calliandra* & *Sesbania* and nutritional advice; 2) receiving reproductive medicines and advice; 3) receiving both group 1 and 2 interventions; and 4) receiving neither intervention. Farm nutritional practices and management data were collected in a questionnaire, and subsequent physical examinations, mastitis tests and milk production of cows on the farm were monitored for 16 months. Measurements and records of all high protein forages were the focus of the weighing scale use on the farms for this trial and weights of other forages were also recorded. Farms in the intervention groups were visited monthly (same visits as the calf nutrition trial) for troubleshooting and milk and feeding data collection, while farms in the comparison group were visited bi-monthly for collection of similar data. For farmers who had forgotten to record the milk and feeding details in the logbook, milk production for the visit was assessed based on the previous day's total milk production for the cow.

Feed weights were also assessed based on the current portions being fed to the cow on the day prior to the visit.

Statistical analyses compared milk production results by intervention groups. However, performance of the shrubs was largely dependent on the farmers' management practices (weeding, watering, manure use, etc.) and prevailing weather conditions (natural availability of water, sunshine, and temperature). Therefore, farmers in the two nutrition intervention groups did not always feed the recommended portions of the foliage, either due to lack of foliage, poor harvesting technique or lack of compliance. For this reason, subsequent data analysis was based on the actual feeding practices of the farmers as opposed to the different study groups.

Descriptive statistics and univariable mixed linear regression were conducted, and multivariable mixed linear regression was used for identification of factors associated ($p < 0.05$) with the natural log transformed daily milk production of cows on a given farm. Adjustments for clustering of visits within cows and cows within farms were made through separate models with random effects, respectively.

In this trial, a total of 607 visits were made to the 80 farms on which a total of 235 cows were included in the study. With a portion of these cows milking at any given visit, 1458 observations were generated during the study period (16 months). Observations when cows were dry were excluded from the analysis. The mean milk production cow $^{-1}$ day $^{-1}$ was 6.39 liters (s.d. 3.5) with a median of 6.0 liters and a range of 0.25 – 27.5 liters. There were no significant differences in milk production between the intervention groups, making the mixed linear regression model important for the statistical analyses.

When controlling for clustering of visits within cows, normal appetite of the animal, BCS, dairy meal, *Calliandra / Sesbania*, and maize silage fed to cows were positively associated ($p < 0.05$) with amount of milk produced on the natural log scale. However, amount of maize germ fed, DIM, pregnancy status of the animal, subclinical mastitis, and sudden changes in their feeding were negatively associated with natural log of daily milk production.

Feeding about 2 kg (wet weight) of *Calliandra / Sesbania* appeared to have the optimum effect of increasing milk production, although this association was not linear, increasing to 2 kg, and then dropping slightly. When controlling for clustering of cows within farms (in a separate analysis), a 1 kg increase of *Calliandra / Sesbania* foliage was estimated to result in 9.4% increase in mean milk production cow $^{-1}$ day $^{-1}$. These leguminous shrubs are high in protein, and thus, supplemented the CP necessary for good milk production in dairy cows feeding on poor quality feed (Paterson et al., 1999; Cook et al., 2005; Franzel et al., 2013).

When controlling for clustering of visits within cows and clustering of cows within farms, milk production was estimated to peak within the first 100 DIM, as expected, before consistently declining for the rest of the lactation period, with a small number of cows in late lactation (500-900 DIM). This milk production curve was similar to other studies that depicted the physiological norm of daily milk production in dairy cows, with peak production experienced about 2 months postpartum (Silvestre et al., 2009; Macciotta et al., 2011). Although the optimum milk production was observed when BCS was 3.5, on rare occasions, cows had a BCS more than 3.5, but they were not accompanied with better milk production because their DIM was high (>275 days). Poor body condition is indicative of a current or previous negative energy balance in a cow (Moran, 2005a), which affects milk production, milk composition and reproduction of dairy cows (Vries & Veerkamp, 2000).

When controlling for clustering of visits within cows or clustering of cows within farms, a kg increase in dairy meal (between 0-7kg) and maize silage (between 0-30 kg) resulted in at least 4% and 0.8% increase in mean milk production cow $^{-1}$ day $^{-1}$, respectively. Dairy concentrate findings of this study were in agreement to several other studies (Romney et al., 2000; Oetzel, 2015; Richards et al., 2016; Bii, 2017). Maize silage in this area was mostly made of whole maize plants harvested at the 'milk' stage. Other additives included during silage preparation were wheat bran / molasses / urea, depending on the preference, accessibility and availability of these products to farmers. Similar practices, such as those aimed at improving the available protein (Yitbarek & Tamir, 2014) and metabolizable energy (ME) content (Kordi & Naserian, 2012) and supporting the fermentation process (Meng-zhen & Yi-xin, 2013) in silage, have been documented in countries such as Zambia (Smith, 2010). Adding a good amount of maize silage to the daily cow ration would provide additional CP and energy necessary for better milk production.

When controlling for clustering of visits within cows, feeding maize germ and abrupt feed change was associated with 27.1% and 10.0% decrease in milk production cow $^{-1}$ day $^{-1}$. Abrupt changes in diets of dairy cows likely resulted in reduced feed intake as the cows' rumens adapted to the new diet introduced. Some farmers using maize germ formulated feed rations at home. This process could have resulted in a diluting effect when nutrients were not balanced due to unavailability of certain feeds, or due to inadequate skill by the farmer to formulate feed (Changwony & Kitilit, 2014). An evaluation of the different homemade concentrate mixes that farmers used on their farms, and their nutritional content, would be helpful in quantifying the effect of this farm practice.

When controlling for clustering of visits within cows, poor appetite resulted in decreased milk production cow $^{-1}$ day $^{-1}$ by 23.4%. The effect of good appetite was similar to findings in other studies where higher DMI was associated with better milk production since such animals would more likely have enough CP and ME for higher milk production (Johnson et al., 2003; Smith & Brouk, 2014). Subclinical mastitis was associated with up to 6% decrease in daily milk production compared to when there was no mastitis. Findings of our study were similar to another study in SDFs in Kenya (Richards et al., 2016). Damage of mammary tissue, due to infection, especially milk secretory epithelia, affects milk yield (Gonçalves et al., 2016) and composition (Batavani et al., 2007).

When controlling for clustering of cows within farms, feeding Napier grass resulted in 7.6% increase in mean milk production cow $^{-1}$ day $^{-1}$. Napier grass provides some CP and energy (Moran, 2005b) to the cows over and above what was received through other diets fed to the cows, thus improving milk production. These findings were in agreement with another study (Karuga, 2011). Pregnancy resulted in a 25.8% drop in mean milk production cow $^{-1}$ day $^{-1}$. Pregnant cows spend more of their energy to support pregnancy and consequently reduce the amount of milk produced (Olori et al., 1997; Bohmanova et al., 2006; Penasa et al., 2016).

The allocation of 20 farms to four groups was based on the intended intervention of *Calliandra / Sesbania* foliage being fed to cows in the 2 intervention groups (nutrition and combined), with the hypothesis that the combined group would experience a synergistic positive effect on conception (results in a related paper). Due to some practical challenges associated with growing the shrubs, farmers in the intervention groups did not all feed equal amounts of the shrub foliage all the time. For this reason, data analysis was based on the actual feeding practices of the farmers as opposed to the different study groups.

In conclusion, our field trial data confirm that use of *Calliandra* / *Sesbania* through agroforestry can improve milk production in semi-commercial SDFs in Kenya. Agroforestry land use systems can be adopted as a way for dairy farmers to cope with feed shortages and low crude protein in farm-available feeds for their cows. Investigations on the financial implications of using agroforestry system to feed *Calliandra* and *Sesbania* to cows compared to their productivity would also elucidate the sustainability and possible wider adoptability of this intervention by SDFs in Kenya.

7.6 Impact of supplementing *Calliandra* and *Sesbania* as cattle feed on sustainable family livelihoods in Naari Sub-Location, Meru County, Kenya

In earlier sections, supplementation of cow and calf diets with *Calliandra* and *Sesbania* was associated with increased milk production and ADG in 80 semi-commercial SDFs involved in the 2 nutrition trials. However, the impact of the *Calliandra* and *Sesbania* supplementation on the incomes and livelihoods of the SDFs remains unclear. The objective of this study was to assess the impact of using *Calliandra* and *Sesbania* as feed supplements for dairy cows on family incomes and livelihoods during a 16-month trial period.

The 80 farms randomly allocated to four intervention groups (nutrition, reproduction, combined nutrition and reproduction, and a comparison group) were enrolled in this study. As mentioned in earlier sections, the nutrition intervention included nutritional management advice and 150 *Calliandra* seedlings and 150 *Sesbania* seedlings to each farm. Farms in the 2 nutrition intervention groups were visited monthly during the trial to troubleshoot any issues with the tending or harvesting of the *Calliandra* and *Sesbania* shrubs, or the reproduction intervention, and to collect data on milk production and feeding practices during the previous day. Farms in the reproduction only group and comparison group were visited monthly and bi-monthly to collect similar milk and nutrition data, respectively.

Seventy of these farms completed the trial and therefore were involved in this analysis. Partial budget analysis was used to assess marginal changes in revenues in Kenya shillings (KES) by comparing farms receiving nutrition interventions with those not receiving nutrition interventions. A comparison of milk production and feeding data was done for the baseline (i.e. first 6 months – July to Dec 2016) and the end-line (i.e. last 6 months of the trial – May to October 2017) for each farm. This partial budget was focused on the milk production revenue and typical purchased feed costs and assumed that all other costs (e.g. labor associated with tending and harvesting fodder crops) were constant. Purchased feeds of interest for the analyses were dairy meal, maize germ, wheat bran and mineral supplementation. Maize silage was also included due to the costs involved in the preparation and storage. Profit was calculated as the difference between average monthly income cow $^{-1}$ and average monthly feeding cost cow $^{-1}$. The profit was used for analysis of net change in monthly profit cow $^{-1}$ between the first six months and last six months within groups by intervention group, and between intervention groups at the end of the trial. The cost of the *Calliandra* and *Sesbania* seedlings was a one-time small cost, and therefore wasn't included in the analysis but is factored in at the end.

Additionally, a post-intervention questionnaire was administered to collect data on the knowledge, attitudes and practices (KAP) of the farmers at the end of the trial period. These data were used to assess KAP differences by intervention group, which contributed to indirect indicators of livelihoods. These indicators included: 1) feeling of empowerment in dairy management, 2) knowledge and awareness of general nutrition and use of *Calliandra / Sesbania* shrubs on their farms, and 3) confidence in management of dairy cows and calves. Focus group discussions (FGDs) provided contextual information on livelihood effects from the trial.

The average farmland size and number of milking cows was similar among the 80 farms starting the trial and the 70 farms completing the trial 16 months later. The average monthly milk production among the 70 farms ranged between 161.5 – 204.5 liters cow $^{-1}$ at baseline, depending on the group, and between 167.9 – 237.2 liters cow $^{-1}$ at the end of the study, which increased in all groups except the farms in the combined group who had a 17.6 liter decrease in their average milk production. These changes in milk production were significant in the nutrition and reproduction groups.

The average price of milk, calculated as an average of prices offered to the farmers by NDFCS during the trial period, was KES 37.00 liters $^{-1}$. The average cost of dairy meal was calculated as the average retail price of all dairy meal brands sold at the NDFCS during the trial period, which was 34.8 KES kg $^{-1}$. The same approach was used for the other feeds of interest, producing the following average costs: maize germ (18.7 KES kg $^{-1}$), bran (19.0 KES kg $^{-1}$), and mineral supplement (0.6 KES g $^{-1}$). The estimated cost of maize silage was 12.8 KES kg $^{-1}$, calculated as an average of retail prices for silage, equipment and labor costs for silage-making documented between 2015 and 2018 (Sawa, 2015; Caroline, 2016; Nanjinia, 2018; Obi, 2018).

The mean monthly feeding expenditure decreased, from an average of KES 3,325.1 – 4,699.6 (USD 32.9 – 46.4) cow $^{-1}$ at baseline, depending on the group, to KES 2,286.9 – 3,597.5 (USD 22.6 – 35.6) cow $^{-1}$ at end-line ($p < 0.05$). There was a KES 2,380.3 (USD 23.5) increase in average monthly profit cow $^{-1}$ in the nutrition only group, comparing the first and last 6 months of the trial, representing a 68.8% improvement ($p = 0.02$). This increase in milk production would be largely attributed to the nutritional interventions implemented on farms in this group. Studies done elsewhere documented similar findings after adoption of different feeding interventions in SDFs (Omore et al., 2004; VanLeeuwen et al., 2012). With an average of more than 50% of household income in SDFs attributed to dairy production, this increase would undoubtedly translate to better livelihoods (VanLeeuwen et al., 2012).

The cost for *Calliandra* and *Sesbania* seedlings at the time of publication in Kenya was approximately KES 25, therefore 300 seedlings would total KES 7,500. Assuming the seedlings were purchased at this price, with the nutrition group having increased its monthly profit by over KES 2,300, the return on the investment would only take 3.5 months, after which time, the additional profit would be available for other expenditures.

Compared to the comparison and reproduction groups, all the farmers in the nutrition group and most of the combined group (88.2%) felt they were more empowered in dairy management. This empowerment was evident through increased knowledge. Significantly more farmers in the nutrition and combined group than the comparison group correctly indicated that the main benefit of colostrum was boosting calf immunity. Better knowledge of dairy nutrition would promote better on-farm and off-farm decision-making, thus resulting in more efficient farm management and increased profits, leading to improved livelihoods (Chapman et al., 2003).

More farmers in both the nutrition and combined groups than the comparison and reproduction groups reported that agroforestry could be a sustainable land use system. Generally, SDFs in this area, as is common in other parts of Kenya, are on relatively small acreages (Richards, 2017; Maina et al., 2018). Adoption of agroforestry would reduce vulnerability to, and effects of, feed shortages on household income and economies, translating to improved and sustainable livelihoods (Kiptot et al., 2014; General Secretariat of the Organization of American States, 2015).

During the FGDs, farmers reported that the leguminous shrubs helped mitigate the effects of feed shortage in milk production. Given the central role of dairy farming in this community, it was clear that any benefits in productivity and profit observed on the farms translated to better livelihoods for the household. Similar findings were observed in a longer study that integrated more interventions to improve SDFs production in rural Kenya (VanLeeuwen et al., 2012). Farmers in Ethiopia, Zimbabwe and Uganda also reported benefits through increased milk production and reduction in feeding costs (i.e. reduced dairy meal use) (Cook et al., 2005; Franzel et al., 2013; Richards, 2017).

In conclusion, the nutritional interventions (education and *Calliandra / Sesbania* shrubs) had positive financial and educational (direct and indirect) impacts on the livelihoods of farmers. Agroforestry, using *Calliandra / Sesbania*, can improve household incomes and livelihoods if adopted by SDFs in Kenya.

Among the limitations of this study, farmers in this trial were not able to accurately indicate how much time they used to plant and manage the shrubs. Lack of that additional information limited the quantification of indirect costs and opportunity costs of having the shrubs on the farm. These potential costs were not factored into the partial budget. However, it is anticipated that the labour to manage the shrubs beyond the first few months when the shrubs were establishing their roots would be minimal and would be similar to the management of other forage crops in terms of tending, fertilizing, and harvesting the forage crops. Secondly, the random allocation did not lead to completely equal farm and animal demographics and management, due to the small size of the farms and there being just 20 farms in each group. Breed, DIM, prevalence of subclinical mastitis, and pregnancy status were not identical between groups, and the number of cow observations during the different seasons was not the same among the four trial groups at baseline. However, factors, such as pregnancy and DIM, would be less likely to affect profit since farmers would likely reduce purchased feeds provided to pregnant cows and those with high DIM, coinciding with their lower milk production. Therefore, these group differences could produce some bias on our findings.

Notwithstanding these possible confounding factors on the milk production and profit, the estimates of improvements to these outcomes from the nutritional interventions are likely conservative for several reasons. The initial 6 months was a quasi-baseline in the sense that there were already nutritional interventions in the form of nutritional advice provided to the farmers during this time. However, a monitoring period prior to this time frame was not possible for logistical reasons. Secondly, the research team noticed that on a minority of farms with leguminous shrubs, the shrubs were already being harvested and fed to the cows during this first six months of baseline. Both of these circumstances likely led to a baseline level of milk production that was likely higher than if neither of these situations happened.

As a third limitation, due to the close geographical placement of the intervention and comparison farms, there was likely some level of unintentional information transfer to the comparison farmers from the intervention farmers. This information transfer could bias the responses from those comparison group farmers and the measurements of their cows. If anything, this bias would only make the estimates in the differences in profits between groups more conservative than they really are.

A more detailed study on the impact of intercropping these shrubs with food crops and using them in the long-term sustainability of agricultural ecosystems and nutrition levels of families would elucidate other benefits not explored in these analyses.

7.7 Linked conclusions

The cross-sectional study established the baseline characteristics of semi-commercial SDFs in the Naari area. The arithmetic mean ADG of calves and heifers < 36 months old on the 200 SDFs in Naari was 0.443 ± 0.375 kg day $^{-1}$ with a median of 0.360 kg day $^{-1}$. This weight gain was within the benchmarked performance typical for dairy farms in the East African region of between 0.4 to 0.5 kg day $^{-1}$. However, for a sub-set of calves (1-12 months), the geometric mean ADG for the 80 farms (nutrition trial) in this study population was 0.275 kg was relatively lower than earlier reported in East Africa. In both study populations, the ADG data were right-skewed, with the majority of animals having poor ADG and some having good or excellent ADG. The key difference between the two populations was that the calf trial population excluded the larger farms from the cross-sectional study population, and it was on these larger farms that there was ample milk to feed calves with larger volumes of milk, and sufficient income to enable consistent feeding of calf pellets or dairy meal to the calves. The SDFs excluding the larger farms clearly have a need for enabling measures to improve their youngstock feeding and nutrition practices.

From the 2 nutrition trials, it was evident that use of *Calliandra* and *Sesbania* had some positive effects on their production units, ADG and milk production for calves and lactating cows, respectively. From the partial budget we found an increase in profits due to increased milk production and reduced feeding expenditure in the nutrition group comparing pre- and post-intervention. The impact of higher ADG on milk productivity from the calf nutrition trial could not be explored due to biological and logistical constraints; the calf nutrition trial was part of a Ph.D. thesis that had a limited time span and the trial calves/heifers were not lactating by the end of the nutrition trial.

Although the level of education of the 200 farmers in the cross-sectional study was significantly associated with calf growth, the subsequent assessments of ADG, milk production, nutrition and mastitis management knowledge in the 3 field trials indicated that formal education was not a significant determinant for successful production enhancement or knowledge gain using cellphones. In the cellphone randomized controlled trial, irrespective of the level of formal education, knowledge on best management practices for dairy farmers was low in both comparison and intervention groups pre-intervention.

In a bid to improve knowledge levels, most smallholder farmers (>60%) in the study attended seminars and training workshops, mostly organized by cooperatives, NGOs and other industry players. However, less than half of the 60 farmers at the start of the cellphone study were able to recall details of the trainings they had attended within the last year pre-intervention, suggesting that booster training, perhaps through cellphones, would provide better long-term benefits of training. Comparison groups in all trials improved somewhat during the trials, demonstrating the desire for information among the farmers, that leads to dissemination of information from intervention to control farms, either intentional or unintentional. For example, the cellphone training led to farmer-to-farmer education as a result of increased discussions following consultations with veterinarians when messages were unclear, contributing to wide dissemination of training, and potentially long-term benefits.

Comparable to studies done elsewhere in Kenya (VanLeeuwen et al., 2012), dairy production was the main source of income for most (55.0%) farmers in this study. However, the land acreages in this study population were generally small, with an average of 2.3 acres available for dairy and crop farming. Farmers reported that they allocated at least 50% of the available land for dairy production. With the severe land constraints, the vertical growth of the leguminous shrubs examined in the ADG and milk production trials could be a very useful agroforestry system for efficient use of available land, particularly in place of existing hedge-rows and property borders.

From the sustainable livelihoods section, it was evident that the nutrition intervention (agroforestry and education) had resulted in not only additional milk production, but also improved knowledge and farmer empowerment. Farmers in the nutrition and combined groups were significantly more knowledgeable and aware of good dairy nutrition practices compared to the comparison and reproduction groups. Better knowledge of dairy nutrition would promote better on-farm and off-farm decision-making, thus resulting in more efficient farm management and increased profits, leading to improved livelihoods. Furthermore, adoption of agroforestry would reduce vulnerability to, and effects of, feed shortages on household income and economies, translating to improved and sustainable livelihoods. In addition, farmers in the nutrition and combined groups felt that agroforestry could be a sustainable land use system, based on their experience in the trial.

7.8 Overall recommendations

Based on the findings of these analyses, we would like to make the following recommendations to semi-commercial SDFs in Kenya and elsewhere where semi-commercial SDFs have similar conditions:

1) One of the challenges for most SDFs is feed shortage during the dry seasons, which is exacerbated by small land acreages used by the farms for dairy production. Agroforestry land management can be used to utilize available resources for optimal dairy production. Feeding cows on 2 kg (wet weight) of *Calliandra* or *Sesbania* cow $^{-1}$ day $^{-1}$ supports better milk production. Benefits from feeding *Calliandra / Sesbania* to calves are best observed if at least 0.2 kg calf $^{-1}$ day $^{-1}$ is fed. Agroforestry land use systems using *Calliandra / Sesbania* should be adopted as a way for dairy farmers to cope with shortages and poor quality of farm-available fodder for their cattle. Institutional support structures, agricultural extension, infrastructure and policies, via public private partnerships, should be improved to promote this land management model for improved and sustainable livelihoods.
2) Nutritional management is a crucial part to optimum dairy farm management. Supplementation of cow or calf diets with maize silage, Napier grass, hay and/or concentrates (dairy meal, wheat bran) results in improved milk production and calf growth and should be promoted in training sessions given by governmental and non-governmental organizations. Abrupt feed changes and improper homemade concentrate formulations have negative impacts on milk production and should be avoided. Smooth transition when changing feed for dairy cows should be practiced for consistent daily milk production. Additionally, only quality-certified concentrate feed should be used. Alternatively, advice on homemade mixes should be sought

from skilled personnel. Governments and institutions of higher education could establish programs and certifications to facilitate this human resource development.

3) Conventional daylong seminars may not be effective for long-term content retention. While on-going agricultural extension and farmers' field school (FFS) can support capacity building among SDFs, sustained regular sessions may also not be possible in some areas. Cellphone text messaging to farmers can effectively supplement the different forms of farmer education. Furthermore, information and communication technology (ICT) could and should be applied in remote areas located far from where regular seminars are conducted for dairy farmers with cellphone coverage.

4) Common calf-hood diseases such as navel ill, diarrhea, and pneumonia affect both calf growth and welfare. Feeding calves appropriate amounts of colostrum in a timely manner enhances passive immunity to some of these calf-hood diseases. Farmers should feed at least 4 liters of colostrum within the first 6 hours of life.

5) Some sociocultural factors influence how most societies distribute roles among genders. There is a synergistic benefit to farm production when both male and female farmers are involved in managing the SDFs, and shared responsibility of farm work should be encouraged. When principal farmers are mostly working off-farms, training and capacity-building for hired help should be done to minimize the farm impact of absences of principal farmers for better calf management and growth.

6) Attention to skin parasites and other chronic diseases, such as subclinical mastitis, should be given routinely on dairy farms to improve youngstock ADG and milk production. Parasites, such as ticks, could predispose calves and cows to diseases, resulting in poor appetite, and reduced weight gain and milk production, respectively.

Moreover, routine testing for mastitis using the CMT and implementation of mastitis prevention practices, such as maintaining udder hygiene and teat dip should be adopted to mitigate the losses due to milk rejection, treatment and reduced production.

7.9 References

Batavani, R. A., Asri, S., & Naebzadeh, H. (2007). The effect of subclinical mastitis on milk composition in dairy cows. *Iranian Journal of Veterinary Research*, *8*(3), 205–211. Retrieved from http://ijvr.shirazu.ac.ir/article_925_8c286f02d8fb54b4bf530539cc1f950c.pdf

Bii, B. (2017). Dairy farmers face high cost of feeds as drought bites - Daily Nation. Retrieved August 11, 2017, from http://www.nation.co.ke/business/Dairy-farmers-face-high-cost-of-feeds/996-3800550-ckwc4oz/index.html

BLGG -Wageningen University. (2013). *Study on the Kenyan Animal Feed and Fodder Sub - sectors. Quality Analysis of animal feedstuffs and fodders in Kenya (Sub-report V). pp 57*. Wageningen.

Bohmanova, J., Miglior, F., Kelly, M., Kistemaker, G., & Loker, S. (2006). Effect of pregnancy on milk yi eld of Canadian dairy cattle. Retrieved July 18, 2018, from https://www.cdn.ca/Articles/GEBSEPT2006/Effect_of_Pregnancy_on_Milk_Yield.pdf

Caroline, W. (2016, April 22). Youth chama turns silage into a money-maker. *Daily Nation*. Retrieved from https://www.nation.co.ke/business/seedsofgold/Youth-group-making-money-from-preparing-silage/2301238-3170310-5hrrfp/index.html

Chapman, R., Slaymaker, T., & Young, J. (2003). *Livelihoods Approaches to Information and Communication in Support of Rural Poverty Elimination and Food Security*. *Bridging Reasearch and Policy*. London, United Kingdom. Retrieved from http://www.odi.org.uk/resources/details.asp?id=164&title=livelihoods-approaches-information-communication-support-rural-poverty-elimination-food-security

Cook, B., Pengelly, B., Brown, S., Donnelly, J., Eagles, D., Franco, A., … Schultze-Kraft, R. (2005). Calliandra calothyrsus. Retrieved June 25, 2018, from http://www.tropicalforages.info/key/forages/Media/Html/entities/calliandra_calothyrsus.htm

Farm Africa. (2015). Testing the Use of Mobile Technology To Improve Smallholder Sesame Cultivation. Retrieved May 14, 2018, from https://www.farmafrica.org/downloads/resources/ict244lowres.pdf

Food and Agriculture Organization. (1993). Parasites in dairy cattle and buffalo. In *Small Scale Dairy Farming Manual* (5th ed., pp. 143–172). Chiangmai, Thailand: Regional Dairy Development and Training Team for Asia and Pacific. Retrieved from http://www.fao.org/AG/againfo/themes/documents/Dairyman/Dairy/V5U10_6.htm

Franzel, S., Carsan, S., Lukuyu, B., Sinja, J., & Wambugu, C. (2013). Fodder trees for improving livestock productivity and smallholder livelihoods in Africa. *Current Opinion in Environmental Sustainability*, *6*(1), 98–103. https://doi.org/10.1016/j.cosust.2013.11.008

General Secretariat of the Organization of American States. (2015). How to rapidly assess the effects of the application of CITES decisions on livelihoods in poor rural communities. In F. A. F. Ochoa (Ed.), *Handbook on CITES and livelihoods* (pp. 1–44). Washington D.C., USA: Department of Sustainable Development.

Gitau, G. K., McDermott, J. J., Waltner-Toews, D., Lissemore, K. D., Osumo, J. M., & Muriuki, D. (1994). Factors influencing calf growth and daily weight gain on smallholder dairy farms in Kiambu District of Kenya. *Preventive Veterinary Medicine*, *21*(2), 179–190.

Gonçalves, J. L., Martins, C. M. D. M. R., Barreiro, J. R., Tomazi, T., Gameiro, A. H., Kamphuis, C., … Santos, M. V. (2016). Effect of bovine subclinical mastitis on milk yield and composition. Retrieved July 18, 2018, from http://nmconline.omnibooksonline.com/nmc-annual-meetings

Johnson, C. R., Lalman, D. L., Brown, M. A., Appeddu, L. A., Buchanan, D. S., & Wettemann, R. P. (2003). Influence of milk production potential on forage dry matter intake by multiparous and primiparous Brangus females. *Journal of. Anim. Sci.*, *81,* 1837–1846.

Karuga, J. (2011, May 10). Napier grass farming method promises higher milk yield. *Business Daily*. Retrieved from https://www.businessdailyafrica.com/magazines/1248928-1159188-ekbw32z/index.html

Kiptot, E., Franzel, S., & Degrande, A. (2014). Gender, agroforestry and food security in Africa. *Current Opinion in Environmental Sustainability*, *6*(1), 104–109. https://doi.org/10.1016/j.cosust.2013.10.019

Kordi, M., & Naserian, A. A. (2012). Influence of wheat bran as a silage additive on chemical composition , in situ degradability and in vitro gas production of citrus pulp silage. *African Journal of Biotechnology*, *11*(63), 12669–12674. https://doi.org/10.5897/AJB12.767

Krpálková, L., Cabrera, V. E., Vacek, M., Stípková, M., Stádník, L., & Crump, P. (2014). Effect of prepubertal and postpubertal growth and age at first calving on production and reproduction traits during the first 3 lactations in Holstein dairy cattle. *Journal of Dairy Science*, *97*(5), 3017–3027. https://doi.org/10.3168/jds.2013-7419

London, M. L., Bernard, J. K., Froetschel, M. A., Bertrand, J. K., & Graves, W. M. (2012). The relationship between weight, age, and average daily gain to show performance of Georgia 4-H and Future Farmers of America (FFA) commercial dairy heifers. *Journal of Dairy Science*, *95*(2), 986–996. https://doi.org/10.3168/jds.2011-4599

Lukuyu, B., Gachuiri, C. K., Lukuyu, M. N., Lusweti, C., & Mwendia, S. (2012). *Feeding dairy cattle in East Africa*. (B. Lukuyu & C. Gachuir, Eds.), *Feeding dairy cattle in East Africa* (First). Nairobi, Kenya: East Africa Dairy Devleopment Project. Retrieved from https://cgspace.cgiar.org/bitstream/handle/.../EADDDairyManual.pdf

Macciotta, N. P. P., Dimauro, C., Rassu, S. P. G., Steri, R., & Giuseppe, P. (2011). The mathematical description of lactation curves in dairy cattle The mathematical curves in dairy cattle. *Italian Journal of Animal Science*, *10*(4). https://doi.org/10.4081/ijas.2011.e51

Maina, F., Mburu, J., Gitau, G., VanLeeuwen, J., & Negusse, Y. (2018). Economic efficiency of milk production among small-scale dairy farmers in Mukurweini, Nyeri County, kenya. *Journal of Development and Agricultural Economics*, *10*(5), 152–158. https://doi.org/10.5897/JDAE2017.0915

Makau, D. N., VanLeeuwen, J. A., Gitau, G. K., Muraya, J., McKenna, S. L., Walton, C., & Wichtel, J. J. (2018). Animal and management factors associated with weight gain in dairy calves and heifers on smallholder dairy farms in Kenya. *Preventive Veterinary Medicine*, *161*, 60–68. https://doi.org/https://doi.org/10.1016/j.prevetmed.2018.10.017

Martin, B. L., & Hall, H. (2011). *Mobile Phones and Rural Livelihoods : Diffusion , Uses , and Perceived Impacts Among Farmers in Rural Uganda* (7 No. 4) (Vol. 7). Annenberg.

Meng-zhen, Q. I. N., & Yi-xin, S. (2013). Effect of Application of a Bacteria Inoculant and Wheat Bran on Fermentation Quality of Peanut Vine Ensiled Alone or with Corn Stover. *Journal of Integrative Agriculture*, *12*(3), 556–560. https://doi.org/10.1016/S2095-3119(13)60257-9

Moran, J. (2005a). Nutrition and young stock. In Peter Storer Editoral Services (Ed.), *Tropical Dairy Farming: Feeding Management for Small Dairy Farmers in the Humid Tropics* (First, pp. 183–190). Collingwood,Australia: CISRO Publishing. Retrieved from http://samples.sainsburysebooks.co.uk/9780643107892_sample_295356.pdf

Moran, J. (2005b). Supplements for milking cows. In Department of Primary Industries (Ed.), *Tropical dairy farming : feeding management for small holder dairy farmers in the humid tropics* (pp. 99–112). Melbourne,Australia: CSIRO Publishing.

Moran, J. (2005c). The nutrient requirements of calves. In Peter Storer Editoral Services (Ed.), *Rearing Young Stock on Tropical Farms in Asia* (First, pp. 31–39). Collingwood,Australia: CISRO Publishing. Retrieved from http://www.publish.csiro.au/ebook/chapter/9780643107427_Chapter4

Mugambi, D. K., Mwangi, M., Kairu, S., & Gitunu, A. M. (2015). Assessment of performance of smallholder dairy farms in Kenya : an econometric approach. *Journal of Applied Biosciences*, *82*, 7891–7899. https://doi.org/10.4314/jab.v85i1.13

Nanjinia, W. (2018, April 7). Silage bale wrapping, new trend in fodder packaging lasts two years. *Standard Digital*. Retrieved from https://www.standardmedia.co.ke/business/article/2001275988/silage-bale-wrapping-new-trend-in-fodder-packaging

Obi, L. (2018, March 31). Storing silage in pits is out of date; savvy farmers now bale it. *Daily Nation*. Retrieved from https://www.nation.co.ke/business/seedsofgold/Introducing-silage-baling/2301238-4365374-90rekvz/index.html

Oetzel, G. R. (2015). Subacute Ruminal Acidosis in Dairy Herds : Physiology , Pathophysiology , Milk Fat Responses , and Nutritional Management. In University of Wisconsin School of Veterinary Medicine (Ed.), *Preconference Seminar 7A: Dairy Herd Problem Investigation Strategies: Lameness, Cow Comfort, and Ruminal Acidosis* (pp. 89–119). Vancouver, BC, Canada: American Association of Bovine Practitioners. Retrieved from https://www.vetmed.wisc.edu/dms/fapm/fapmtools/2nutr/sara1aabp.pdf

Olori, V., Brotherstone, S., Hill, G. W., & McGuirk, B. J. (1997). Effect of gestation stage on milk yield and composition in Holstein Friesian dairy cattle. *Livestock Production Science*, *52*, 167–176. https://doi.org/10.1016/S0301-6226(97)00126-7

Omiti, J., Wanyoike, F., Staal, S., & Delgado, C. (2006). Will Small-Scale Dairy

Producers in Kenya Disappear Due to Economies of Scale in Production ? Retrieved July 22, 2018, from https://ageconsearch.umn.edu/bitstream/25674/1/cp060516.pdf

Omore, A., Mulindo, J. C., Islam, S. M. F., Nurah, G., Khan, M. I., Staal, S. J., & Dugdill, B. T. (2004). *Employment generation through smallscale dairy marketing and processing* (FAO Animal and Production Health No. 158). Rome. https://doi.org/ISBN: 9251049807 ISSN: 0254-6019

Paterson, R. T., Kiruiro, E., & Arimi, H. K. (1999). Calliandra calothyrsus as a supplement for milk production in the Kenya highlands. *Tropical Animal Health and Production*, *31*(2), 115–126. https://doi.org/10.1023/A:1005119808090

Penasa, M., Marchi, M. De, & Cassandro, M. (2016). Short communication : Effects of pregnancy on milk yield , composition traits , and coagulation properties of Holstein cows. *Journal of Dairy Science*, *99*, 4864–4869. https://doi.org/10.3168/jds.2015-10168

Richards, S. M. (2017). *Productivity and welfare of cows on smallholder dairy farms in Kenya*. University of Prince Edward Island. Retrieved from https://www.islandscholar.ca/islandora/object/ir%3A21369/datastream/PDF/download

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G. K., Kamunde, C., Uehlinger, F., & Wichtel, J. (2015a). Associations of farm management practices with annual milk sales on smallholder dairy farms in Kenya. *Veterinary World*, *8*(1), 88–96. https://doi.org/10.14202/vetworld.2015.88-96

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G. K., Kamunde, C., Uehlinger, F., & Wichtel, J. (2015b). Associations of farm management practices with annual milk sales on smallholder dairy farms in Kenya. *Veterinary World*, *8*(1), 88–96. https://doi.org/10.14202/vetworld.2015.88-96

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G. K., Wichtel, J., Kamunde, C., & Uehlinger, F. (2016). Randomized controlled trial on impacts of dairy meal feeding interventions on early lactation milk production in smallholder dairy farms of Central Kenya. *Preventive Veterinary Medicine*, *3954*, 1–8. https://doi.org/doi:10.1016/j.prevetmed.2016.01.006

Romney, D., Kaitho, R., Biwott, J., Wambugu, M., Chege, L., Omore, A., … Thorpe, W. (2000). Technology development and field testing: access to credit to allow smallholder dairy farmers in Central Kenya to reallocate concentrates during lactation,. In *3rd All Africa Conference on Animal Agriculture.* (pp. 1–7). Alexandria, Egypt: Egyptian Society of Animal Production. Retrieved from https://cgspace.cgiar.org/handle/10568/1588

Sawa, P. (2015, December 7). Kenya Dairy farmers make maize silage to maximize profits. *Barzawire*. Retrieved from http://wire.farmradio.fm/en/farmer-stories/2015/12/kenya-dairy-farmers-make-maize-silage-to-maximize-profits-13241

Silvestre, A. M., Martins, A. M., Santos, V. A., Ginja, M. M., & Colaço, J. A. (2009). Lactation curves for milk , fat and protein in dairy cows : A full approach. *Livestock Science*, *122*(2–3), 308–313. https://doi.org/10.1016/j.livsci.2008.09.017

Smith, J. F., & Brouk, M. J. (2014). Factors affecting dry matter intake by lactating dairy cows. *Kansas Agricultural Experiment Station Research Reports*, *0*(2), 52–58. https://doi.org/10.4148/2378-5977.319

Smith, T. (2010). Some Tools To Combat Dry Season Nutritional Stress in Ruminants Under African Conditions. In *Development and field evaluation of animal feed supplementation packages* (pp. 145–152). Austria: Internatonal Atomic Energy Agency. Retrieved from https://www.researchgate.net/publication/237254680

Staal, S. J., Waithaka, M., Njoroge, L., Mwangi, D. M., Njubi, D., & Wokabi, A. (2003). *Costs of milk production in Kenya: Estimates from Kiambu, Nakuru and Nyandarua Districts*. Nairobi, Kenya. https://doi.org/10.13140/2.1.2945.9206

The World Bank. (2012). Using ICT to enable Agricultural Innovation Systems for Smallholders ICT innovations. Retrieved May 14, 2018, from http://www.fao.org/docrep/018/ar130e/ar130e.pdf

Ueno, R. K., Neumann, M., Marafon, F., Ambrogi, M., Daros, B. A., & Pletz, E. (2014). Effect of hay on performance of Holstein calves at suckling and post-weaning. *Revista Ceres*, *61*(5), 668–674. https://doi.org/10.1590/0034-737X201461050010

Vanleeuwen, J. A., Mellish, T., Walton, C., Kaniaru, A., & Gitau, R. (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*, 231–238. https://doi.org/10.1007/s11250-011-0003-2

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*, 231–238. https://doi.org/10.1007/s11250-011-0003-2

Windeyer, M. C., Leslie, K. E., Godden, S. M., Hodgins, D. C., Lissemore, K. D., & LeBlanc, S. J. (2014). Factors associated with morbidity, mortality, and growth of dairy heifer calves up to 3 months of age. *Preventive Veterinary Medicine*, *113*(2), 231–240. https://doi.org/10.1016/j.prevetmed.2013.10.019

Yitbarek, M. B., & Tamir, B. (2014). Silage Additives : Review. *Open Journal of Applied Sciences*, (April), 258–274. https://doi.org/10.4236/ojapps.2014.4502

Chapter 8.0 Appendices

This thesis research shared the study population and trial groups with another Ph.D. thesis by Joan Muraya. Part of that research has been published and is included here as appendix 8.1.

Since this research was closely related with another Ph.D. thesis, some of the unpublished chapters of that thesis have also been mentioned here. These unpublished chapters highlight some determinants of reproductive performance of dairy cows in smallholder dairy farms in the study area in rural Kenya.

Appendices 8.2, 8.3 and 8.4 are data collection tools for this research. Appendix 8.2 was used for the cross-sectional study (chapter 2) and as the baseline for the nutrition randomized controlled trials (chapters 3 and 5). Appendix 8.3 was used for follow-up data collection during the monitoring visits of the nutrition randomized controlled trials (chapters 3 and 5). Appendix 8.4 was used for data collection in the cellphone training randomized controlled trial (chapter 4).

8.1 Cross-sectional study of productive and reproductive traits of dairy cattle in smallholder farms in Meru, Kenya

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Abstract

A cross-sectional study was conducted to determine the farm management and milk production and reproductive performance of dairy cattle in smallholder dairy farms in eastern rural areas of Kenya, and to determine farm- and cow-level factors associated with milk production. A total of 200 farms were randomly selected from a list of the farmers shipping milk to a local dairy society. Structured questionnaires were used for data collection on management and demographic information, and farm visits occurred where the lactating cows on the farm received a physical examination. A mixed linear regression model with a random effect for farm was fit to determine associations with the natural log of daily milk production.

The majority of the farmers had one to three milking cows (mean = 1.40), with an average milk production of 6.70 kg/cow/day from the 314 lactating cows on the 200 farms in the study. At the time of the study, 43.4% of the lactating cows were bred and/or pregnant, with 28.7% of the cows being confirmed to be over three months pregnant. The cows that were cycling and non-pregnant (n=74) had a mean of 304 days-in-milk (DIM), while those cows that were anestrous (n=95) had a mean of 201 DIM.

Explanatory cow- and farm-level variables in the final milk production model were reproductive status of the cow, breed type, weight, DIM, dairy meal fed during the last month of pregnancy and land allocated for growing fodder for dairy cows. Exotic breed crosses, producing 6.80 kg of milk per day, on average, had higher milk production than the indigenous breeds, producing an average of 4.90 kg of milk per day. Heavier animals yielded more milk on the day of the visit; cows that weighed over 550 kilograms had twice as much milk production as those that weighed 250kg and less. The study categorized the cows into different reproductive statuses (early pregnancy/anestrous, pregnant, and cycling) and noted a steady increase in milk produced by cows in these different groups, with the cows that were cycling recording a 19.8% higher daily milk production over those in early pregnancy or anestrous. Milk yield reduced steadily as DIM increased beyond the first hundred days. Milk production from cows that received dairy meal in the last month of gestation was 34.3% higher compared to those that did not receive any. The percentage of land allocated to growing fodder for dairy cows was positively associated with the cow's milk yield per day, with a 15.6% increase for every 25% increase in land set aside for growing fodder.

We conclude that, even though smallholder dairy farmers in this area of Kenya have made attempts to improve their animals by cross-breeding them with exotic breeds, the milk production was still low. This can likely be largely attributed to poor feeding (especially as young-stock and during the transition period) and reproductive management. A more detailed cohort study or trial is recommended that can examine all the changing cow and management factors over time, providing necessary recommendations for farmers that account for these changes over time.

Key words: *days in milk, mixed model, pregnancy, reproductive performance, transrectal palpation*

Introduction

The smallholder dairy (SHD) sub-sector in Kenya accounts for 80% of the total number of cattle in the country, contributing to 70% of the total milk output (IFAD 2006; Odero-Waitituh 2017). Irrespective of the large numbers of animals, per cow milk productivity of the dairy sector is still very low. The SHD farmer is faced with limitations to achieving optimum milk production, including poor management, poor nutrition, lack of desirable breeds, infertility, reproduction disorders, animal diseases and a poor marketing system (VanLeeuwen et al 2012). The reproductive performance of the herd or animal is a key indicator of sustainability of a dairy farming system (Swai et al 2007). In the north American dairy sector, if a cow cannot show heat promptly, conceive at an optimal time, and deliver a calf per year, lifetime milk production is suboptimal, and the enterprise is not considered very profitable or sustainable (Hare et al 2006).

Assessment of reproductive performance depends on composite parameters, with the main indices being average Calving Interval (CI) and days open. Average days open has been advocated as the most appropriate measure of current reproductive performance (Radostits et al 2001), but for SHD farms, this measure is too variable with the small herd size. In order to achieve the optimal CI of 12-13 months, a Calving-to-Conception Interval (CCI) of 85-110 days is recommended (Radostits et al 2001). These intervals are negatively influenced by biological (postpartum diseases, delayed resumption of heat, and cystic ovarian disease) and management factors (poor nutrition, heat detection problems, poor breeding techniques, and long voluntary wait periods) (Radostits et al 2001).

Reproductive performance in smallholder dairy enterprises in Kenya has been described as poor (Odima et al 1994; Bebe et al 2003; Owen et al 2005). It is characterized by long calving intervals of about 633 days (Bebe et al 2003). These low reproduction indices, together with high youngstock mortality rates, have resulted in farmers being unable to produce enough replacement heifers. In order to overcome these and many reproductive constraints facing farmers, effective input services are required. Interventions from the government in terms of service provision and subsidies, and also strengthening of farmers' cooperative societies, are ways of achieving these reproductive goals. Romney et al (2000) reported that in the Kenyan highlands, farmers were willing to purchase supplemental feeds when given access to credit facilities.

Previous studies on reproductive performance in Kenya have been done in the 1990s and early 2000s (Odima et al 1994; Bebe et al 2003; Owen et al 2005), and there have been efforts to improve reproductive performance since those reports. These studies however were done in the peri-urban and urban areas surrounding Nairobi, and management, ecological and production factors in these peri-urban areas are not similar to those of rural settings of Kenya, such as the Meru highlands.

Due to Kenya's steady population growth, progressive land subdivision has been ongoing and that has rendered these small portions of land too small for subsistence crop agriculture (Asoka et al 2013). Small-scale farmers in these rural areas have now intensified dairy production as their main source of income, and this has opened a door for the need to improve their production and reproduction. For this intensification to happen, studies are needed to determine the state of the industry and the challenges farmers are facing, and to make feasible recommendations that will lead to the improvements needed. This study was therefore designed to determine the production and reproductive performance of dairy cattle in smallholder dairy farms in the Naari area of Meru, and to determine associations between reproductive status (main predictor of interest) and milk production (outcome of interest), while investigating other important variables and controlling for confounding. The results of this study provide a baseline assessment for a larger project that involved a dairy cooperative society, a Canadian non-governmental organization called Farmers Helping Farmers, and supplementation of nutritional and reproduction interventions for their animals.

Methodology

Study area

The study was conducted within 10-15 km radius around the rural area of Naari in Meru County, Kenya. Meru County is located in the eastern parts of Kenya (longitudes 37° 18' 37" to 37° 28' 33" east and latitudes 00° 07' 23" to 00° 26' 19" south), approximately 270 km north of Nairobi, and has a population of approximately 1.5 million people, of whom, 84% reside in the rural areas (Mutarari 2010). The precipitation in this county is bimodal, with short rains around the months of March to May and long rains around the months of October to December. The highest amount of rainfall approaches 2200 mm in the highest altitude areas of this county, while only 500 mm may fall in the lowest altitude areas of the county. Average daily temperatures in the highlands range between 14°C to 17°C while those of the lowlands are between 22°C to 27°C. Agriculture is one of the main economic activities in Meru County, with both cropping and livestock being common.

According to the welfare monitoring report by the government of Kenya, the percentage of households living below the poverty line in 2008 in Meru North was 44.7, with this number expected to rise (GoK Meru-North district Development Plan 2004-2008).

Study farms and cows

The sampling frame for the study consisted of 568 farms that were identified from the Naari Dairy Farmers Cooperative Society (NDFCS or Naari Dairy) database as active members shipping milk to the Dairy in the month of February 2015. A total of 200 farms were randomly selected from the database for the study.

In computing the necessary sample size, a confidence of 95% and power of 80% were assumed using Epi-Info version 6.04b (CDC Atlanta USA 1996) to detect associations between the main dependent variable (milk production) and the main independent variable (reproductive status – pregnant or not), based on a mean milk production of 5.52 kg/cow/day in pregnant cows and 6.69 kg/cow/day in non-pregnant cows, with a combined standard deviation of 1.41 kg/cow/day (Melaku and Gurmessa 2012). Sample size estimation results indicated 200 farms were necessary from the sampling frame of 568 smallholders for the study. Farms were estimated to have 1-3 milking cows (2 cows on average) for this sample size to be considered adequate. All milking cows from the selected farms were included in the study.

Data collection

The farms were visited once (cross-sectional study) during the period of May-August 2015, and a questionnaire was administered to collect all the relevant information. This involved detailed tracing of all milking cows on the farm, and examination of any written records, if any, so that all ages of the cattle, calving dates, history of reproductive diseases and conditions around parturition, such as mastitis cases, were recorded chronologically. Other information collected through the questionnaire included details on feeding and mineral supplementation, whether the cattle owner had attended any dairy husbandry training, herd size, awareness and monitoring of heat signs, age of the cows and source of animals.

The animals were examined physically, and the following information was collected: live weights using a weight measuring tape around the girth area, height at the withers, body condition scored on a 5-point scale where 1 represented very thin and 5 represented grossly overweight, using half point increments (Nicholson and Butterworth 1986), and any clinical abnormalities. A California mastitis test (CMT) was performed, and pregnancy status and ovarian status were obtained by way of transrectal palpation.

Definition of reproduction parameters

Days open was calculated as the period between the last calving and conception if the cow was pregnant, or the visit date if the cow was open. It was hard to get the actual days open for all cows since farmers did not practice good record-keeping, and their recall of dates when the cows were served or last delivered a calf was approximate to the nearest month. Therefore, estimates of days open used the 15th day of the month reported for calving and breeding where there was no physical record of them.

Days in milk (DIM) was defined as the number of days during the current lactation that a cow had been milking, beginning with the last date of calving to the current date. Abortion was defined as the expulsion of one or more calves <271 days after natural mating or artificial insemination. Foetal membranes were considered retained if they remained unexpelled for at least 24 hours after calving or abortion. Dystocia was considered to occur if parturition was assisted either by the farmer or by a veterinary field officer.

Statistical analysis

Data were entered and organized in an Excel spreadsheet (Microsoft, Sacramento, California, USA). The unit of analysis was the individual lactating cow in the farm at the time of visitation. Descriptive statistics for the animal- and farm-level variables and analytical statistics were carried out using STATA/IC 13.0 (StataCorp LLC, College station, Texas, USA).

For the analytical statistical analyses, the main outcome (dependent) variable investigated was the reported natural log of kilograms of milk produced per cow per day for the day prior to the visit. Due to the lack of records kept by most farmers, leading to possible measurement error, continuous variables of age, days open and DIM were modified into categorical variables to minimize information bias for the analytical statistics. Farm was included as a random effect because cows on one farm are not statistically independent of one another (Kristula et al 1992).

In the first step of the modeling, relationships between each independent variable and the outcome variable were individually investigated. In the second step, any variables that were associated at the $p<0.15$ level were eligible to be included in multivariable models. Correlation matrices between variables meeting the cut-off level ($-0.3<r<0.3$) were examined to determine correlations among these variables. Both forward stepwise and backward elimination regressions were used to identify the most parsimonious model in which all independent variables retained at the $p< 0.05$ level. Other variables not in the final model were examined for confounding of the variables in the final model, as recommended (Dohoo et al 2009). Interactions between variables in the final model were investigated. Model fit was examined by checking the standard residual diagnostics, performing predictions, and checking shrinkage of the model used.

Results and discussion

Farm characteristics and management

Since all 200 selected farms agreed to participate in the study, there was a 100% response rate. The principal farmers were primarily women (52.5%), although there were instances where both the male and female jointly considered themselves as principal farmers (16.5%). Most of the principal farmers were married (79.5%), but a few of them were young people who were single and establishing themselves as dairy farmers (9%). The majority of the principal farmers had either none or primary level of education, whether male (56%) or female (57%), indicating the low literacy levels among the farmers, and leaving a huge need for training on dairy farming matters. The mean (±SE) household size recorded in this study was 3.78 ± 0.12 with a minimum of 1 person and a maximum of 11. Higher man's education was positively associated with log of milk production as an ordinal variable in the univariable regression analyses ($p<0.05$), with 31.9% and 7.0% of male farmers having completed secondary and tertiary education, respectively (Table 1).

Among the farmers interviewed, 61% of them indicated that other than dairying, they also practiced crop farming, which supported their source of income and food, while the crop residues were used as feed for their cows. Only 13% of the farmers had wage or salaries coming to either them or their spouse, while 10% of the farmers had no other source of income other than the dairy cows. It has been reported that cattle production plays an important role in improving the livelihood for farmers in Kenya (Thornton 2010), and our research would corroborate this assertion. In our study region, cattle were mainly kept for food and cash income (milk and/or meat), but also for draught purposes and farm manure/fertilizer. Source of income met the eligibility criteria for multivariable regression modeling (Table 1), being marginally associated with natural log of milk production as an ordinal variable ($p<0.05$).

Table 1. Univariable mixed linear regression results of variables meeting the $P\leq0.15$ cut-off for eligibility for multivariable modeling of the natural log of daily milk production (kg/cow/day) for 316 cows on 200 Kenyan smallholder dairy farms in 2015

Variable	**Variable type**	**Coefficient**	**95% CI**		***p***
Man's education	Ordinal	0.167	0.062	0.271	0.002
Income source	Ordinal	-0.067	-0.157	0.022	0.147
Land allocated for dairy use	Ordinal	0.240	0.144	0.337	0.001
Dairy meal fed to cows on the farm in last month of gestation	Dichotomous	0.374	0.205	0.544	0.001
Cow Breed	Ordinal	-0.117	-0.187	-0.045	0.001
Cow Reproductive status	Ordinal	0.072	0.028	0.116	0.001
Cow current mastitis status	Dichotomous	-0.225	-0.350	-0.100	0.001
Cow Weight	Continuous	0.333	0.217	0.449	<0.001

The mean total land holdings owned by the respondents was 2.04 ± 0.17 acres, although the farmers indicated having access to other pieces of land in the form of leasing it, borrowing it, or using part of the nearby government-owned forest which was leased to them for some time. These additional portions of land were small and made up a mean of 0.41 ± 0.06 acres. A majority of the respondents (51%) indicated that, of all the combined land pieces, they allocated between 25-50% of the farmland to growing feed for their dairy cows, and this was because dairy farming was considered the major source of income. Land allocated for dairy use was positively associated with natural log of milk production as an ordinal variable (Table 1) in the univariable regression analyses.

Half (51.2%) of the farmers indicated that they had obtained their milking cows through purchasing them as adult cows, as compared to those who purchased them as youngstock (28.4%) or raised them on their farm (20.4%). The animals were reported to be obtained from the neighbouring smallholdings within the greater Meru County, as buying from large-scale establishments in Rift Valley and Central provinces of Kenya was considered expensive and those animals were less adaptable to the local challenging feeding management. Purchased animals had also been indicated as a common source of cows in a study in the Kenyan highlands nearby (Kiambu, Machakos, Kirinyaga, Maragua, Nakuru, Nyandarua and Narok former districts) for supplying milk to Nairobi (Bebe et al 2003). However, the farmers also indicated a preference for raising heifers born on their farms as replacement stock as it was considered cheaper than purchasing an animal, and the fertility and production history was known for home-raised heifers.

Artificial insemination (AI) services were readily available, and offered by private practitioners, government veterinary officers and veterinary technicians. However, 13% of the study farmers still preferred to use bulls for breeding. Even among the farmers that used AI for breeding their animals, a majority did not have the knowledge to choose which sire to use on their cows, with the majority allowing the AI or veterinary technicians to choose which bull to use, or to advise them on what bull to use, even though most of them had attended some form of dairy training. A few of the farmers were specific in their answers, saying they used “imported” or “Canadian” sexed semen on their cows, and reporting “good results” with that semen as well. This semen is usually highly priced in Kenya, and so most farmers shy away from using it, especially due to reported perceived low conception rates compared to regular semen (Norman et al 2010), potentially leading to a repeat service. Kenya’s Animal Genetic Resource Centre (KAGRIC) is responsible for keeping the AI bulls and distributing semen in the country, as well as in neighbouring countries (Wakhungu et al 2000). There is also a presence of imported gametes, in terms of semen and embryos, that come into the country through the veterinary services office, and lately, sexed semen from different countries has been made available through this avenue (APSK 2015).

The basal dairy cattle feeds in our study were based on natural pastures and home-grown fodder, mainly maize stover, Napier grass and crop residues. Of the 200 farms, 73% zero-grazed exclusively, while the remainder utilized cattle grazing on their land at least some of the time. Napier grass contains moderate crude protein (CP) content (6-12%) when it is fed at 1- 1½ meters in height but declines to less than 5% when it is fed at 2½ - 3 meters in height (Njoka-Njiru et al 2006). When natural pastures and other cultivated pastures are available during the rainy season, Napier grass is usually not fed to animals but instead is left to grow tall and then fed during the dry season, usually leading to milk production dropping substantially.

During the dry season in our study, maize stover was a common crop fed to cows; over 80% of the farmers reported using it. Although dry maize stovers are important sources of roughage, they have low nutritive values with CP as low as 2.5% of dry matter, and neutral detergent fiber exceeding 70% of dry matter, making them a poor choice for lactating dairy cow feed. Crop residues that were available and sometimes fed to the study cows included relatively nutritious cowpea pods (7.10%), bean pods (63.7%), and sweet potato vines (15.5%). However, poor storage methods practiced by the farmers predisposed the crop residues to rains and sunlight, likely resulting in further deterioration of the nutritive quality of the feed.

To counteract some of this diminishing quality of feeds, concentrates were usually fed to cows, with dairy meal being the principal commercial supplement offered. Milling by-products, such as wheat or rice bran, wheat pollard and maize germ, have also been used as they are seen as a quick cheap source of energy for the cows. All of these products were available in the Naari Dairy consumer shop or at feed stores located in the local shopping centres. Farmers indicated their preferences to using the Naari Dairy consumer shop since they had access to credit there as Naari Dairy members. About 84% of the farmers indicated feeding dairy meal to their lactating cows, while only 58% were giving dairy meal to dry cows during the transition period. The 16% of farmers that did not give dairy meal to their cows cited high cost as the main constraint, and they were occasionally feeding the cheaper milling by-products mentioned. Dairy meal fed to cows on the farm in last month of gestation was positively associated with natural log of milk production as a dichotomous variable in the univariable regression analyses ($p<0.05$).

Mineral supplements in the form of powdered salts, blocks or molasses were available to farmers in this area. A total of 88% of farmers fed mineral powders to their cows, and 48% of those not giving the powders indicated using mineral blocks. Molasses was only used in the dry season and mixed with dry fodder to increase its palatability.

The quantity of mineral and dairy meal supplements fed was generally low, and in most cases, a fixed amount was used throughout the lactation without adjustments according to the amount of milk produced. For example, 33% of farmers were giving cows a 1 kg can of dairy meal twice per day to lactating cows (equivalent to 1.3 kg of dairy meal per day), regardless of milk production or desire to get the cow pregnant. Similar findings had been reported in the central highlands of Kenya (Rufino et al 2009) and in the semi-arid areas of eastern Kenya (Njarui et al 2011). It was clear that most farmers were unaware that not providing the required amounts of mineral and dairy meal supplementation to lactating dairy cows will lead to lower milk production and delayed conceptions (Moran 2005).

Cow variables

The 200 farms had 316 total milking cows at the time of the study. There were two cows that were very hostile, and therefore a transrectal palpation was not carried out to confirm their reproductive status, although they were reported to be open. Therefore, reproductive status results are based on 314 cows.

Mean and median milk yield of the 316 lactating cows was 6.7 ± 0.23 and 6.0 kg/cow/day, respectively, with 35% of the farms producing less than 5 kg/cow/day at the time of the study, while the upper 10% produced over 12 kg/cow/day of milk, on average. Milk yield was not normally distributed, and 3.8% of the farms produced more than 15 kg/cow/day. As reported elsewhere, this low average milk yield could be attributed to underfeeding of lactating cows and giving poor feed quality, since most of the farms in smallholder dairy farming in Kenya rely on Napier grass as the main roughage, which can be very poor in quality if it is allowed to grow to 2 metres or more (Omondi and Njehia 2014).

Dairy stock kept included *Bos taurus* crosses (Friesian, Ayrshire, Jersey, and Guernsey) and *Bos indicus* crosses (Zebu, Boran). A majority (48.1%) of the respondents preferred Friesian to Guernsey (31.9%) or Ayrshire or Jersey crosses (12.3%), due to the perception that Friesian cows have a higher milk production. The Friesian-Holstein crosses produced an average of 7.50 kg of milk per day, which was the highest production of all the breeds. Guernsey crosses gave 6.24 kg/cow/day, which was higher than the Ayrshire or Jersey crosses (5.38 kg/cow/day). The least common breed (Zebu or other indigenous crosses) only produced 4.90 kg of milk per day on average. However, DIM and other factors affecting milk production are not considered in these means, and therefore multivariable model coefficients that control for other production confounders should be examined to provide valid breed comparisons. Although the preference for the Zebu breed was low in this area (7.59%), their positive attributes of easy-keeping cattle with high resistance to disease, better adaptation to harsh climates and powerful draught abilities were still anecdotally recognized by those owners who had them. Breed was negatively associated with natural log of milk production as an ordinal variable in the univariable regression analyses, according to the order of breeds presented above ($p<0.05$).

For this study, the largest proportion of cows (45.6%) was relatively young between two and five years of age. Age was not recorded as one of the major reasons farmers culled their milking cows, with the oldest cow encountered in the area being 17 years old. There were 37.3% of cows between the ages of 5 and 8 years, while 13.3% of the cows were over eight years old. These age trends were seen as a result of heifers taking a long time before they reached breeding sizes due to nutritional deficiencies that slowed their growth rates (Makau et al 2018 n.d.). Younger animals that were less than five years old produced an average of 6.48 kg/day of milk and this increased to 7.05 kg/day for the middle-aged cows (5-8 years) and then the mean dropped (6.15 kg/day) for cows older than 8 years old. This pattern follows the natural trend of milk production when cows are expected to reach maximum production around 5-6 years of age and at the third parity (Lee and Kim 2006).

The lactating cows had an overall mean and median DIM of 300 and 243 days, respectively, and were categorized into various lactational stages (e.g. early, mid, late, extended, and very long, for cows with DIM of $\leq$ 100, 101-200, 201-300, 301-400, and >400 days). There were 44, 78, 33, 53 and 108 cows in early (13.9%), mid (24.7%), late (10.4%), extended (16.8%), and very long lactation (34.2%), respectively. DIM was negatively associated with natural log of milk production as a continuous variable in the univariable regression analyses (Table 1).

The 314 lactating cows that were palpated were categorized into various reproductive states (e.g. anestrus, cycling, possible early pregnancy (no diagnosis on rectal examination), and pregnant confirmed by rectal examination). At the time of the study, 43.4% of the lactating cows were bred and/or pregnant, with 28.7% of the cows being confirmed to be over three months pregnant. According to ovary palpation findings, 30.6% of the lactating cows were in an anestrous phase at the day of the rectal examination, with no palpable structures identified from both ovaries. This group of cows had a mean of 201.2 DIM. The cows that were cycling and non-pregnant (n=74) had a mean of 304 DIM. Since these cows were not yet pregnant, these estimates of days open were expected to increase until the cows conceived. With the poor records kept by farmers, it was not possible to determine calving intervals or days open for previous lactations. It was also not possible to reliably determine first service conception percentages or number of breeding per conception. Cow reproductive status was positively associated with natural log of milk production as an ordinal variable in the univariable regression analyses (Table 1), according to the order of states presented above.

The proportion of all the milking cows currently with subclinical mastitis based on CMT $\geq$ 1 was 44.0%. Cow current mastitis status was negatively associated with natural log of milk production as a dichotomous variable in the univariable regression analyses (Table 1).

The overall mean and median weight of all the milking cows was 388.4 and 362.0 kg, respectively. There were 5.38%, 64.6%, 28.1% and 1.89% cows that weighed <250, 251-400, 401-550, and over 550 kg, respectively. Cow weight was positively associated with natural log of milk production as an ordinal variable in the univariable regression analyses (Table 1).

The overall mean body condition score (BCS) for the lactating cow was 2.44 ± 0.31. No cow was recorded to have a score of 1 or over 4. A majority of the cows (59.4%) had a body condition score less than or equal to 2.0, which is below the desired body condition score, and this could have been due to the time the cross-sectional study was carried out, with many cows being examined months after the most recent dry season, likely leading to insufficient quantities of low quality feed being available to most farmers for feeding. Fisher's exact test revealed that there were strong differences in body condition for different reproductive status groups, and the body condition differed in different lactation stages. There were also differences (p=0.004) in BCS in cows on those farms that had received training on dairy husbandry (BCS=2.49) versus those who had not received training (BCS=2.26). Imparting knowledge on the farmers was done through farmer training days by extension officers. When the farmers were asked about the topics on which they had received training, cow feeding regimes seemed to be the most common topic (23.1%) that most farmers could recall.

Factors associated with milk yield

In the first step of the modeling of factors associated with the natural log of milk yield, nine variables were found to be associated with the outcome variable at (p<0.15) when individually investigated (Table 1). The correlation matrix did not indicate any serious correlation among these variables; all correlation coefficients were lower than 0.17.

Table 2 shows the results of the final mixed model: one farm characteristic, four cow variables and one farm management factor were strongly associated with the natural log of daily milk, while controlling for the other variables in the model. Many of the expected factors of milk production were in the final model, and we start the model description with them.

Breed type of the cow was associated with milk yield. The indigenous crosses (e.g. Zebu) showed a 23.7% lower milk yield when compared to exotic crosses, which was the baseline as shown in Table 2. Milk yield within these two breed groups did not differ in the final model when the model controlled for other confounding variables, such as weight, DIM and reproductive status, indicating that these other variables were primarily responsible for breed differences in milk production within the two model categories. These results corroborate other findings in Kenya that the low performance of dairy herds on smallholder dairy farms in the region are associated with the type of breeds kept (Omondi and Njehia 2014). The predominance of exotic crossbreeds in this study is an indication of attempts by these farmers at higher milk production, even though other factors hindered production. Farmers that preferred keeping Jersey cows indicated their preference to a smaller cow that was not feeding as much as the other exotic breeds, even with their perceived low milk production.

Heavier cows were found to have yielded more milk on the day prior to the visit. Cows that weighed over 550 kilograms yielded over twice much milk as those that weighed below 250 kilograms. Heavier cows were more likely to have an adequate body condition (BCS≥2.75) and were reflective of good feeding management in terms of quality and quantity of feeds, explaining a higher milk yield. Emaciated cows that weighed less than 250 kilograms had the lowest daily milk yield (3.24 kg/cow/day), that was way lower than the means of all the other weight groups. Body weight changes are also affected by the parity of cows, and higher-parity dairy cows often lose more body weight in early lactation compared to lower-parity cows (Roche et al 2007a). The relationship between parity and post-partum body weight changes could not be explored in this cross-sectional study because parity records were not kept on the cows, but cows estimated to be over eight years of age did weigh more than cows less than five years of age, although there was no difference in milk yield between the three different age groups (p=0.269).

Cows in early lactation had 26.4% more milk than cows in mid-lactation (101-200) days. The differences in milk production increased as we moved farther towards cows in later DIM categories; with 55.1% lower milk production in the cows above 400 days in milk, compared to early lactation cows. When all the categories above 100 DIM were compared to the baseline, all the means were clearly different from the baseline. With non-overlapping 95% confidence intervals between 101-300 DIM and >400 DIM (Table 2), cows in this very long DIM category had lower milk production than the mid-lactation and late-lactation cows. Farmers should rebreed their cows sooner to avoid long DIM to ensure good utilization of the animal’s productive life and better milk production. Long

DIM is indicative of animals not coming into noticeable heat, getting served in a timely manner, conceiving and/or retaining a pregnancy. Lactation stage was also associated with milk production elsewhere, as reported by Baul et al (2012).

For this study, reproductive status was categorized into groups, namely anestrous, cycling, early pregnancy and pregnant. Nearly a third (30.6%) of the cows in the present study were anestrus, defined as milking, not pregnant and not cycling at the time of examination. Our study showed an increase in milk produced by the cows in different reproductive status groups compared to those cows that were in early pregnancy, which was set as the baseline. Being a pregnant cow was associated with a modest increase in milk yield when compared to those cows that were in early pregnancy. However, cows that were open and cycling had a 28.9% higher milk yield ($p<0.05$) compared to cows in early pregnancy. It is hypothesized that open and cycling cows were more likely to be in a positive energy balance, while pregnancy above 3 months of gestation can also draw on energy and protein intake. Unfortunately, during the time of this study, cows were found to have extended days open sometimes over 600 days, a situation that was likely brought about by long periods of drought and poor feed storage and management.

Table 2. Final multivariable mixed linear regression model of variables associated with the natural log of daily milk production (kg/cow/day) for 314 cows on 200 Kenyan smallholder dairy farms in 2015

Variable	**Coefficient**	**95% CI**		***p***	**Exponentiated Coefficient**[1]
Cow breed					
1. Exotic crosses	Baseline				
2. Indigenous crosses	-0.270	-0.486	-0.054	0.014	0.763
Cow weight (kg)				<0.001*	
1. < 250	Baseline				
2. 250-400	0.303	0.0414	0.568	0.023	1.354
3. 401-550	0.608	0.329	0.887	<0.001	1.837
4. > 550	0.734	0.235	1.233	0.004	2.083
Cow days in milk				<0.001*	
1. 0-100 days in milk	Baseline				
2. 101-200 days in milk	-0.306	-0.504	-0.108	0.002	0.736
3. 201-300 days in milk	-0.352	-0.601	-0.104	0.005	0.703
4. 301-400 days in milk	-0.539	-0.761	-0.317	<0.001	0.583
5. Over 400 days in milk	-0.802	-1.011	-0.593	<0.001	0.449
Cow reproductive status				0.039*	
1. Early pregnancy	Baseline				
2. Anestrous	0.123	-0.069	0.315	0.209	1.131
3. Pregnant	0.208	-0.023	0.392	0.028	1.231
4. Cycling	0.254	0.070	0.438	0.007	1.289
Dairy meal fed to cows on the farm in last month of gestation					
1. No	Reference				
2. Yes	0.304	0.171	0.436	<0.001	1.355
% land allocated for dairy use	0.140	0.063	0.216	<0.001	1.150

P-value: Global P-value*

[1]*Exponentiated coefficient used to determine percent change for each variable or level of categorical variable. For example, for cows that were fed some Dairy meal on the last month of gestation, the percentage change would be 1.355-1.0= +0.355 indicative of a 35.5% increase in milk output and for*

days in milk, the percent change would be 0.736 – 1.0 = -0.64 for a 26.4% less milk produced by cows between 101-200 days that those in the first 100 days of lactation.

There were a few other variables associated with milk production that were interesting. Feeding dairy meal during the last month of gestation lead to increased milk yield such that 35.5% more milk was obtained from the cows that had been received some extra supplementation with high protein concentrate (dairy meal) during the transition period compared to those that had not received any. It has been demonstrated that supplementing dairy cows with 0.5 to 2 kg of dairy meal concentrate per day before parturition, with increasing amounts as parturition approaches has been associated with cows attaining higher levels of milk production during the early days of lactation (Richards et al 2015; Richards et al 2016). Our results confirm that the impact of this management factor may have a lasting effect beyond the first 2 months of lactation. Farmers should be encouraged to practice this management recommendation.

The percentage of land allocated to dairy feed was positively associated with the cow's milk yield per day. A 25% increase in the land allocated to growing dairy feeds was associated with a 15.0% increase in milk produced, holding all the other factors constant. Due to a constantly increasing population in this area of Kenya, land holdings per owner have decreased by more than half over the past few decades, mainly because of subdivision through family inheritance (Bebe et al 2003). Farmers indicated owning a mean of 2.04 acres of land, leading to competition between growing food for people and feed for the cows. The study showed that with more land allocated to growing feed for their cows, more milk yield could be obtained.

Another factor that has been found to affect the amount of milk produced by cows in the tropics is suckling calves. Some farmers in the tropics still practice restricted suckling in any of its three forms namely: (i) the calf may initiate milk letdown; the cow is milked, and the calf sucks residual milk; (ii) the calf is allowed to suck one quarter; or (iii) the calf may suck the residual milk once milking is completed. Restricted suckling has been associated with many advantages over bucket rearing, including increased milk production, increased persistence of lactation and extended lactation, reduced incidence of mastitis, and increased calf growth and survival (Preston and Vaccaro 1989; Little et al 1991; Agyemang et al 1993; Msanga and Bryant 2004; Juhlin 2013). The greatest disadvantage of this practice is said to be its adverse effects on reproduction (Little et al 1991). In the current study, the aspect of restricted suckling was not explored as farmers rarely allowed calves to suckle cows other than for colostrum. Calf rearing and calf management in this study population was described and reported in a separate publication (Makau et al 2018 n.d.).

The intraclass correlation of 0.246 indicated that there was substantial correlation of cows within farms, confirming the need to adjust for clustering of cows within farms using a random herd effect. There was no confounding of model variables among the other variables not in the final model, and no interaction between model variables. The R^2 of the final model was 0.468, suggesting that 47% of the milk variation was explained by the model.

The quartile plot of the standardized residuals did not indicate any serious deviations from the normal distribution, and the residual plot did not reveal any serious concerns after the data were log transformed. Based on the residual and leverage diagnostics, farm 43 had somewhat high values, though within the acceptable range of 3 and -3. The magnitude and the influence of the residuals for farm 43 did not reveal any problems; when the model was analyzed without this farm, there was little change in the variables, and thus farm 43 was retained in the final model.

Research limitations included a language barrier, especially with aged farmers who could only communicate in the native Kimeru language. This needed an interpreter who was fluent in the native language to relay the message and convey the respondents' answers to the research team. Suspicion and mistrust were also noted among some respondents, particularly with details surrounding their personal life, and this got in the way of data collection. It was however mitigated by assuring them that the information given would be treated with utmost confidentiality, respect and professionalism. There were a few uncooperative and unfriendly respondents, but this situation improved when word went around the community about the project and its objectives.

Data quality was considered to be good by the researchers because collection was carried out by a well-trained team, and the questionnaire used was adopted from a previous study carried out in a different part of Kenya, and thus it had been pretested and modified. Participants of this study were randomly selected to avoid any selection bias, and of the 200 farmers that were selected for the study, they all agreed to participate and provided the requested data. Physical, clinical and rectal examinations were done by qualified veterinarians and veterinary students under the supervision of veterinarians.

Since this was a cross-sectional study, we cannot use results herein to determine causality of the model factors, but the results obtained were used to as a guide in the randomized control trials that were to follow the project. A more detailed cohort study or trial is recommended to test hypothesized model factors, to document and examine all the changing cow and management factors over time, and to provide the necessary evidence for recommendations for farmers, in turn improving the output from their dairy enterprises.

Conclusions

- The mean and median milk yield for the study cows in this study was 6.7 ± 0.23 and 6.0 kg/cow/day respectively.

- The principal farmer was female in 52.5% of the farms and had either none or only the basic level of formal education (grade 8), leaving a need of training in area that would lead to improvement of the dairying enterprise.

- A third of the farmers practiced crop farming as a way to supplement their income. As the mean total land holdings owned by the respondents was small (2.04 acres), the farmers were in dire need to find ways to support their families, including improved efficiency with the land they had.

- Reproductive performance among the study cows was sub-optimal, with over half of the milking cows being open at the time of the study and had an average of 253 DIM among these open cows. Only 28.7% of the milking cows were confirmed pregnant at the time of the study.

- The sub-optimal milk production of the dairy cows recorded in this area was associated with cow-level factors including; breed type, weight, reproductive status, and lactation stage as well as farm-level factors including; education levels of the male farmer, percentage of land allocated to growing fodder for dairy cows, and whether or not the farmers provided high protein supplements to dry cows before parturition.

- Extension services for training SHD farmers on best management practices associated with record-keeping, dairy cattle management (especially nutrition and reproduction), and fodder growing, and conservation should be improved to enhance milk production on these farms.

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References

Agyemang K, Clifford D and Little D A 1993 An assessment of the biological and economic efficiency in conversion of milk to growth in N'Dama calves. Animal Production, 56(02), 165–170.

APSK 2015 Proceedings of the APSK Annual Scientific Symposium, (April).

Asoka N, Thuo G W and Bunyasi M M 2013 Effects of Population Growth on Urban Infrastructure and Services: A Case of Eastleigh Neighborhood Nairobi, Kenya. Journal of Anthropology & Archaeology, 1(1), 41–56.

Baul S, Cziszter L T, Acatincăi S, Gavojdian D, Tripon I, Erina S and Răducan G G 2012 Phenotypic Correlations among Milk Yield and Chemical Composition per Normal Lactation in Romanian Black and White Breed, 45(2), 275–277.

Bebe B, Udo H M, Rowlands G and Thorpe W 2003 Smallholder dairy systems in the Kenya highlands: cattle population dynamics under increasing intensification. Livestock Production Science, 82(2–3), 211–221.

Dohoo I R, Martin S W and Stryhn H 2009 Veterinary Epidemiologic Research. VER Incorporated.

Government of Kenya (n.d.) Meru North District Development plan. From meru.go.ke/lib.php?com=114&&res_id=618

Hare E, Norman H D and Wright J R 2006 Trends in Calving Ages and Calving Intervals for Dairy Cattle Breeds in the United States. Journal of Dairy Science, 89, 365–370. http://doi.org/10.3168/jds.S0022-0302(06)72102-6

IFAD 2006 small holder dairy commercialization programme. Retrieved from http://www.sdcp.or.ke/index.php

Juhlin L 2013 Traditional milk production in cattle in a semi-arid area in Kenya. Retrieved from http://www.slu.se/husdjurmiljohalsa

Kristula M A, Curtis C R, Galligan D T and Bartholomew R C 1992 Use of a repeated measures logistic regression model to predict chronic mastitis in dairy cows. Preventive Veterinary Medicine, 14(1 2), 57 68; 18 ref.

Lee J-Y and Kim I-H 2006 Advancing parity is associated with high milk production at the cost of body condition and increased periparturient disorders in dairy herds. Journal of Veterinary Science, 7(2), 161–6. From http://doi.org/10.4142/JVS.2006.7.2.161

Little D A, Anderson F M and Durkin J W 1991 Influence of partial suckling of crossbred dairy cows on milk offtake and calf growth in the Ethiopian highlands. Tropical Animal Health and Production, 23(2), 108–114. http://doi.org/10.1007/BF02361194

Makau D, VanLeeuwen J A, Gitau G K, Muraya J, McKenna S L, Walton C and Wichtel J J (n.d.) Animal and management factors associated with weights gain in dairy calves/heifers on Smallholder Dairy farms in Kenya. Preventive Veterinary Medicine (accepted for publication).

Melaku A and Gurmessa J 2012 Effect of Lactation Stage, Pregnancy, Parity and Age on Yield and Major Components of Raw Milk in Bred Cross Holstein Friesian Cows. World Journal of Dairy & Food Sciences, 7(2), 146–149.

Moran J 2005 Tropical dairy farming: feeding management for small holder dairy farmers in the humid tropics. Csiro publishing. From http://www.publish.csiro.au/book/5126/

Msanga Y N and Bryant M J 2004 Productivity of crossbred dairy cows suckling their calves for 12 or 24 weeks post calving. Tropical Animal Health and Production, 36(8), 763–73.

Mutarari M P 2010 Influence of socio-economic factors on rural poverty: A case of Uringu division of Meru-North district in Eastern province, Kenya. University of Nairobi.

Nicholson M and Butterworth M H 1986 A guide to condition scoring of zebu cattle. Retrieved from https://cgspace.cgiar.org/handle/10568/49674

Njarui D M G, Gatheru M, Wambua J M, Nguluu S N, Mwangi D M and Gichene A K 2011 Development and up-scaling of green manure legume technologies in Kenya. Kenya Agricultural Research Institute. From http://www.lrrd.org/lrrd23/5/njar23111.htm

Norman H D, Hutchison J L and Miller R H 2010 Use of sexed semen and its effect on conception rate, calf sex, dystocia, and stillbirth of Holsteins in the United States. Journal of Dairy Science, 93(8), 3880–3890.

Odero-Waitituh J A 2017 Smallholder dairy production in Kenya; a review. Livestock Research for Rural Development, 29(7).

Odima P A, McDermott J and Mutiga E 1994 Reproductive performance of dairy cows on smallholder dairy farms in Kiambu District, Kenya: Design, methodology, and development considerations., 18(2), 366–368.

Omondi, W and Njehia B 2014 Herd Characteristics on Smallholder Dairy Farms in Western Kenya. Journal of Animal Science Advances, 4(8), 996. From http://doi.org/10.5455/jasa.20140827111904

Owen E, Smith T, Kitalyi A and Jayasuriya N 2005 Livestock and wealth creation: improving the husbandry of animals kept by resource-poor people in developing countries. (1st edition). Nottingham University Press.

Preston T R and Vaccaro L 1989 '' Dual purpose cattle production systems", New Techniques in Cattle Production, (C.J.C. Phillips Ed.) Butterworths and Co. London.

Radostits O M, Leslie K E and Fetrow J 2001 Herd health food animal production medicine (3rd edition). W. B Saunders Company Philadelphia.

Richards S, VanLeeuwen J A, Shepelo G, Gitau G K, Wichtel J, Kamunde C and Uehlinger F 2016 Randomized controlled trial on impacts of dairy meal feeding interventions on early lactation milk production in smallholder dairy farms of Central Kenya. Preventive Veterinary Medicine. From http://doi.org/10.1016/j.prevetmed.2016.01.006

Richards S, VanLeeuwen J A, Shepelo G, Gitau G K, Wichtel J, Kamunde C and Uehlinger F 2015 Associations of farm management practices with annual milk sales on smallholder dairy farms in Kenya. Veterinary World.

Roche J R, Macdonald K A, Burke C R, Lee J M and Berry D P 2007 Associations among body condition score, body weight, and reproductive performance in seasonal-calving dairy cattle. Journal of Dairy Science, 90(1), 376–91.

Romney D, Kaitho R, Wambugu M, Chege L, Omore O, Staal S and Wanjohi P 2000 Technology development and field-testing: Access to credit to allow smallholder dairy farmers in central Kenya reallocate concentrates during lactation. In Conference of the Egyptian Society of Animal Production, Alexandria, Egypt. (pp. 133–139).

Rufino M C, Herrero M, Van Wijk M T, Hemerik L, De Ridder N and Giller K E 2009 Lifetime productivity of dairy cows in smallholder farming systems of the Central highlands of Kenya. Animal, 3(07), 1044–1056. From http://doi.org/10.1017/S1751731109004248

Swai E S, P Kyakaisho and Ole-kawanara M S 2007 Studies on the reproductive performance of crossbred dairy cows raised on smallholder farms in eastern Usambara mountains, Tanzania. Livestock Research for Rural Development, 19(5).

Thornton P K 2010 Livestock production: recent trends, future prospects. Philosophical Transactions of the Royal Society of London. Series B, Biological Sciences, 365(1554), 2853–67. From http://doi.org/10.1098/rstb.2010.0134

VanLeeuwen J A, Mellish T, Walton C, Kaniaru A, Gitau R, Mellish K and 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.

Wakhungu J W, Mosi R O and Charles A B 2000 Dairy Cattle breeding policy for Kenyan smallholders: evaluation based on demographic stationary state productivity model. In Proc. Dairy Cattle Breeding in East Africa Sustainable Artificial Insemination Service, KARI HQs (pp. 17–18).

8.2 Questionnaire for Management and Feeding Practices on Naari Smallholder Dairy Farms

Farm Number: Survey Visit Date: Interviewer Initials: Farm Number

I. Farm overview:

1. How many people live in this household for more than 5 days per week? _____
2. Gender of principal farmer (person who takes care of the cows): male / female
3. Marital status of principal farmer (person who takes care of the cows):
   __ single __ married __ separated/divorced __widowed
4. Woman's education completed: ____ primary ___ secondary ____ college/university ___ n/a
5. Man's education completed: ____ primary ___ secondary ____ college/university ___ n/a
6. Woman's age: _____ years ___ n/a
7. Man's age: _____ years ___ n/a
8. a) Percent of total income coming from dairy production: ____< 50% ____50-75% ____> 75%
   b) Other sources of income _______________ ___________________ ___________________
9. Area of land owned: _______________ acres / hectares (circle units)
10. Area of land rented: _______________ acres / hectares (circle units)

II. Feeding - Part A – Normal feeding: 11. Some feeds are only given seasonally. Over the last year, please check which of the following you fed to your cattle (amounts not needed).

Feed name	Calves/Heifers	Cows
a. Napier Grass		
b. Silage		
c. Grass Hay		
d. Desmodium		
e. Sweet potato vines		
f. Other high protein forages – Lucerne, alfalfa, clover –identify which one(s) ____________________________		
g. Tree fodders – identify which one(s) ______________		
h. Banana leaves		

i. Other fodder ___________________________________		
j. Dairy meal		
k. Wheat Bran		
l. Maize "Jam"		
m. Vitamin/mineral powder		
n. Vitamin/mineral block		
o. Calf pellets/calf pencils. If yes, until what age?		
p. Other feeds (specify) _____________		
q. Water available (always/sometimes)	A/S	A/S
r. Source of water		

12a. Do you usually feed dairy meal or grain to cows for the month before calving? __YES __NO

13a. Do you feed vitamins/minerals to cows during the month before calving? ___YES ___NO

13b. If yes, what brand?

Brand: _______________ (*from bag: Ca:P ratio:* ____ *Selenium amount & unit:* ______*)*

13c. If yes, how much is given to the cow? Amount (in spoons or grams per day): ___________

14. How much dairy meal and/or grain (e.g. maize "jam") do you give cows on the day they calve?

dairy meal ______ kg in morning ______ kg in evening
other grain ______ kg in morning ______ kg in evening

15a. In general, during the first 5 months after calving, do you normally change the amount of dairy meal or grain you feed per day to your cows? _____YES _____NO

b. If yes, what factors affect how much dairy meal or grain you feed per day?

____

16. At what height do you normally cut and feed your Napier grass for milking cows?

a. Cows (rainy season)
1. mostly < 1.0 meter _______
2. mostly < 1.5 meters _______

b. Cows (dry season)
1. mostly < 1.0 meter _______
2. mostly < 1.5 meters _______

3. mostly < 2.0 meters _______ 3. mostly < 2.0 meters _______
4. mostly > 2.0 meters _______ 4. mostly > 2.0 meters _______

c. Are these the same heights for Napier grass fed to calves and heifers too? Yes_____ No_____
If no, what is different? ____

17a. For your cows, did you experience a shortage of feeds over the last year? Yes_____ No_____
17b. If yes, which feeds were inadequate (check all that apply)?
___Forages ___Grain or meals ___Vitamin-minerals ___Water ___Other(specify)___________

18a. Did you store forage for the dry season over the last year? Yes_____ No_______
18b. If yes, what is the method of storage (circle all that apply)?
___Grass hay ___Silage ___Maize stover ___Other (specify)_____________________

19a. How frequently do you normally deworm your cows?
Every ___ months ____when suspect it is a problem ___when not pregnant

19b. How frequently do you normally deworm your calves/heifers?
Every ___ months ____when suspect it is a problem ___other (specify: ___________________)

20. How many calves died in the last year? ____
If yes, from what causes____

21. How many heifers died in the last year? _____
If yes, from what causes ____

22. How many heifers died in the last year? _____
If yes, from what causes ____

III. Mastitis Prevention Management Ask AFTER initial accelerometer readings

23. a) Do you wash the udder pre-milking? Yes __No __
b) Do you use soap when washing the udder? Yes__ No__
c) Is a different wash cloth used for each milking cow? Yes __No __
d) Is the udder dried before milking with a clean cloth or paper? Yes __No __
e) Is a different drying cloth used for each milking cow? Yes __No __
f) If you have > 1 milking cow, do you wash your hands between milking cows? Yes __No __

g) Do you wash and rinse out your wash cloth(s) & hang them to dry out between milkings? Yes __No __
h) Do you use a teat dip post milking? Yes __No __
i) Do you give fresh feed after milking? Yes __No __
j) Do you use dry cow treatment when drying cows off prior to calving? Yes __No __
k) If you have more than one cow, and are treating a cow for mastitis, do you milk her last? Yes __No __

24. a) How many cases of mastitis did you have in the last year? _____
b) How many cases of mastitis did you treat in the last year? _____
c) How many cows leaked milk in the last year? _____
d) How many times did you have milk rejected in the last year? _____

IV. Cow Stall Design and Management

25. How often do you remove manure from where the milking cows lie down?
a) more than once a day
b) once a day
c) every other day
d) twice a week
e) once a week
f) less than once a week

26. What kind of bedding is used where the milking cows lie down?
a) grass/hay b) straw c) sawdust d) pea/bean waste e) none f) other (please specify _________)

27. How often do you add new bedding to where milking cows lie down?
a) every day
b) every other day
c) twice a week
d) once a week
e) less than once a week

28. How often do you add new bedding to where dry cows lie down?
a) every day
b) every other day
c) twice a week
d) once a week

e) less than once a week

29. How often do you trim your cows' feet?
    a) every 3 months
    b) every 6 months
    c) every 12 months
    d) less often or never

30. Do your cows do any of the following behaviours (circle all that apply – observe to confirm)?
    a) perching (standing partly in the stall and partly out of the stall for more than a few minutes)
    b) standing backwards in stall
    c) idle standing in the stall (standing fully in the stall for more than a few minutes)
    d) dog-sitting in the stall (sitting on hind legs but standing on front legs)
    e) kneeling in the stall (sitting on hind legs but kneeling on front legs)
    f) lying restless in the stall (shifting position in the stall every 15 minutes or less)
    g) nose-pressing against a post or board while standing or sitting in the stall
    h) lying somewhere other than in the stall
    i) Other behaviours you wonder about (please specify __________)

31. Do cows hit any of the following body parts when lying down or getting up
    (circle all that apply – observe to confirm)?
    a) chin
    b) skull
    c) withers / shoulders
    d) feet
    e) knees
    f) other body parts (please specify __________)

For observation:

32. Is the roof appropriate (observe – no holes, extends to cover udder area)? Yes __No __

33. What is the type of the floor where the milking cows lie down?
    1) concrete 2) dirt 3) other (please specify: _________________)

34. Is the floor (observe - check all that apply):
    1) flat (no pooling water)

2) lumpy
3) wet in the udder area

35. Is water/urine/feces able to flow (by gravity) under the udder where the milking cows lie down (observe)?

36. Results of the stall knee tests?

a) Impact force Pass______ Fail______
b) Level of Wetness Pass______ Fail______________

Dimensions of stalls Preintervention:

Stall	a. Width (cm)	b. Body Resting Length (cm)	c. Total Stall Length (cm)	d. End Board Height (cm)	e. Neck Rail Height (cm)	f. Brisket Board Height (cm)	g. Side Rail Height Lowest Board (cm)	h. Side Rail Mid Board (cm)	i. Side Rail High Board (cm)
#1 (Q37)									
#2 (Q38)									
#2 (Q39)									
#2 (Q40)									

VI. Health and Productivity of Cows

Examination of Cows:	Cow1 (Q41) ID_________	Cow2 (Q42) ID________	Cow3 (Q43) ID_________	Cow4 (Q44) ID_________
a. "Age (years)"				
b. Breed				
c. "Number of calvings"				
d. "Last calving date"				

e. "Last breeding date"				
f. "Number of breedings for last calving"				
g. "Number of times used sexed semen"				
h. "Number of times used Canadian semen"				
i. "# of times used hormones for breeding"				
j." Current daily milk yield (kg/day)"				
k. "Is this expected yield, based on feeding?"	Y/N	Y/N	Y/N	Y/N
l. "Mastitis in last 12 months"	Y/N	Y/N	Y/N	Y/N
m. "Abortion in last 12 months"	Y/N	Y/N	Y/N	Y/N
n. "Other disease (RP) in last 12 months" ____	Y/N	Y/N	Y/N	Y/N
o. Weight				
p. Height				
q. Body condition score				
r. TPR/physical exam Normal / Abnormal? (manure, feet, skin, lymph nodes, eyes, rumen)	N / A	N / A	N / A	N / A
s. CMT (circle CMT result if milk looks abnormal as well)	LF LH RF RH __ __ __ __	LF LH RF RH __ __ __ __	LF LH RF RH __ __ __ __	LF LH RF RH __ __ __ __
t. Reproductive status (*preg confirmed?)*	Preg Y/N	Preg Y/N	Preg Y/N	Preg Y/N
u. Ovaries cycling	Y/N	Y/N	Y/N	Y/N
v. Month of last deworming				
w. Hock lesion score (1-3)				

x. Neck lesion present (Yes/No)				
y. Knee lesion score (1-3)				
z. Lameness score (1-3)				
aa. Udder hygiene score (1-4)				
ab. Leg hygiene score (1-4)				
ac. Cow photo digital file name				

Youngstock health and productivity (calves and heifers that have never calved yet):

	Calf/Heifer #1 (Q45) ID_______	Calf/Heifer #2 (Q46) ID________	Calf/Heifer #3 (Q47) ID_________	Calf/Heifer #4 (Q48) ID_________
a. "Birthdate or Age (months)"				
b. Sex				
c. Breed				
d. "Last breeding" (month and year or n/a)				
e." Number of breedings to date"				
f. "Had diarrhea"	Y/N	Y/N	Y/N	Y/N
g. "Had pneumonia"	Y/N	Y/N	Y/N	Y/N
h. "Had navel-ill"	Y/N	Y/N	Y/N	Y/N
i. Weight				
j. Height				
k. Body condition score				

l. TPR/physical exam Normal / Abnormal? (manure, feet, skin, lymph nodes, eyes, rumen)	N / A	N / A	N / A	N / A
m. Udder hygiene score (1-4)				
n. Reproductive status (*preg. confirmed?)*	Preg Y/N	Preg Y/N	Preg Y/N	Preg Y/N
o. Ovaries cycling	Y/N	Y/N	Y/N	Y/N
p. Month of last deworming				

49. How do your calves usually receive their first colostrum?
Choose only ONE of the options that is MOST commonly used
____ free choice suckles ____assisted suckle ____nursing bottle _____bucket
____other -specify:__________

50. How soon would most of your calves receive 4L of colostrum? Choose ONE answer only
___ < 6 hours ___ 6 - 12 hours ___ 12 - 24 hours ___ > 24 hours ___ unknown

51. What do you usually do if a calf is weak and unable to drink colostrum during the first day of life?
_____Bottle feed ___Tube feed ____Other (specify)____________________

52a. In the last year, how frequently did your cows have an abrupt feed change? (for example, you completely run out of one type of feed one day, such as napier grass, so you switch to a different type of feed the next day, such as maize stover) Choose ONE
_____Never _____Occasionally in the dry season _____ 1 time/month _____more than 1 time/month

52b. In the last year, how frequently did your calves have an abrupt feed change? Choose ONE
_____Never _____Occasionally in the dry season _____ 1 time/month _____more than 1 time/month

8.3 Experimental Study Survey for Cost-Benefit Nutritional and Reproductive Study of Smallholder Kenyan Dairy Farmers: for subsequent farm visits after the study calf is born

Farmer Name: Farm Number:

Temp: Time Visit Date: Group:

Visit Number: 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 Interviewer Initials:

<u>Part A. Post-birth visit question (ask these only at the first visit after a birth)</u>

i. Was the birth observed (was someone around)? Y / N
ii. What time of day was the birth? ___________________________
iii. Did you need to give assistance to deliver the calf? Y / N
iv. Sex of calf M / F
v. Was the calf weak during the first 6 hours (not drink on its own)? Y / N
vi. Were any treatments given to the calf? Y / N (specify ______________________

<u>Part B. For every post-natal visit</u>

1. If the owners did not fill in the weekly log of what was fed to the calf and cow:
Please indicate the brand/product (if applicable) and average amounts (in kg, or kasuku container levels, or cups or spoons/day) of the feeds listed that were given to the study calf and cow <u>daily since the last visit</u>. Indicate if always available free choice (FC).

	Brand	Calf yes/no	Calf amount	Cow yes/no	Cow amount
Milk					
Calf pellets					
Calf pencils					
Mineral block lick					
Vitamin/mineral powder					
Dairy meal					

Maize “jam” germ					
Wheat bran					
Other purchased feed (specify)					
Calliandra or Sesbania					
Napier grass					
Other grasses					
Grass silage					
Maize silage					
High-protein plants (like Desmodium, Lucerne)					
Other forage (weeds, banana leaves, other -specify)					
Water availability?		Always / Sometimes		Always / Sometimes	
Milk Produced (kg/d)					

3a. At what height did you cut and feed your Napier grass for <u>cows</u> since the last visit?

_____ most < 1.0 meter _____ most < 1.5 meters

_____ most < 2.0 meters _____ most > 2.0 meters

3b. At what height did you cut and feed your Napier grass for <u>calves</u> since the last visit (answer only if different from above)?

_____ most < 1.0 meter _____ most < 1.5 meters

_____ most < 2.0 meters _____ most > 2.0 meters

4. a) Did you make any sudden / unusual changes in feed (amount or type) to your cows or calves since the last visit? _____YES _____NO

b. If yes, describe: ___________________________________

5. a) Did you change the amount of dairy ration or grain you fed according to the cow’s milk yield since the last visit? _____YES _____NO

b) If yes, describe: ___________________________________

6. a) Do you still own the study cow? Yes_______ No______

b) If no why____

7. a) Do you still own the study calf? Yes_______ No_______
b) If no why____

8. a) Are you spending more on feed since the last visit (Y/N)
b) By how much more (give range) ____________

9. a) Has your revenue from dairy cows increased since the last visit (Y/N)
b) Describe how ____

10. Health Examination of Cattle. Study Calf and Cow

Italics are answered by owner	Calf ID_______	Calf ID_______	Calf ID_______	Cow ID________	Cow ID________	Cow ID________
a. Navel status	N / A	N / A	N / A			
b. Weight (calf) or BCS (cow)						
c. Height						
d. "Any disease since last visit?"	Y/N ________	Y/N ________	Y/N ________	Y/N ______	Y/N ________	Y/N ________
e. "Appetite normal?"	N / A	N / A	N / A	N / A	N / A	N / A
f. TPR normal?	N / A	N / A	N / A	N / A	N / A	N / A
g. Cardio/pulmonary system normal?	N / A	N / A	N / A	N / A	N / A	N / A
h. Gastrointestinal system normal?	N / A	N / A	N / A	N / A	N / A	N / A
i. Feet condition normal?	N / A	N / A	N / A	N / A	N / A	N / A
j. Skin parasite/condition normal?	N / A	N / A	N / A	N / A	N / A	N / A
k. Uterus normal? (preg?)				N / A Y/N	N / A Y/N	N / A Y/N

l. Ovaries (CL, follicle, in heat, anestrus):				L R	L R	L R
m. Given repro medicine?				Y /N (specify: ___________)	Y /N (specify: ___________)	Y /N (specify: ___________)
n. Eligible for breeding? (Uterus OK, BCS 2.5 or 2.0 but up, cycling?)				Y/N	Y/N	Y/N
o. Eligible for PG shots to set up for sexed semen				Y/N	Y/N	Y/N
p. Any other current ailment	Y /N________	Y /N________	Y /N________	Y /N________	Y /N________	Y /N________
q. Pen comfort / hygiene (out of 6) if changed from last visit						
r. CMT status				LF LH RF RH __ __ __ __	LF LH RF RH __ __ __ __	LF LH RF RH __ __ __ __

Note: Comfort Score (/6) is a function of:
For cows: 1) Stall Length 2) Stall Width 3) Stall Lunge Space 4) Stall Softness 5) Stall Shade 6) Stall hygiene.

So, an index from 1 to 6, getting a 1, ½ or 0 for each of these for good (equals or surpasses minimum requirement), fair (approaches the minimum requirement) or poor (nowhere near the minimum requirement). If the cow uses the stall appropriately, then it is likely not too bad. (Stall wetness will affect mastitis - but we will assess udder CMT).

For calves: put emphasis on stall space (1/6), shade (1/6), and hygiene (4/6).

8.4 Experimental Study Survey for Cellphone Training on Dairy Cow Management for Smallholder Kenyan Dairy Farmers

Farmer Name: Gender: Farm Number:

Date: Phone number:

I. Farm overview:

1. How many people live in this household for more than 5 days per week? _____
2. Gender of principal farmer (person who manages/takes care of the cows): male/female/both
3. Marital status of principal farmer (person who manages/takes care of the cows):
   __ single __ married __ separated/divorced __widowed __
4. Woman's education completed: ____ primary ___ secondary ____ college/university ___ n/a
5. Man's education completed: ____ primary ___ secondary ____ college/university ___ n/a
6. Woman's age: _____ years ___ n/a
7. Man's age: _____ years ___ n/a

9. a) Percent of total income coming from dairy production: ___< 50% ___50-75% ___> 75%

10a. Area of land owned: _______________ acres / hectares (circle units)

10b. Percent of land used for crop and fodder production for cattle?

10c. Area of land rented/used (unpaid): _______________ acres / hectares (circle units)

10d. Percent of land used for crop and fodder production for cattle?

11a. Have you attended any training on milk production in the last year? Y/N

11b. If yes, what was this training about? ________________________________

II. Mastitis Prevention Management

1. Every time you check for milk quality in a cow with mastitis it will always be positive (true/false)
2. How often should you check for mastitis in your cows?
   a. Monthly
   b. Daily
   c. Weekly
   d. Never
3. Which of these help with mastitis prevention?

Practice	Tick (√)
Using a different wash cloth used for each milking cow?	
Drying udder before milking with a clean cloth or paper?	
Using a different drying cloth used for each milking cow?	
Using a teat dip post milking?	
Giving fresh feed after milking?	
Using dry cow treatment when drying cows off prior to calving?	
Leaving milk in the udder to allow calves to suckle?	

III. Feeding and diarrhea management

1. A cow should eat as much as it can, and the manger should never stay empty (true/false)
2. At what height is napier grass most nutritious/ideal for a dairy cow
   a. < 1.0 meter ,1.0- 1.5 meters, 2.0 meters,> 2.0 meters
3. At what stage of pregnancy should you start steaming up pregnant dairy cow?
   a. How much dairy meal should you start with?
4. How long do should newborn calves on your farm wait to receive 4 liters of first colostrum (how

many hours post calving)?

    a. < 6 hours, 6 - 12 hours, 12 - 24 hours, > 24 hours

5. How can you prevent diarrhea in calves: (Tick all applicable)?
    a. Keep the calf in a clean and dry place
    b. Providing bedding always
    c. Removing manure from stall daily
    d. Keeping calf with the mother
    e. None of the above
    f. All of the above

IV. General questions

1. A retained placenta from a fresh calving cow should be removed immediately the cow calves (true/false)
2. Name the most important cause of retained after birth ____________________
3. How long should you wait after a cow calves before calling the vet for a retained placenta?
   a) 1 hour
   b) 3 hours
   c) 1 day
   d) 3 days
   e) one week
4. Some skin problems like rain scald can be managed by ensuring the cow is getting adequate and quality diet (true/false)
5. Teat blocking can be caused by: (tick all applicable)
   a) Teat infections
   b) Improper milking
   c) Inheritance from dam
   d) Feeding cows lots of dairy meal
   e) Feeding cows lots of mineral supplements
6. How frequently should you deworm your cows
   a) every 3 months
   b) every 6 months
   c) every 12 months
   d) when not pregnant
7. How often should you spray/dip your cows
   a) every 3 months
   b) every 6 months
   c) every 1 months
   d) every 2 weeks

V. Cell phone messages intervention

1. In the past 3 months, did you receive any cell phone messages from AFRICASTKING about dairy farming? Yes No

   a) How many messages did you receive over the past 3 months?
   b) How many messages did you read per week?
   c) How much of each message did you read?

- ☐ 0 if not read all of the message (0%)
- ☐ 1 if read all of the message (100%)
- ☐ 2 if read half of the message (50%)
- ☐ 3 if read most of the message (>75%)

If the participant did not read all the messages, go to question 2

If the participants read all the messages, go to question 3

2. Why did you not read all the messages that were sent to you?
- ☐ Got so busy
- ☐ Forgot to read them
- ☐ Can’t read some words
- ☐ Was not important so ignored it
- ☐ Only received ________ messages
- ☐ Others, specify ___________________________________

3. About the content of the messages:

a) How understandable were the messages to you?
- ☐ Very easy to understand
- ☐ Easy to understand
- ☐ Somewhat easy to understand
- ☐ Difficult to understand
- ☐ Very difficult to understand

b) How informative were the messages?
- ☐ Very informative
- ☐ Somewhat informative
- ☐ Informative
- ☐ Not very informative
- ☐ Not informative at all

4. How motivated were you to practically implement the messages concerning the dairy cow management? Prompts: For example, the message on mastitis prevention or napier grass feeding
- ☐ Extremely motivated
- ☐ Very motivated
- ☐ Somewhat motivated
- ☐ Not motivated
- ☐ Not motivated at all

5. How effective do you think these messages were to your practical implementation of these messages concerning your dairy production? Prompts: For example, the message on retained placenta management
- ☐ Extremely effective
- ☐ Very effective
- ☐ Somewhat effective
- ☐ Not effective
- ☐ Not effective at all

6. Did you have any questions or concerns relating to the number of messages received during the 3 months?
(Yes/ No)

a) What are some of the questions and concerns that you had?
____
____

b) How did you handle these questions and concerns?
____
____
_

Probes:

i. Did you ask for help reading the messages? (Yes No)
Why?

ii. Did you ask someone to help you understand what the message said? (Yes No)
Why?

8. a) Please tell me how much that any of the following were challenges during the 3months of cell phone messaging

i. I didn't know who to call/text back when I had questions and concerns

Not challenging at all Extremely challenging

1 2 3 4 5

ii. Messages were too long

Not challenging at all Extremely challenging

1 2 3 4 5

iii. Messages were not clear

Not challenging at all Extremely challenging

1 2 3 4 5

iv. Had problems with my cell phone. Specify…………………………………………………….

Not challenging at all Extremely challenging

1 2 3 4 5

v. Others.
Specify……………………………………………………………………………...……………

Not challenging at all Extremely challenging

1 2 3 4 5

b) How much did this challenge(s) make it difficult to implement the messages?

Not challenging at all Extremely challenging

1 2 3 4 5

9. a) What did you like about receiving the cell phone messages?

b) What did you not like about receiving the cell phone messages?