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Farmer-led feeding and breeding approaches for overcoming seasonality-driven milk fluctuations in smallholder dairy farms in Kenya and Tanzania

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FARMER-LED FEEDING AND BREEDING APPROACHES FOR OVERCOMING SEASONALITY-DRIVEN MILK FLUCTUATIONS IN SMALLHOLDER DAIRY FARMS IN KENYA AND TANZANIA

Ongadi, Patrick Mudavadi

A Thesis Submitted in Partial Fulfilment of the Requirements for the Degree of Doctor of Philosophy in Life Sciences and Bioengineering of the Nelson Mandela African Institution of Science and Technology

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ABSTRACT

Seasonality-driven changes in farmer-led feeding and breeding approaches are increasingly captured as contributing to fluctuations in milk yield and reproductive performance of dairy cows in smallholder dairy farms in Eastern Africa. This study aimed to assess the effects of location, agro-ecology, production systems, breed types and seasonal changes on milk yield and reproductive performance of dairy cows; and to propose potential modifiable farmer-led interventions for overcoming fluctuations in dairy production. A cross-sectional household survey from 400 smallholder dairy farming households in highlands and lowlands of Kenya and Tanzania, followed by an observational monitoring study for a period of one year, were used to establish the effects of seasonality on milk yield and reproductive performance. Questionnaire and Feed Assessment Tool (FEAST) were used to collect data. Descriptive statistics and regression analysis using multivariate/multinomial analysis of variance (MANOVA) were employed to display variable seasonal differences in performance. Mean separation was carried out using least significant difference (LSD) at $P \leq 0.05$ significance level. Results revealed that year round rainfall seasonality and differences in location, agro-ecology, breeds and production systems, significantly ($P < 0.05$) resulted into changes in reproductive performance and milk yield. Mean values for AFS, AFC and CI were higher in the dry season than in wet season (32.34 SEM = 0.90 v's 29.14 SEM 0.90 months; 38.05 SEM = 0.61 v's 36.23 SEM 0.62 months; and 469.60 SEM = 8.78 v's 445.49 SEM 8.94 days), respectively. Wet and dry season variation (%) in calving interval was +/-6.30%, ranging from +/-5.00-15.00% between breeds within agro-ecologies. Similarly, daily milk yield per cow (L) was lower in the dry season than in wet season (8.44 SEM = 0.27 v's 9.01 SEM 0.30). Season variation (%) in daily milk yield, between wet and dry seasons was +/-6.22%, which was lower for local zebu (+/-3.96%) and highest for improved breeds (+/-14.50%). There was significant ($P < 0.05$) year round variation in feeds and fodder sources (quality and quantity) and usage, with the exception of concentrate feeding. *In vitro* culture of crop residues pre-treated with urea and urea plus molasses, and further comprehensive *in vitro* culture of maize stover, showed positive effects ($P < 0.05$) on chemical and nutritional composition in terms of total gas production (GP), dry matter digestibility (DMD), crude protein (CP) and metabolizable energy (ME), amongst all other parameters. This study concludes that iinterventions for increasing farmers' experience and knowledge in overcoming seasonality driven milk fluctuations, must be holistic, in due consideration of seasonality and environment effects, in order to improve milk yield and reproductive efficiency sustainably over time. It is recommended that the new knowledge gained with this research can

be incorporated into a holistic model of optimization of cow performance and thereby be one among other tools for optimizing production economy of smallholder dairy farmers in Eastern Africa.

DECLARATION

I, Ongadi, Patrick Mudavadi, do hereby declare to the Senate of Nelson Mandela African Institution of Science and Technology (NM-AIST) that this Thesis is my own original work submitted by me for the Degree of Doctor of Philosophy in Life Sciences and Bioengineering (Sustainable Agriculture) and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

Ongadi, Patrick Mudavadi — **19th July 2021**

Name and Signature of the Candidate — **Date**

The above declaration is confirmed

Dr. Emmanuel Abraham Mpolya — **19th July 2021**

Name and Signature of Supervisor — **Date**

Dr. Bernard Adubwa Lukuyu — **19th July 2021**

Name and Signature of Supervisor — **Date**

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CERTIFICATION

The undersigned certify that they have read and recommend for examination of a Thesis titled "Farmer-led feeding and breeding decisions for overcoming seasonality driven milk fluctuations in smallholder dairy farms" in fulfilment of the requirements for the Degree of Doctor of Philosophy (PhD) in Life Sciences (Sustainable Agriculture) at the Nelson Mandela African Institution of Science and Technology (NM-AIST), Arusha, Tanzania.

Dr. Emmanuel Abraham Mpolya	**19th July 2021**
Name and Signature of Supervisor	**Date**

Dr. Bernard Adubwa Lukuyu	**19th July 2021**
Name and Signature of Supervisor	**Date**

DEDICATION

Firstly, to my Lord Almighty God in Christ Jesus, for guidance, strength, awesome favour and perfect health during the entire course of this study, both in Tanzania and Kenya.

Secondly, to my parents the Late Silas Gidali Mudavadi and Late Esther Alivitsa Gidali for their inspiration.

Thirdly, to my children, Silas (Chem. Eng., TUK), Paul (B. Comm., MUK), Raphael and Esther for their immense encouragement and support.

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Finally, to the Smallholder Dairy Farmers in Eastern Africa who are constantly struggling to overcome seasonality driven milk fluctuations for better incomes and livelihoods.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

ACIAR	Australian Council for International Agricultural Research
ADL	Acid Detergent Lignin
AFC	Age at First Calving
AFS	Age at First Service
ANOVA	Analysis of Variance
BCS	Body Condition Score
BMGF	Bill and Melinda Gates Foundation
CAS	Chinese Academy of Sciences
CGIAR	Consultative Group on International Agricultural Research
CI	Calving Interval
CP	Crude Protein
DM	Dry Matter
DMD	Dry Matter Digestibility
EA	Eastern Africa
EE	Ether Extracts
FAO	Food and Agriculture Organization of the United Nations
FFP	Farmer Feeding Practice
GLMM	General Linear Mixed Models
ILRI	International Livestock Research Institute
ISA	Institute of Sub-Tropical Agriculture, China
KALRO	Kenya Agricultural and Livestock Research Organization
LBW	Live Body Weight
LSD	Least Significance Difference
MANOVA	Multivariate Analysis of Variance

ME	Metabolizable Energy
MUMS	Molasses Urea treated Maize Stover
NDF	Nutrient Detergent Fibre
NDS	Nutrient Detergent Soluble
NM-AIST	Nelson Mandela African Institution of Science and Technology
OECD	Organization for Economic Cooperation and Development
PEHPL	Programme for Enhancing Health and Productivity of Livestock
SDFS	Smallholder Dairy Farming Systems
SIMLESA	Sustainable Intensification of Maize and Legumes in Eastern and Southern Africa
SEM	Standard Error of Mean
SPSS	Statistical Package for Social Scientists
SSA	Sub Saharan Africa
TN	Total Nitrogen
UMS	Urea treated Maize Stover

CHAPTER ONE

INTRODUCTION

1.1 Background of the prioblem

The value of milk and dairy products as part of the human diet is very well documented. According to OECD-FAO Agricultural Outlook 2016-2025, milk production's enormous potential in economic development and food security in rural areas makes dairy an important subsector in SSA (Liu, 2017; Mukasa *et al.,* 2017). Within Southern and Eastern Africa, commercialization of the sector has illustrated dairy's potential to provide a regular income source that reduces poverty and improves living standards (Mukasa *et al.,* 2017). Eastern Africa currently constitutes more than half of total milk production in SSA and a vibrant smallholder farming sector made a considerable contribution to milk production growth of 37% over the past decade, rising by an annual average of 2.7% in Eastern Africa and 2.5% in SSA (Bingi & Tondel, 2015). The contribution of dairy cattle to the smallholder rural economy in Eastern Africa has not been commensurate with the number of animals or the extent of land resources available (Bingi & Tondel, 2015; Njwe, Kwinji *et al.,* 2001; Notenbaert *et al.,* 2017).

The overall productivity is generally low mainly because the region is characterized by smallholder production systems that rely on indigenous breeds and poor quality feeds (Bakrie *et al.,* 1996; Henderson *et al.,* 2016; Mujibi *et al.,* 2019; Thornton *et al.,* 2009; VandeHaar & St-Pierre, 2006). The inability of smallholder dairy farmers to feed animals adequately (quality and quantity) throughout the year is the most widespread constraint to improving animal productivity in Africa (Bakrie *et al.,* 1996; Duguma *et al.,* 2016; Oosting *et al.,* 2014). In the drier regions the quantity of forage is insufficient for the number of livestock. In the wetter regions feed supplies are usually ample but the forages are of poor quality, and usually deficient in protein and mineral nutrients. Also, the crop residues and agro-industrial by-products that could be fed to livestock are largely wasted or inefficiently used because of poor infrastructure for transport and processing or lack of appropriate processing technologies (Duguma *et al.,* 2016; Guadu & Abebaw, 2016; Wanapat *et al.,* 2017). Seasonality is a crucial factor in smallholder dairy farming with livelihood strategies revolving around seasonal patterns of water and forage availability and corresponding agro-climatic variability (Kariuki *et al.,* 2017; Mburu, 2015; Negesse, 2019). There is without doubt a seasonal increase in vulnerability to milk fluctuations when livestock feed (forage and water) becomes scarce, in turn limiting milk availability for human consumption (Fratkin *et al.,* 2006). Seasonal fluctuations in animal nutritional and eventual milk production status are noted to vary considerably by environment, genotypes and interaction.

Studies in Eastern Africa document decline in milk production status in the dry season, following significant seasonal variation in rainfall and feed availability (Arndt *et al.,* 2015; Lukuyu *et al.,* 2012; Martínez-García *et al.,* 2014). There is high animal performance variability during the dry season among smallholder dairy farmers compared with their large scale counterparts, suggesting that in the smallholder farming systems context, seasonality determined feed and water availability is a significant determinant of dairy cattle nutritional status. The development of the smallholder dairy industry in Eastern Africa must not only be viewed as a means of providing food for the increasing human population but also as a livelihood in existing smallholder farming systems (Duncan *et al.,* 2013; Mcdermott *et al.,* 2010). Although the potential for increasing production in such systems is considerable, this can only be achieved in a secure and sustainable way through comprehensive studies of their current production methods and constraints that prevent improvement (Baker *et al.,* 2015). Only then can problem oriented approaches be developed and applied to overcome these constraints and seasonality related milk fluctuations.

Smallholder dairy farmers produce milk in diverse production environments where productivity of dairy breeds is increasingly challenged directly and indirectly with the impacts of variable and changing climate (Marshall *et al.,* 2019; Thornton *et al.,* 2009; Weindl *et al.,* 2015). In Eastern Africa milk decline, as a result of seasonality related changes, is not usually linked to the milk "hunger gap" but occurs in the early half of the year linked to the dry season, the end of which is considered to be the most dangerous period for smallholder dairy farmers due to decreased forages (pasture and fodder), reduction in milk production and increased work-loads (Duncan *et al.,* 2013; Mayberry *et al.,* 2017). Low levels of productivity of dairy cattle is also associated with poor reproductive management which reduces the reproductive efficiency and the productivity of the animal (Ghavi Hossein-Zadeh, 2013; Sartori *et al.,* 2010). Poor nutrition in association with poor reproductive management leads to delayed puberty, inefficient estrus detection, long post-partum anestrus, low conception rates, high rates of embryonic mortality, long calving intervals and a general lowering in the fertility of the herd (Bahmani *et al.,* 2011; Ghavi Hossein-Zadeh, 2013; Guadu & Abebaw, 2016; Tadesse & Tegegne, 2018). It has been observed that different types of dairy animals require different quantities and combinations of feeds and fodders. Further, milk production and productivity has been observed to decline, to a considerable extent, during dry season (Maleko *et al.*, 2018) .

Systematic efforts are, therefore, warranted to increase milk production so as to ensure un-interrupted supply and bridge the gap between availability and requirement of milk in Eastern Africa. Studies have revealed that milk yield of East African Shorthorn Zebu or indigenous (local zebu) cows can be increased to the extent of 40 to 50 per cent through balanced and optimized feeding alone (Lukuyu *et al.*, 2019; Marshall *et al.*, 2019; Rewe *et al.*, 2015). Therefore, a significant potential exists for increasing smallholder dairy production by better breed management and proper feeding. Past studies revealed that improvement in animal nutrition through strategic use of available feed resources and improving animal genetics have a tremendous potential to increase dairy productivity (Herrero *et al.*, 2016; Hristov *et al.*, 2013; Garg, 2012; Mcdermott *et al.*, 2010). Breeds differ in their efficiency of feed utilization; maintenance requirements and efficiency of energy use for maintenance and production. Most dairy cattle production systems in Eastern Africa are faced with one or more seasons with low feed availability in quantity and quality, and production during such times is low because animals are fed sub optimally, relying solely on low quality crop residues (Amenu *et al.*, 2013; Guadu & Abebaw, 2016; Hristov *et al.*, 2013; Negesse, 2019; Richards *et al.*, 2015; Zewdie & Yoseph, 2014).

Overcoming these constraints often seems an elusive goal and technical feed interventions tend to adopt a trial-and-error approach which often fails to adequately diagnose the nature of the feed problem and therefore, the means to deal with it. Therefore, there is the need to adopt a systematic process for assessing feed resources at farming systems level with a view to developing farm specific strategies for improving feed supply and utilization (Negesse, 2019). Adoption of new productivity enhancement technologies is essential, but utilization of the data and action lists that these smallholder systems generate for making appropriate feeding management decisions is still largely unrealized. There is also the need for smallholder production systems to follow a year-round strategy incorporating a coordinated set of practices undertaken to meet specified objectives in terms of output and to maintain a level of efficiency that is consistent with genetic capabilities in the face of seasonal (environmental) variability. However, in most smallholder mixed crop/dairy systems, this is a part and not always the high-priority of the whole farm system. For the smallholder dairy farmers to remain competitive, it is important to increase industry capability to manage the implications of seasonality on smallholder milk production. The possibilities of using animal body, milk and reproduction indices for diagnosing seasonality effects and monitoring are considerable. Genetic and genomic selection for increased tolerance/resistance to seasonality effects offers substantial potential but requires collection of additional phenotypic data (Hoffmann, 2010; Hristov *et al.,* 2013; Marshall *et al.,* 2019; Mujibi *et al.,* 2019; Ojango *et al.,* 2019).

Farmer-led feed-year strategies involve matching the cycles of dairy production with the changing availabilities of all sources of nutrients over time. These feeding strategies must be consistent with the diverse production objectives of farmers and with the feasibility of achieving the nutritional support required. These in turn vary with farmers' bio-physical, socio-political, economic and environmental circumstances. Therefore, understanding seasonal changes/variation in feeding management decisions is important in future planning and development of appropriate and sustainable technologies/interventions to ensure resilience of smallholder dairy systems in Eastern Africa to seasonality driven milk fluctuations.

1.2 Statement of the Problem

Constraints to the development of a suitable strategy to overcome seasonal milk fluctuations in smallholder dairy farms, concerns the animals' nutritional demands in relation to the desired breed, level and timing of product outputs; the nutritional characteristics of the locally available feeds and water resources, and possible mismatches in timing or location. In most cases, conventionally, emphasis is usually placed on developing knowledge and skills on high quality feeding and breeding management systems. But, improvement of the already existing breeds (genotypes) or replacement with superior types depends on the knowledge of their bio-physical attributes, environmental (non-genetic), cultural, socio-political and economic factors that affect production in those environments. Coupled with the natural cycle in milk yield and reproductive performance, as influenced by year round seasonality (environmental) change effects and the smallholder dairy farmer, conventional methods lack awareness on feeding management decisions operating within the existing smallholder farmer constraints. Therefore, information on farmer-led feeding and breeding management decisions, in face of year round seasonality driven challenges, is crucial and a sustainable approach for improving milk fluctuations and the efficiency and effectiveness of the current smallholder dairy production in Eastern Africa.

1.3 Rationale of the Study

The value of milk and dairy products as part of the human diet is very well documented. According to OECD-FAO Agricultural Outlook 2016-2025, milk production's enormous potential in economic development and food security in rural areas makes dairy an important subsector in SSA (Liu, 2017; Mukasa *et al.*, 2017). Smallholder dairy farmers produce milk in diverse production environments where productivity of dairy breeds is increasingly challenged directly and indirectly with the impacts of variable and changing climate (Marshall *et al.*, 2019; Thornton *et al.*, 2009; Weindl *et al.*, 2015). In Eastern Africa milk decline, as a result of seasonality related changes, is not usually linked to the milk "hunger gap" but occurs in the early half of the year linked to the dry season, the end of which is considered to be the most dangerous period for smallholder dairy farmers due to decreased forages (pasture and fodder), reduction in milk production and increased work-loads (Duncan *et al.*, 2013; Mayberry *et al.*, 2017). Low levels of productivity of dairy cattle is also associated with poor reproductive management which reduces the reproductive efficiency and the productivity of the animal (Ghavi Hossein-Zadeh, 2013; Sartori *et al.*, 2010). Poor nutrition in association with poor reproductive management leads to delayed puberty, inefficient estrus detection, long post-partum anestrus, low conception rates, high rates of embryonic mortality, long calving intervals and a general lowering in the fertility of the herd (Bahmani *et al.*, 2011; Ghavi Hossein-Zadeh, 2013; Guadu & Abebaw, 2016; Tadesse & Tegegne, 2018). Overcoming these constraints often seems an elusive goal and technical feed interventions tend to adopt a trial-and-error approach which often fails to adequately diagnose the nature of the feed problem and therefore, the means to deal with it. Therefore, there is the need to adopt a systematic process for assessing feed resources at farming systems level with a view to developing farm specific strategies for improving feed supply and utilization (Negesse, 2019). Adoption of new productivity enhancement technologies is essential, but utilization of the data and action lists that these smallholder systems generate for making appropriate feeding management decisions is still largely unrealized. There is also the need for smallholder production systems to follow a year-round strategy incorporating a coordinated set of practices undertaken to meet specified objectives in terms of output and to maintain a level of efficiency that is consistent with genetic capabilities in the face of seasonal (environmental) variability.

1.4 Objectives of the Study

1.4.1 Main Objective

To elucidate the contribution of feeding and breeding approaches to productivity as influenced by seasonality and thereby provide farmer-led management suggestions on interventions adopted to overcome seasonal milk fluctuations.

1.4.2 Specific Objectives

(i) To investigate and synthesize information flows on cow feeding and breeding and how this affects decision making in face of seasonality by smallholder dairy farmers.

(ii) To evaluate the current pattern of seasonality driven changes in feed availability and year-round variations in feed sources.

(iii) To model and test “best-bet” interventions for overcoming the seasonality driven milk fluctuations in smallholder dairy farms.

(iv) To assess potential benefits associated with the model “best-bet’ interventions for overcoming seasonality driven milk fluctuation in smallholder dairy farms.

1.5 Research Questions

The direction to which farmer-led management approaches on feeding and breeding by smallholder dairy farmers should assume in order to overcome seasonality driven milk fluctuations have been uncertain. The following research questions highlight some of the prominent gaps:

(i) What smallholder farmer-led feeding and breeding approaches affect productivity (milk yield and reproduction) of dairy cattle in different agro-ecologies, production systems and seasons?

(ii) Do smallholder dairy farmers make deliberate decisions to feed (includes water) their dairy cattle breeds for milk yield or reproduction in the face of seasonality?

(iii) Are there socio-political, cultural, economic and bio-physical aspects working to counter, meeting the biological requirements (for milk yield and reproduction) of dairy cattle?

(iv) What is the current pattern in year-round feed availability and variation in sources in smallholder dairy farms as influenced by seasonality changes?

(v) Are approaches by smallholder dairy farmers on feeding to overcome seasonal fluctuations in productivity determined by the complexities and interactions between the farmer, bio-physical, socio-political, cultural, environmental and economic factors and the need to maximize profitability?

(vi) What are the model "best bet" interventions that can be tested and validated to overcome seasonality driven milk fluctuations in smallholder dairy farms?

(vii) What are the potential benefits associated with the model "best-bet' interventions for overcoming seasonality driven milk fluctuation in smallholder dairy farms?

1.6 Significance of the Study

Considerable progress has been witnessed in dairy production and technology in bringing about genetic improvement of dairy animals for increasing milk production in Eastern Africa. But, improved breeding is not substitute for better feeding. Therefore, the new knowledge gained with this thesis on the production responses to environmental factors can be incorporated in farmer-led decision making for optimization of seasonal feed and fodder variations in dairy cow feed rations, and thereby be one among other tools for optimizing the production economy for the dairy farmer. Detailed information on the status of production in face of seasonality driven changes is required for planning of further interventions to increase productivity and also useful for gauging the level of progress accruing from the various farmer-led feeding management decisions. The findings have a potential positive contribution towards policy formulation and planning of development interventions in smallholder dairy cattle production systems in Eastern Africa. Informed policy and strategy formulation is an effective means of achieving respective country goals for poverty reduction and increasing the income level of smallholder dairy farmers. Finally, the document may serve as a reference material for those who are interested in the area of seasonality analysis in smallholder dairy production.

1.7 Delineation of the Study

Seasonality due to rainfall variability was the main driver of continuous year-round fluctuation in milk production and reproductive performance in smallholder dairy farms in Kenya and Tanzania. These seasonality effects were also evident in the deliberate efforts or investment by smallholder farmers in dairy cattle feeding and breeding management approaches. This study focused on Farmer-led innovative management approaches to reduce the effects of the dry season period, mainly feed and water shortage, while increasing reproductive performance, live body weight and milk yield in smallholder dairy farms.

CHAPTER TWO

LITERATURE REVIEW

2.1 Theoretical Model

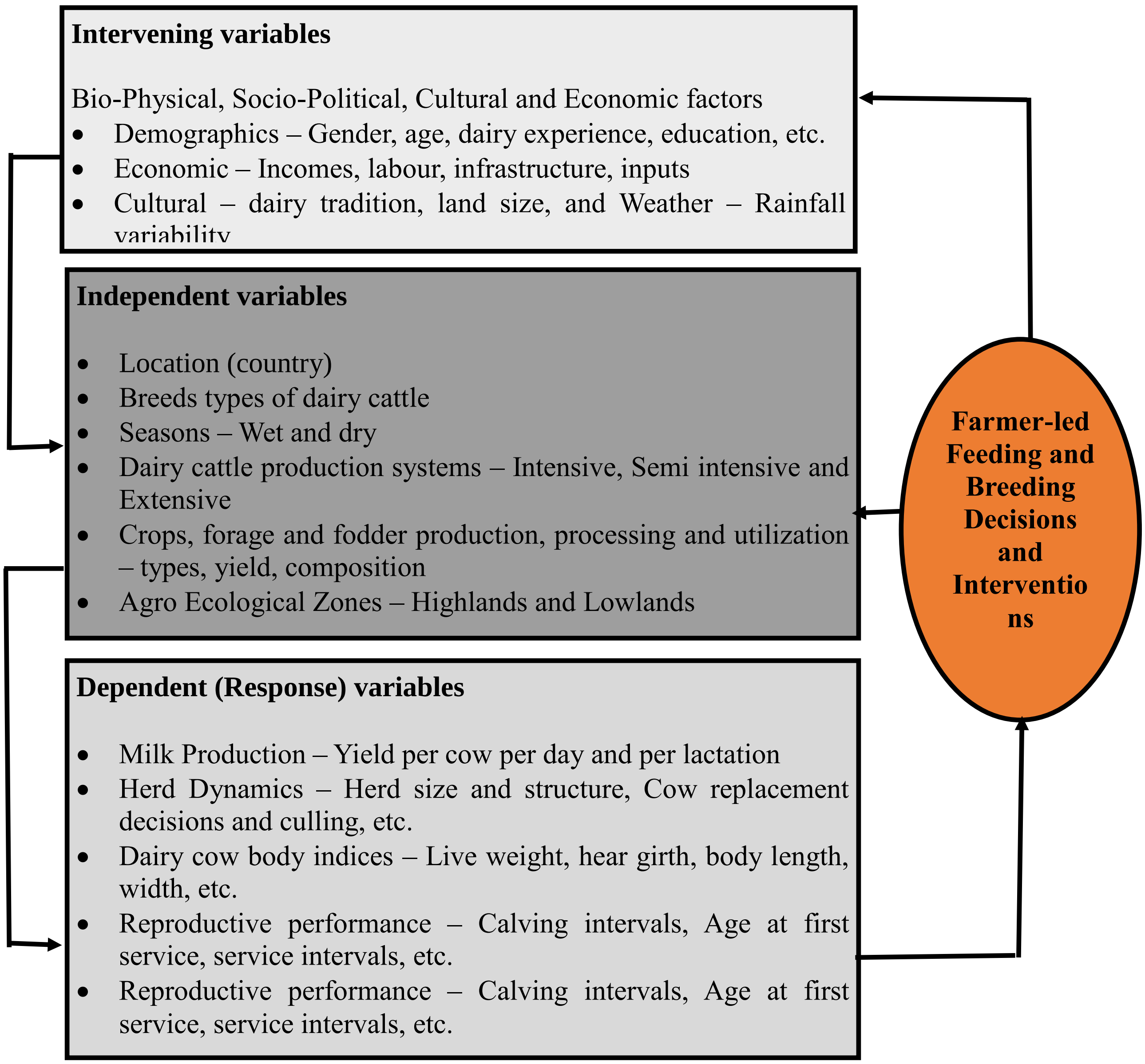


Figure 1: Conceptual framework of intervening, independent and dependent variables influencing farmer-led feeding and breeding management decisions and interventions

A theoretical research framework (Fig. 1) was developed to guide collection of information required for study objectives, identify measurable variables and design tools for measurements and interventions. The dependent (response) variables (factors), measured smallholder dairy farmerled approaches and outcomes on feeding and breeding, which was improved productivity, measured as: milk yield (daily and lactation milk yield per cow); reproductive performance (herd dynamics, live body weight (LBW), live body weight changes, calving intervals (CI), age at first calving (AFC), age at 1st service (AFS) and body condition score); cow replacement investment decisions, and feeds sources (concentrates, crop residues, pasture, legumes and fodder trees/shrubs).

These dependent variables were influenced by a group of independent (environmental) variables (fixed effects), which were the cause of effect (seasonal fluctuation in milk yield and reproductive performance), which consisted of location (Kenya and Tanzania), seasons (wet and dry), agro-ecological zones (highlands and lowlands), production systems (extensive, intensive and semi-intensive) and breed types (local zebu, Ayrshire, Ayrshire cross, Holstein-Friesian and Friesian cross). The independent variables, were in turn influenced by intervening (explanatory) variables (random effects) and comprised farm household characteristics, which were socio-political (demographics such as gender, age, sex, education levels and dairying experience), cultural and economic profiles of the smallholder dairy farmer and bio-physical factors (land size, land use and rainfall variability).

2.2 Global and regional trends in dairy cattle production

The demand for animal source foods is rapidly increasing in developing countries: for example, in low income countries the demand in 2030 for beef, milk, poultry and eggs is predicted to be a 124, 136, 301, and 208% increase over that in 2000, respectively (FAO, IFAD, UNICEF, 2017). This demand increase has been largely attributed to population growth, income growth and increasing urbanization (Duncan *et al.,* 2018; FAO, 2017; Notenbaert *et al.*, 2017). In these developing countries, the livestock sector, specifically the dairy cattle sub-sector, plays a key role in the provision of livelihoods as well as food and nutrition security (Marshall *et al.,* 2019). The majority of dairy cattle are kept by the rural poor, where they serve multiple functions (FAO, 2017; Marshall *et al.*, 2019; Notenbaert *et al.*, 2017). These include: savings and insurance, food security (meat and milk), income, livelihood diversification and thus risk reduction (such as in mixed crop-livestock systems), inputs to crop production (draft power, manure as fertilizer), transportation, various uses of hides and skin (such as for housing), allowing households to benefit from common-property resources (such as communal grazing areas), and fulfilling social obligations (such as being used in special ceremonies or for dowry), amongst other (Marshall *et al.*, 2019; Nyamushamba *et al.,* 2017; Tadesse, 2018).

The dairy cattle sub-sector also benefits other actors in the associated value chains, such as input providers, traders, processors and retailers, through the provision of employment and income (Duncan *et al.,* 2018; Marshall *et al.,* 2019; Notenbaert *et al.,* 2017). Critically, animal source foods–consumed in even small amounts - play a key role toward food and nutritional security of the poor, as they provide quality protein and micronutrients essential for normal development and good health (Msangi *et al.*, 2014; Notenbaert *et al.*, 2017; Richards *et al.*, 2015). To ensure this demand is met, large increases in dairy cattle production within developing countries will be required (Mcdermott *et al.*, 2010; Rojas-Downing *et al.*, 2017; Thornton *et al.*, 2009). Achieving this outcome in a sustainable manner is expected to be challenging, with a key component of this recognized to be increasing dairy productivity (output per unit of input). Increasing dairy productivity in developing countries generally requires simultaneous interventions in the areas of animal feed, health and genetics (Garg, 2012; Marshall *et al.,* 2019; Mcdermott *et al.,* 2010; Mwanga *et al.,* 2018; Thornton *et al.,* 2009).

In many dairy development programs these interventions take the form of capacity building of the dairy keepers and other value chain actors, ensuring the availability and accessibility of inputs, provision of new technologies or customization of existing technologies, support to private and/or public sector involvement, and advocacy for supportive policies (Marshall *et al.*, 2019; Mcdermott *et al.,* 2010; Tadesse, 2018). However, to date, the majority of African dairy cattle production systems have not benefited from dairy technologies to the extent that developed countries have, including in relation to feeding and genetic improvement strategies (Marshall *et al.*, 2019). Contributing factors to this include: the lack of public and private sector investment; lacking or weak supportive policies and institutional arrangements; the heterogeneity of dairy systems, farm-scales, management practices, and needs and preferences of dairy cattle keepers; poor infrastructure; climatic changes (rainfall and temperature variability) and limited capacity, amongst others (Marshall *et al.*, 2019; Mcdermott *et al.*, 2010).

2.3 Dairy cattle production in Eastern Africa

East Africa is biophysically diverse, with altitude and topography ranging from lowland coastal zones and plains (0-1500 m) to highland landscapes over 1500 m with steep slopes (Duncan *et al.*, 2018). Soils are also very diverse, ranging from young soils developed on volcanic deposits in the Rift Valley, to highly weathered old soils of various types, which dominate most of the region. Agriculture is mainly rain fed, and both unimodal and bimodal rainfall patterns are found within the region and even within some countries (Duncan *et al.*, 2018). The result of this diversity is a variety of farming systems, where the Maize-Mixed Farming System integrated with livestock is the crop-livestock system dominating in the sub-humid areas of Eastern Africa (Baudron *et al.,* 2014; Njwe *et al.,* 2001). A high proportion of the population is engaged in agricultural activities, and depends on the farm for their food and nutrition security and their livelihood. Due to favourable biophysical conditions, the highlands are highly populated, with densities as high as 500 persons/km^2 (Duncan *et al.,* 2018). These high densities lead to small farm sizes and herd sizes, with most smallholders cultivating less than 1 ha and 1-4 cows (Duncan *et al.,* 2018; Herrero *et al.,* 2016; Jayne *et al.,* 2014; Mujibi *et al.,* 2019; Oosting *et al.,* 2014; Place *et al.,* 2009).

Livestock, and mainly dairy cattle is a key component of the mixed crop-livestock farming systems in East Africa (Mcdermott *et al.,* 2010). Within farming communities, farming households have varying access to resources with poorer households commonly having less livestock, land and labour. This variation in resource endowment has been conceptualized into a series of household types (Tittonell *et al.,* 2010; Pablo 2014). This range of biophysical conditions along with access to and allocation of resources, plays a major role in the integration of crops (includes feeds and forages) and dairy cattle into existing farming systems (Chagunda *et al.,* 2016). Therefore, as dairy cattle systems within Eastern African countries are both diverse and dynamic, intervention packages typically need to be customized for each dairy sector.

2.4 The case of dairy cattle production in Kenya and Tanzania

In Kenya and Tanzania, the large majority of milk is produced by smallholder farmers who typically milk 1–5 cows (Chagunda *et al.,* 2016; Duncan *et al.,* 2013; Place *et al.,* 2009). Smallholders mostly keep crosses between indigenous cattle and exotic dairy breeds such as Holstein, Friesian, Ayrshire, and Jersey (Hristov *et al.,* 2013; Marshall *et al.,* 2019). There is no systematic breeding of crossbred cattle and smallholder farmers rarely keep pedigree or performance records (Philipsson, 2003). Most mating events involve local crossbred or indigenous bulls, where the crossbred bulls are of unknown breed composition (Marshall *et al.,* 2019). Farmer production environments vary greatly and this translates into a wide range of production output per cow, from less than 1000 litres milk per annum to more than 5000 litres, with the large majority likely in the range 1000 to 3000 litres milk (Herrero *et al.,* 2016; Marshall *et al.,* 2019).

There is limited information about which breed composition works best for different production environments, other than the general observation that high grade exotics (cows with a very high proportion of exotic dairy breed composition) can do well in very good environments, while the intermediate grades do better in poorer production environments (Chagunda *et al.,* 2016; Chindime & Chagunda, 2017; Marshall *et al.,* 2019). According to Ojango *et al.* (2019) showed that intermediate to low grade (<50% exotic breed ancestry) cows performed best in the majority of the smallholder farms, while animals with higher grades (>50%) only performed better than lower grades in the best environments (those supporting >1800 litres/cow/year). The potential of genetic improvement to increase dairy cattle production and productivity is, however, increasingly being recognized by decision makers, with many East African countries now explicitly including genetic improvement within their national dairy development plans (Kariuki *et al.,* 2017; Marshall *et al.,* 2019; Ojango *et al.,* 2019). However, genetic improvement is not a substitute for improved feeding in smallholder dairy farms in these countries.

2.5 Seasonality of Milk production and Reproductive performance

Seasonality in milk production is a crucial factor in smallholder dairy farming systems (SDFS) with livelihood strategies (Makate & Mango, 2017) revolving around seasonal patterns (Mcdermott *et al.,* 2010) of water and forage availability and corresponding agro-climatic variability (Weindl *et al.,* 2015). Studies in Eastern Africa document decline in milk production status in the dry season, following significant seasonal variation in rainfall (Fig. 2) and feed availability. Duncan *et al.* (2013, 2018), describes high variability during the dry season among smallholder dairy farmers compared with their large scale counterparts (Kariuki *et al.,* 2017), and suggest that in the smallholder dairy farming systems context, seasonally determined feed and water availability is a significant determinant of dairy cattle nutritional status, hence production and productivity.

Smallholder dairy farmers produce milk in diverse production environments (Henderson *et al.,* 2016), where productivity of dairy breeds is increasingly challenged directly and indirectly with the impacts of variable and changing climate (Hristov *et al.,* 2013). Milk decline and fluctuation, as a result of seasonality related changes is usually linked to the 'milk deficit/gap' (Duncan *et al.,* 2013; Mayberry *et al.,* 2017; Notenbaert *et al.,* 2017); and occurs in the end to early half of the year linked to the dry season, the end of which is considered to be the most dangerous period for SDFS. Milk yield of cows as reported in SDFS varies widely across the different seasons, agro-ecologies and dairy production systems, and ranges from 1.5 litres per cow per day in pastoral and agro-pastoral systems to 20 litres per cow per day in intensive systems.

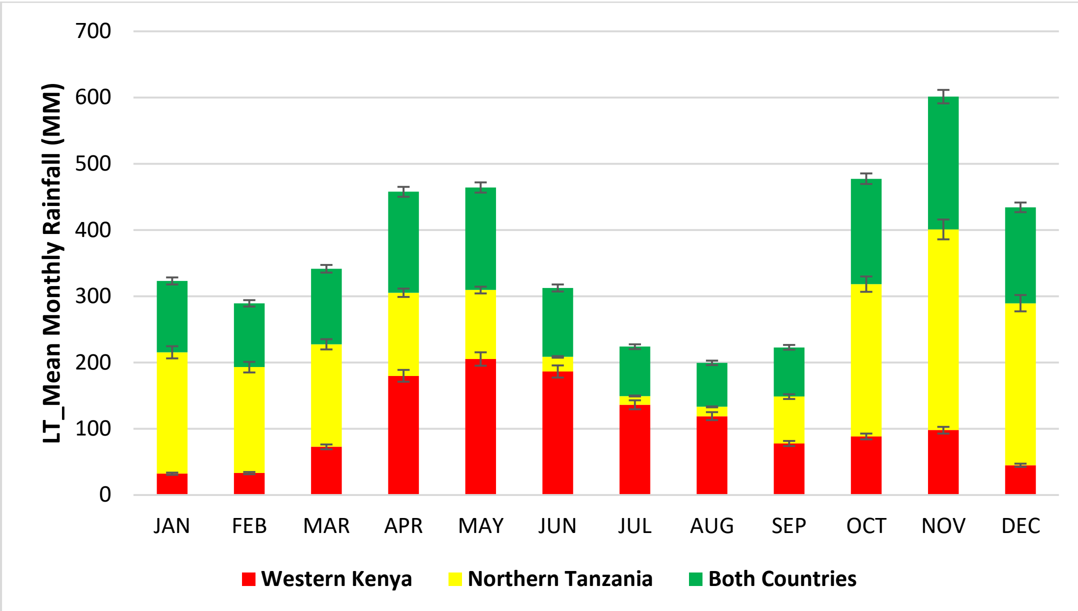


Figure 2: ong term mean (LTM) monthly rainfall (mm) in Western region of Kenya and Manyara region of Northern Tanzania from 2002-2018 (Source: Meteorological Services and www.climate-data.org/Kratu/Kakamega/Mbulu/Siaya)

High milk fluctuations arise because most farmers depend on rain for feed production and rarely make provisions for preserving fodder for the dry season. In addition to seasonality of feed supply, the diets are largely made of low quality feed products such as crop residues between 30-35% and native pastures of poor nutritive value (56% - 90%), hence the optimal targets for milk yield and reproductive performance are never attained (Duncan *et al.,* 2013; Thornton *et al.*, 2009). Seasonality, therefore results into low or inconsistent performance of smallholder dairy cows in terms of milk yields and composition, lactation length and persistency, milking practices and interval, estrus cycle, waiting period, days open, calving rates, age at first calving and calving intervals observed in SDFS, and is attributable to low levels of breeds (genetics), nutrition and management (Marshall *et al.,* 2019; Nyamushamba *et al.*, 2017). Whereas, milk production is greater from systems growing a range of forages, including high energy forages, the cost of the increase in complexity of such systems is likely to more than offset the increase in income. The full expression of an animal's genetic potential in terms of milk production and reproductive performance depends on the provision of adequate nutrition (Maleko *et al.,* 2018; Marshall *et al.,* 2019; Mwanga *et al.,* 2018). Genetic potential, however, is not the guiding principle for farm optimization, with limited access to additional feed resources (Paul, 2014;

Philipsson, 2003). Therefore, for SDFS and development agents alike, the fundamental challenge is to develop a combination of animals and feeds that assures satisfactory levels of growth, reproduction and lactation. This must be based in large part on the optimal use locally available feed resources like crop residues and by-products.

2.6 Seasonal changes in feed resource base, feed-year strategies and intakes

The principal determinants of the types of food-feed crops grown and animals reared in any particular location are the prevailing agro-climatic conditions (Khan *et al.,* 2012; Notenbaert *et al.,* 2017; Thornton *et al.,* 2014). Climate especially, and to a lesser extent soil, affects the natural vegetation and influence farmers' choice of food-feed crops (Notenbaert *et al.,* 2017; Weindl *et al.,* 2015). The food-feed crops in turn determine the feed base and its quantity, quality and dispersion (Jayne *et al.,* 2014; Maleko *et al.,* 2018; Marshall *et al.,* 2019; Mcdermott *et al.,* 2010). The feed resources provide a direct link between crops and animals, and the interaction of the two, together with other environmental challenges, largely dictate the development of smallholder mixed farming systems (Duncan *et al.,* 2013; Oosting *et al.,* 2014; Thornton *et al.,* 2009). The total feed resource base for dairy cattle may be divided into three categories: permanent natural rangeland, crop residues (including cultivated fodder), and energy feeds–grains, concentrates or agro industrial by-products. Feed-year strategies involve matching the cycles of dairy production with the changing availabilities of all sources of nutrients over time (Bakrie *et al.,* 1996; Khan *et al.,* 2012). The strategy must be consistent with the diverse production objectives of farmers and with the feasibility of achieving the nutritional support required. These in turn vary with farmers' bio-physical, socio-political, economic and environmental circumstances, and range from fully commercial to small-scale or subsistence farmers (Duncan *et al.,* 2018; Hristov *et al.,* 2013; Mapiye *et al.,* 2007; Martínez-García *et al.,* 2014; Nyhodo *et al.,* 2014). There is need to develop a suitable feeding strategy concerning the animals' nutritional demands in relation to the desired output type (milk or reproduction), level and timing of product outputs, the nutritional characteristics of the feeds available, and possible mismatches in timing or location. Further, there is also need to optimize overall crops and dairy cattle productivity from available resources through an integrated set of practices. Therefore, understanding various feed resources and coping strategies used to overcome dry season feed shortages, is important in future planning and development of appropriate technologies to ensure resilience of smallholder dairy systems to seasonality driven milk shortages.

The Feed Assessment Tool (FEAST) is a systematic methodology that has been developed and used to assess local feed resource availability and use (www.ilri.org/feast). It offers a systematic and rapid methodology to assess feed resources at site/location level with a view to developing a site/location-specific intervention strategy to improve and optimize feed supply, utilization and animal production through technical or organizational interventions (Dror *et al.*, 2015; Padmakumar *et al.*, 2014). The FEAST differs from conventional feed assessment approaches that focus on the feeds, their nutritive value, and ways to improve them. The FEAST broadens this assessment to account for the importance of livestock in local livelihoods, the relative importance of feed problems locally, and the local situation related to feed availability, seasonality, and utilization (Negesse, 2019).

Smallholder dairy farmers cultivate a variety of forage associations (pasture, fodder, legumes) and crops (maize, potatoes, beans, peas) in order to increase their returns and simultaneously reduce risks and impacts of seasonality This crop diversity on small cultivated areas leads to difficulties in providing a constant feeding diet to their dairy cattle in a green forage-based system. Therefore, feeding decisions for smallholder dairy farmers are highly variable considering the complexity of animal characteristics, management effects, available feed resources and agro-climatic variability (Herrero *et al.*, 2016; Hoffmann, 2010). Continuous seasonal differences in temperature and rainfall characteristic of the East Africa region are also strongly reflected in cropping and feeding calendars. For example, inter-annual fluctuations in rainfall can also affect crop residue yield, which may in turn affect the ratio between edible and non-edible fractions within residues. Utilization of good quality grazing or cultivated pastures in these smallholder dairy farming systems is a good feeding strategy that results in higher milk yields to the traditional cut and carry strategy using Napier grass, as it reduces feeding costs up to 25% and increases margins over feeding to 15%, which enhances the sustainability of the systems by improving the economic scale. Therefore, introduction of improved feeding practices based on strategic supplementation of locally available feed resources is required not only to enhance milk production (by overcoming seasonal milk fluctuations), but also to introduce sustainable farming practices that will ensure a continuous supply of milk and milk products at lower production costs in smallholder dairy farms for sustainability and competitive advantage.

2.7 Utilization of crop residues in smallholder dairy cattle feeding systems

Smallholder dairying is important in sustaining livelihoods in Eastern Africa, where dairy cattle diets are forage based (Maleko *et al.*, 2018). In the past, this would be provided through grazing, or more recently by growing planted forages mainly Napier grass (Muia, 2000). However, as farm sizes decrease through inter-generational subdivision and farms intensify, farmers seek to maximize food security by growing food crops (cereals and legumes) alongside planted forage feeds (Duncan *et al.*, 2018; Mtimuni, 2012). For many small holder farmers, feeding dairy cattle over the dry season period when forages are scarce is a major challenge (Atuhaire *et al.*, 2014).

The inadequate forage feed availability and supplies is aggravated by seasonal variations in quantity and quality that causes fluctuations in animal nutrition and productivity throughout the year (Mudavadi *et al.,* 2020). Hence, to bridge the feed gap, majority of smallholder farmers mainly depend on crop residues to meet the nutrient requirements of the animals (Maleko *et al.*, 2018; Sheikh *et al.,* 2018; Zewdie & Yoseph, 2014). Crop residues are roughages, potentially rich sources of energy, as about 80% of their dry matter (DM) consists of polysaccharides, but are usually underutilized because of their highly lignified fibre, deficiency in mineral nutrients such as nitrogen (N), Sulphur (S), Phosphorus (P) and Cobalt (Co), which are essential to rumen microorganism function and their low digestibility (Ejigu, 2018; Onyango, 2018). Crop residues, such as maize stover, bean haulms, sunflower straw, pigeon pea haulms, rice straw, groundnut husks, sugarcane tops, wheat straw, etc., are abundant in the food crop growing areas), as largely underutilized by-product because of their low digestibility, which limits feed intake (Smith, 2002; Wachirapakorn *et al.,* 2016).

Crop residue based diets in their natural form, cannot meet nutrient requirements of dairy cattle and often result in low milk production, sub-optimal reproductive performance and general poor health (Hristov *et al.,* 2013). However, these poor quality roughages have potential to improve nutritional value and animal feeding systems through employing different treatment strategies (Smith, 2002; Wachirapakorn *et al.,* 2016). Urea-Molasses treatment is well documented and has emerged as the method of choice for use at farm level in the tropics as it is best adapted to the conditions of smallholder farmers (Dove, 2009). Moreover, fertilizer grade urea is readily available and relatively cheap compared to other chemical treatments with either aqueous or anhydrous ammonia. It is recognized that when animals are offered a low-nitrogen, high fibre roughage diets, as with most cereal crop residues, one of the critical limiting nutrients is fermentable nitrogen (N) available to rumen microbes (Mahesh & Mohini, 2014; Wanapat *et al.*, 2017).

The use of urea-molasses is a convenient way to avoid excessive intake of urea N which would result in Ammonia-Nitrogen losses from the rumen, and will ensure an almost continuous supply of Ammonia-Nitrogen, along with readily soluble carbohydrate for microbial growth (Ahmed *et al.,* 2002; Bakrie *et al.,* 1996; Eroni & Aregheore, 2006). The cost of feeding is a major component of the total cost of milk production, up to about 60-65%, and hence reduction of feeding cost needs to receive due emphasis. The introduction of improved feeding practices, based on strategic supplementation of locally available forage feed resources, especially during the dry season, is required not only to enhance milk production, but also to introduce a sustainable farming practice that will ensure a continuous supply of milk even during feed scarcity (Moran, 2005). Therefore, the use urea-molasses pre-treated crop residues for feeding and/or supplementing dairy cattle will have a positive effect, when inclusion in feed rations is justified both from the biological point of view and financial returns (Kashongwe *et al.,* 2017; Manzana *et al.,* 2014; Sheikh *et al.,* 2018).

However, details of information on the incubation (pre-treatment) of crop residues with urea-molasses and utilization practices are not well documented for the study locations. Additionally, the inclusion levels, incubation period, cost effectiveness and utilization of crop residue pre-treated with urea-molasses for feeding lactating dairy cows has not been studied under the study region conditions. As a result, due consideration on assessment, development and evaluation of feeding options with urea-molasses pre-treated crop residue based feeding for milk production and other animal performance indices is vital. The target end user is the smallholder dairy farmer in Eastern Africa, and it is hoped that this intervention will increase value of output without adding significant cost hence enhance adoption of urea-molasses pre-treatment for utilization of crop residues.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Location of the Study

The study was carried out in highlands and lowlands agro-ecological zones in Kenya and Tanzania in Eastern Africa. A reconnaissance survey was carried out to have an understanding of the study areas in the two countries and to select representative agro-ecologies before proceeding to formal survey and observational study. The two countries were stratified into highlands agro-ecology (1500 to 2500 meters above sea level) and lowlands agro-ecology (1000 to 1499 meters above sea level) based on the Kenyan and Tanzanian agro-ecological classification (Jaetzold *et al.,* 2005), and secondary data obtained from government livestock offices. Four distinct locations representing the highlands and lowlands agro-ecologies were selected, namely Mbulu (highlands) and Karatu (lowlands) in Manyara region of Northern Tanzania; and Kakamega (highlands) and Siaya (lowlands) in Western region of Kenya (Fig. 3). Karatu lies within Latitude 3.3454ºS and Longitude 35.6697ºE, with altitude range from 1000-1495 m.a.s.l. Mbulu lies within Latitude 4.0805 ºS and Longitude 35.5466 ºE, with altitude range from 1500-2450 m.a.s.l. Siaya lies within Latitude 0.0998 ºN and Longitude 34.2747 ºE, with altitude range from 1140-1490 m.a.s.l. Kakamega lies within Latitude 0.2827 ºN and longitude 34.7519 ºE, with altitude range from 1500-1950 m.a.s.l. Karatu and Mbulu receive rainfall range from 400-1800 mm/year, with short rains from November-December, long rains from February-May and long dry cold periods from June-October with mean annual temperature range from 10-25 ^{o}C. Kakamega and Siaya receive rainfall range from 800-2214 mm/year, with long rains from March-June and short rains from September-November, and dry period from December to February with annual temperature range from 15-25 ^{o}C. Therefore, the four study areas in the two countries have a bimodal rainfall pattern, which is unevenly distributed throughout the year with maize as the main food crop and dairy cattle as main livestock.

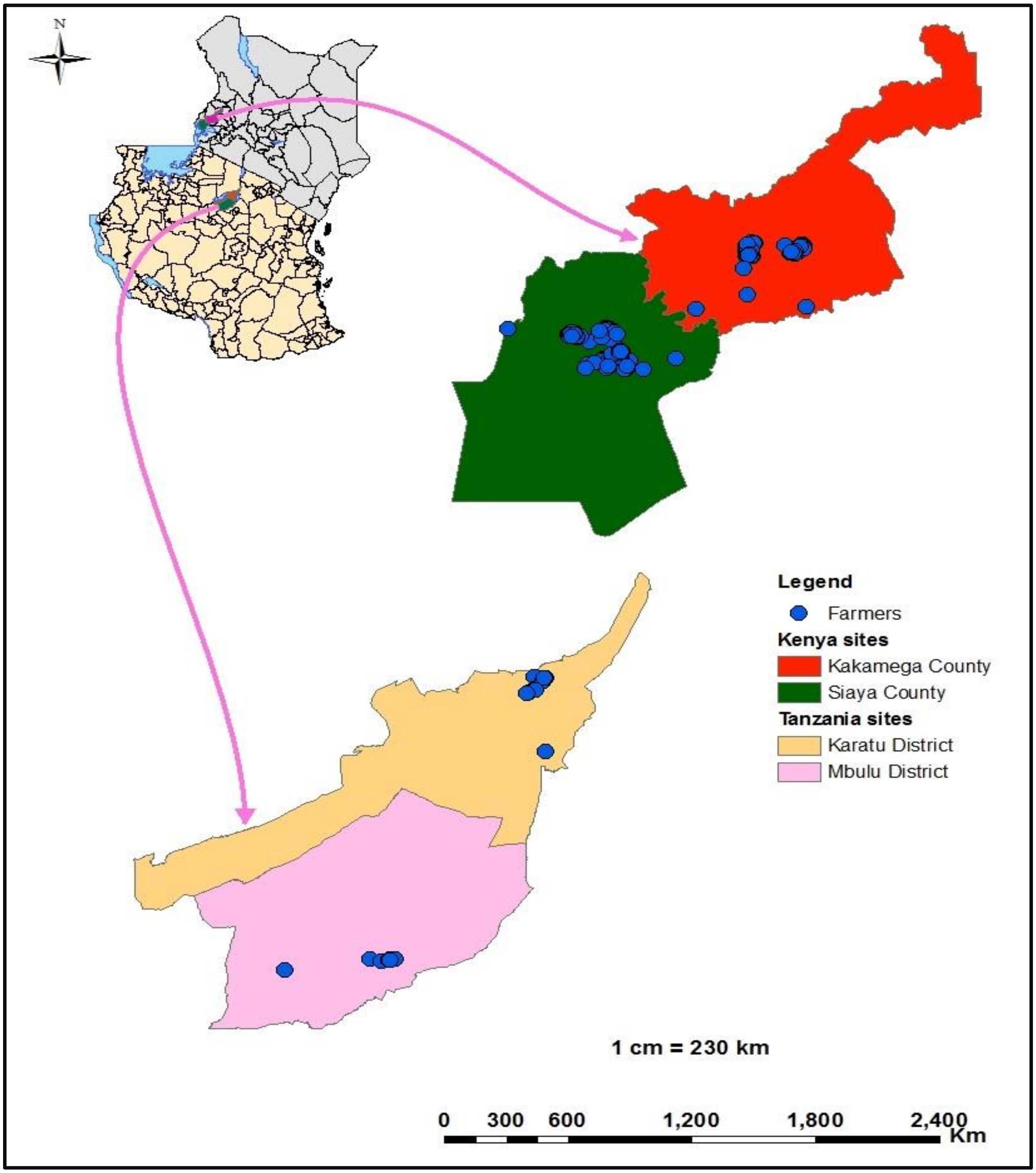


Figure 3: Map showing study sites that comprised Kakamega and Siaya in Western Kenya and Karatu and Mbulu in Manyara, Northern Tanzania

3.2 Study Design and Implementation

The main cross-sectional household survey questionnaire was divided into sections covering: dairy cattle production systems, rainfall variability, household demographics, household assets and activities, land ownership and land use, livestock ownership and inventory: breeds and breeding systems, herd structure and dynamics, milk production and reproductive performance, water availability and use, crops, fodder production and utilization, feeding decisions and strategies, costs of production and constraints (Appendices 1 and 2 and 3, which were the Focus Group Discussion Checklist, Kiswahili and English versions of the questionnaire, respectively). The study was carried out in two phases, the cross sectional survey and observational monitoring study. Data for cross sectional survey was collected from October 2016 to June 2017. While, for each of the selected farms for observational study, data was collected from October 2017 to June 2019. Enumerators were selected and trained to collect the data. Protocols and data collection tools were developed to guide the observational monitoring study in Kenya and Tanzania.

3.3 Phase 1: Cross Sectional Survey and Observational Study

This involved a cross-sectional survey to investigate and synthesize information flows on feeding and breeding, and how this affects decision making by smallholder dairy farmers in face of seasonality. Further, to evaluate the current pattern of seasonality driven changes in feed availability and year-round variations in feed sources. A pre-tested structured household questionnaire and Feed Assessment Tool (FEAST) through Focused Group Discussions (FGDs) and Rapid Rural Appraisal (RRA) were utilized to collect data in Phase 1 (Appendices 1-FGD Checklist; 2-Kiswahili version; and 3-English version).

3.4 Study population

The study population consisted purposively of mixed crop-livestock smallholder dairy cattle keepers, who had dairy cattle (local zebu and exotic/improved breeds) managed under the extensive, semi-intensive and intensive production systems within the highlands and lowlands agro-ecological zones in each country. Accordingly, semi-intensive system included all animals that were partly kept in door and fed and watered in their house/shade by cut and carry system while intensive system covered all animals which were kept in closed housing system and feed concentrate as well as mixed feed. Extensive management system included all animals that were kept out-door during the day time and allowed to graze on a communal or private owned pasture land. The cows comprised East African Shorthorn (indigenous/local) Zebu breed of *Bos indicus* origin, Crossbreeds and Pure/Exotic breeds *of Bos taurus* origin.

3.5 Secondary data collection

Secondary data, such as climate (weather) data were obtained from Meteorological and Online Services (www.climate-data.org). Data on disease control measures, feeding constraints, methods of breeding and extension services were collected using reports from the village representatives'/opinion leaders, Government Livestock Offices and other development programmes operating within/around the study areas. Data obtained enhanced the understanding of the factors that affect the performances of dairy cattle kept by small-scale dairy farmers. Rainfall data was collected from each study country/district Meteorological Service station and www.climate-data.org/kakamega/karatu/mbulu/siaya.

3.6 Sample size determination

A total of 400 dairy cows from 400 dairy cattle keeping households were randomly sampled from Kenya highlands, Kenya lowlands, Tanzania highlands and Tanzania lowlands. The sample size was obtained according to Fox *et al.* (2009), by estimating the number of observations potentially needed to distinguish between the two (highlands and lowlands) agro-ecological zones by a difference of 7% in some of the important farm household variables. Therefore, assuming a desired confidence interval of 95% with a precision of 5%, and a coefficient of variation of 51%, the sample was estimated from the formula: $\mathrm{N} = 2(\mathrm{Zc}/\mathrm{d})^2$; where, N=Minimum sample size, z=1.96 for 95% confidence interval, c=Coefficient of Variation, d=Level of difference.

3.7 Sampling Strategy

Multistage purposive sampling technique (Rosie, 2006) and a single-visit multi subject formal survey method were used for the cross sectional survey using a pre-tested structured questionnaire (Omair, 2014). Country (District-Tanzania and County-Kenya), Agro-ecological zones (highlands and lowlands), dairy production systems (extensive, semi-intensive and intensive) and dairy farm households were the primary, secondary, tertiary and fourth sampling units respectively. At each stage, sampling units were selected randomly (Rosie, 2006). From each district/county, three villages/sub-counties were taken using purposive sampling for administering the survey tools. These comprised G-Arusha, Ayalabe and Rhotia in Karatu (lowlands); Hydom, Dongobesh and Tumati in Mbulu (highlands); Karemo, Alego Usonga and Bor in Siaya (lowlands); and Lurambi, Navakholo and Kakamega Central in Kakamega (highlands). A total of 400 dairy cattle keeping households were randomly sampled across delineated transects, 104 from Kakamega (Kenya highlands), 96 from Siaya (Kenya lowlands), 102 from Mbulu (Tanzania highlands) and 98 from Karatu (Tanzania lowlands).

3.8 The Feed Assessment Tool (FEAST)

The Feed Assessment Tool (FEAST) is a systematic method to assess local feed resource availability and use (www.ilri.org/feast). Qualitative data collection using FEAST was through Participatory Rural Rapid Appraisal (PRRA) focus group discussions (FGD) handled by a facilitator, interpreter, two note takers and one observer in each session (Appendix 8.1 and FEAST Tool). The farmers (PRA and FGD participants) were selected based on information from interaction of key informant with community members through which smallholder mixed crop and livestock farmers were identified and classified into four categories (wet and dry seasons in highlands agro-ecology and wet and dry seasons in lowlands agro ecology) in both Kenya and Tanzania. In each agro ecology (highlands and lowlands), 18 farmers (12 men and 6 women) were selected for the survey, giving a total of 108 farmers in both countries.

3.9 Quantitative data collection

Quantitative data was collected through individual dairy farm household interviews. A pre-tested structured questionnaire was used to collect information from a purposive representative sample of 400 smallholder dairy farmers from highlands and lowlands agro-ecological zones in the two countries, by trained enumerators on visit interviews between October 2016 and May 2017 to capture the season’s effect (wet and dry). The cross sectional survey was followed by a purposive observational (monitoring) study covering two seasons (wet and dry) in the study locations between July 2017 and June 2019, to monitor and capture the seasonal/year-round variations in feed and fodder sources and usage including milk yield and animal performance.

3.10 Statistical Model

The influence of both independent (fixed) and intervening (random) factors on the response (dependent) variables, which was milk yield and reproductive performance of dairy cattle, were investigated using a generalized linear mixed effect statistical model (GLMM). The cause and effect factors in the model comprised environmental influence of location, breed type, production systems, seasons, agro-ecological zones and farm household characteristics. The breed consisted of East African Shorthorn (indigenous/local) Zebu type, Crossbreeds and Exotic (European genes/blood) types. The production systems comprised of free grazing (extensive), semi-zero grazing (semi intensive) and confined or zero grazing (intensive). Seasons comprised wet and dry, based on rainfall variability from January to December. Agro-ecological zones comprised of highlands and lowlands, based on elevation (metres above sea level). The generalized linear mixed effect statistical model (GLMM) for this study was thus represented as:

$$Y = b_0 + \sum_{i=1}^{p} b_i X_i + e$$

Where: Y= Response variable (milk yield and reproductive performance of dairy cattle); β_0 = the value of Y when all independent variables equal zero; β_i = the coefficient associated with independent and explanatory (intervening) variables X_i and X_i = are independent and intervening variables described above.

3.11 Farmer-led estimates of monthly rainfall and variation in feed sources

During the cross-sectional survey, the long-term monthly rainfall pattern and variation in feeds and fodder sources were scored on a five-point scale of 0-5 [where 0=none (0%); 1=moderately low (1-20%); 2=low (21-40%); moderately high (41-60%); 4=high (61-80%) and 5=very high (81-100%)] and validated during the wet and dry seasons of observational study. Further, actual rainfall data was collected from each study country/district meteorological service station www.climate-data.org/kakamega/karatu/mbulu/siaya. Formal verification of this 5-point scoring method was achieved through comparison of farmer-led estimates of monthly rainfall, scored using the five-point scale (0-5) and actual meteorological measurement of mean monthly rainfall recorded at Karatu (Tanzania lowlands) in 2018 as shown in Table 1. The rainfall data was then normalized on the five-point scale (Table 1). The normalized actual meteorological data and the farmer-led estimates on the five-point scale were used to plot the rainfall variability graph for method verification (Fig. 4). The line graphs for farmer-led estimates, meteorological-normalized rainfall data and long term mean (LTM) monthly rainfall data (2002-2018) for the study sites (Fig. 5) were almost similar, an indicator that the method was valid and highly applicable for this study, as it was un-biased and non-subjective (Fig. 5).

Table 1: Comparison of farmer-led estimates (5-point scale) and meteorological measurement of rainfall from Karatu in Tanzania lowlands for method verification

Rainfall	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Rainfall (0-5) – farmer-led estimates	2	1	4	5	3	1	0	1	2	3	4	3
Meteo - Normalized to 5 point scale	1.9	2.7	2.9	5.0	2.5	0.5	0.2	0.9	2.3	2.8	3.5	2.7
Meteorological average (mm)	69	100	106	183	92	20	9	34	86	102	127	100

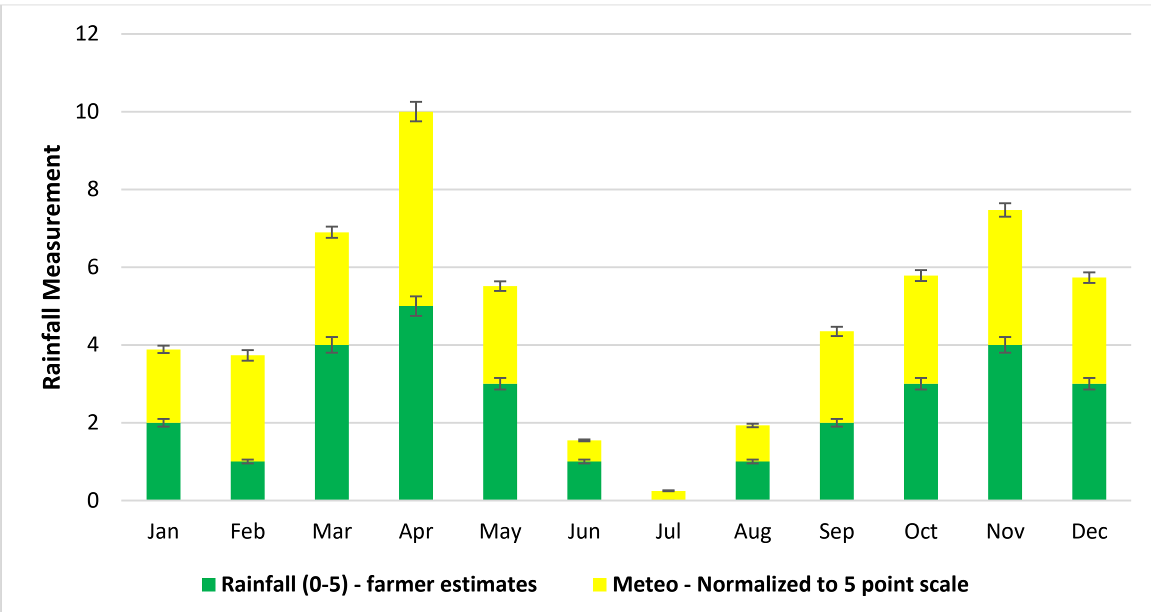


Figure 4: Comparison of farmer-led estimates of rainfall on 5-point scale and normalized meteorological measurement of rainfall from Karatu for method verification

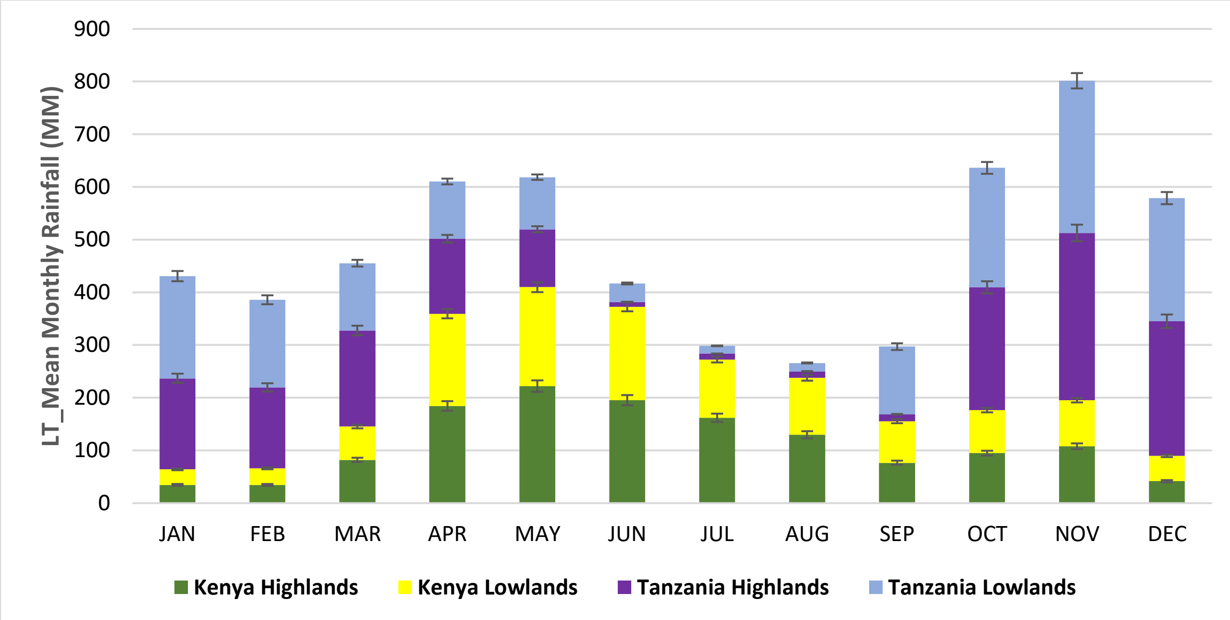


Figure 5: Actual long term mean (LTM) monthly rainfall (mm) in highlands and lowlands Kenya and Tanzania) from 2002-2018 (Meteorological Services and www.climate-data.org)

4.2.1 Cattle performance and measurement of cow body indices

Dairy cows under different production systems (extensive, intensive and semi-intensive) were included in this study during the period from October 2016 to June 2019 (cross sectional study and observational monitoring). Number of cows lactating, non-lactating, and pregnant (in-calf) or either and daily milk yield was recorded (Appendix 4). Cattle numbers, identification, breeds, sex, age and parity data was collected from each household farm for the dairy cattle (Appendix 5). Dates of the most recent calving and of the previous calving were recorded. Body condition (BCS) of the study animals was scored based on the criteria, which ranged from 1- 5-point scale with 0.25 intervals (ELANCO Animal Health Inc. USA), where 1 was severely under-conditioning or emaciated and 5 for severely over-conditioning (Appendix 6).

Live body weight (LBW) of dairy cows (local zebu and exotic/improved) was estimated from the heart girth (cm) and body length (cm) measurements, and standardized to 350-kg average LBW for cows in smallholder dairy farms in Eastern Africa using modified Schaeffer's formula as: $\text{Live Body Weight (kg)} = [(\text{Heart Girth}^2)\text{cms} * \text{Body Length})\text{cms}]/350 * 0.04536$.

The Schaeffer's formula (Wangchuk *et al.*, 2017) for calculating the body weight (BW) of animals is given as: $\text{Live Body Weight (kg)} = [(\text{Heart Girth}^2) * \text{Body Length})\text{Inches}]/300 * 0.4536$.

Body indices measured using a measuring tape while the animal was standing on an even surface, with the head in normal position and the four legs set squarely under the body, comprised: Body length, BL (point of shoulder to the pin bone), Body height, BH (base of the hoof to the highest point of the wither), Heart girth, HG (circumference of the body immediately behind the forelegs); Paunch girth, PG (circumference around the umbilicus), Height at withers, HW (distance from the surface of the soil/platform to the dorsal point of the withers), Neck girth, NG (circumference at the base of the neck) and Thigh circumference, TCM (middle of thigh).

Daily milk yield (morning and evening) was recorded daily, covering both the wet and dry seasons, from which the 305-day lactation yield was estimated. Age at 1st service and age at first calving was determined from information on birth date and the time of first service and first calving of the cows. Calving interval was calculated from information obtained from the time of previous calving and last calving. Number of services per conception represented the number of services required for the cow's last pregnancy. Other herd performance data captured comprised herd dynamics – herd structure, herd composition, herd entry (births, purchases/gift-ins), herd exit (voluntary and involuntary culling through deaths, sales/gift-outs) and cow replacement decisions as influenced by rainfall seasonality.

3.12 Phase II: Evaluation and validation of "best bet" Feeding interventions

The study focused on data collection from a small sample 50 farms from the original 400 smallholder dairy farm households to determine effects of the factors identified and considered in Phase I on milk production and reproductive performance of dairy cows. The aim was to model and test promising "best bet" interventions for overcoming seasonality driven milk fluctuations, and assess potential benefits associated with those promising "best bets' interventions in smallholder dairy farms.

The study in Tanzania (highlands and lowlands) was supported by an additional grant from Sustainable Intensification of Maize-Legume Systems for Food Security in Eastern and Southern Africa (SIMLESA II) Project: Scaling out promising ("best bets") forages and feed processing technologies in existing mixed crop livestock systems of Mbulu and Karatu, in Manyara region, Northern Tanzania. The study was also supported by the Institute of Sub-Tropical Agriculture (ISA), the Chinese Academy of Sciences (CAS) in China for chemical (Appendix 7) and nutritional analysis of feed samples (Appendix 8), under the National Natural Science Foundation of China - Consultative Group for International Agricultural Research (NSFC-CGIAR) project on Mechanisms of Hydrogen Transferring during Ruminal Fibre Degradation and Methane Production and Methane Mitigation Strategies. Protocols were developed to guide implementation and data collection in Phase II.

3.12.1 Protocol for testing the menu of promising "best bet" forage-feed options with smallholder farmers in high and low altitude areas in Manyara region, Tanzania

This project adopted a novel methodological innovation platform framework for developing scenarios of feeding strategies through a stakeholder-driven process that produced qualitative, quantitative and spatial outputs of feeding decision features. These reflected different stakeholder perspectives and predictions of milk seasonality change at the study site and region scale. Faced with changes and trade-offs between bio-physical, socio-economic, cultural and environmental sustainability goals, approaches that combined farmer-led "bottom up" perspectives with "top down" research backstopping and data sets that could be used to assess potential impacts on feeding, and how these interact with location, agro-ecology, production systems, breeds and seasons were tested and evaluated. The menu of promising "best bet" was drawn up based on the need to scale forage innovations tested under the Africa RISING Project in Babati and the feed planning and diagnosis (cross-sectional household survey) in Mbulu and

Karatu. Forage options selected by the volunteer host farmers in Mbulu highlands and Karatu lowlands are presented in Chapter 10 – The Final report for SIMLESA II project in Tanzania. The trials were managed by the volunteer host farmers with backstopping from the area government agricultural extension officers and the research team. Data was collected on agronomic performance parameters, biomass yield and nutrient composition over a 12 month (two seasons) period. The results of Feeds Nutrient Analysis are presented in Appendix 8.

3.12.2 Protocol for forage and crop residue sampling for nutritional component analysis, with results presented in Appendix 8.8

Fresh samples of forages were collected from the cross-sectional survey and ground (pulverized) before being air dried on polythene tubing to rid excess moisture. Forages collected consisted of maize stover, bean haulms, pigeon peas haulms, sunflower hulls/husks, rice straw, *Dolichos lablab*, sorghum stover, *Amaranthus spinosus*, Napier grass varieties (Ouma, Gold coast, Songho, Bana, South Africa), natural grass, soybean stover, Rhodes grass (Boma), *Pannicum maximum*, Green leaf desmodium (*Desmodium intortum*), Kales ("Sukuma wiki"), *Bidens pilosa* (Black jack), sugar cane tops, sweet potato vines, groundnuts stover/hulls, *Calliandra carlothyrsus*, Nandi setaria, Guatemala grass and maize silage. Two hundred and fifty (250) gms of the sun dried forage samples (less than 85% dry matter) was dried at 55 to 60 ^{o}C (maximum) in a forced air oven for a maximum of 24 hours to reduce moisture content prior to grinding. The loss of moisture was recorded as Partial dry matter (%). The ground material was then oven dried at 105^{o}C in a forced air oven for 3 hours to achieve 90 to 95% dry matter. The loss of moisture was recorded as Laboratory dry matter (%). This was then used to determine the total dry matter content calculated as: % Total dry matter content (% DMC) = {(Partial dry matter %) x (Laboratory dry matter %)} /100. The final sample (laboratory dry matter) was ground properly using a cyclone mill to pass through a 1 mm sieve, weighed 50 gms in robust ("press-sealed") plastic bags and tightly sealed to exclude air and labelled (Fig. 6). The final samples were shipped via the International Livestock Research Institute, Nairobi to the Institute of Sub-Tropical Agriculture of the Chinese Academy of Sciences for nutritional composition analysis using the In-vitro gas method (Appendix 1). The method is based on the quantification of forage substrate degraded or microbial protein produced using internal or external markers and of gas or short chain fatty acid (SCFA) production in an *in vitro* rumen fermentation system based on syringes (Contreras-Lara *et al.*, 2004). The forage nutritional parameters determined were total gas production (GP, ml gas/g DM), dry matter (% DM) and ash calculation, dry matter digestibility (% DMD), crude protein (% CP), Metabolizable energy (ME, MJ Kg DM), crude fibre (% CF), crude fat (% CF) and Ash. Metabolizable Energy was determined from the formula cited by (Makkar, 2004), where ME = (2.20 + 0.136*Gp + 0.057*CP)/4.186.

3.12.3 Protocol for urea and urea plus molasses pre-treatment of dry crop residues and analysis by in-vitro culture, with analysis results presented in Appendix 8.9

(i) Fresh crop residue sample collection

Fresh dry crop residue samples were collected in highlands and lowlands agro-ecological zones in Mbulu and Karatu, which were the Africa RISING and SIMLESA II projects districts of Manyara region, Northern Tanzania. The crop residue samples consisted of maize (*Zea mays*) stover, bean (*Phaseola vulgaris*) haulms, sunflower (*Carthamus tinctorius*) husks, pigeon pea (*Cajanus cajan*) haulms, sorghum (*Sorghum bicolor*) stover and rice (*Oryza sativa*) straw.

(ii) Substrate preparation and pre-treatment (incubation)

Pre-treatment with urea and urea plus molasses and incubation was carried out at the Nelson Mandela African Institution of Science and technology (NM-AIST) laboratory, Arusha, Tanzania. Fresh dry crop residue samples were sun-dried and chopped (pulverized) into ≤1 cm length and partitioned into three replicates of 0.5 kg. Samples were pre-treated using two formulated solutions- urea solution (125 g of urea was dissolved by 0.5 L water) and urea plus molasses solution (125 g of urea and 10 mL of molasses were dissolved by 0.5 L water). The urea used for making solutions had 46% Nitrogen concentration. The crop residue samples were pre-treated with these two solutions: (a) urea pre-treatment- urea solution mixed well with 0.5 kg crop residue samples; and (b) urea plus molasses pre-treatment- urea plus molasses solution mixed well with 0.5 kg crop residue samples. Nylon bags (20 x 10cm with an average pore size of 50µm) were used for incubation. The urea and urea plus molasses pre-treated samples were properly labelled and incubated for 28, 45 and 90 days. Each sample upon completion of incubation period was oven dried in temperature of 70 °C for 48 hours. The samples were then cooled for 3 hours and ground to pass through 2 mm sieve. Fifty grams (50 gms) of samples were packed in small clear zip plastic bags (Fig. 6) and shipped to the Institute of Sub-Tropical Agriculture, Chinese Academy of Sciences in China for further analysis by *in-vitro* culture. Phytosanitary certificate and clearance for shipping of the samples was obtained from Kenya Plant Health Inspectorate Services and the Ministry of Agriculture in Nairobi, Kenya by the international Livestock Research Institute in Nairobi, who also met the shipping costs.

(iii) Experimental design for in-vitro culture

The in-vitro culture experimental design was completely randomized block with 3 runs (replicates) and 3 crop residue treatments (control, urea, urea + molasses), with duplicates of 2 bottles for each treatment within a run.

(iv) In vitro incubation and sampling procedures

All animal procedures used in this study were reviewed and approved by the Animal Care Committee, Institute of Subtropical Agriculture, the Chinese Academy of Sciences, Changsha, China. Mixed rumen fluid from 3 healthy adult ruminally-cannulated Xiangdong black goats (25.0 SEM = 2.0 kg average body weight) was used to prepare the inoculum for the *in vitro* batch culture fermentation. Goats were fed a total mixed ration containing 500 g kg^{-1} rice straw and 500g kg^{-1} concentrate (554 g corn grain, 198 g wheat bran, 185 g soybean meal, 30 g soybean oil, 12 g calcium carbonate, 11 g sodium chloride, and 10 g premix with vitamins and microelements per kg of DM), offered twice per day at 08:00 and 18:00. Goats received 600 g/day of fodder and they had free access to water. Rumen contents were collected from the rumen before the morning feeding. Rumen inoculum was prepared by filtering the whole rumen contents through 4 layers of sterile cheese-cloth into a pre-warmed insulated bottle, then mixing it with artificial saliva (Makkar, 2004), using a ratio of 1:4 (rumen fluid: saliva) to prepare the buffered rumen fluid. Substrate (1.2 g) was weighed into each 135 mL serum bottles in duplicate; and 60 ml buffered rumen fluid added under a stream of carbon dioxide (CO). The bottles were immediately sealed with butyl rubber stoppers, and incubations carried out at 39.5 °C in an automated *in vitro* batch incubation system with venting pressure set at 10.0 kPa. The gas was automatically vented into a gas chromatograph (Agilent 7890 A, Agilent Inc., Palo Alto, California, USA) for measuring CH_4 and H_2 concentrations (Appendix 7). The *in vitro* fermentation was terminated after 48 h or 72 h (for comprehensive *in vitro* culture) of incubation to collect liquid, solid and microbial samples.

(v) Comprehensive in-vitro culture of maize stover

In vitro-culture of all the crop residue samples in this study showed that only maize stover had significant ($P \leq 0.05$) urea and urea plus molasses pre-treatment effect, and was therefore, considered for further comprehensive *in vitro* culture (fermentation). About 2 mL of liquid without particles was collected from each bottle and centrifuged at 15 000 *g* for 10 min at 4°C. The supernatant (1.5 mL) was acidified using 0.15 mL of 25% (w/v) meta-phosphoric acid, and stored at -20°C for analysis of volatile fatty acids (VFA) and ammonia. Microbial samples (1 mL × 3 replications) were collected after intense shaking of the bottle to ensure the samples included representative portions of liquid and particle fractions. Microbial samples were immediately frozen with liquid N_2 and stored at -80 °C until DNA extraction. After sampling for VFA and DNA, the pH was measured immediately with a portable pH meter (Starter 300; Ohaus Instruments Co. Ltd., Shanghai, China). The residuals were filtered into pre-weighed Gooch filter crucibles, dried at 105 °C to constant weight and weighed to determine degradation of incubated substrates and neutral detergent fiber (NDF).

(vi) Analytical methods

The forage samples were analyzed in triplicate for dry matter (DM), neutral detergent fibre (NDF), acid detergent fibre (ADF), ether extract (EE) and nitrogen (N) content. The DM (Method 930.15), OM (Method 942.05), EE (Method 963.15) and N (Method 970.22) were analyzed according to standard procedures of AOAC (2006). The NDF and ADF were assayed according to the methods of Van Soest *et al*. (1991), and expressed as inclusive of residual ash. Heat stable α-amylase was added during the NDF analysis.

Neutral-detergent soluble (NDS) was calculated using the Equation:

NDS (g/kg DM) = (1000 – NDF, g/kg DM) (1)

Hemicellulose was calculated from NDF and ADF using the following Equation:

Hemicellulose (g/kg DM) = NDF-ADF (g/kg DM) (2)

The *in vitro* NDF degradation (NDFD) was calculated according to the following Equation as described by Wang *et al.* (2016); and Zhang *et al.* (2019):

$$\text{NDFD (g/kg)} = (1-(W_2 \times NDF_2) / (W_1 \times NDF_1)) \times 1000 \quad (3)$$

Where NDF_1 is NDF content in the substrate before incubation, NDF_2 is NDF content in the residue after 72 h incubation; W_1 is DM weight of substrate before incubation, W_2 is DM weight of residue after 72 h of incubation. The VFA concentration was measured according to the procedure described by Wang *et al.* (2016), using a gas chromatograph (Agilent 7890 A, Agilent Inc., Palo Alto, California, USA). Ammonia concentration was measured according to Chaney and Marbach (1962).

The DNA was extracted according to the protocol for pathogen detection of stool using a E.Z.N.A.^{TM} Stool DNA Kit (Omega bio-tech, USA). The quantitative real time polymerase chain reaction (qPCR) was performed according to the procedure described by Kralik and Ricchi (2017). Forward primer (F) and reverse primer (R) were selected from the literatures for qPCR groups. A standard curve was generated using plasmid DNA containing the exact 16S/18SrRNA gene inserts and the standard curve met the following requirements (R^2 >0.99, 90% < E < 120%). The quantitative PCR assay was performed on a Light Cycler^{TM} 480 (Roche Molecular Systems, Inc. USA) with a sample volume of 10 µL that contained 5 µL SYBER Green Mix (TaKara Inc., Dalian, China), 1 µL of genomic DNA (10 ng/µL), 0.25 µL of each primer and 3.5 µL of ddH_2O.

Comprehensive *in-vitro* analysis was performed on maize stover that had significant ($P \leq 0.05$) urea-molasses pre-treatment effect. The hexose fermented (HF), estimated net H_2 production relative to the amount of total VFA produced (R_{NH2}), H_2 generated, H_2 utilized, H_2 recovery and fermentation efficiency (FE) was calculated by the flow of reducing equivalences based on VFA and CH_4 produced using the equations described by Wang *et al.* (2016) as follows: R_{NH2} = [2 (acetate + butyrate + isobutyrate) – (propionate + valerate + isovalerate)]/VFA (4).

Total gas production (GP, ml gas/g DM) over the 72-h incubation was estimated from the cumulative pressure in the headspace of the bottle over time. Methane and hydrogen gas concentrations were measured each time the gas was vented from each bottle, thus CH_4 production at a particular incubation time was estimated from the values at the nearest two time points assuming a linear relationship. The fractional rates of total GP or CH_4 production were estimated using the Nonlinear Regressions Analysis Program (NLREG, version 5.4) (Sherrod, 1998), and calculated according to the equations described by Wang *et al.* (2016):

$GP_t = Vf \times (1 - \exp(-kt) \times (1 + \exp(b-kt)$ (5)

Where GP_t is the accumulated gas production at time t, Vf is the final asymptotic gas production (mmol /g), k is the fractional rate of gas production, b is the shape parameter.

The data were the average of the two bottles per treatment within each run. The final data were analyzed using the general linear model procedure of SPSS 21.0 (Chicago, IL, USA) using a model that included the fixed effects of treatment (n = 2) and run (n = 3). Statistical significance was considered at $P \leq 0.05$ with $0.05 \leq P \leq 0.10$ considered as a trend.

3.12.4 Feeding validation of urea and urea plus molasses pre-treated maize stover on intake and milk yield of Friesian cows

(i) Preparation of compacted urea and urea plus molasses pre-treated maize stover

The feeding trial was conducted in Siaya lowlands in Western region of Kenya between April and June 2019. Maize stover was pulverized (fine chopped), pre-treated using urea and molasses and incubated for 28 days before being compacted into 5 kg feed blocks (Fig. 6). This was necessary for enhancing efficiency of handling and utilization, feeding value and controlled feeding during the trials. Three treatment diets were tested during the on-farm validation study and these included farmer-led feeding practice (FFP), urea plus molasses pre-treated maize stover block (MUMS), and urea pre-treated maize stover block (UMS). The diets were prepared in situ at the farms where the studies were conducted. Urea plus molasses pre-treated maize stover (MUMS) basal diet consisted of 10.0 kg DM pulverized/shredded (≤1.0 cm) maize stover. Then 200 grams of urea (N=46% grade for Kenya and Tanzania), 200 g ruminant salt, and 1.0 kg molasses dissolved in 5.0 L of water in a bucket. The liquid mixture was sprinkled on the shredded maize stover spread on a polythene sheet, then thoroughly mixed and incubated for 28 days in an airtight container before compacting for feeding. Urea pre-treated maize stover (UMS) basal diet was prepared with 400 g urea (N=46%) dissolved into 5 L of water and then sprinkled on pulverized/shredded (≤ 1.0 cm) maize stover (10 kg DM) spread on a polythene sheet. After ensuring a thorough mixing of ingredients, the diet was transferred into a large airtight polythene bag. The mixture was incubated for 28 days so as to give ample time for urea to act on the straw. After 28 days the bags were opened and straw was ready for feeding but prior to feeding the urea pre-treated straw was aerated to remove any unreacted ammonia and compacted into feed block.

Figure 6: Urea and Urea plus molasses pre-treated maize stover compacted into 5 kg feed blocks using a local feed compactor

(ii) Dairy cows and their management

Twelve (12) farmers among those sampled during cross sectional survey were selected on the criteria of owning at least three milking cows, willingness to fully dedicate 2 milking cows to the experiment to the end, and acceptance of modest compensation for use of the animals. For each of the collaborating farms in the on-farm validation study, two lactating Friesian cows were selected based on similarity in their breed (Frisian), milk yields (9.45 SEM = 0.46 kg of milk per day), stage of lactation (early-mid lactation period), live body weights (mean 397.37 SEM = 15.09 kg) age (6-7 years). The farmers were located in Siaya lowlands and reared their dairy cows in intensive (stall feeding only) production system. The reasoning was that cows with the same yielding ability would likely show similar responses in milk yields.

(iii) Experimental design and feeding

Selected Friesian dairy cows were allocated in a three-period crossover design, following a sequence of dietary treatment administration of diet 1 (FFP), diet 2 (MUMS), and diet 3 (UMS). During the initial seven (7) days, the current farmer-led feeding practice (FFP) was administered by the farmer but monitored by the project data clerks at each of the twelve (12) collaborating farms, selected randomly from the cross sectional survey. This was because animal performance under farmer-led feeding practice was to be compared with improved pre-treated maize stover diets. For the FFP (diet 1), the animals were fed on Napier grass (cut and carry) as basal feed with dairy concentrate/meal (2 kg/day) and mineral block, supplemented during milking time in the morning and evening prior to and during the experiment as positive control. The pre-treated urea and urea plus molasses maize stover basal diets 2 and 3 (UMS and MUMS) were offered to the cow free choice, with dairy concentrate/meal offered during milking time at rate of 2 kg/day/cow (morning and evening) and mineral block as supplementary feed. There was a 14 days' adaptation between two diets administration. The nutritive value of Napier grass, dry maize stover, pre-treated MUMS and UMS is given in Table 3. Milking was done twice a day in the morning (06 00 h) and evening (at 17 00 h). Milk yield was weighed and recorded every day throughout the study period. Data was collected daily by the corresponding author and trained government extension staff from the two areas on observational visit interviews and monitoring. Records on cow performance, feed offered, intake levels and refusals, and milk yield were collected.

3.13 Overall Study Data Analysis

Data collected was stored and managed using Microsoft Excel, 2013 Software. The final data were analyzed using the general linear mixed model (GLMM) procedure of SPSS 21.0 (Chicago, IL, USA) using models that included the fixed effects, random effects and dependent variables. Descriptive statistics and tests of significance using the least square difference were carried out. Statistical significance was considered with a *P-value* less than 0.05 ($P < 0.05$). Fixed factors (independent variables) considered in this study consisted of: country (Kenya and Tanzania), district (Kakamega, Siaya, Mbulu and Karatu); agro-ecological zones (highlands and lowlands); seasons and year (wet and dry from January-December); dairy cattle production systems (intensive, semi-intensive and extensive); and breed types (Holstein Friesian, Ayrshire cross, Local zebu, Friesian cross and Ayrshire).

The response (dependent) variables consisted of reproductive performance parameters (cow age in months, age at 1st service in months, age at 1st calving in months, calving interval in months, number of calvings); Milk production parameters (morning milk in litres, evening milk in litres, milk yield in litres per cow per day, milk for home use in litres, milk for sales in litres, milk for calves in litres, and 305-day lactation milk yield in litres); Animal body indices (measurements): live body weight (kg), body height (cm), body length (cm), body condition score (1-5), height of withers (cm), height at withers (cm), heart girth (cm), paunch girth (cm), neck girth (cm) and thigh circumference (cm); Herd dynamics: herd entry (births, purchases/gift-ins), herd exit – voluntary and involuntary culling (deaths/slaughter, sales/gift-outs) and cow replacement decisions; and Variation in feeds and fodder sources and usage: concentrates feeds, green crop residues, dry crop residues, improved (planted) fodder, pasture (natural grass), legume forage and fodder trees/shrubs. In some instances, the response variables were controlled for by intervening dependent variables (random effects) that comprised: land size, land use, household head years in school and in the village, age of household head in years, dairy farming time/experience of household head in years and total number of people in household.

The analysis was achieved using multivariate/multinomial analysis of variance (MANOVA) at 95% confidence level (Alpha = 0.05) as it allowed comparison of multiple dependent (response) variables and factors (Independent) in the model. The results included multivariate (MANOVA), univariate (ANOVA) and post hoc analysis. For this study, MANOVA had several advantages over ANOVA. First, by measuring several dependent variables in a single study, with a better chance of discovering the factors that were truly important. Second, it protected against Type I errors that occurred if multiple ANOVA's were to be conducted independently. Additionally, it revealed differences not discovered by ANOVA tests. If the overall multivariate test was significant, we concluded that the respective effect of independent factors was significant. However, our next question was of course whether only one or several dependent variables were affected. Therefore, after obtaining a significant multivariate/multinomial test for a particular main effect or interaction, customarily we would examine the univariate F tests and Chi-square (X_2) tests for each variable to interpret the respective effect. In other words, we identified the specific dependent variables that contributed to significant overall effect. Further, we carried out association tests using Pearson's correlation analysis (coefficient of determination, R^2 and significance, $P \leq 0.05$) to determine the relationship between some of the dependent (response) variables across the high and low altitude areas in Kenya and Tanzania.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Information flow on feeding and breeding and how this affects decision making in face of seasonality

(i) Farm Household Characteristics

Results showed that both country and agro-ecology were significant (*P < 0.05*) on land ownership and use (Table 2). Hence, land size in acres and land in use for agriculture (crops and livestock production) for households in high and low altitude areas was higher in Tanzania than in Kenya. Land size and land use in high altitude areas in Tanzania was slightly higher (*P < 0.05*), compared to the lowlands. However, land use throughout the year in Kenya and Tanzania highlands was slightly higher (*P < 0.05*), compared to the lowlands (Fig. 7).

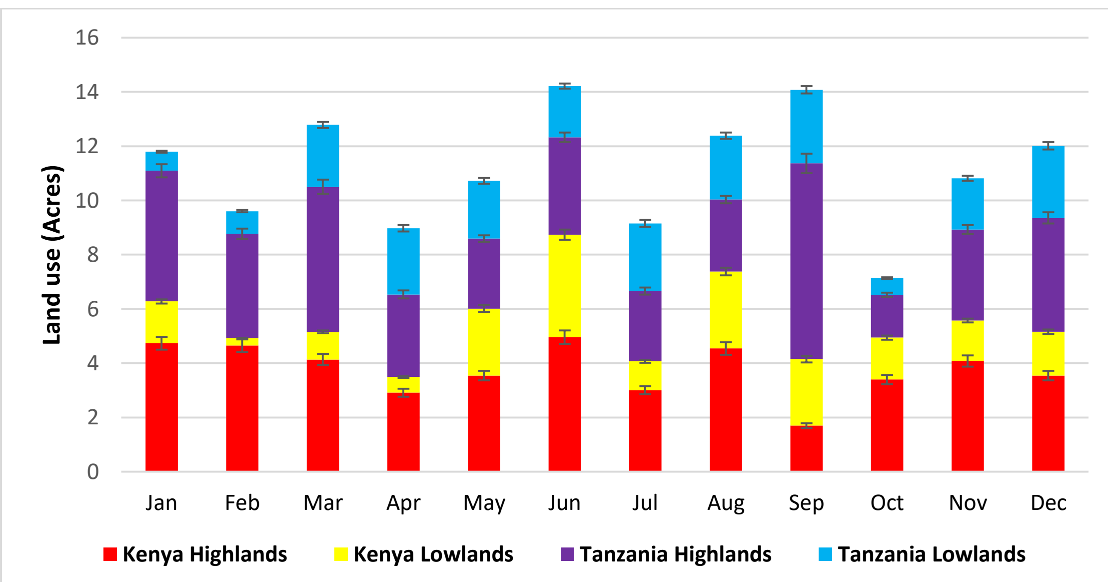


Figure 7: Year-round usage of land (acres) for crops and livestock production (Mean ± SEM) within high and low altitude areas in Kenya and Tanzania

Table 2: Least Square means of the household characteristics within high and low altitude areas in Kenya and Tanzania

Farm Household Characteristics	Agro Ecological Zones				SEM	P-value
	Kenya High	Kenya Low	Tanzania High	Tanzania Low		
Land size (acres)	2.89[a]	3.73[ab]	5.00[c]	3.82[b]	0.31	0.002
Land use (acres)	2.87[a]	3.53[ab]	4.32[b]	3.34[a]	0.30	0.017
HH years in school	9.98	9.29	9.23	8.65	0.56	0.138
HH years in village	39.60	40.38	40.29	37.23	1.56	0.072
HH age (years)	51.38[b]	47.28[a]	51.52[b]	51.06[b]	1.26	0.022
Dairying experience (yrs)	11.43[b]	8.26[a]	10.98[b]	12.09[b]	0.74	0.009
Total HH persons	6.41	6.99	6.52	6.68	0.36	0.102

Means with different superscript letters were significantly different ($P<0.05$); SEM=Standard Error of Mean difference

Results in Table 2, also showed that agro-ecology had significant influence ($P \leq 0.05$) on age of household head (years) and dairy farming experience (years). Therefore, the age of the household head and dairy farming experience were slightly higher ($P < 0.05$) in other agro-ecologies compared to Kenya lowlands. Overall, from this study, the average age of the smallholder dairy farmers in Kenya and Tanzania was 50.31 SEM = 0.64 years, with average dairy farming experience of 10.69 SEM = 0.38 years, having spent average 9.29 SEM = 0.28 years in formal schooling and 39.38 SEM = 0.78 years in the village. The number of persons per household was similar ($P > 0.05$) in both Kenya and Tanzania (Table 2).

Results in Fig. 8, showed that dairy farming experience was higher ($P < 0.05$) for farmers with Holstein-Friesian breed in Tanzania lowlands, compared to those with Holstein-Friesian in Kenya lowlands. In contrast, dairy farming experience was higher ($P < 0.05$) for farmers rearing Ayrshire cross cows in Tanzania highlands and local zebu cows in Kenya highlands, compared to those with Holstein-Friesian in Kenya highlands.

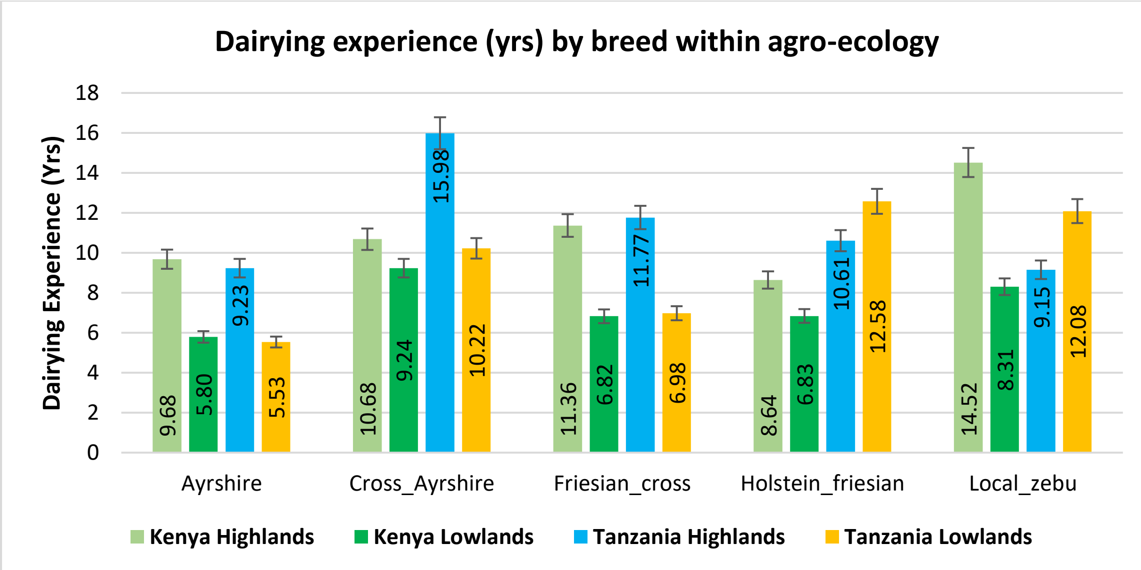


Figure 8: Years of dairy farming experience (Mean ± SEM) of smallholder farmers by breed types within high and low altitude areas in Kenya and Tanzania

Smallholder dairy farmers reared their breeds mainly under the semi-intensive production system compared to the extensive and intensive production system (Fig. 9 and 10). There was continuous year round variation along the rainfall pattern seasonality, hence feed resource availability, in the utilization of the different production systems for rearing cows within high and low altitude areas in Kenya and Tanzania (Fig. 11). Throughout the year, smallholder dairy farmers in both Kenya and Tanzania, reared their cows under the semi intensive system, and less the extensive and intensive systems. However, during the low rainfall months from June to December in both countries, there was a slight increase in farmers rearing their cows under the intensive system (Fig. 11).

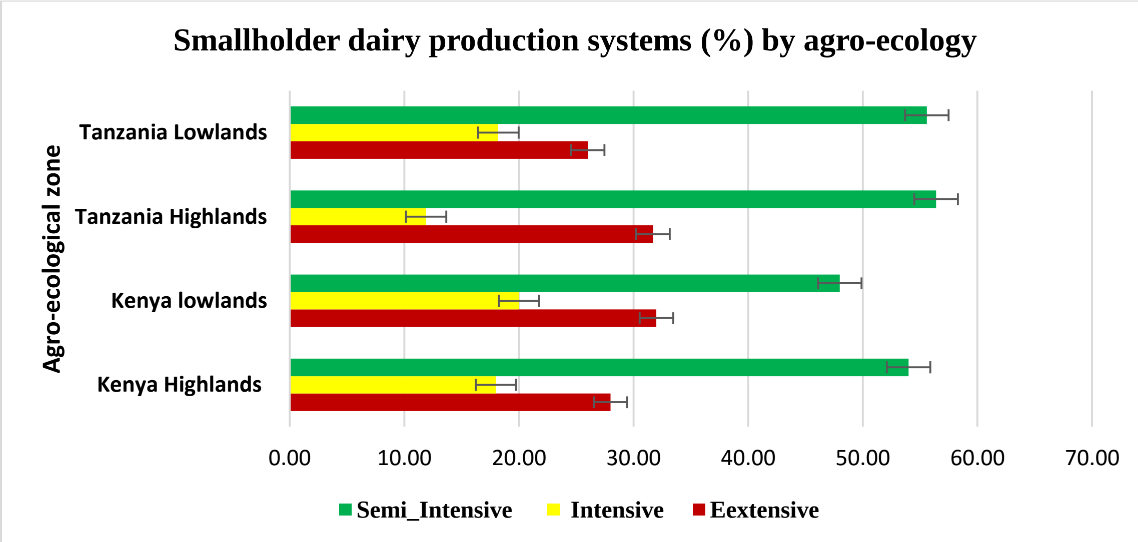


Figure 9: Distribution (%) of smallholder dairy farmers in different cattle production systems (%) within high and low altitude areas (95% CI) in Kenya and Tanzania

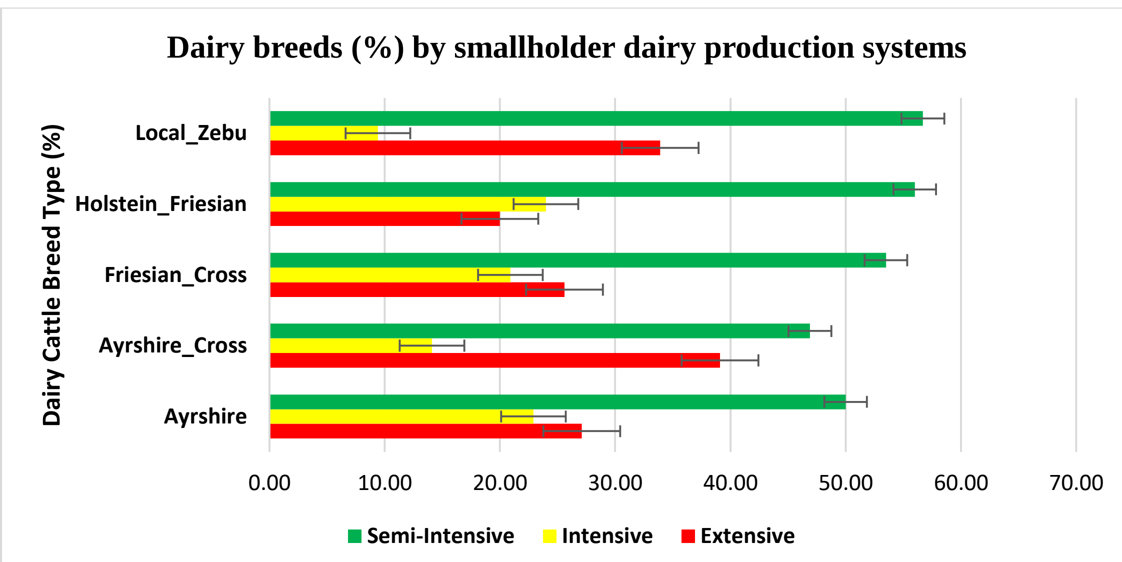


Figure 10: Distribution (%) of dairy cattle breeds under different dairy cattle production systems in Kenya and Tanzania

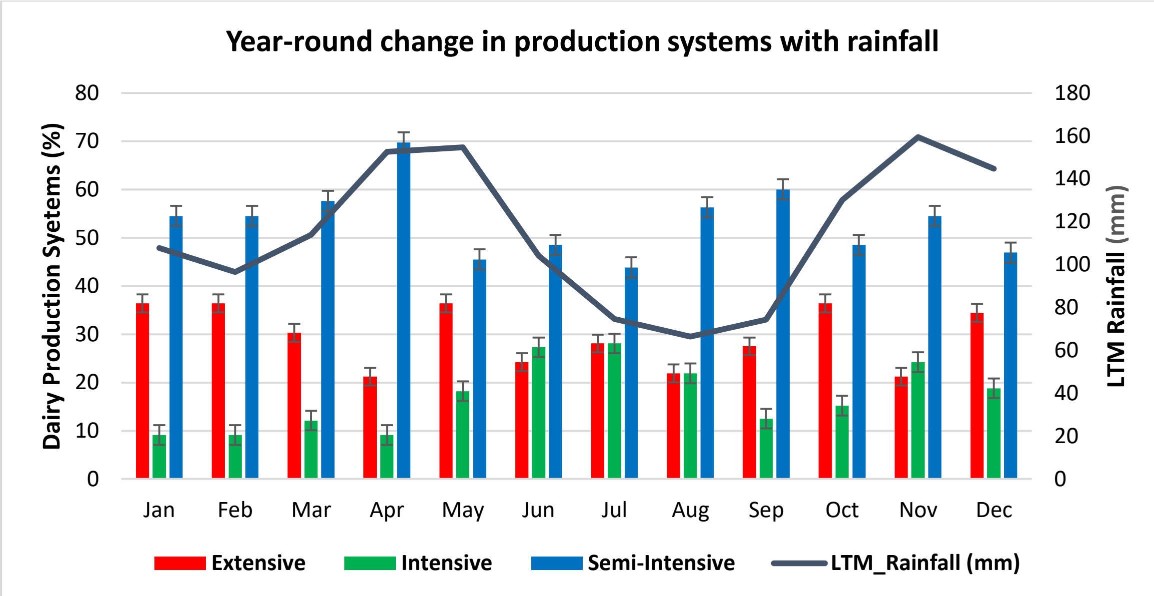


Figure 11: Year round changes (%) in usage of dairy production systems with long-term mean (LTM) monthly rainfall variability in Kenya and Tanzania

Results in Table 3 showed that there was a moderate (R^2 = 0.392), but highly significant ($P \leq 0.001$) positive relationship between the age of the household head and dairy farming experience across high and low altitude areas in Kenya and Tanzania. Further, the relationship between the number of years that the household head had spent schooling and the age of the household head was also moderate, positive (R^2 = 0.342), and highly significant ($P \leq 0.001$). There was a strong (R^2 = 0.941) and highly significant ($P \leq 0.001$) positive relationship between the size of land owned by the household and the amount of land allocated or utilized for crops and livestock production in Kenya and Tanzania. Therefore, smallholder dairy farmers who owned larger land parcels committed more to crops and livestock production and vice versa.

Table 3: Correlation (coefficient and significance) amongst farm household characteristics in Kenya and Tanzania

Farm Household Characteristics	Dairying Experience	Total HH people	Age of HH (Years)	HH Years in School	HH Years in Village	Land Size (Acres)
Total HH people	0.026					
Age of HH (Years)	0.392***	0.039				
HH Years in School	0.197***	-0.019	0.342***			
HH Years in Village	0.025	0.099**	-0.159***	-0.129***		
Land Size (Acres)	-0.003	0.073	0.046	0.137***	-0.021	
Land Use (Acres)	-0.03	0.069	-0.014	0.157***	-0.015	0.941***

*HH=Household/Household head; Correlation Coefficients (R^2) and level of significance test *=P<0.05, **=P<0.01, ***=P<0.001*

(ii) Reproductive Performance of the Smallholder Dairy Cows

The number of cows in milk (lactating) within high and low altitude areas in Kenya and Tanzania are shown in Table 4. The number of lactating cows per household was lower ($P > 0.05$) in Kenya lowlands compared to the other agro-ecologies. The number of lactating cows per household was also slightly lower ($P > 0.05$) for the local zebu breed compared to the improved breeds (Table 5). Further the number of cows in milk per household was slightly higher ($P < 0.05$) in semi-intensive system compared to the other smallholder dairy production systems (Table 6).

Table 4: Least Square Means for reproductive performance of dairy cows under different agro-ecologies in Kenya and Tanzania

Reproductive Performance Parameters	Agro Ecological Zones				SEM	P-value
	Kenya Highlands	Kenya Lowlands	Tanzania Highlands	Tanzania Lowlands		
No. of cows in Milk	1.82	1.62	1.78	1.72	0.09	0.080
No. of calving's per cow	2.99[a]	2.32[ab]	2.26[ab]	2.41[a]	0.23	0.010
Cow age (months)	58.66[ab]	63.42[b]	56.57[a]	60.22[ab]	2.02	0.013
Age at 1st service (months)	30.77[ab]	31.03[a]	28.07[ab]	33.43[b]	1.26	0.047
Age at 1st calving (months)	37.17[ab]	37.31[ab]	35.73[a]	38.53[c]	0.87	0.041
Calving interval (days)	451.48	462.00	441.18	478.06	12.53	0.910

Means with different superscript letters were significantly different (P<0.05); SEM=Standard Error of Mean difference

Table 5: Least Square Means for the reproductive performance of different dairy cattle breeds in Kenya and Tanzania

Reproductive Performance Parameters	Dairy Cattle Breeds					SEM	P-value
	Ayrshire	Ayrshire Cross	Friesian Cross	Holstein-Friesian	Local Zebu		
No. of cows in Milk	1.71	1.95	1.75	1.73	1.62	0.20	0.053
No. of calving's per cow	1.93	2.62	2.43	2.16	2.72	0.30	0.081
Cow age (months)	56.40[a]	59.44[ab]	57.58[a]	55.57[a]	65.36[b]	2.34	0.035
Age at 1st service (months)	30.06	31.84	30.19	28.92	32.12	1.44	0.213
Age at 1st calving (months)	36.44	37.13	37.09	36.93	38.25	1.01	0.432
Calving interval (days)	442.42	469.36	452.25	451.00	466.57	14.14	0.982

Means with different superscript letters were significantly different (P<0.05); SEM=Standard Error of Mean difference

Table 6: Least Square Means for the reproductive performance of dairy cows under different production systems in Kenya and Tanzania

Reproductive Performance Parameters	Dairy Production Systems			SEM	P-value
	Extensive	Intensive	Semi Intensive		
Cow age (months)	61.07[a]	57.16[b]	58.70[b]	1.88	0.035
No. of cows in Milk	1.70	1.72	1.83	0.08	0.513
No. of calving's per cow	2.30	2.15	2.56	0.24	0.580
Age at 1st service (months)	33.57[b]	31.29[ab]	29.14[a]	1.21	0.042
Age at 1st calving (months)	39.49[b]	37.93[ab]	35.69[a]	0.80	0.005
Calving interval (days)	491.85[b]	465.49[ab]	437.12[a]	11.48	0.009

Means with different superscript letters were significantly different ($P<0.05$); SEM=Standard Error of Mean difference

The number of calving's per cow were higher ($P < 0.05$) in the Kenya highlands compared to the other agro-ecologies (Table 4). The number of calving's per cow were also higher ($P < 0.05$) for the local zebu compared to crosses and purebreds (Table 5). Further, the number of calving's per cow were higher ($P < 0.05$) in semi-intensive system as opposed to the intensive and extensive production systems (Table 6). Generally, the age of cows was lower ($P > 0.05$) in Kenya and Tanzania highlands compared to the lowlands in both countries (Table 4). The age of cows was higher ($P < 0.05$) for local zebu compared to the crosses and purebreds (Table 5). The overall age of cows was also higher ($P < 0.05$) in the extensive system compared to the intensive and semi-intensive production systems (Table 6). The age of dairy cows at 1st service (months) in Kenya and Tanzania are also shown in Table 4. The age of cows at 1st service was higher ($P < 0.05$) in the lowlands of both Tanzania and Kenya compared to the highlands. The age of cows at 1st service (Table 5) was slightly higher ($P < 0.05$) for the local zebu breed and lower ($P > 0.05$) for the Holstein-Friesian breed in comparison with the other breeds. Age at 1st service (Table 6) was also higher ($P < 0.05$) in extensive than intensive system.

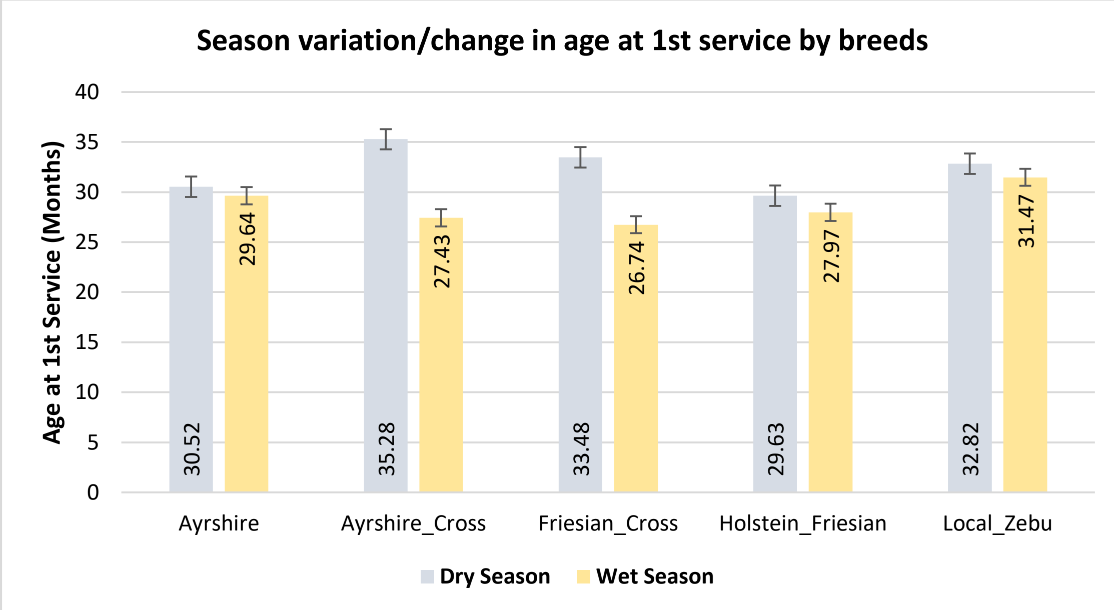


Figure 12: Age at 1st service (Months) for different dairy cattle breeds as influenced by seasons in Kenya and Tanzania

The age of cows at 1st service was higher (*P > 0.05*) during the dry season period (32.34 SEM = 0.90) and lower (*P < 0.05*) during the wet season period (29.14 SEM = 0.90). The season variation/change (%) in attaining age at 1st service (Fig. 12) between dry and wet seasons by different breeds, was +/-12.00%, specifically, +/-2.86% (Ayrshire), +/-25.48% (Ayrshire cross), +/-21.87% (Friesian cross), +/-5.38% (Holstein-Friesian) and +/-4.28% (local Zebu). Therefore, the crossbreeds (Ayrshire cross and Friesian cross) varied from about +/-20-25% between wet and dry season in attaining age at 1st service, compared to local zebu and pure breeds (Ayrshire and Holstein-Friesian).

The mean values of the age of the dairy cows at 1st calving (months) in Kenya and Tanzania are also presented in Table 4. Dairy cows in Tanzania lowlands were 1st calved with higher (*P < 0.05*) age than those in Tanzania highlands. There were no breed differences (*P > 0.05*) in the age at 1st calving (Table 5), though it was slightly lower (*P < 0.05*) for Ayrshire and Holstein-Friesian cows compared to the other breeds. The age of cows at 1st calving (Table 6) was slightly higher (*P < 0.05*) in extensive production system compared to the other production systems.

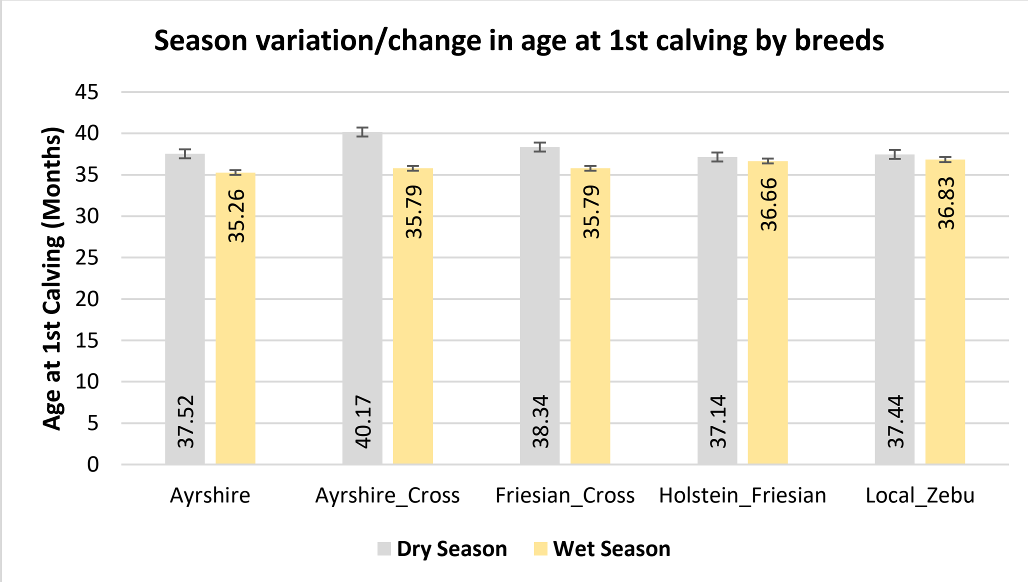


Figure 13: Age at 1st calving (Months) for different dairy cattle breeds as influenced by seasons in Kenya and Tanzania

Similarly, as shown in Fig. 13, the age of dairy cows at 1st calving (months) for the different breeds was higher during the dry season period and lower during the wet season (rainfall) period in both Kenya and Tanzania. The season variation/change (%) in attaining age at 1st calving (Fig. 13) between the dry and wet seasons for the different breeds (calculated as dry season age – wet season age/Mean AFS*100) was +/-6.08% (Ayrshire), +/-11.78% (Ayrshire cross), +/-6.87% (Friesian cross), +/-1.30% (Holstein-Friesian) and +/-1.64% (Local Zebu). Therefore, dry and wet season variation in age at 1st calving was higher (+/-6-12%) for Ayrshire, Ayrshire cross and Friesian cross compared to Holstein-Friesian and local zebu breeds.

Mean calving interval (days) for smallholder dairy cows (Fig. 14a), within high and low altitude areas in Kenya and Tanzania was 458.09 SEM = 6.29. Calving interval (Fig. 14a), was slightly lower ($P < 0.05$) for Ayrshire and Holstein-Friesian breeds in Kenya compared to those in Tanzania. Similarly, calving interval was slightly lower ($P < 0.05$) for local zebu breed in Tanzania compared to Kenya.

Mean calving interval (Table 4), was slightly lower ($P < 0.05$) in Tanzania highlands and Kenya highlands compared to the lowlands. Across the different agro-ecologies (Fig. 14b), calving interval for Ayrshire breed ranged from 390 – 475 days, but was lower ($P < 0.05$) in Tanzania and Kenya highlands compared to the lowlands. Calving interval (Table 5), was slightly higher

($P < 0.05$) for local zebu and slightly lower ($P < 0.05$) for Ayrshire compared to the other breeds.

Calving interval (Fig. 16c) was lower ($P < 0.05$) during the wet season compared to the dry season in both Kenya and Tanzania. However, the influence of season on calving interval was more in Ayrshire breed, Ayrshire and Friesian crosses compared to the Holstein-Friesian and local Zebu breeds. Season variation/change (%) in calving interval (CI) between the wet and dry seasons was calculated as: (CI in wet season – CI in dry season)/Mean CI*100). Therefore (Fig. 16c), calving interval varied between the wet and dry seasons by about +/-5 – 15% for Ayrshire and the crosses, which was specifically, +/-5.99% (Ayrshire), +/-15.50% (Ayrshire cross) and +/-9.20% (Friesian cross). Season variation in calving interval was lower ($P < 0.05$) for the Holstein-Friesian and local zebu breeds, which was +/-0.65% and +/-0.20%, respectively (Fig. 16c).

Generally, calving interval (Table 6) was lower ($P < 0.05$) in semi-intensive, and higher ($P < 0.05$) in extensive system. However, across the three smallholder dairy production systems (Fig. 14d), Ayrshire and Friesian crosses had a calving interval range from about 430 – 500 days, which was lower ($P < 0.05$) in semi intensive system than other systems. Similarly, Ayrshire and Holstein-Friesian reeds had a calving interval range from about 410 – 470 days, which was also lower ($P < 0.05$) for Ayrshire in semi-intensive system and Holstein-Friesian in intensive system (Fig. 14d). Local zebu cows had the highest ($P < 0.05$) calving interval range across the three production systems (450 – 535 days), which was lower ($P < 0.05$) in semi-intensive system compared to the other production systems (Fig. 14d).

Results presented in Table 7 showed that there was a highly significant *($P \leq 0.001$)* positive relationship between calving interval with age of the dairy cows at 1^{st} service ($R^2 = 0.925$) and age at 1^{st} calving ($R^2 = 0.882$) within high and low altitude areas in Kenya and Tanzania. This implied that Ayrshire and Holstein-Friesian breeds with lower cow age at 1^{st} service and 1^{st} calving had shorter calving intervals (Table 7). Similarly, local zebu cows with higher cow age at 1^{st} service and 1^{st} calving had longer calving intervals (Table 7). There was also a strong ($R^2 = 0.812$) and highly significant *($P \leq 0.001$)* positive relationship between age of cows at 1^{st} service with age of cows at 1^{st} calving within high and low altitude areas in Kenya and Tanzania.

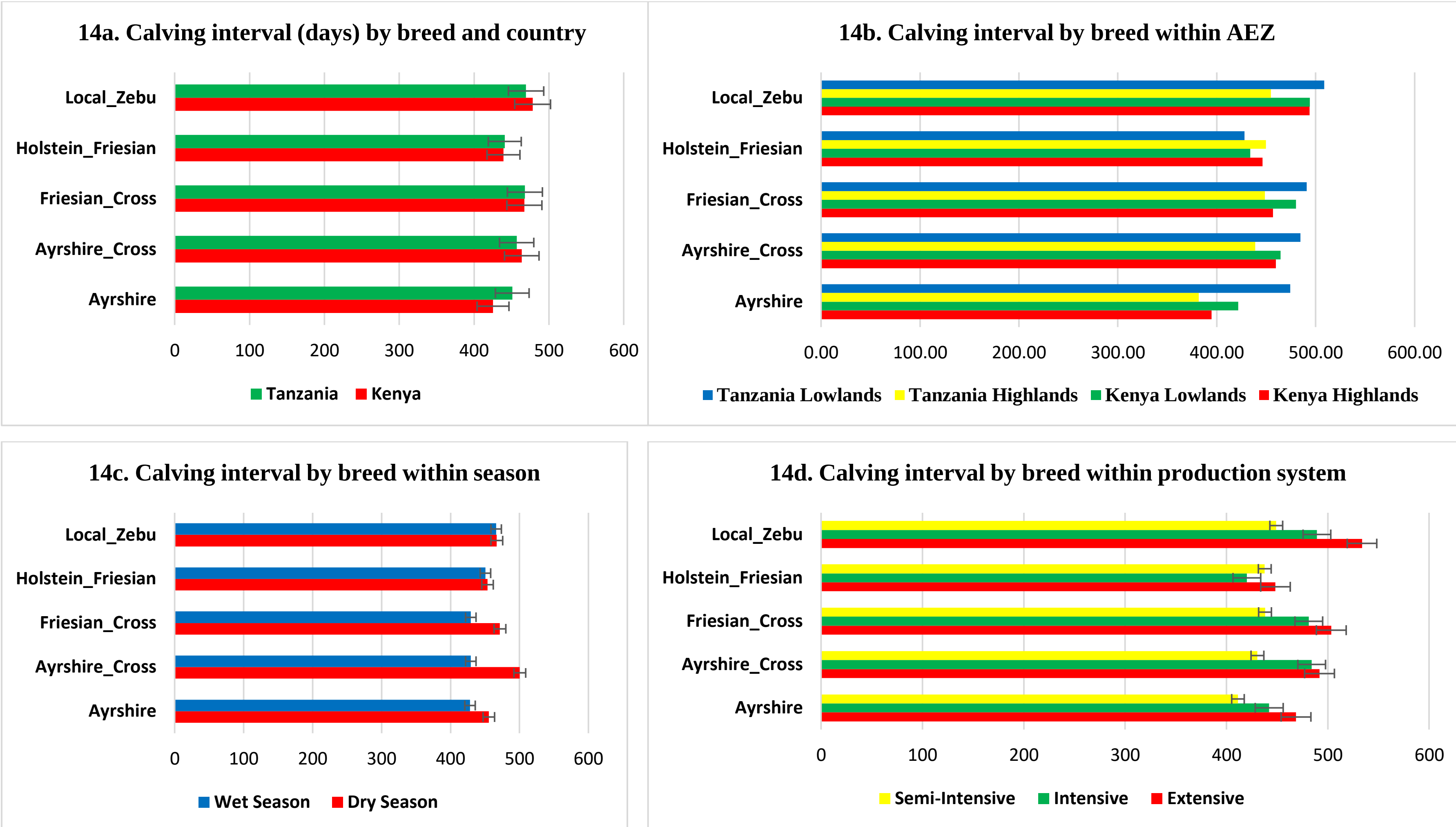


Figure 14: Calving interval (days) of various dairy cattle breeds as influenced by country (14a), agro-ecology (14b), season (14c) and production system (14d)

Table 7: Pearson's correlation (coefficient and significance) amongst reproductive performance parameters for dairy cows in Kenya and Tanzania

Reproductive Parameter	Calving Interval (D)	Age at 1st Calving (M)	Age at 1st Service (M)	Cow Age (M)	Cows in Milk/HH
Age at 1st Calving	0.925***				
Age at 1st Service	0.882***	0.812***			
Cow Age	0.230***	0.206***	0.283***		
Cows in Milk per HH	0.004	-0.017	-0.031	0.065	
Number of Calvings/Cow	-0.165***	-0.155***	-0.035	0.420***	-0.008

HH=Household; D=Days; M=Months; Correlation Coefficients (R^2) and level of significance test, ***=P<0.001

(iii) Live body weight, body condition score and morphometric linear body indices

Live body weight (LBW)

Mean live body weight (LBW, kg) of smallholder dairy cows in Kenya and Tanzania was 357.95 SEM = 6.76. Mean LBW for all breeds was similar ($P > 0.05$) between the two countries (Fig . 15a), but slightly higher (Table 8) in Tanzania highlands and Kenya highlands ($P < 0.05$) compared to the lowlands (Fig. 15b).

Mean LBW was slightly higher ($P < 0.05$) for Ayrshire compared to the other improved breeds, but lowest for local zebu (Table 9). Unlike the other breeds (Fig. 15a), Holstein-Friesian was slightly larger ($P < 0.05$) in Kenya compared to Tanzania, while Ayrshire cross was slightly smaller in Kenya compared to Tanzania. The mean LBW for smallholder dairy cows (Table 10) was significantly higher ($P < 0.05$) in intensive compared to semi intensive and extensive systems.

The season effects on LBW of dairy cattle across high and low altitude areas in Kenya and Tanzania were considered as shown in Fig. 15c. Live body weight (LBW) of dairy cows within the four agro-ecologies were higher ($P < 0.05$) during the wet season period compared to the dry season period. The season change/variation (% loss/gain) in LBW for different breeds, between wet season and dry season was calculated as: (Wet season LBW – Dry season LBW)/Mean LBW*100. Therefore, the season change (loss/gain) in LBW for dairy cows within the four agro-ecologies was +/-6.32%. This season change was lowest for local zebu cows (+/-3.33%) during both the wet season and dry season periods (Fig. 15c). The season variation (Fig. 15c) in LBW between wet and dry seasons for improved breeds was highest for the Friesian cows (Holstein-Friesian and Friesian cross) compared to the Ayrshire cows (Ayrshire and Ayrshire cross). Holstein-Friesian and Friesian cross had season variation in LBW of +/-13.02% and +/-13.41%, respectively. While, Ayrshire and Ayrshire cross had season variation of +/-7.72% and +/-6.94%.

The improved (pure) breeds (Ayrshire and Holstein-Friesian) had similar ($P > 0.05$) LBW (Fig. 15d) in intensive, semi intensive systems and extensive systems. Ayrshire cross had slightly higher ($P < 0.05$) LBW in extensive system, while Friesian cross had slightly higher ($P < 0.05$) LBW in extensive and semi intensive systems. Local zebu cows had slightly higher ($P < 0.05$) LBW in extensive and semi intensive systems as opposed to intensive system (Fig. 15d).

The study (Fig. 16) revealed continuous year-round seasonal fluctuation in LBW due to rainfall variability (hence water and feed resources availability in quantity and quality). This seasonal fluctuation in LBW was higher for the improved dairy cows compared to local zebu within high and low altitude areas in Kenya and Tanzania.

Table 8: Least Square Means for LBW, BCS and Morphometric body indices of dairy cows within high and low altitude areas in Kenya and Tanzania

Dairy Cow Body Indices	Agro Ecological Zone				SEM	P-value
	Kenya Highlands	Kenya Lowlands	Tanzania Highlands	Tanzania Lowlands		
Live Body Weight (kg)	368.56^{bc}	346.22^{ab}	389.00^{c}	327.41^{a}	14.86	0.007
Body Condition Score	3.14^{a}	3.04^{a}	3.15^{ab}	3.28^{b}	0.06	0.000
Body Height (cm)	117.45^{b}	112.75^{ab}	116.50^{b}	109.28^{a}	1.79	0.023
Body Length (cm)	122.09^{ab}	117.37^{a}	124.36^{b}	117.43^{a}	2.04	0.032
Heart Girth (cm)	149.72^{b}	148.66^{b}	152.51^{b}	143.09^{a}	2.02	0.000
Paunch Girth (cm)	181.01^{b}	181.32^{b}	182.69^{b}	171.77^{a}	2.70	0.008
Height of Withers (cm)	54.97^{ab}	57.32^{b}	54.54^{ab}	52.34^{a}	1.61	0.000
Neck Girth (cm)	67.80	68.41	70.04	66.80	1.61	0.057
Thigh Circumference (cm)	47.53^{ab}	0.97	49.35^{b}	1.23	1.13	0.062

Means with different superscript letters were significantly different ($P<0.05$); SEM=Standard Error of Mean difference

Table 9: Least Square Means for LBW, BCS and morphometric body indices of different dairy cattle breeds in Kenya and Tanzania

Dairy Cow Body Indices	Dairy Cattle Breeds					SEM	P-value
	Ayrshire	Ayrshire Cross	Friesian Cross	Holstein Friesian	Local Zebu		
Live Body Weight (kg)	424.82[c]	372.92[b]	397.37[bc]	411.69[bc]	266.70[a]	14.55	0.004
Body Condition Score	3.18[ab]	3.10[ab]	3.02[a]	3.17[ab]	3.24[b]	0.06	0.022
Body Height (cm)	119.10[b]	117.23[b]	117.91[b]	118.01[b]	105.46[a]	2.04	0.000
Body Length (cm)	129.17[c]	121.33[b]	123.74[bc]	127.99[c]	109.34[a]	2.33	0.000
Heart Girth (cm)	157.27[c]	150.67[b]	154.78[bc]	155.76[bc]	135.61[a]	2.14	0.016
Paunch Girth (cm)	192.71[b]	181.67[b]	186.49[ab]	186.88[ab]	163.46[a]	2.90	0.001
Height of Withers (cm)	55.38[b]	61.28[b]	55.66[ab]	58.11[ab]	48.77[a]	1.84	0.030
Neck Girth (cm)	74.31[b]	70.72[b]	71.16[b]	72.85[b]	60.09[a]	1.75	0.009
Thigh Circumference (cm)	53.96[c]	50.56b[c]	48.93[b]	52.48[c]	39.87[a]	1.21	0.029

Means with different superscript letters were significantly different (P<0.05); SEM=Standard Error of Mean difference

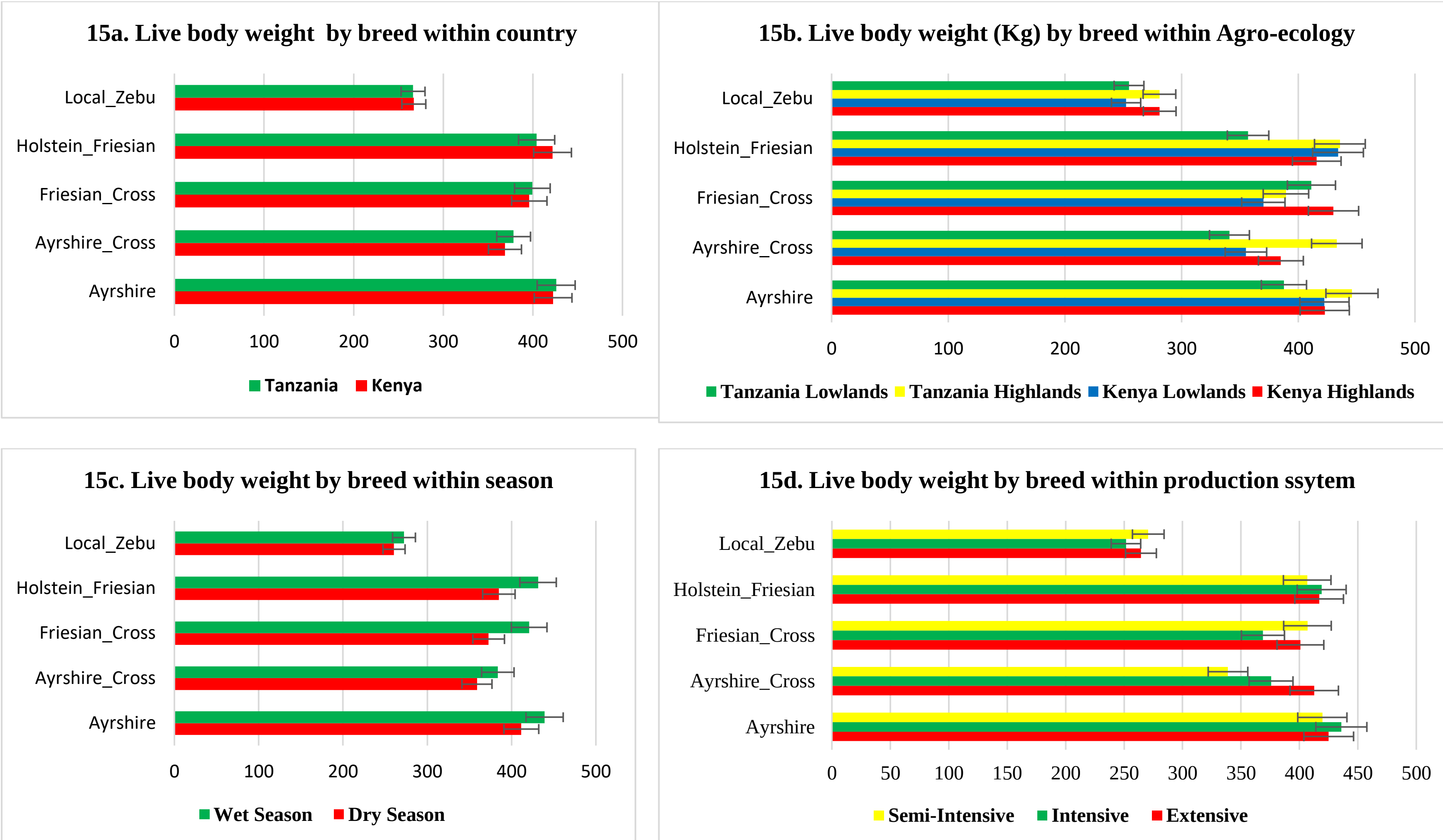


Figure 15: Live body weight (kg) of different dairy cattle breed types as influenced by country (15a), AEZ (15b), season (15c) and production system (15d) in Kenya and Tanzania

Table 10: Least Square Means for LBW, BCS and morphometric body indices of dairy cows under different production systems in Kenya and Tanzania

Dairy Cow Body Indices	Dairy Cattle Production Systems			SEM	P-value
	Extensive	Intensive	Semi Intensive		
Live Body Weight (kg)	358.33[a]	373.19[b]	352.90[a]	12.92	0.035
Body Condition Score	3.14	3.09	3.18	0.05	0.210
Body Height (cm)	113.65	116.81	113.32	1.67	0.061
Body Length (cm)	120.86	121.91	119.11	1.91	0.277
Heart Girth (cm)	147.61	151.38	148.11	1.87	0.107
Paunch Girth (cm)	177.03	183.25	179.16	2.55	0.112
Height of Withers (cm)	55.70	55.97	53.93	1.54	0.483
Neck Girth (cm)	67.63	71.75	67.52	1.50	00.080
Thigh Circumference (cm)	48.11	49.49	46.69	1.08	0.602

Means with different superscript letters were significantly different (P<0.05); SEM=Standard Error of Mean difference

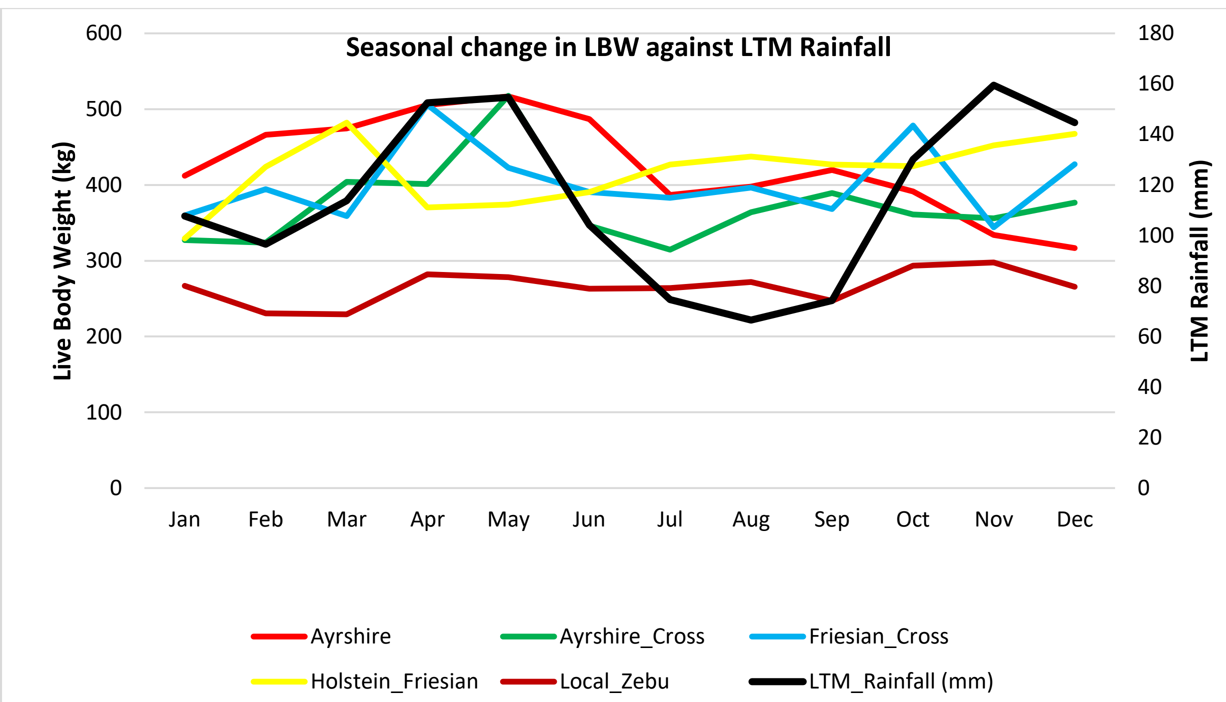


Figure 16: Year-round changes in LBW against long term mean (LTM) monthly rainfall (2016-2018) for different breeds of dairy cows in Kenya and Tanzania

Body Condition Score (BCS)

The mean values of body condition score (BCS) based on ELANCO Animal Health chart 5-point body condition scoring system, within high and low altitude areas of Kenya and Tanzania are also presented in Table 8. The mean BCS was higher (*P* < 0.05) for dairy cows in Tanzania lowlands than other ecological areas and similar (P > 0.05) to the mean value for Tanzania highlands. Mean BCS (Table 9) for dairy cows within the four agro-ecologies was higher ($P < 0.05$) for local zebu than Friesian cross, but similar ($P > 0.05$) to those for Ayrshire cows and Holstein Friesian cows. The BCS (Table 10) was slightly lower ($P < 0.05$) for dairy cows under intensive system compared to extensive and semi intensive systems in Kenya and Tanzania.

Morphometric body measurements (indices)

Mean values of body height (BH) and length (BL) for smallholder dairy cows in Kenya and Tanzania were ranged from 105 – 130 cm. Mean values of heart girth (HG) and paunch girth (PG) for the dairy breeds ranged from 130 – 200 cm. Mean values of height of withers (HW), neck girth (NG) and thigh circumference (TCM) ranged from 30 – 80 cm. Mean values of BH and BL (Table 8) were slightly higher ($P < 0.05$) in Kenya and Tanzania highlands compared to the lowlands. Heart girth was slightly higher (Table 8) in Tanzania highlands, but lower in Tanzania lowlands compared to Kenya highlands and lowlands ($P < 0.05$). Even though the mean value for Paunch girth was slightly lower in Tanzania lowlands, it was almost the same ($P > 0.05$) in the other three agro-ecologies.

The mean values HW, NG and TCM were similar across the four agro-ecologies (Table 8). All morphometric body indices (Table 9) were higher ($P < 0.05$) with improved breeds (Ayrshire, Ayrshire cross, Friesian cross and Holstein-Friesian) compared to the Local zebu breed in Kenya and Tanzania. Further, Table 9 showed that morphometric body indices were slightly higher ($P < 0.05$) for purebreds compared to the crossbreeds. However, morphometric body indices for the different breeds were similar ($P > 0.05$) within extensive, semi-intensive and extensive smallholder dairy production systems (Table 10).

Correlation between LBW with BCS and Morphometric body indices

Results in Tables 11 and 12 shows that there was no significant ($P \geq 0.05$) relationship between BCS with LBW and all morphometric body indices for both improved and local zebu cows within high and low altitude areas in Kenya and Tanzania. However, there was a highly significant (P $\leq$ 0.001) positive relationship for improved dairy cows between LBW with BH (R^2 = 0.712), BL (R^2 = 0.794) and HG (R^2 = 0.893). Similarly, there was a high significant ($P < 0.05$) positive relationship for local zebu cows between LBW with BH (R^2 = 0.620), BL (R^2 = 0.930) and HG (R^2 = 0.614). The relationship between BH with BL was highly significant ($P \leq$

0.001) and positive for both improved dairy cows (R^2 = 0.660) and local zebu cows (R^2 = 0.589). The relationship between HG with BH and BL was also highly significant ($P \leq 0.001$) and positive for both improved (R^2 = 0.621 and R^2 = 0.525) and local zebu cows (R^2 = 0.419 and R^2 = 0.320) respectively, within high and low altitude areas in Kenya and Tanzania. The relationship between PG with BH, BL and HG for improved dairy cows was highly significant ($P \leq 0.001$), moderate and positive (R^2 = 0.566, R^2 = 0.418 and R^2 = 0.594, respectively), compared to local zebu cows.

Table 11: Correlation (coefficient and significance) amongst LBW, BCS and morphometric body indices for improved dairy cows in Kenya and Tanzania

Improved Breeds	LBW	BCS	BH	BL	HG	HW	NG	PG
BCS	0.022							
BH	0.712***	0.004						
BL	0.794***	0.008	0.660***					
HG	0.893***	0.039	0.621***	0.525***				
HW	0.307***	0.070	0.200***	0.182***	0.338***			
NG	0.396***	0.038	0.391***	0.230***	0.422***	0.147**		
PG	0.586***	-0.005	0.566***	0.418***	0.594***	0.026	0.485***	
TCM	0.397***	0.028	0.308***	0.385***	0.322***	0.350***	0.311***	0.179***

LBW= Live body weight; BCS=Body condition score; BH=Body height; BL=Body length; HG=Heart girth; HW=Height of withers; NG=Neck girth; PG=Paunch girth; TCM=Thigh circumference; Correlation Coefficients (R^2) and level of significance test *=P<0.05, **=P<0.01, ***=P<0.001

Table 12: Correlation (coefficient and significance) amongst LBW, BCS and morphometric body indices for local zebu cows in Kenya and Tanzania

Local Zebu	LBW	BCS	BH	BL	HG	HW	NG	PG
BCS	-0.059							
BH	0.620***	-0.125						
BL	0.930***	-0.007	0.589***					
HG	0.614***	-0.166	0.419***	0.320***				
HW	-0.089***	0.528	0.406***	0.410***	0.503***			
NG	0.135**	-0.062	0.140**	0.057	0.294***	0.244***		
PG	0.208***	-0.082	0.319***	0.291***	0.047	0.203***	0.326***	
TCM	-0.046	0.001	0.009	-0.057	0.000	-0.134**	0.051	0.046

LBW= Live body weight; BCS=Body condition score; BH=Body height; BL=Body length; HG=Heart girth; HW=Height of withers; NG=Neck girth; PG=Paunch girth; TCM=Thigh circumference; Correlation Coefficients (R^2) and level of significance test *=P<0.05, **=P<0.01, ***=P<0.001

(iv) Milk Production

Daily morning and evening milk yield

Mean morning milk yield (litres/cow/day) for smallholder dairy cows was 3.94 SEM = 0.12. Morning and evening milk yield for dairy cows (Table 13), was slightly higher ($P < 0.05$) in intensive production system, and lower ($P < 0.05$) in extensive system compared to semi intensive system. Further, results (Table 14), revealed that morning milk cows was similar ($P > 0.05$) within high and low altitude areas in Kenya and Tanzania. Evening milk yield (litres/cow/day) for the dairy cows was 3.83 SEM = 0.12, Evening milk yield was slightly higher ($P < 0.05$) in Kenya highlands and Tanzania highlands compared to the lowlands.

Results in Table 15 showed that morning and evening milk yield by different dairy breeds was lower ($P < 0.05$) for local zebu cows compared to the improved dairy cows. Amongst the improved dairy cow breeds (Table 15), morning and evening milk yield was slightly higher ($P < 0.05$) for the purebreds (Ayrshire and Holstein-Friesian) compared to the crossbreeds.

As shown in Fig. 17, slightly more morning and evening milk yield per dairy cow was realized during the wet season ($P < 0.05$) compared to the dry season period. Further (Fig. 17), local zebu and Ayrshire cross cows had slightly lower variation in morning and evening milk yield, compared to the other breeds. However, Ayrshire, Friesian cross and Holstein-Friesian had slightly higher ($P < 0.05$) morning milk yield during the wet season compared to the dry season within the different agro-ecologies in Kenya and Tanzania.

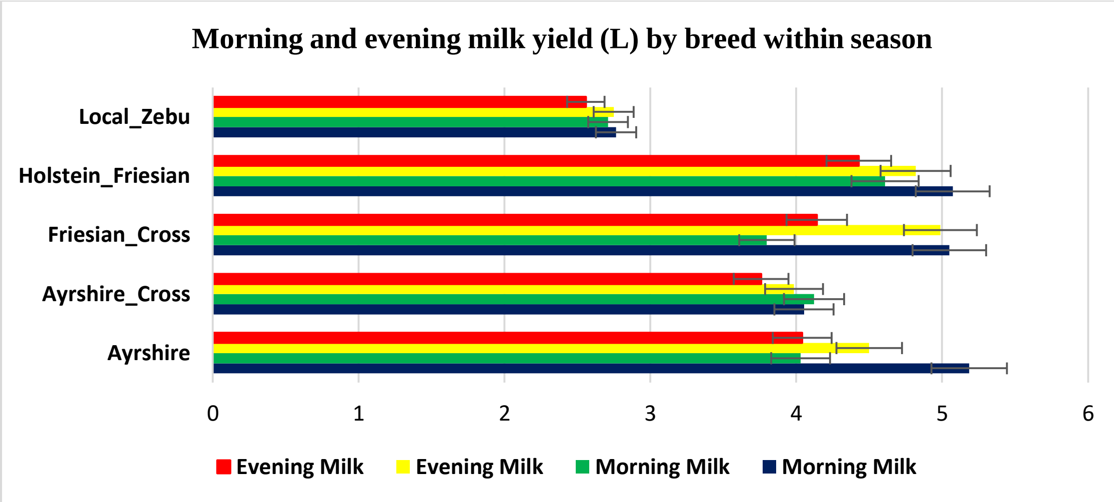


Figure 17: Morning and evening milk yield (L) during wet and dry seasons for different dairy breed types across high and low altitude areas of Kenya and Tanzania

Table 13: Least Square Means for milk production (Litres) from smallholder dairy cows under different production systems in Kenya and Tanzania

Milk Production	Dairy Cattle Production Systems			SEM	P-value
	Extensive	Intensive	Semi Intensive		
Milk yield/cow/day	8.31[a]	9.70[b]	8.71[a]	0.40	.000
Morning milk/cow/day	3.68a	4.66[b]	3.92[a]	0.24	.023
Evening milk/cow/day	3.66[a]	4.49[b]	3.75[a]	0.24	.000
Milk for home use	1.88[a]	2.53[b]	1.92[a]	0.13	.032
Milk for sale	3.74[a]	4.88[b]	4.17[a]	0.31	.000
Milk for calves	1.59	1.81	1.69	0.12	.057
305-days Lactation Milk	2521.20[a]	2963.40[b]	2654.20[ab]	120.59	.013

Means with different superscript letters were significantly different (P<0.05); SEM=Standard Error of Mean difference

Table 14: Least Square Means for milk production (Litres) from smallholder dairy cows within high and low altitude areas in Kenya and Tanzania

Milk Production	Agro Ecological Zone				SEM	P-value
	Kenya Highlands	Kenya Lowlands	Tanzania Highlands	Tanzania Lowlands		
Milk yield/cow/day	9.40[b]	8.10[a]	9.05[ab]	8.53[ab]	0.41	0.000
Morning milk/cow/day	4.11	3.91	4.28	3.59	0.24	0.057
Evening milk/cow/day	4.22[b]	3.57[a]	4.09[ab]	3.50[a]	0.25	0.000
Milk for home use	2.07[ab]	1.76[a]	2.23[b]	1.97[ab]	0.13	0.000
Milk for sale	5.01[a]	4.06[a]	4.21[ab]	3.39[a]	0.33	0.002
Milk for calves	1.49[a]	1.46[a]	1.92[b]	1.66[ab]	0.12	0.000
305 day Lactation Milk	2858.60[b]	2458.70[a]	2756.60[ab]	2594.60[ab]	124.59	0.000

Means with different superscript letters were significantly different (P<0.05); SEM=Standard Error of Mean difference

Table 15: Least Square Means for milk production (Litres) from different dairy cattle breeds in Kenya and Tanzania

Milk Production	Dairy Cattle Breeds					SEM	P-value
	Ayrshire	Ayrshire Cross	Friesian Cross	Holstein Friesian	Local Zebu		
Milk yield/cow/day	10.19[b]	9.37[ab]	9.45[ab]	9.93[b]	6.78[a]	0.52	.035
Morning milk/cow/day	4.58[b]	4.11[b]	4.46[b]	4.89[b]	2.80[a]	0.31	.034
Evening milk/cow/day	4.55[b]	3.89[b]	4.26[b]	4.69[b]	2.70[a]	0.30	.005
Milk for home use	2.21[b]	1.97[b]	2.31[b]	2.41[b]	1.50[a]	0.17	.000
Milk for sale	4.73[b]	4.17[ab]	4.91[b]	5.26[b]	2.78[a]	0.41	.000
Milk for calves	2.00[b]	1.72[b]	1.86[b]	2.00[b]	1.08[a]	0.15	.000
305 day Lactation Milk	3110.10[b]	2848.50[ab]	2882.70[ab]	3023.40[b]	2052.86[a]	159.02	.000

Means with different superscript letters were significantly different (P<0.05); SEM=Standard Error of Mean difference

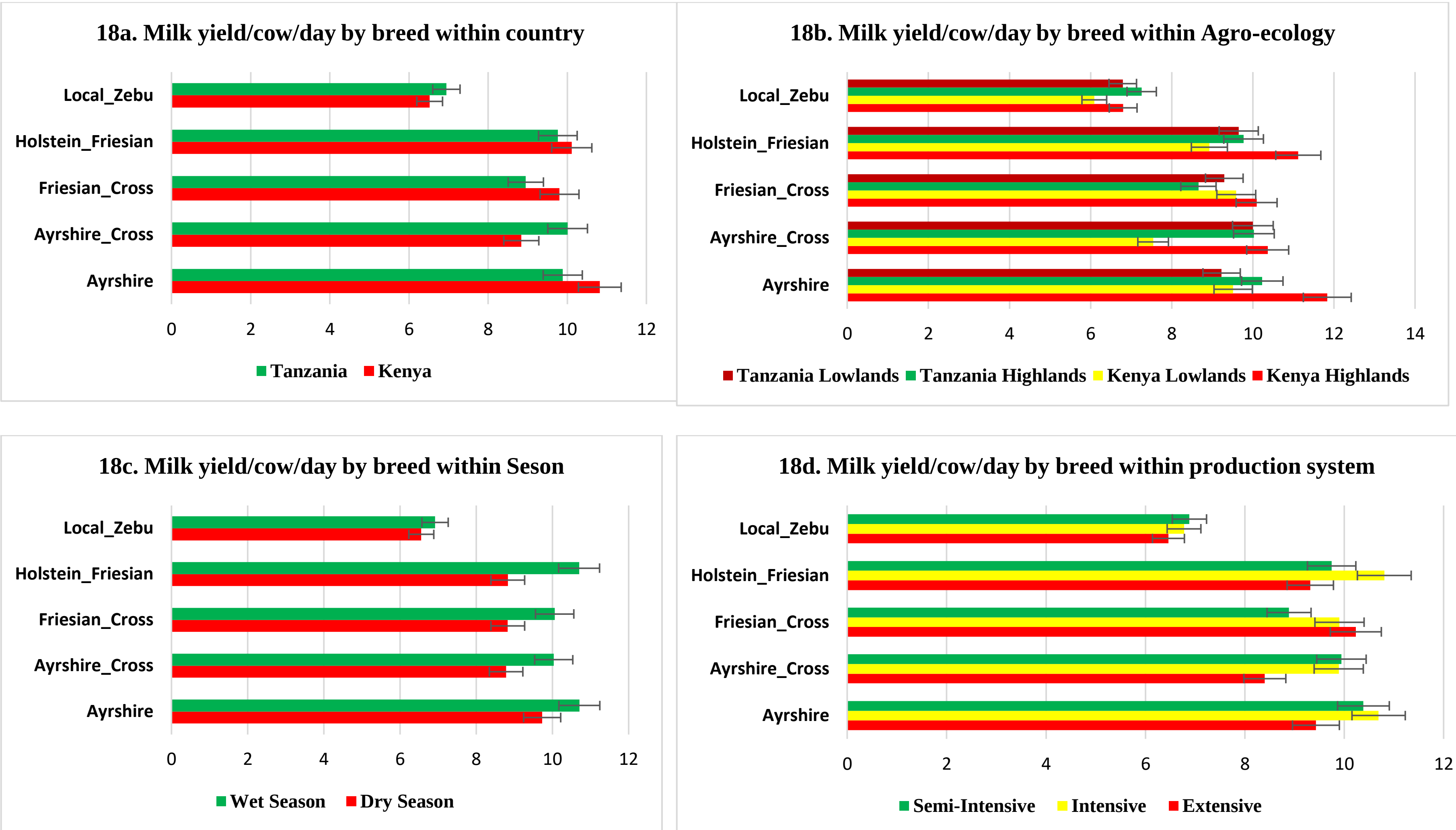


Figure 18: Milk yield/cow/day by country (18a), agro-ecology (18b), season (18c) and production system (18d) from different dairy cattle breeds in Kenya and Tanzania

Daily and 305-day lactation milk yield

Mean values for daily milk yield per cow amongst the different dairy cattle breeds in Kenya and Tanzania are presented in Fig. 18a, and was similar in both countries ($P < 0.05$). Daily and 305-day lactation milk yield (Table 13) was higher from dairy cows reared under intensive production system and lower in extensive system compared to the semi intensive system ($P < 0.05$).

Mean values for milk yield for dairy cows in litres per cow per day within high and low altitude areas in Kenya and Tanzania are presented in (Table 14). Milk yield was slightly higher ($P < 0.05$) in Kenya highlands and Tanzania highlands compared to Kenya lowlands and Tanzania lowlands. As shown in Fig. 18b, Holstein-Friesian and Ayrshire produced slightly higher milk in Kenya highlands compared to the other agro-ecologies.

Higher ($P < 0.05$) daily and 305-day lactation milk yields (Table 15) were realized from Ayrshire and Holstein-Friesian breeds in Kenya and Tanzania compared to the crossbreeds (Ayrshire cross and Friesian cross) and local zebu ($P < 0.05$). The least ($P < 0.05$). Daily and 305-day lactation milk yield was realized from local zebu cows under different agro-ecologies (Fig. 18b) across the two countries. Similarly, as shown in Fig. 18d, local zebu cows also produced the least ($P < 0.05$) daily and 305-day lactation milk across the three dairy production systems.

The season effect on daily milk yield within high and low altitude areas in Kenya and Tanzania is shown in Fig. 18c. Milk yield for dairy cows was slightly higher ($P < 0.05$) during the wet season compared to the dry season. Similarly, the 305-day lactation milk yield was higher ($P < 0.05$) during the wet season compared to the dry season. The seasonal variation/change (%) in daily milk yield for dairy cows between the wet and dry seasons was estimated as: (Wet season milk yield – Dry season milk yield)/Mean milk yield*100. Therefore, seasonal variation in milk yield for different dairy breeds between the wet and dry seasons was +/-6.22%. However, seasonal variation in milk yield was lower for local zebu (+/-3.96%), but higher for improved breeds (+/-14.50%), and more so the Holstein-Friesian (+/-20.31%).

The season change (%) in milk yield for the other improved breeds between the wet and dry seasons was: Ayrshire (10.61%), Ayrshire cross (13.56%) and Friesian cross (13.37%). Results (Fig. 19), revealed continuous year-round seasonal fluctuation in daily (and hence 305-day lactation) milk yield with long term mean (LTM) monthly rainfall variability, which was higher ($P < 0.05$) for the improved cows compared to local zebu cows both in Kenya and Tanzania.

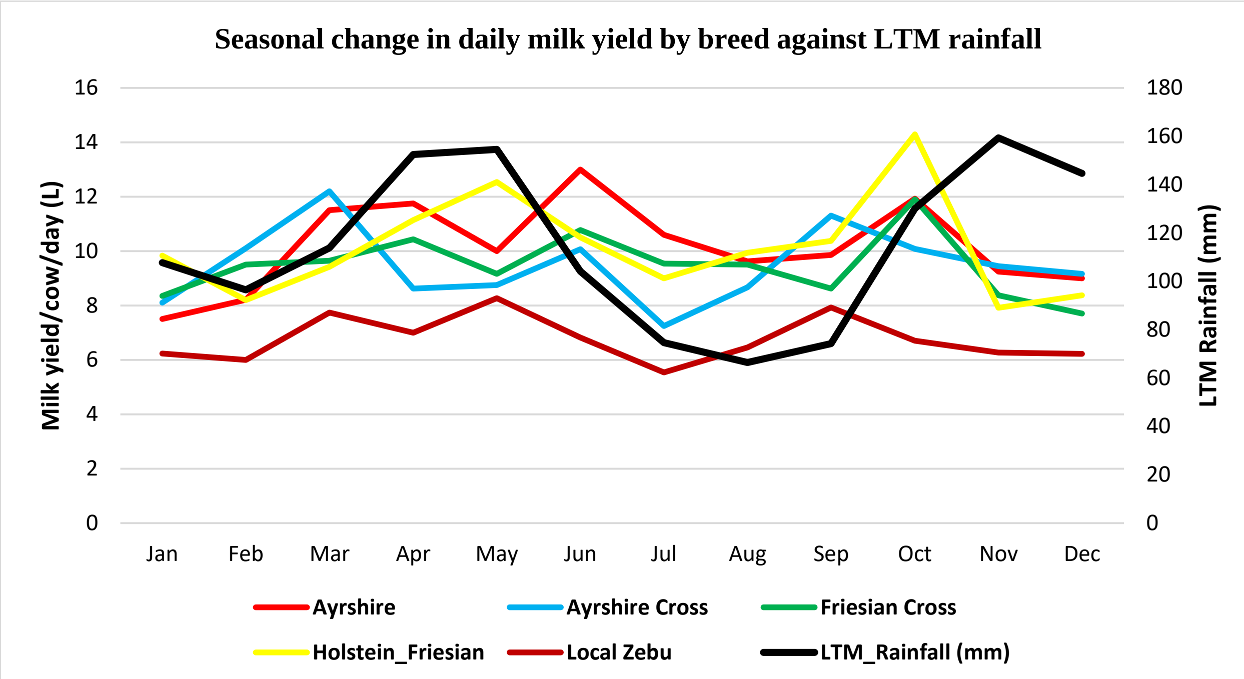


Figure 19: Year-round seasonal changes in milk yield per cow (L) by breed against long term mean (LTM) monthly rainfall (mm) in Kenya and Tanzania

Daily milk (Litres) for Home use, Sales and Calves

Daily milk for home use (litres/cow) within high and low altitude areas in Kenya and Tanzania was 2.16 SEM = 0.07. Daily milk for sales was 4.43 SEM = 0.19, while daily milk for calves was 1.74 SEM = 0.07. Daily milk yield for home use, sales and calves (Table 13) was slightly higher in intensive production system and lower in extensive system compared to the semi intensive system ($P < 0.05$).

Daily milk (Table 14) for home use (consumption) was slightly higher in Tanzania highlands and lower in Kenya lowlands compared to the other agro-ecologies ($P < 0.05$). Similarly, daily milk for sale was slightly higher in Kenya highlands and lower in Tanzania lowlands compared to the other agro-ecologies ($P < 0.05$). Daily milk for calves was slightly lower in Kenya highlands and lowlands compared to Tanzania highlands and lowlands ($P < 0.05$).

Daily milk for home use, sales and calves (Table 15) was generally lower ($P < 0.05$) for the local zebu cow compared to the improved breeds within the four agro-ecologies. However, (Table 15), daily milk for home use and sales was slightly higher ($P < 0.05$) from Holstein-Friesian and

Friesian cross compared to Ayrshire and Ayrshire cross. Daily milk for calves (Table 15) was slightly higher (*$P < 0.05$*) from Holstein-Friesian and Ayrshire purebreds compared to the crossbreeds and local zebu cows.

Correlation of milk production parameters for dairy cows in Kenya and Tanzania

Results (Table 16) revealed a strong and highly significant ($P \leq 0.001$) positive relationship between morning and evening milk with daily milk yield ($R^2 = 0.709$) and 305-day lactation milk yield ($R^2 = 0.735$). There was also a strong and highly significant ($P \leq 0.001$) positive relationship between daily milk for sales with morning milk ($R^2 = 0.826$), evening milk ($R^2 = 0.821$) and daily, hence 305-day lactation milk yield ($R^2 = 0.682$).

Table 16: Correlation (coefficient and significance) of milk production parameters for dairy cows in Kenya and Tanzania

Milk Production	Milk yield/cow/day	Morning Milk	Evening Milk	Milk for Home use	Milk for Sales	Milk for Calves
Morning Milk	0.709***					
Evening Milk	0.709***	0.735***				
Milk for home use	0.461***	0.551***	0.548***			
Milk for sales	0.682***	0.826***	0.821***	0.309***		
Milk for calves	0.472***	0.570***	0.557***	0.402***	0.333***	
305d Lactation yield	0.995***	0.709***	0.709***	0.461***	0.682***	0.472***

d=days; Correlation Coefficients (R^2) and level of significance test, ***=P<0.001

The relationship between milk for home use, sales and calves with daily and hence 305-day lactation milk yield was moderate, but very highly significant ($P \leq 0.001$) and positive ($R^2 = 0.461$, $R^2 = 0.682$, and $R^2 = 0.472$, respectively). The relationship between milk for home use with morning and evening milk was also moderate, very highly significant ($P \leq 0.001$) and positive ($R^2 = 0.551$ and $R^2 = 0.548$, respectively). Similarly, the relationship between milk for calves with morning and evening milk was moderate, highly significant ($P \leq 0.001$) and positive ($R^2 = 0.570$ and $R^2 = 0.557$, respectively). Findings (Table 16) further revealed a strong, highly significant ($P \leq 0.001$) and positive ($R^2 = 0.995$) relationship between daily and 305-day lactation milk yield for dairy cows within high and low altitude areas in Kenya and Tanzania.

(v) Smallholder dairy cattle Herd dynamics and Cow replacement decisions

Smallholder dairy cattle breed composition in Kenya and Tanzania

The breed composition of dairy cattle herd (Fig. 20 and 21) within high and low altitude areas in Kenya and Tanzania was: Ayrshire (16.92%), Holstein-Friesian (13.63%), their crosses - Ayrshire cross (16.92%) and Friesian cross (21.27%), and local zebu (20.97%). The proportion of other breeds, namely Brown Swiss, Fleckvieh, Guernsey and Jersey in the dairy cattle herd was less than 5% across the two countries.

A large proportion of dairy cattle herd within agro-ecologies in Tanzania comprised local zebu (30.35%), while in Kenya, herds comprised only 11.59% of local zebu. The proportion of Ayrshire cross and Friesian cross in dairy herds within agro-ecologies in Kenya was slightly higher (22.86% and 24.99%, respectively), compared to Tanzania (19.56% and 17.55%, respectively). Similarly, the proportion of Ayrshire and Holstein-Friesian was slightly higher in Kenya (18.44% and 16.45%, respectively), compared to Tanzania (15.39% and 10.81%).

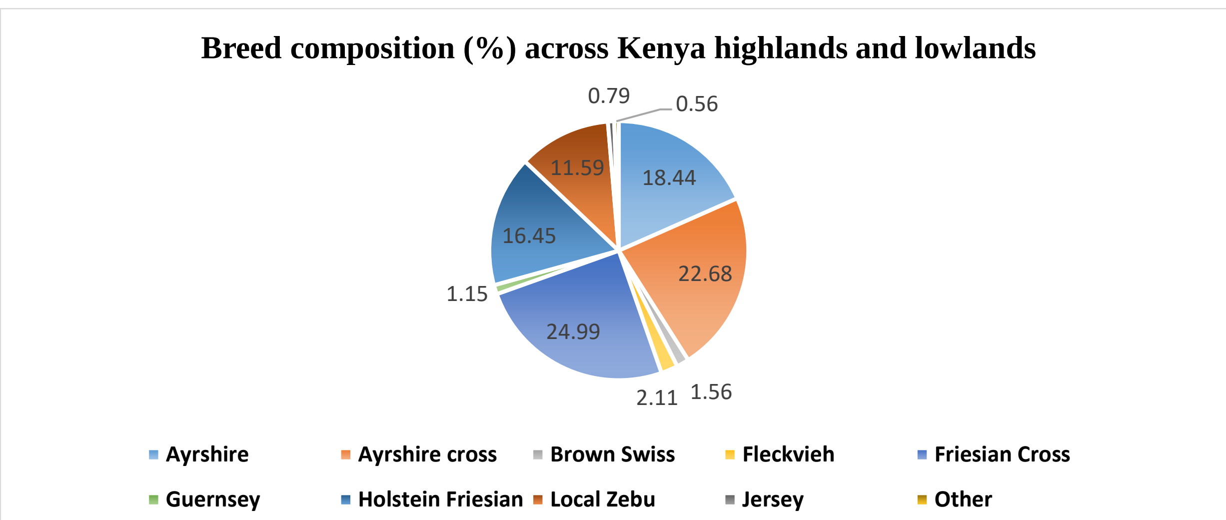


Figure 20: Smallholder dairy cattle breed composition (%) across agro-ecologies in Kenya

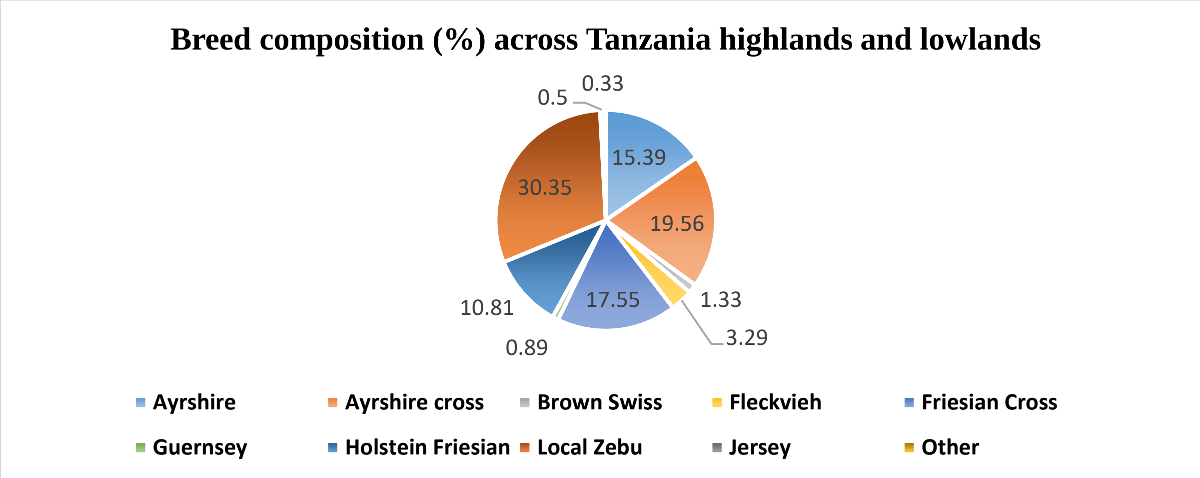


Figure 21: Smallholder dairy cattle breed composition (%) across agro-ecologies in Tanzania

Smallholder dairy cattle herd structure in Kenya and Tanzania

Results revealed that smallholder dairy cattle herd size in Kenya and Tanzania was 4.64 SEM = 0.24. Neither country nor agro-ecologies (Table 17), breed (Table 18) or production system (Table 19) had influence ($P > 0.05$) on the herd sizes of the stallholder dairy cattle in Kenya and Tanzania.

The proportion (%) of bulls and castrated adult males in smallholder dairy herds within high and low altitude areas in Kenya and Tanzania was 5.51% SEM = 0.14 and 4.89% SEM = 0.15, respectively. However, neither the agro-ecologies nor production systems had influence ($P > 0.05$) on the proportion of bulls in the herd, with exception of the breed ($P < 0.05$).

The proportion (%) of cows, heifers and female calves in smallholder dairy herds in Kenya and Tanzania was 29.75% SEM = 0.25, 18.35% SEM = 0.18 and 16.96% SEM = 0.21, respectively. Cows and heifers in the dairy herd (Table 17) were higher ($P < 0.05$) in Tanzania highlands and lowlands compared to Kenya highlands and lowlands. However, female calves were slightly lower ($P < 0.05$) in Kenya highlands compared to the other agro-ecologies. Neither the breed (Table 18), nor the production system had an influence ($P > 0.05$) on the proportion of heifers, cows and female calves in the dairy herd in Kenya and Tanzania.

The proportion (%) of immature males and male calves in smallholder dairy herd Kenya and Tanzania was 6.26% SEM = 0.16 and 10.56% SEM = 0.25 respectively. Neither agro-ecologies (Table 17) or the production system (Table 19) had an influence ($P > 0.05$) on the proportion of immature males and male calves in the dairy herd. However, the breed had an influence ($P < 0.05$) on the proportion of male valves, and not immature males ($P > 0.05$) in the smallholder dairy herd in both countries (Table 18).

Table 17: Least Square Means for smallholder dairy cattle herd structure (%) within high and low altitude areas in Kenya and Tanzania

Herd Structure	Agro Ecological Zones				SEM	P value
	Kenya Highlands	Kenya Lowlands	Tanzania Highlands	Tanzania Lowlands		
Herd size (No.)	5.02	4.50	4.62	4.60	0.48	0.452
Bulls	5.10	5.51	5.59	5.87	0.28	0.182
Castrated males	4.41	5.28	4.82	5.06	0.28	0.121
Cows	29.83[ab]	28.62[a]	30.23[b]	30.33[b]	0.48	0.001
Female calves	17.28	16.45	17.13	17.00	0.42	0.298
Heifers	18.74[b]	17.12[a]	18.92[b]	18.63[b]	0.35	0.003
Immature males	6.12	6.09	6.13	6.74	0.33	0.078
Male calves	11.27	10.43	9.98	10.57	0.49	0.210

Means with different superscript letters were significantly different ($P<0.05$); SEM=Standard Error of Mean difference

Table 18: Least Square Means for smallholder dairy cattle herd structure (%) by different breed types in Kenya and Tanzania

Herd Structure	Dairy Cattle Breeds					SEM	P value
	Ayrshire	Ayrshire Cross	Friesian Cross	Holstein Friesian	Local Zebu		
Herd size (No.)	4.09	5.30	5.20	4.32	4.44	0.53	0.499
Bulls	6.11^{c}	5.03^{ab}	5.48^{abc}	4.95^{a}	5.94^{bc}	0.32	0.050
Castrated males	5.70^{c}	4.27^{a}	4.69^{ab}	4.46^{ab}	5.33^{bc}	0.33	0.022
Cows	28.96	30.18	30.09	29.31	30.08	0.59	0.392
Female calves	16.45	17.38	17.00	16.67	17.25	0.48	0.657
Heifers	18.57	18.26	18.69	17.96	18.31	0.43	0.588
Immature males	6.63	6.04	6.42	6.04	6.27	0.37	0.807
Male calves	10.50^{ab}	9.41^{a}	10.31^{ab}	11.48^{b}	10.91^{ab}	0.56	0.017

Means with different superscript letters were significantly different (P<0.05); SEM=Standard Error of Mean difference

Table 19: Least Square Means for smallholder dairy cattle herd structure (%) within the different production systems in Kenya and Tanzania

Herd Structure	Dairy Cattle Production Systems			SEM	P value
	Extensive	Intensive	Semi Intensive		
Herd size (No.)	5.03	4.13	4.67	0.56	0.150
Bulls	5.54	5.12	5.63	0.26	0.880
Castrated males	5.08	4.30	4.99	0.26	0.279
Cows	29.80	29.59	29.78	0.47	0.757
Female calves	16.87	17.13	16.96	0.40	0.878
Heifers	18.09	18.09	18.60	0.35	0.728
Immature males	6.13	6.12	6.40	0.31	0.853
Male calves	10.28	11.25	10.50	0.48	0.585

Means with different superscript letters were significantly different (P<0.05); SEM=Standard Error of Mean difference

Correlation amongst smallholder dairy cattle herd structure in Kenya and Tanzania

Results (Table 20) revealed that the relationship between bulls with castrated adult males was very highly significant ($P \leq 0.001$), strong and positive (R^2 = 0.583). Cows, on the other hand, had a very highly significant ($P \leq 0.001$) and moderate positive relationship with bulls (R^2 = 0.434). The relationship between female calves with bulls and cows was very highly significant ($P \leq 0.001$), moderate and positive (R^2 = 0.500 and R^2 = 0.633, respectively). There was a very highly significant ($P \leq 0.001$), moderate and positive relationship between heifers with cows (R^2 = 0.580) and female calves (R^2 = 0.543). Male calves had relatively strong very highly significant ($P \leq 0.001$), moderate relationship with cows (R^2 = 0.446) and female calves (R^2 = 0.555).

Table 20: Correlation (Coefficient and significance) amongst dairy cattle herd structure (%) in Kenya and Tanzania

Herd Structure	Bulls	Castrated males	cows	Female calves	Heifers	Immature males
Castrated males	0.583***					
cows	0.430***	0.175***				
Female calves	0.500***	0.210***	0.653***			
Heifers	0.160**	0.008	0.580***	0.543***		
Immature males	0.267***	0.243***	0.121*	-0.182***	-0.117**	
Male calves	0.161**	0.078	0.446***	0.555***	0.196***	-0.247***

Correlation Coefficients (R^2) and level of significance test *=P < 0.05, **=P < 0.01, ***=P < 0.001

Seasonal effects on smallholder dairy herd structure in Kenya and Tanzania

Year round seasonal changes within high and low altitude areas in Kenya and Tanzania, as a result of rainfall variability, was clearly reflected in smallholder dairy cattle herd structure and dynamics. This was in terms of herd entry (births, purchases/gift-ins), herd exit (voluntary–sales/gift-outs and slaughter, involuntary–deaths, due to i.e. disease, accidents) and cow replacement investment decisions. Smallholder dairy cattle herd structure (Fig. 22 and 23) in terms of the proportion (%) of cows, female calves and heifers was slightly variable in Kenya from November to March, and in Tanzania from June to September. These were the dry season months in both countries, characterized by low rainfall, resulting into decreased proportion of cows, heifers and female calves in the herds. Conversely, the period between April to August in Kenya and November to April in Tanzania were characterized by a slight increase in the proportion of cows, female calves and heifers, as these were the long rainfall months in both countries.

The proportion (%) of bulls and castrated adult males in smallholder dairy herd (Fig. 22 and 23) was slightly more during the long rains months in Kenya (April to August) and Tanzania (November to April), which also coincided with the cropping season. The proportion (%) of immature males and male calves (Fig. 22 and 23) in smallholder dairy herds in the two countries was highly variable, but more pronounced during the low rainfall periods. Year round seasonal changes in herd structure were reflected in the multiple roles/uses of dairy cattle in smallholder farms i.e. milk production, income, insurance, manure production and work, etc., within the high and low altitude areas in Kenya and Tanzania.

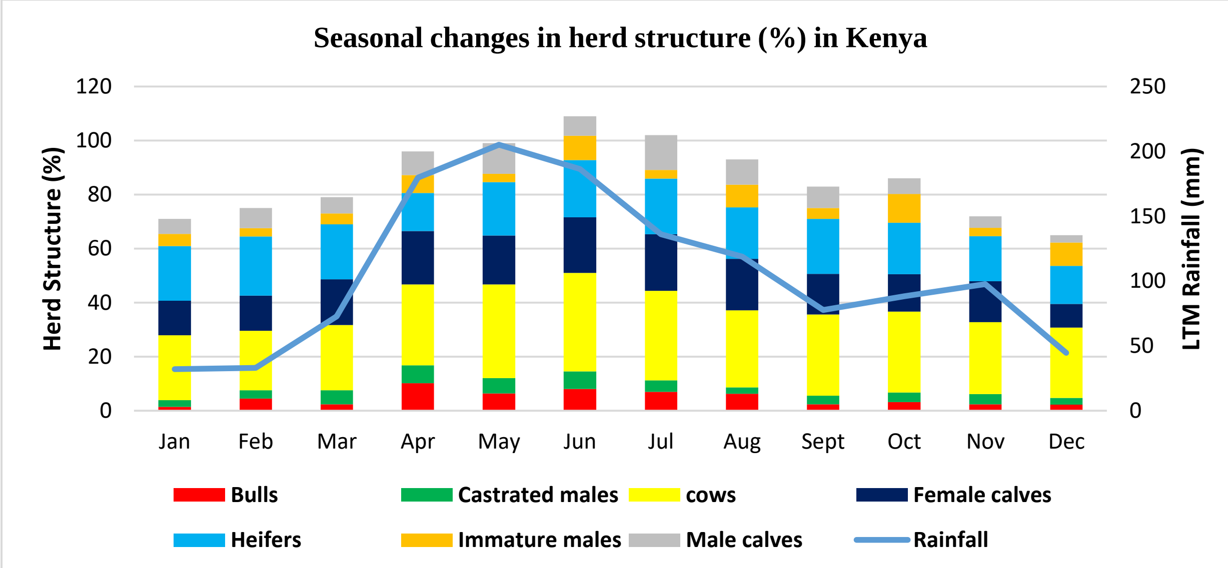


Figure 22: Year round seasonal changes in smallholder dairy cattle herd structure (%) with long-term mean (LTM) monthly rainfall in Kenya

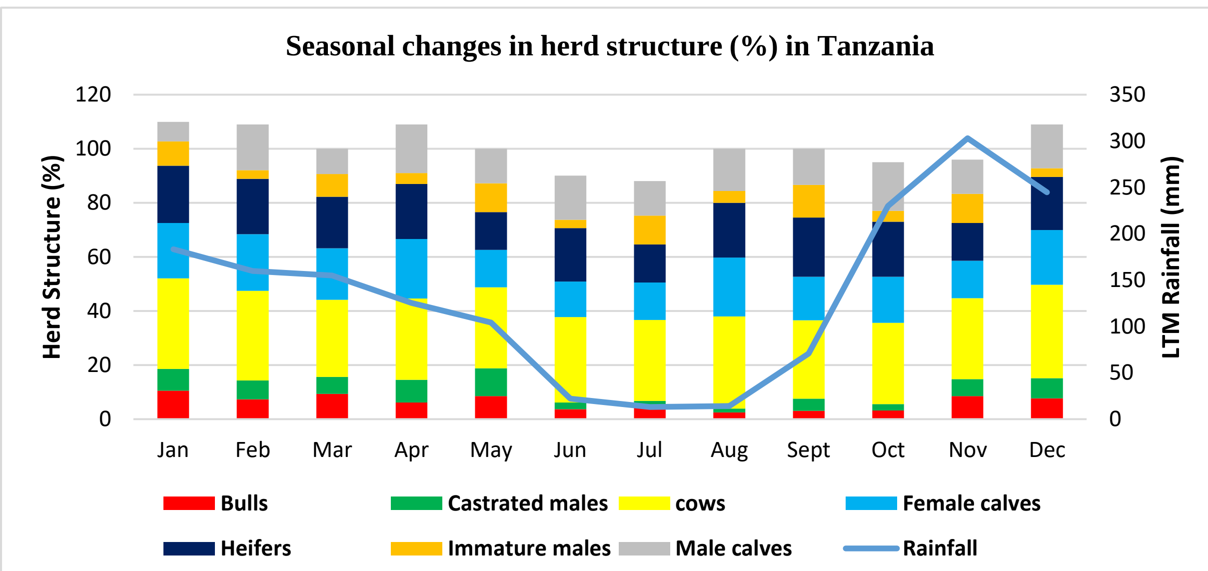


Figure 23: Year round seasonal changes in smallholder dairy cattle herd structure (%) with long-term mean (LTM) monthly rainfall in Tanzania

Seasonal effects on smallholder dairy herd entry in Kenya and Tanzania

Herd entry constituted an increase in herd size and/or herd surplus within high and low altitude areas in Kenya and Tanzania (Fig. 24 and 25). Year round rainfall seasonality was reflected in herd entry through births as an indicator of fertility within the two countries. Births throughout the year as a proportion (%) of the smallholder dairy herd, were on average 7.29% and 12.48% for improved and local zebu breed types respectively within the two countries. Therefore, smallholder dairy cows within high and low altitude areas in Kenya (Fig. 24) gave birth mainly during the long rainfall season months from March to July and the short rainfall months from September and November for both the improved and local zebu breeds. The months between December and February were dry season months in Kenya with limited rainfall and had less than 5% births for both improved and local zebu breeds (Fig. 24).

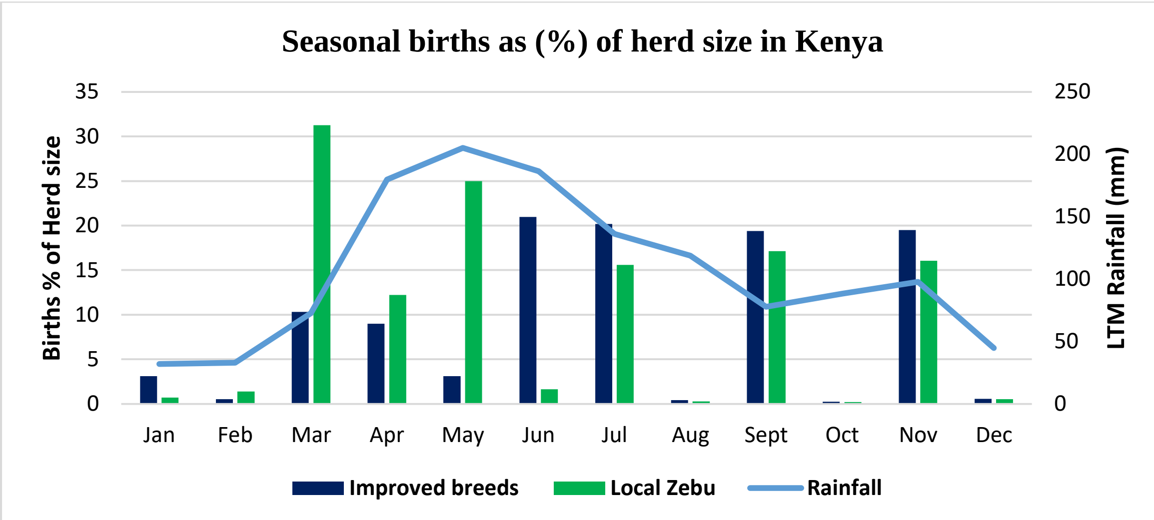


Figure 24: Year round seasonal changes in births as (%) of herd size with long-term mean (LTM) monthly rainfall in Kenya

Similarly, smallholder dairy cows within high and low altitude areas in Tanzania (Fig. 25) gave births mainly during the rainfall months from January to April and the short rainfall months from September and November for both the improved and local zebu breeds. The dry season months from June to August in Tanzania (Fig. 25), had less births, especially for the improved breeds. Therefore, in both Kenya and Tanzania, smallholder dairy cows (improved and local zebu breeds), naturally mate to mainly calve down during the rainfall, hence cropping season months when there is abundant locally available natural feed resources and water supply. This seasonality determined births scenario could be exploited in planned mating systems using artificial insemination (AI), or through natural synchronization to ensure that the animals calve down during the rainfall, when there is abundant feed and water supply, as opposed to the dry season months.

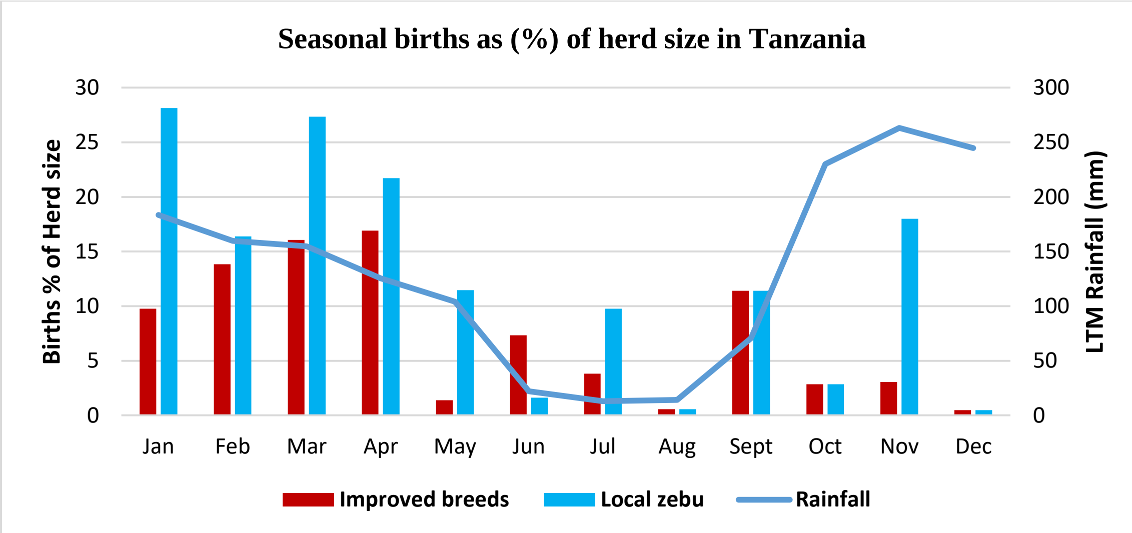


Figure 25: Year round seasonal changes in births as (%) of herd size with long-term mean (LTM) monthly rainfall in Tanzania

Year round rainfall seasonality (Fig. 26 and 27) was also reflected in herd entry though purchases and gift-ins (i.e. dowry) for the dairy cattle herd in smallholder farms within high and low altitude areas in Kenya and Tanzania. The proportion (%) of purchases and gift-ins throughout the year (Fig. 26) across different categories of animals in the smallholder dairy herd in Kenya was 7.83%. These comprised: bulls (0.96%), castrated adult males (2.68%), cows (19.02%), female calves (1.34%), heifers (28.01%), immature males (1.38%) and male calves (1.38%).

Most (15.0-30.0%) purchases and gift-ins for cows and heifers in Kenya were staggered, but occurred in the long rains season from May, July and towards the short rainfall season from September to November. There were few (<5.00%) purchases and gift-ins during the dry season (low rainfall) months from December to March, within high and low altitude areas in Kenya. There were also few (<3.0%) purchases and gift-ins for female calves, male calves, immature males, bulls and castrated adult males in Kenya.

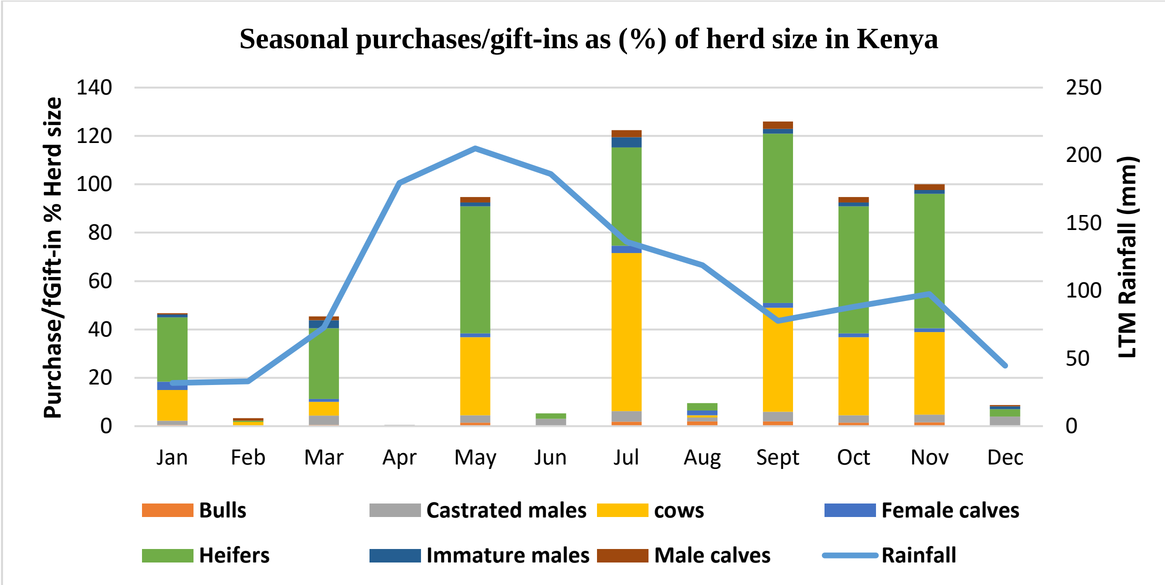


Figure 26: Year round seasonal changes in purchases/gift-ins as (%) of herd size with long-term mean (LTM) monthly rainfall in Kenya

The proportion of purchases and gift-ins throughout the year (Fig. 27) across different categories of animals in the smallholder dairy herd in Tanzania was 7.54%. These comprised: bulls (1.14%), castrated adult males (2.40%), cows (21.18%), female calves (6.40%), heifers (15.26%), immature males (1.86%) and male calves (4.56%). A sizeable proportion (5.00 - 25.00%) of year round purchases and gift-ins for the dairy cattle herd in Tanzania were mainly cows and heifers, but also female calves and male calves. Most (5.00 - 25.00%) purchases and gift-ins for cows, heifers, female calves and male calves were also staggered, but occurred during the rainfall season in November, January, March to May and September across the high and altitude areas of Tanzania. There were few purchases and gift-ins (<5.00%) during the dry season (low rainfall) months from June to August in Tanzania. Additionally, there were also few (<3.00%) purchases and gift-ins for bulls, castrated adult males and immature males in Tanzania.

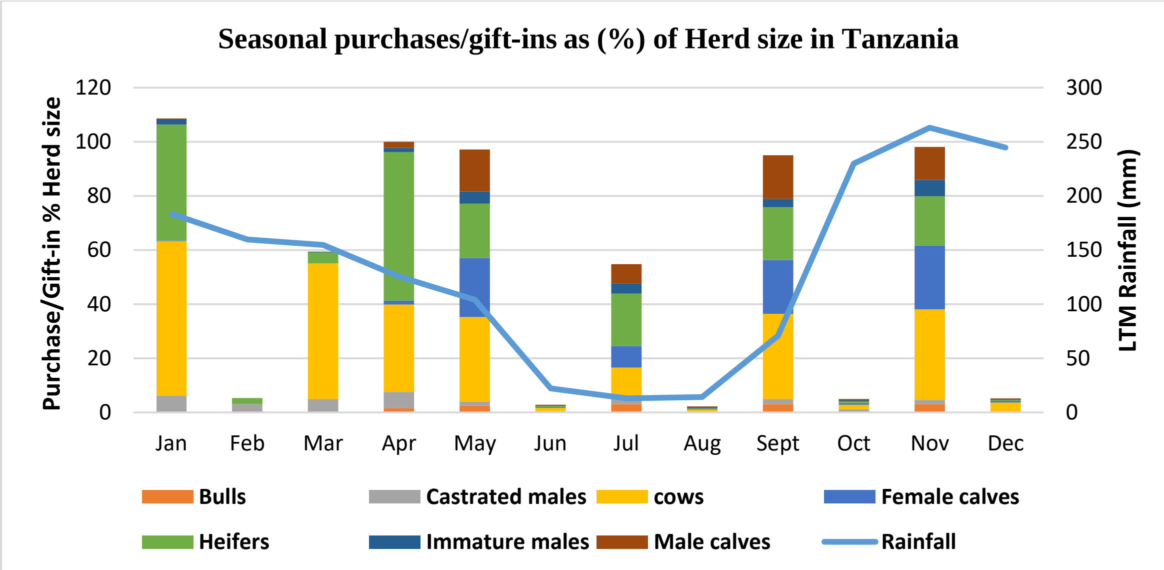


Figure 27: Year round seasonal changes in purchases/gift-ins as (%) of herd size with long-term mean (LTM) monthly rainfall in Tanzania

Seasonal effects on smallholder dairy herd exit in Kenya and Tanzania

Herd exit constituted a decrease in herd size and/or herd surplus through voluntary and involuntary culling of the smallholder dairy cattle herd within high and low altitude areas in Kenya and Tanzania. Year round rainfall seasonality (Fig. 28 and 29) was reflected in involuntary culling through deaths from animal health related causes (pests and diseases), slaughter for various purposes, environmental changes (heat stress, drought, fluctuations in feed and water) and managerial capability of herd owners. The proportion (%) of deaths throughout the year (Fig. 28) across different categories of animals in the smallholder dairy herd in Kenya was 3.66%. These comprised: bulls (2.07%), castrated adult males (0.94%), cows (6.90%), female calves (5.08%), heifers (7.77%), immature males (1.22%) and male calves (1.63%). Deaths throughout the year in Kenya were slightly more (5.00 - 8.00%) amongst cows, female calves and heifers compared to the bulls, castrated adult males, immature males and male calves that had <2.50% (Fig. 28). Most deaths across different categories of animals in Kenya, occurred during the rainfall season months from March to September, and less during the dry season (low rainfall) months from January to February.

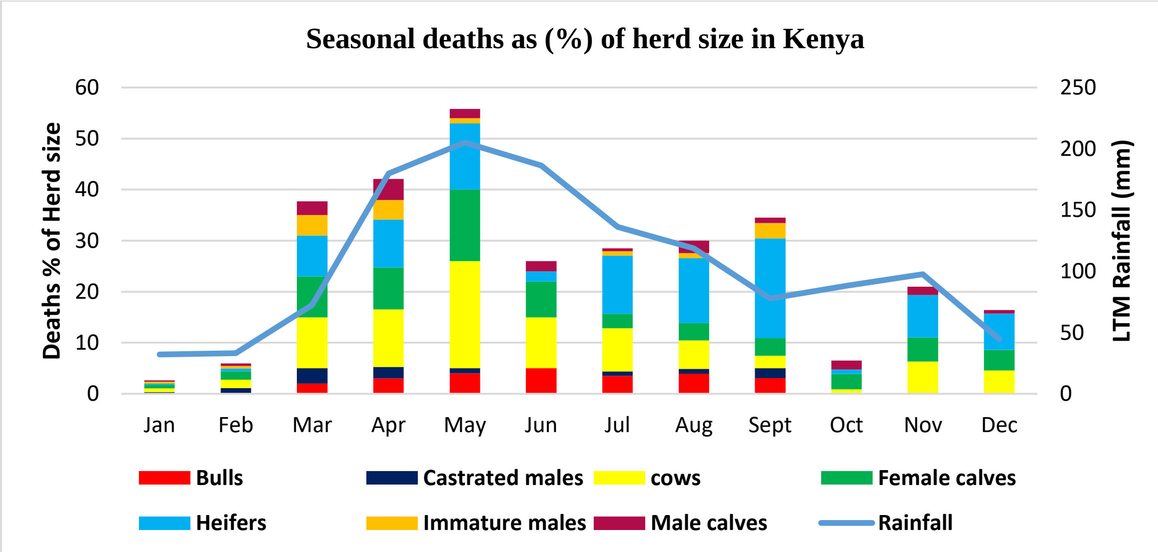


Figure 28: Year round seasonal changes in deaths as (%) of herd size with long-term mean (LTM) monthly rainfall in Kenya

The proportion (%) of deaths throughout the year (Fig. 29) across different categories of animals in the smallholder dairy herd in Tanzania was 6.02%. These comprised: bulls (2.60%), castrated adult males (1.59%), cows (11.02%), female calves (9.02%), heifers (8.14%), immature males (4.16%) and male calves (5.58%). Most deaths across different categories of animals in Tanzania, occurred during the rainfall months from September to December, and also during the dry season (low rainfall) months from May to August. As shown in Fig. 28 and 29, most deaths occurring during the rainfall season months in the two countries were attributed to build up of pest and diseases, while from November to December were due to end year festivities and socio-cultural activities.

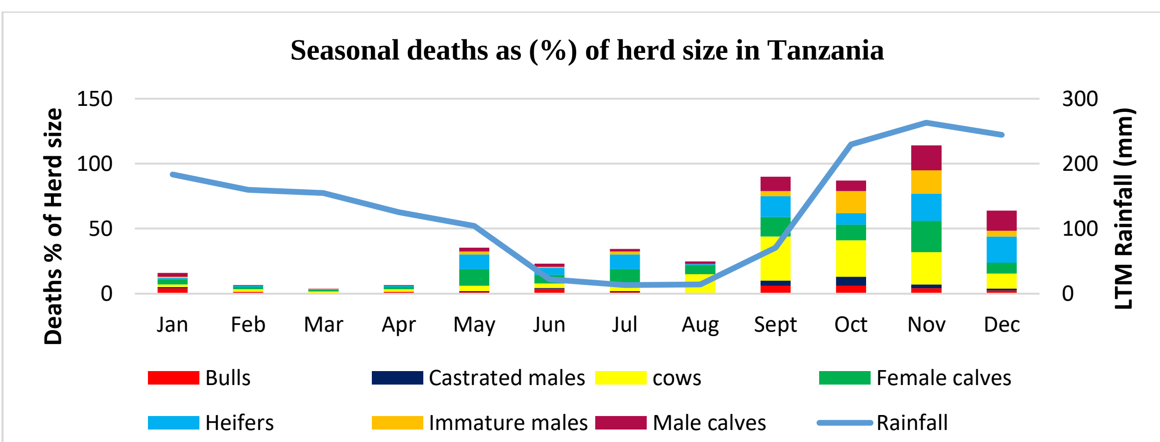


Figure 29: round seasonal changes in deaths as (%) of herd size with long-term mean (LTM) monthly rainfall in Tanzania

Year round rainfall seasonality (Fig. 30 and 31) was reflected in herd exit though sales and gift-outs (i.e. family needs, sickness, school fees, dowry) for smallholder dairy cattle herd in within high and low altitude areas in Kenya and Tanzania. The proportion (%) of sales and gift-outs throughout the year (Fig. 30) across different categories of animals in the smallholder dairy herd in Kenya was 9.72%. These comprised: bulls (6.34%), castrated adult males (6.84%), cows (22.82%), female calves (5.10%), heifers (12.76%), immature males (5.31%) and male calves (8.87%). Year round sales and gift-outs in Kenya were staggered, but occurred during the months of January, March, May July and mainly the short rainfall season towards the end of the year from September to December).

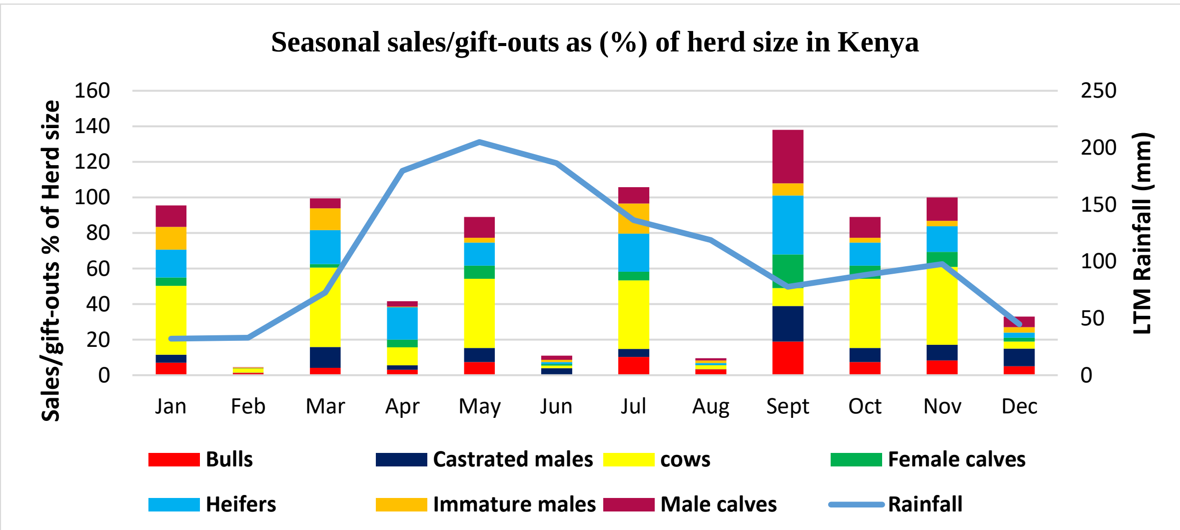


Figure 30: Year round seasonal changes in sales/gift-outs as (%) of herd size with long-term (LTM) monthly rainfall in Kenya

The proportion of sales and gift-outs throughout the year (Fig. 31) across different categories of animals in the smallholder dairy herd in Tanzania was 9.96%. These comprised: bulls (5.89%), castrated adult males (12.49%), cows (16.96%), female calves (5.85%), heifers (10.36%), immature males (7.01%) and male calves (11.19%). Similar to Kenya, year round sales and gift-outs in Tanzania, were also staggered, but occurred mainly during the rainfall season months from February to May and during the dry season (low rainfall) months from July to September.

Results from this study showed that a sizeable proportion of year round purchases (Fig. 26 and 27) for the smallholder dairy herd within high and low altitude areas in both Kenya and Tanzania were mainly cows, heifers, female calves and male calves. However, a sizeable proportion of year round sales and gift-outs (Fig. 30 and 31) from the smallholder dairy herd within high and low altitude areas in Kenya and Tanzania were mainly cows, heifers, female calves, male calves, bulls, immature males and castrated adult males. Therefore, in both countries, year round purchases and gift-ins were mainly targeted at investment in cow replacement and strengthening the productive and reproductive herd, while year round voluntary culling through sales and gift-outs were mainly for meeting specific family obligations/needs.

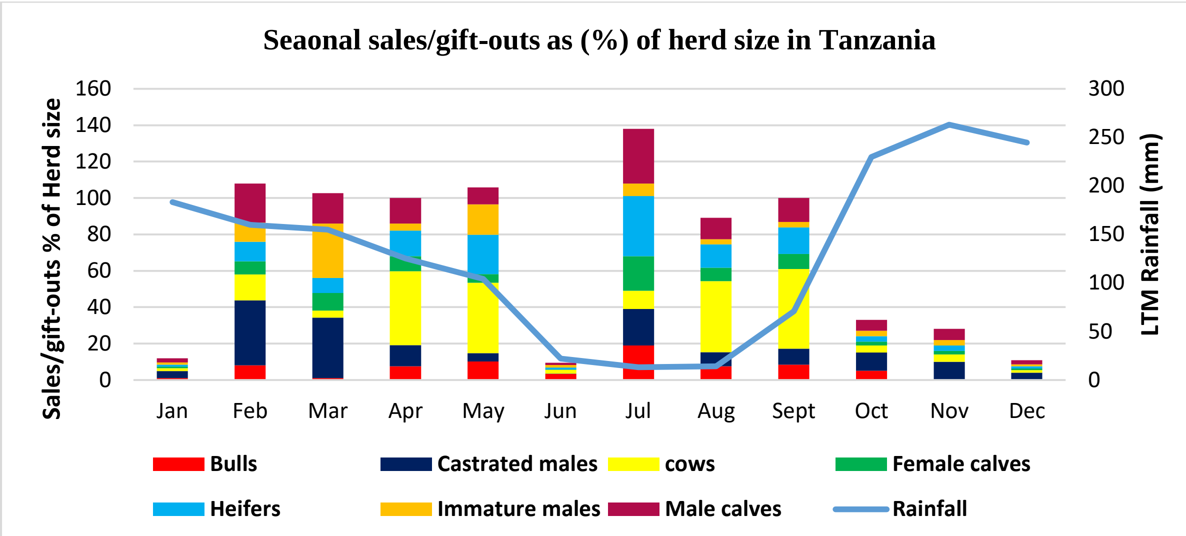


Figure 31: Year round seasonal changes in sales/gift-outs as (%) of herd size with long-term (LTM) monthly rainfall in Tanzania

Farmer-led investment decisions on dairy cow replacement in Kenya and Tanzania

Multinomial logistic regression results in Table 21, showed that agro-ecological zone as a factor had statistical significant ($P < 0.05$) relationship with the dairy cow replacement investment decisions to: increase herd size, $X^2(3)=36.418$, $P=0.001<0.05$ in Tanzania lowlands; decrease herd size, $X^2(3)=49.938$, $P=0.003<0.05$ in Tanzania Lowlands and $X^2(3)=43\text{-}615$, $P=0.006<0.05$ in Tanzania highlands; keep herd size stable, $X^2(1)=10.317$, $P=0.016<0.05$ in Tanzania lowlands; increase herd surplus $X^2(3)=45.706$, $P=0.00<0.05$ in Tanzania lowlands; and keep herd surplus stable, $X^2(3)=17.201$, $P=0.009<0.05$ in Tanzania lowlands.

Table 21: Environment effects on farmer-led cow replacement investment decisions within high and low altitude areas in Kenya and Tanzania

Decision	Effects	DF	Model	Chi-Square	P-Value
Increase herd size	Tanzania lowlands	3	13.627***(4.60-40.41)	36.418	0.001
Decrease herd size	Tanzania lowlands	3	10.683**(4.22-27.02)	49.938	0.003
	Tanzania highlands	3	8.553**(3.31-22.10)	43.615	0.006
Keep herd size stable	Tanzania lowlands	3	2.353**(1.29-4.29)	10.317	0.016
	Extensive system	2	1.853*(1.16-3.05)	6.077	0.048
Increase herd surplus	Tanzania lowlands	3	14.925***(5.02-44.38)	45.706	0.000
	Extensive system	2	2.134*(1.201-3.793)	8.082	0.018
	Country-Kenya	1	0.541*(0.328-0.891)	5.935	0.015
Decrease herd surplus	Extensive system	2	3.363*(1.073-10.539)	9.832	0.020
Keep herd surplus stable	Tanzania lowlands	3	0.546**(0.298-0.999)	17.201	0.009
	Extensive system	2	2.585**(1.579-4.233)	14.450	0.005
Keep herd size stable	Holstein-Friesian	4	18.457**(7.66-44.48)	96.996	0.001
Keep herd surplus stable	Holstein-Friesian	4	13.661**(6.04-30.89)	92.980	0.002

Reference category: 2 (No); Level of significance test: *P < 0.05; **P < 0.01; ***P < 0.001; 95% confidence interval in parentheses

Therefore, smallholder dairy farmers from lowlands mainly, but also highlands agro-ecological zones of Tanzania were more likely than those from highlands and lowlands agro-ecological zones of Kenya to prefer dairy cow investment decisions to increase herd size, decrease herd size, keep herd size stable, increase herd surplus and keep herd surplus stable. The production system as a factor had statistical significant relationship with the dairy cow replacement investment decision to keep herd size stable, $X^2(2) = 6.077$, $P = 0.048 < 0.05$ in extensive system; increase herd surplus $X^2(2) = 8.082$, $P = 0.018 < 0.05$ in extensive system; decrease herd surplus $X^2(3) = 9.832$, $P = 0.020 < 0.05$ in extensive system; and keep the herd surplus stable $X^2(2) = 14.450$, $P = 0.001 < 0.05$ in extensive system.

Therefore, smallholder dairy farmers who reared their dairy cows under extensive production systems were more likely than those from other dairy production systems to prefer the dairy cow investment decisions to keep herd size stable, increase herd surplus, decrease herd surplus and keep their herd surplus stable.

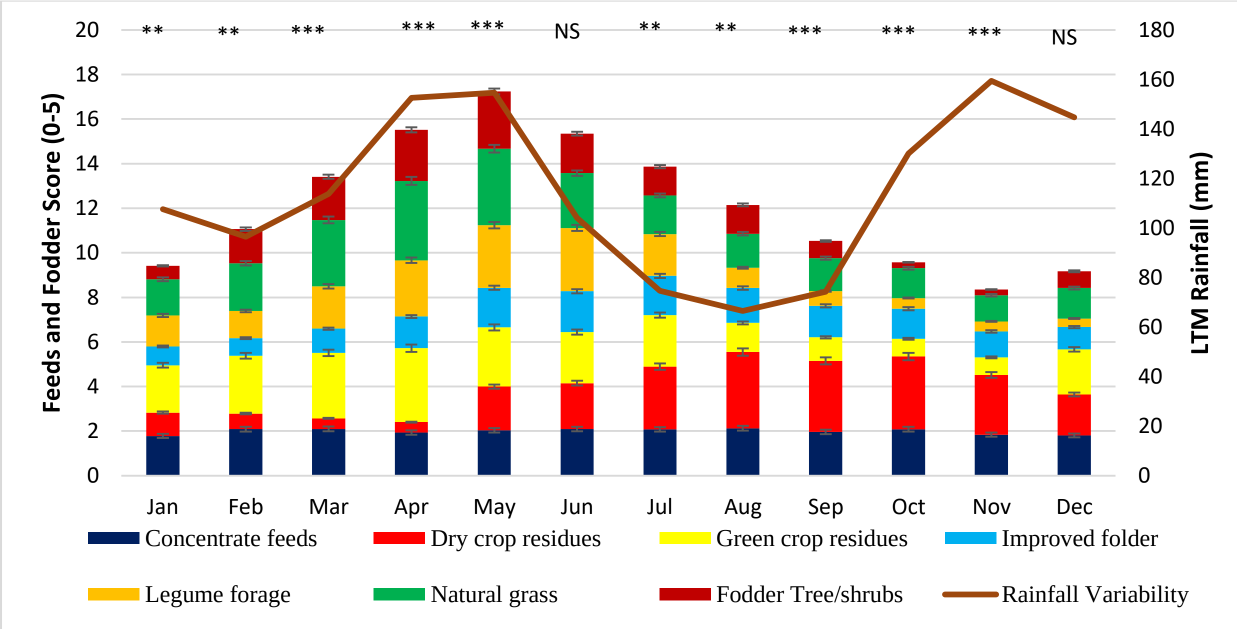
Country as a factor had statistical significant relationship with the dairy cow replacement investment decision to increase herd surplus $X^2(1) = 5.935$, $P = 0.015 < 0.05$ in Kenya. Hence, smallholder dairy farmers in Kenya were more likely to prefer the cow replacement investment decision to increase herd surplus, compared to those in Tanzania.

Breed as a factor had statistical significant relationship with the dairy cow replacement investment decision to keep herd size stable $X^2(4) = 96.998$ $P = 0.001 < 0.05$ in Holstein-Friesian and keep the herd surplus stable $X^2(4) = 92.980$, $P = 0.002 < 0.05$ in Holstein-Friesian. Hence, smallholder dairy farmers in Kenya and Tanzania, who had the Holstein-Friesian breed were more likely to prefer the cow replacement investment decision to keep both herd size and herd surplus stable compared to those with the other breeds.

4.1.2 Current pattern of year-round seasonality driven changes in feed and fodder sources and usage

(i) Variation in overall feeds and fodder availability and usage in Kenya and Tanzania

Results (Table 22) showed that the agro-ecological zone had no significant influence ($P > 0.05$) on year-round feeds and fodder availability and utilization in Kenya and Tanzania. However, country, feeds and fodder type and their interaction had significant influence ($P < 0.05$) on feeds and fodder availability and utilization (Table 22). Overall, with exception of concentrates feeding, the other feeds and fodder resources varied greatly by country and type throughout the year based on rainfall variability (Fig. 32). Feeds and fodder availability and utilization was, however, not significant ($P \geq 0.05$) in the two countries for the months of June and December (Fig. 32). However, the mean difference (Fig. 32) significantly ($P \leq 0.05$) showed that both Kenya and Tanzania had more feeds and fodder available and utilized from the months of March to August.



NS=Not Significant (P ≥ 0.05); *** Significance level (P ≤ 0.001); ** Significance level (P ≤ 0.01)

Figure 32: Variation in overall year round feeds and fodder sources and usage with long-term mean (LTM) monthly rainfall in Kenya and Tanzania

Table 22: Influence of country, agro-ecological zone, feed and fodder type and their interaction on year-round feeds and fodder availability and utilization score (scale 0-5) within highlands and lowlands areas in Kenya and Tanzania

Months	AEZ			Country			Feed and Fodder			Country*Feed and Fodder		
	MS	F val	Sig.	MS	F val	Sig.	MS	F val	Sig.	MS	F val	Sig.
January	0.009	0.010	0.919	1.917	9.272	0.005	2.348	11.358	0.000	5.569	26.942	0.000
February	0.010	0.009	0.923	18.948	100.389	0.000	4.185	22.174	0.000	7.321	38.789	0.000
March	0.000	0.000	0.998	25.795	164.497	0.000	6.643	42.360	0.000	8.855	56.471	0.000
April	0.028	0.019	0.892	19.917	114.788	0.000	9.184	52.932	0.000	10.814	62.323	0.000
May	0.007	0.004	0.949	10.513	49.190	0.000	2.659	12.441	0.000	11.767	55.060	0.000
June	0.000	0.000	0.992	0.398	1.775	0.194	1.102	4.917	0.002	11.937	53.258	0.000
July	0.002	0.001	0.970	1.485	8.130	0.008	1.867	10.225	0.000	10.691	58.537	0.000
August	0.016	0.012	0.915	10.756	73.616	0.000	5.508	37.693	0.000	9.747	66.707	0.000
September	0.016	0.015	0.904	8.170	58.935	0.000	5.948	42.908	0.000	7.827	56.466	0.000
October	0.003	0.002	0.963	3.042	16.351	0.000	8.564	46.035	0.000	9.662	51.939	0.000
November	0.001	0.001	0.973	2.844	21.036	0.000	5.598	41.418	0.000	7.090	52.450	0.000
December	0.000	0.001	0.980	0.408	2.510	0.124	3.080	18.958	0.000	3.667	22.566	0.000

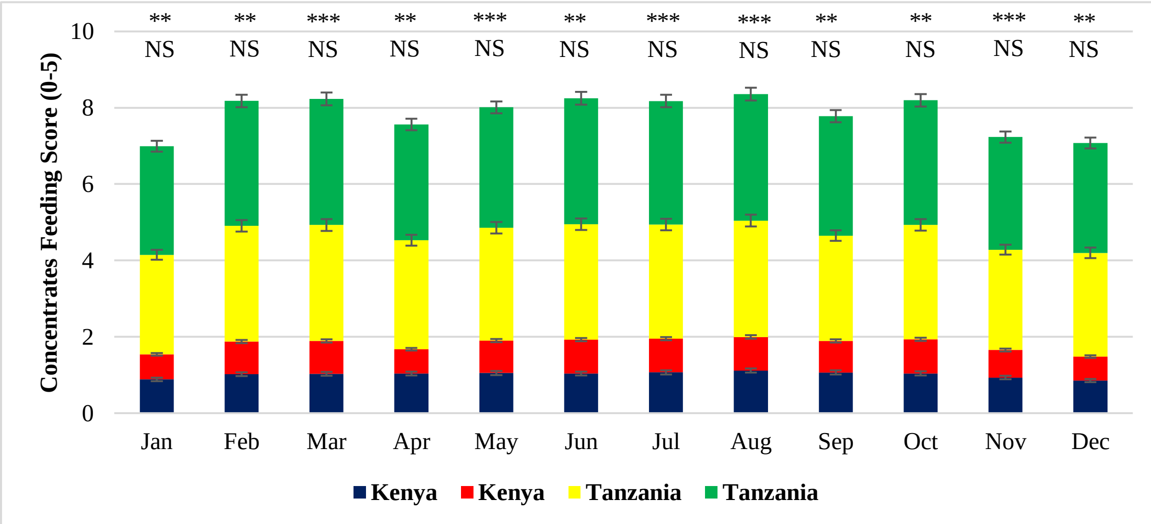
MS-Mean Squares; F val-F value (T-Test); Sig. Significance level ($P \leq 0.05$)

Table 23: Least square means for year-round feeds and fodder availability and utilization score (scale 0-5) within highlands and lowlands areas in Kenya and Tanzania

Feed and Fodder	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Concentrate feeds	1.78^{de}	2.09^{cd}	2.10^{c}	1.93^{bc}	2.03^{abc}	2.09^{ab}	2.08^{bc}	2.12^{c}	1.97^{c}	2.08^{c}	1.84^{d}	1.81^{de}
Dry crop residues	1.05^{abc}	0.70^{a}	0.48^{a}	0.47^{a}	1.96^{ab}	2.06^{ab}	2.82^{d}	3.42^{d}	3.18^{d}	3.26^{d}	2.68^{e}	1.84^{de}
Green crop residues	2.12^{e}	2.60^{d}	2.94^{d}	3.32^{e}	2.65^{cd}	2.29^{abc}	2.30^{cd}	1.31^{ab}	1.06^{ab}	0.80^{ab}	0.79^{bc}	2.03^{e}
Improved folder	0.84^{ab}	0.78^{a}	1.08^{b}	1.42b	1.78^{a}	1.83^{a}	1.77^{ab}	1.56^{b}	1.41^{b}	1.35^{b}	1.16^{c}	1.00^{bc}
Legume forage	1.40^{dcd}	1.22^{ab}	1.90^{c}	2.52^{d}	2.81^{d}	2.84^{c}	1.88^{bc}	0.91^{a}	0.67^{a}	0.48^{a}	0.46^{ab}	0.39^{a}
Natural grass	1.62^{cde}	2.14^{cd}	2.98^{d}	3.56^{e}	3.42^{e}	2.46^{bc}	1.73^{ab}	1.53^{b}	1.48^{b}	1.34^{b}	1.17^{c}	1.37^{cd}
Fodder Trees/shrubs	0.61^{a}	1.53^{bc}	1.94^{c}	2.29^{cd}	2.57^{bcd}	1.77^{a}	1.30^{a}	1.29^{ab}	0.77^{a}	0.27^{a}	0.26^{a}	0.75^{ab}
SEM	0.33	0.36	0.39	0.43	0.45	0.46	0.43	0.41	0.37	0.41	0.35	0.27

SEM-Standard Error of Mean; ^{abcde}-Means with different superscript letters were significantly different ($P \leq 0.05$)

(ii) Concentrate feeding (home compounded ration)

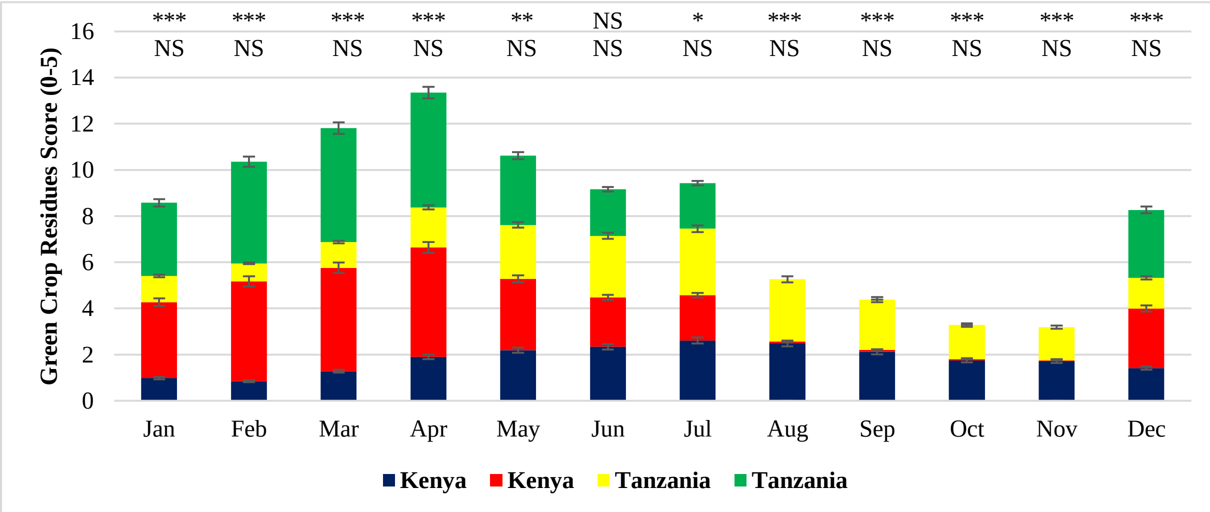


*NS=Not Significant (P ≥ 0.05); *** Significance level (P ≤ 0.001); ** Significance level (P ≤ 0.01)*

Figure 33: Seasonal changes in year-round availability and utilization of concentrates feeding within highlands and lowlands in Kenya and Tanzania

Results (Fig. 33) showed that country ($P < 0.01$), but not agro-ecology ($P > 0.05$), had influence on year-round availability and utilization of concentrate feeding (home compounded ration) in Kenya and Tanzania. The common locally available concentrates consisted of commercially mixed ration/dairy meal, cereal bran and grains, molasses, agro-industrial crop by products and home compounded rations. The mean difference (Table 23) between the two countries in year-round availability and utilization of concentrates feeds was significant ($P \leq 0.05$). Hence, more concentrates feeds were available and utilized in Tanzania compared to Kenya (Fig. 33). Year-round availability and utilization of concentrates feeds, of whichever type as listed above, for supplementary feeding was slightly higher in Tanzania, but utilization trend within high and low altitude areas in both countries was similar. Therefore, smallholder dairy farmers within the two countries gave uniform amounts of concentrates for supplementary feeding (i.e. 1.00 – 5.00 kg per cow/day) throughout the year, regardless of the season.

(iii) Green crop residues/cropping by products usage



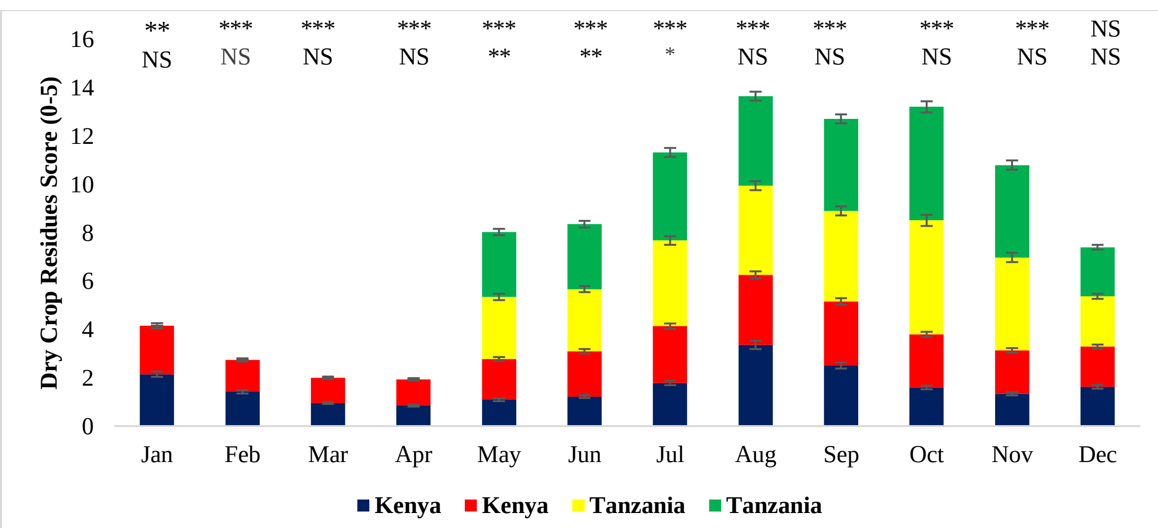
*NS=Not Significant (P ≥ 0.05); *** Significance level (P ≤ 0.001); ** Significance level (P ≤ 0.01); * Significance level (P ≤ 0.05)*

Figure 34: Seasonal changes in year-round availability and utilization of green crop residues in highlands and lowlands in Kenya and Tanzania

Results (Fig. 34) showed that country ($P < 0.05$) had significant influence on year-round availability and utilization of green crop residues Kenya and Tanzania, except during the month of June ($P > 0.05$). Agro-ecology had no significant influence ($P > 0.05$) on availability and utilization of green crop residues (Fig. 34). The green crop residues, which were the cropping/farming by products consisted of cereal crops thinning's, i.e. maize, sorghum, etc.; cut and carry natural grass/weeds, sugarcane tops, banana pseudo stems, kales (*Brassica oleracea*) and cabbages waste, left over or waste from assorted vegetables (home use). The mean difference (Table 23) in availability and utilization of green crop residues between the two countries was significant ($P \leq 0.05$) throughout the year, except during the month of June (Fig. 34). There were more green crop residues available and utilized in Tanzania from the months of December to May (Fig. 34), compared to Kenya. This period in Tanzania coincided with the long rains and cropping period. However, much green crop residues were available and utilized in Kenya from the months of July to November (Fig. 34), a period that coincided with harvesting and short rains season. Hence, availability and utilization of green crop residues was closely related to the cropping season.

(iv) Dry crop residues/farming waste/by products usage

Results (Fig. 35) showed that country ($P < 0.05$) had significant influence on year-round availability and utilization of dry crop residues Kenya and Tanzania, except during the month of December ($P > 0.05$). Agro-ecology had no significant influence ($P > 0.05$) on availability and utilization of dry crop residues (Fig. 35), except during the months of May to July ($P < 0.05$). The dry crop residues, which were the farming waste/by products, consisted of cereal crops residues i.e. maize stover, sorghum/millet stover, rice straw, wheat straw; legume crops residues i.e. beans and pigeon pea haulms, groundnuts hulls, sunflower husks. The mean difference (Table 23) in availability and utilization of dry crop residues was significant ($P \leq 0.05$) throughout the year between the two countries, except during the month of December (Fig. 35). Much drier crop residues were available and utilized in the highlands and lowlands agro-ecological zone of Tanzania as opposed to Kenya (Fig. 34). However, much drier crop residues were available and utilized in Kenya from the months of January to April compared to Tanzania. Similarly, much drier crop residues were available and utilized in Tanzania from the months of May to November compared to Kenya. Therefore, though dry crop residues were year-round, abundant availability and utilization was after the end of the cropping season after harvesting within the two countries and also during the dry season period (Fig. 35).

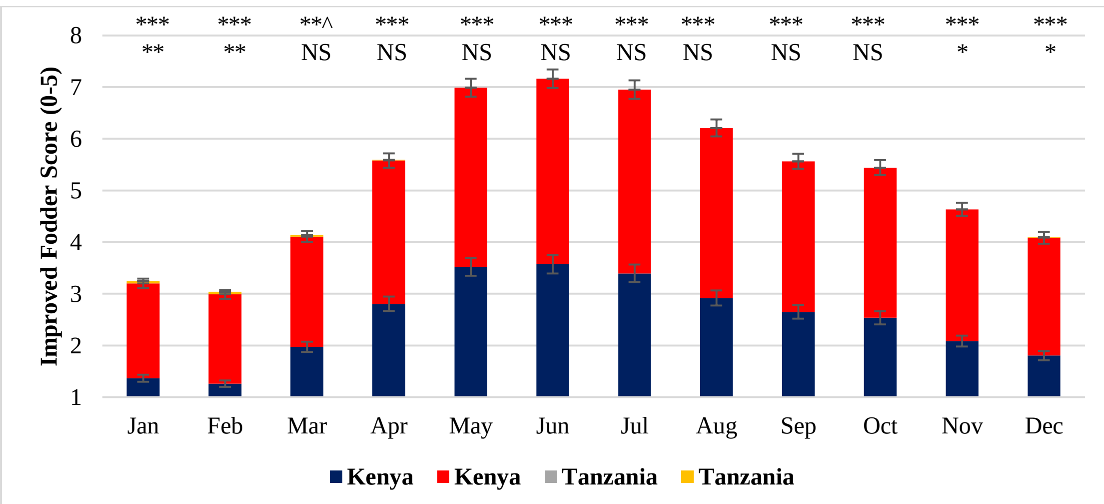


*NS=Not Significant ($P \geq 0.05$); *** Significance level ($P \leq 0.001$); ** Significance level ($P \leq 0.01$); * Significance level ($P \leq 0.05$)*

Figure 35: Seasonal changes in year-round availability and utilization of dry crop residues in highlands and lowlands in Kenya and Tanzania

(v) Improved/planted fodder usage

Results (Fig. 36) showed that country (*P < 0.05*) had significant influence on year-round availability and utilization of green crop residues Kenya and Tanzania. Agro-ecology had no significant influence (*P > 0.05*) on availability and utilization of green crop residues (Fig. 34), except during the months of November to February (*P < 0.05*). Notable improved/planted fodder types encountered within the two countries consisted of Napier grass (*Pennisetum purpureum* Schumach), Rhodes grass (*Chloris gayana*), Giant Setaria grass (*Setaria sphacelata*), Bracharia, spp (*Bracharia ruziziensis*–Mulato) Congo signal (*Bracharia brizantha*), Pannicum *spp* (*Pannucum maximum*), Guatemala grass (*Tripsacum laxum*), Stylo (*Stylosanthes guiyanensis*), Italian rye grass (*Lolium multiflorum*), *Hyperrhenia rupa*, Bermuda grass (*Cynodon dactylon*), sweet potato vines (*Ipomea batatas*), Sunflower (*Helianthus anuus*), Sorghum (*Sorghum bicolor*), Oats *(Avena sativa*), Maize (*Zea mays*) and fodder beat (*Beta vulgaris*), among others.



*NS=Not Significant (P ≥ 0.05); *** Significance level (P ≤ 0.001); ** Significance level (P ≤ 0.01); * Significance level (P ≤ 0.05)*

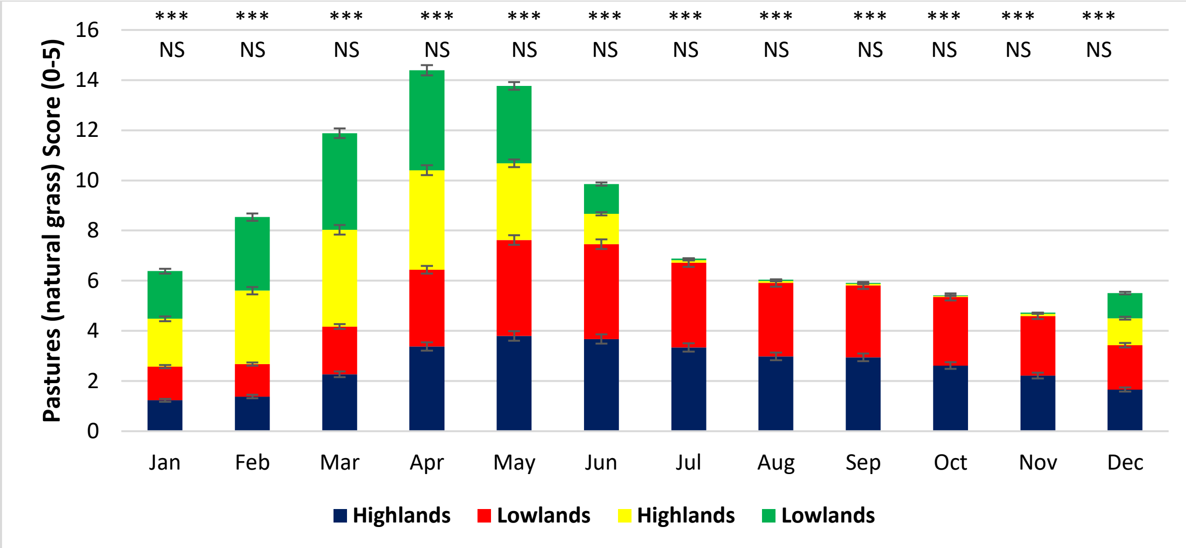
Figure 36: Seasonal changes in year-round availability and utilization of improved/planted fodder within highlands and lowlands in Kenya and Tanzania

The mean difference (Table 23) was significant *(P ≤ 0.05)* throughout the year on availability and utilization of improved/planted fodder in the two countries. However, much improved fodder was available and utilized in the highlands and lowlands areas of Kenya, as opposed to Tanzania (Fig. 36), where it was very minimal or non-existent. The mean difference in availability and utilization of improved fodder between the different agro-ecological zones of both countries was significant *(P ≤ 0.05)* the two countries from the months of December to February (Fig. 36). During the months of April to May, more improved fodder was available and utilized in Kenya highlands compared to Kenya lowlands (Fig. 36). While, during the months of June to November, more improved fodder was available and utilized in Kenya lowlands compared to Kenya highlands. There was higher ($P < 0.05$) year-round availability and utilization of improved fodder during the rainfall/cropping season in Kenya highlands and lowlands compared to Tanzania highlands and lowlands.

(vi) Pastures (natural grass) usage

Results (Fig. 37) showed that country ($P \leq 0.001$), but not agro-ecology ($P > 0.05$) on availability and utilization of pastures and natural grasses in Kenya and Tanzania. Some of the naturalized pastures encountered in the two countries consisted of Kikuyu grass (*Pennisetum clandestinum*), *Eragrostis superba*, Wire/themeda grass (*Themeda triandra*), *Cynodon dactylon*, Couch grass (*Cenchrus cilliaris*), coloured guinea (Panicum coloratum), star grass (Cynodon plectostachyus), molasses grass (Melinis minutiflora), Columbus grass (*Sorghum almum*), edible cana (*Cana edulis*), *Sporobolus fimbriatus, Digitaria milanjiana, Digitaria abyssinica, Eragrostis cilianensis, Eustachyus paspaloides, Aristida adscensionis, Aristida kenyansis, Bothriochloa insculpta and Heteropogon contortus.* The mean difference (Table 23) was significant ($P \leq 0.05$) for year-round availability and utilization of natural grass in both Kenya and Tanzania. Rainfall seasonality was a crucial factor in determining the availability and utilization of pastures in both the highlands and lowlands agro-ecologies within the two countries. There was more availability and utilization of natural pastures in highlands and lowlands areas in Tanzania from the months of January to April (Fig. 37), a period that coincided with the long rains season (Fig. 5).

The months of July to November were the dry season (low rainfall) period in Tanzania (Fig. 5), hence the absence of pastures and natural grasses. However, there were communal grazing areas in both the highlands and lowlands of Tanzania. The scenario was different in Kenya (Fig. 37), where despite absence of communal grazing areas in both the highlands and lowlands, natural pastures, though available and utilized year-round, were more during the long and short rainfall season months from March to November compared to dry season (low rainfall) months from December to February (Fig. 5).



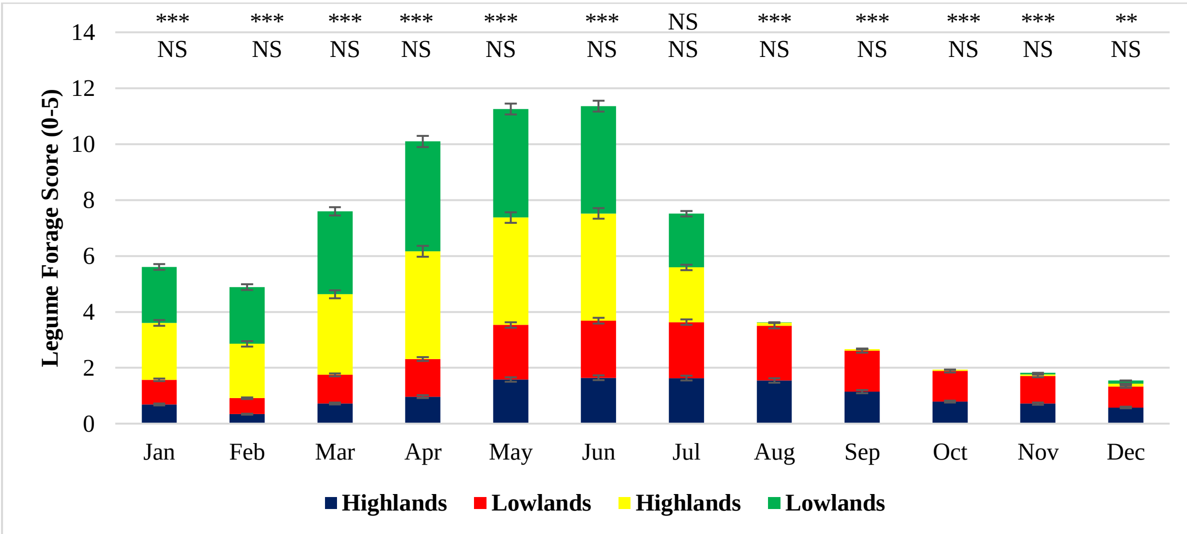
*NS=Not Significant ($P \geq 0.05$); *** Significance level ($P \leq 0.001$)*

Figure 37: Seasonal changes in year-round availability and utilization of natural pastures within highlands and lowlands in Kenya and Tanzania

(vii) Legume forage usage

Results (Fig. 38) showed that country ($P < 0.05$) had significant influence on year-round availability and utilization of legume forage in Kenya and Tanzania, except during the month of July ($P > 0.05$). Agro-ecology had no significant influence ($P > 0.05$) on availability and utilization of legume forage. Legume forages encountered within the two countries consisted of *Macroptilium atropurpureum* (cv. Siratro), velvet or mucuna beans (*Stizolobium spp*.), Vetch (*Vicia vilosa*), Lablab (*Lablab purpureus*), Lucerne (*Medicago sativa*), White sweet clover (*Melilotus alba*), Desmodium (*Desmodium intortum/uncinatum*), Pigeon pea (*Cajanus cajan*), Soybean (*Glycine max*), beans (*Phaseola vulgaris*), Lupins (*Lupinus angustifolius*) and groundnuts (*Arachis hypogaea*). Mean difference (Table 23) was significant ($P \leq 0.05$) throughout the year on availability and utilization of legume forage in Kenya and Tanzania, except during the month of July. There was more availability and utilization of legume forage in Tanzania from the months of January to June, compared to Kenya (Fig. 38). Similarly, there was more availability and utilization of forage legume in Kenya from the months of August to December, compared to Tanzania (Fig. 38).

Forage legumes in the two countries provided a feed reserve in the dry season, when the quantity and quality of the natural pasture was at minimum. The introduction of forage legumes into the crop rotation served also to break crop disease cycles, provide nitrogen through atmospheric nitrogen fixation, raise soil organic matter content and reduce soil erosion by providing more effective ground cover. Therefore, availability and utilization of forage legumes in the two countries followed rainfall variability, and hence the cropping season (Fig. 39).

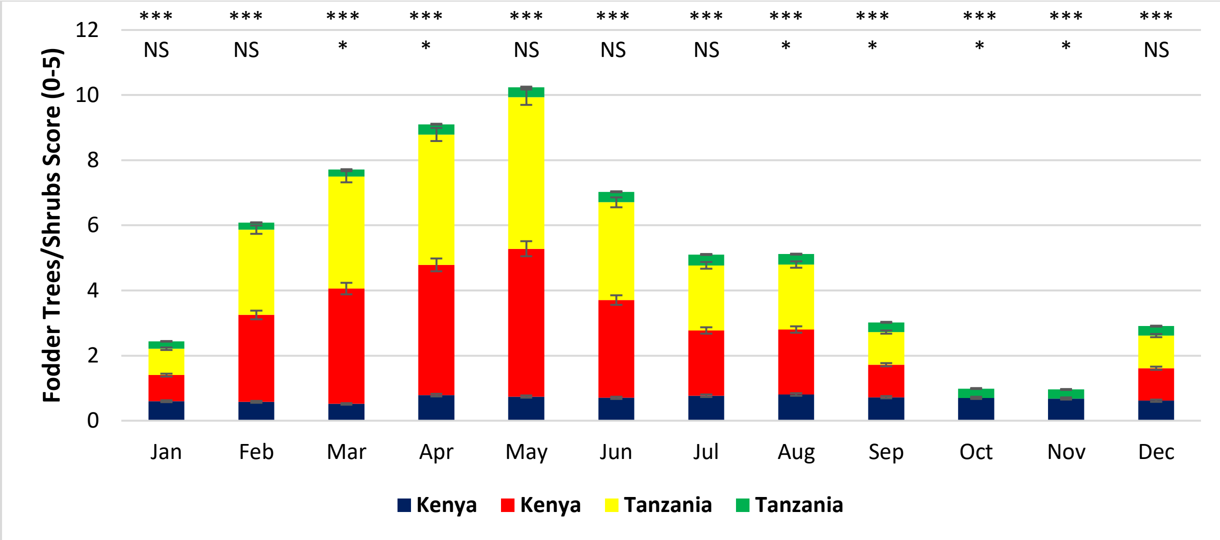


*NS=Not Significant; *** Significance level (P≤0.001); ** Significance level (P≤0.01)*

Figure 38: Seasonal changes in year-round availability and utilization of legume forage within highlands and lowlands in Kenya and Tanzania

(viii) Fodder trees and shrubs usage

Results (Fig. 39) showed that country ($P < 0.05$) had significant influence on year-round availability and utilization of fodder trees and shrubs in Kenya and Tanzania. Agro-ecology had significant influence ($P < 0.05$) on availability and utilization of legume forage during the months of March to April and August to November. While, agro-ecology had no significant influence ($P > 0.05$) on availability and utilization of legume forage during the months of December to February and May to July. Some of the fodder trees and shrubs encountered within the two countries consisted of Calliandra (*Calliandra carlorthysus)*, Gliricidia (*Gliricidia sepium*), Sesbania (*Sesbania sesban*), Leucaena (*Leucaena leuococephala), Gravillea (Gravillea robusta)*, Mulberry (*Morus alba*), Tegaste (*Chamacytisus prolifera*), Trichandra (*Leucaena trichandra*), Eucalyptus trees (*Eucalyptus spp*), European nettle tree (*Celtus australis*), Fig tree (*Ficus carica*) and Accacia spp (*Acacia anguisstissima*).



*NS=Not Significant; *** Significance level (P≤0.001); * Significance level (P≤0.05)*

Figure 39: Seasonal changes in year-round availability and utilization of fodder trees/shrubs within highlands and lowlands in Kenya and Tanzania

The mean difference (Table 23) was significant *($P \leq 0.05$)* throughout the year for availability and utilization of fodder trees and shrubs in both Kenya and Tanzania. There was high availability and utilization of fodder trees and shrubs in Tanzania from the months of December to September in comparison to Kenya (Fig. 39). However, there was high availability and utilization of fodder trees and shrubs between the months of October and November in Kenya compared to Tanzania (Fig. 39). The mean difference (Fig. 39) was also significant *($P \leq 0.05$)* for availability and utilization of fodder trees and shrubs in both highlands and lowlands in Kenya and Tanzania. In both countries more fodder trees and shrubs were available and utilized throughout the year in highlands compared to the lowlands. Fodder trees and shrubs have great potential as a source of protein and mineral nutrients, to supplement diets of dairy cattle normally fed nutritionally unbalanced and low digestibility roughage such as natural pasture, stubble and untreated crop residues. Across the two countries (Fig. 39), fodder trees/shrubs were available and utilized mostly during the rainfall and cropping season from February to August.

(ix) Association amongst different feeds and fodder sources and usage in Eastern Africa

Results (Table 24) showed that there was a highly significant *($P \leq 0.001$)* inverse relationship (R^2 = -0.661) between dry crop residues with green crop residues across the high and low altitude areas of Kenya and Tanzania. There was also a highly significant *($P \leq 0.001$)*, but inverse (negative) relationship (R^2 = -0.783) between improved (planted) fodder with concentrate feed. The relationship between pasture (natural grass) with concentrate feed was highly significant *($P \leq 0.001$)*, moderate, but also inverse (R^2 = -0.344). While, the relationship between pasture with dry crop residues was also highly significant *($P \leq 0.001$)*, but inverse (R^2 = -0.676). However, the relationship between pasture with green crop residues and improved (planted) fodder was highly significant *($P \leq 0.001$)*, and positive (R^2 = 0.725 and R^2 = 0.531, respectively). The relationship between legume forage with green crop residues and pasture was highly significant *($P \leq 0.001$)*, moderate and positive (R^2 = 0.507 and R^2 = 0.388, respectively). The relationship between fodder trees/shrubs with concentrate feed, green crop residues, pasture and legume forage was highly significant *($P \leq 0.001$)*, strong and positive (R^2 = 0.560, R^2 = 0.597, R^2 = 0.255 and R^2 = 0.539). However, the relationship between fodder trees/shrubs with dry crop residues and improved (planted) fodder was very highly significant *($P \leq 0.001$)*, moderate, but inverse (R^2 = 0.245 and R^2 = 0.541, respectively).

Table 24: Correlation (Coefficient and significance) amongst feed and fodder sources and usage within high and low altitude areas in Kenya and Tanzania

Feed and Fodder Type	Concentrate feed	Green residues	Dry residues	Improved fodder	Pasture	Legume forage
Green crop residues	0.099					
Dry crop residues	0.111	-0.661***				
Improved fodder	-0.783***	-0.065	-0.163			
Pasture	-0.344***	0.725***	-0.676***	0.531***		
Legume forage	0.082	0.507***	-0.139	-0.030	0.388***	
Fodder trees/shrubs	0.560***	0.597***	-0.245**	-0.541***	0.255**	0.539***

Correlation Coefficients (R^2) and level of significance test **=P<0.01; ***=P<0.001

4.1.3 Evaluation of promising "best-bet" interventions for overcoming seasonality driven milk fluctuations

(i) Effect of urea and urea plus molasses pre-treatment and incubation period on nutrient and chemical composition of dry crop residues

Results (Table 25) showed the influence of type of crop residue, agro-ecology, incubation additive, incubation period and interaction between crop residue type and incubation additive on nutrient and chemical composition of pre-treated crop residues. The type of crop residue had significant influence ($P < 0.05$) on nutrient and chemical composition of treated crop residues (Table 25). However, agro-ecology (highlands and lowlands), had a significant influence ($P < 0.05$) on crude fibre (%) and not the other nutrient and chemical composition parameters ($P > 0.05$). This was because crop residues from lowlands region were more likely to have more crude fibre than those from the highlands, due to environment effects. The incubation additive had a significant influence (*$P < 0.05$*) on dry matter digestibility (DMD), dry matter (DM), crude protein (CP) and crude fibre (CF). The incubation period had no significant influence ($P \geq 0.05$) on nutrient and chemical composition of dry crop residues pre-treated with molasses, urea and urea plus molasses additives. However, the interaction between the crop residue type and incubation additive had a significant influence ($P \leq 0.05$) on DMD, CP and CF (Table 25).

Table 25: Influence of crop residue type, agro-ecology, incubation additive, incubation period and interaction between crop residue type and additive on nutrient and chemical composition of crop residues from high and low altitude areas in Tanzania

Nutrient Composition	Crop Residue Type		Agro-Ecology		Incubation Additive		Incubation Period		Residue*Additive	
	MS	**P-Value**	**MS**	**P-Value**	**MS**	**P-Value**	**MS**	**P-Value**	**MS**	**P-Value**
Gas_48 hrs	27524.10	0.00	278.31	0.64	2138.66	0.18	761.10	0.54	1423.98	0.32
DMD	981.36	0.00	1.15	0.85	101.45	0.04	26.82	0.45	65.33	0.02
DM	3.28	0.00	0.41	0.49	2.44	0.03	0.39	0.64	1.15	0.19
Ash	164.84	0.00	75.61	0.14	22.84	0.52	63.87	0.17	29.84	0.59
CP	106.76	0.00	1.49	0.52	61.15	0.00	4.30	0.31	15.30	0.00
Fat	72.29	0.01	11.06	0.46	8.78	0.65	34.41	0.19	23.61	0.30
Fibre	176.23	0.00	192.58	0.00	103.95	0.02	51.41	0.15	50.54	0.03
ME	27.96	0.00	0.25	0.66	2.17	0.20	0.88	0.51	1.49	0.33

Gas = Total gas production after 48hr (ml gas/g DM); DMD = Dry matter digestibility (%); DM = dry matter (%); CP = Crude protein (%); Fat = Crude fat (%); Fibre = Crude fibre (%); ME = Metabolizable energy (MJ/Kg DM); MS-Mean Sum of Squares; P-Value = Significance level ($P \leq 0.05$)

Table 26: Least Square Means for nutrient and chemical composition of pre-treated crop residues from high and low altitude areas in Tanzania

Nutrient Composition	Crop Residues						SEM	P value
	Bean haulms	Maize stover	Pigeon pea haulms	Rice straw	Sorghum stover	Sunflower hulls		
Gas_48 hrs	264.02^{cd}	221.81^{b}	276.25^{d}	219.59^{b}	242.85^{bc}	165.86^{a}	9.63	0.004
DMD (%)	53.87^{d}	46.94^{b}	51.61^{bc}	47.22^{b}	53.01^{bc}	33.98^{a}	1.57	0.003
DM (%)	90.70	91.84	92.04	92.18	91.67	91.72	0.24	0.148
Ash (%)	9.92^{ab}	9.45^{ab}	6.22^{a}	16.59^{c}	9.19^{ab}	13.04^{bc}	1.62	0.019
CP (%)	9.39^{c}	7.87^{b}	7.23^{b}	5.49^{a}	11.17^{d}	12.85^{e}	0.52	0.062
Fat (%)	5.37^{a}	5.11^{a}	3.79^{a}	7.63^{ab}	3.66^{a}	8.91^{b}	1.23	0.020
Fibre (%)	36.41^{a}	29.88^{b}	30.10_{b}	28.22^{ab}	25.24^{a}	31.32^{b}	1.42	0.002
ME	9.18^{cd}	7.80^{b}	9.55^{d}	7.76^{b}	8.47^{bc}	6.04^{a}	0.31	0.026

Gas = Total gas production after 48hr (ml gas/g DM); DMD = Dry matter digestibility (%); DM = dry matter (%); CP = Crude protein (%); Fat = Crude fat (%); Fibre = Crude fibre (%); ME = Metabolizable energy (MJ/Kg DM); SEM-Standard Error of Mean; ^{abcde} -Means with different superscript letters were significantly different ($P \leq 0.05$)

Results (Table 26) showed least square means for nutrient and chemical composition of pre-treated crop residues. Total gas production after 48 hours of incubation was higher ($P < 0.05$) in pigeon pea haulms (276.25 SEM = 8.85 mL gas/g DM) and lower ($P < 0.05$) in sunflower hulls/husks (165.86 SEM = 7.69 ml gas/g DM) compared to the other crop residues. Dry matter digestibility (DMD) was higher ($P < 0.05$) in bean haulms (53.87% SEM = 1.60) and lower ($P < 0.05$) in sunflower hulls/husks (33.98% SEM = 1.26) compared to the other crop residues. However, the DM for all the crop residues was similar ($P > 0.05$), ranging between 90.0 – 92.0%. The ash content was higher ($P < 0.05$) in sunflower hulls/husks (13.04% SEM = 1.29) and lower ($P < 0.05$) in pigeon pea haulms (6.22 SEM = 1.48). Similarly, CP content was higher ($P < 0.05$) in sunflower hulls/husks (12.85% SEM = 0.41) and lowest ($P < 0.05$) in rice straw (5.45% SEM = 0.60) in comparison with the other crop residues. Further, crude fat was also higher ($P < 0.05$) in sunflower hulls/husks (8.91% SEM = 0.98) and lower ($P < 0.05$) in sorghum stover (3.66% SEM = 1.27) and pigeon pea haulms (3.79% SEM = 1.13).

Crude fibre was higher ($P < 0.05$) in bean haulms (36.41% SEM = 1.44) and lowest ($P < 0.05$) in sorghum stover (25.24% SEM = 1.46). Metabolizable energy (MJ/Kg DM) was higher ($P < 0.05$) in pigeon pea haulms (9.55% SEM = 0.29) and lower ($P < 0.05$) in sunflower hull/husks (6.04% SEM = 0.25). These findings, generally, showed that sunflower hulls/husks, with lower total gas production, dry matter digestibility and metabolizable energy, had higher ash, crude protein and crude fat contents. On the other hand, pigeon pea haulms, with higher total gas production and metabolizable energy, had lower ash and crude fat content. Results (Table 27) showed the least square means for incubation additive (urea, molasses and urea plus molasses) on nutrient and chemical composition of crop residues. Nutrient composition in terms of DMD was higher ($P < 0.05$) for crop residues pre-treated with urea plus molasses (49.85% SEM = 1.07) and lower ($P < 0.05$) for urea (45.56% SEM = 1.08) compared to molasses (47.90% SEM = 1.20). Crude protein content was also higher ($P < 0.05$) for crop residues pre-treated with urea plus molasses (10.51% SEM = 0.35) and lower ($P < 0.05$) for molasses (7.45% SEM = 0.39) compared to urea (9.05% SEM = 0.35). Crude fibre was higher ($P < 0.05$) for urea pre-treated crop residues (32.44% SEM = 0.97) compared to urea plus molasses (29.51% SEM = 0.96) and molasses (28.64% SEM = 1.08). The incubation additive had no significant influence ($P > 0.05$) on the other nutrient and chemical composition parameters for the crop residues (Table 27).

Table 27: Least Square Means for incubation additive on nutrient and chemical composition of pre-treated crop residues from high and low altitudes in Tanzania

Nutrient Composition	Molasses		Urea		Urea + Molasses	
	Mean	SEM	Mean	SEM	Mean	SEM
Gas_48 hrs	238.83	7.32	221.57	6.59	234.79	6.54
DMD (%)	47.90[a]	1.20	45.56[a]	1.08	49.85[b]	1.07
DM (%)	91.89	0.19	91.44	0.17	91.74	0.17
Ash (%)	10.54	1.23	9.96	1.11	11.72	1.10
CP (%)	7.45[a]	0.39	9.05[b]	0.35	10.51[c]	0.35
Fat (%)	5.06	0.93	6.18	0.84	6.00	0.83
Fibre (%)	28.64[a]	1.08	32.44[b]	0.97	29.51[ab]	0.96
ME	8.35	0.24	7.81	0.21	8.24	0.21

Gas = Total gas production after 48hr (ml gas/g DM); DMD = Dry matter digestibility (%); DM = dry matter (%); CP = Crude protein (%); Fat = Crude fat (%); Fibre = Crude fibre (%); ME = Metabolizable energy (MJ/Kg DM); SEM-Standard Error of Mean; [abcde]-Means with different superscript letters were significantly different ($P \leq 0.05$)

Results (Table 28) showed Pearson's correlation (coefficient of determination and significance) amongst nutrient and chemical composition parameters of pre-treated crop residues. The relationship between DMD and ME with total Gas production after 48 hours was highly significant ($P \leq 0.001$), very strong and positive (R^2 = 0.736 and R^2 = 0.999, respectively). The relationship between ME and DMD was highly significant ($P \leq 0.001$), very strong and positive (R^2 = 0.730). However, the relationship between Ash, CP and Crude Fat with total Gas production after 48 hours was highly significant ($P \leq 0.01$), relatively strong but inverse (R^2 = -0.349, R^2 = -0.292 and R^2 = -0.288, respectively). Similarly, the relationship between CP and Crude Fat with DMD was highly significant ($P \leq 0.001$), relatively strong, but inverse (R^2 = -0.355 and R^2 = -0.342, respectively). The relationship between ME with Ash, CP and Crude Fat was also highly significant ($P \leq 0.01$), relatively strong but inverse (R^2 = -0.345, R^2 = -0.289 and R^2 = -0.252, respectively).

Table 28: Correlation (Coefficient and significance) amongst nutrient and chemical composition of pre-treated crop residues from high and low altitude areas in Tanzania

Item	[1]Gas_48 hrs	DMD	DM	Ash	CP	Fat	Fibre
DMD (%)	0.736***						
DM (%)	-0.144	-0.092					
Ash (%)	-0.349***	-0.173	0.015				
CP (%)	-0.292**	-0.355***	-0.182	-0.071			
Fat (%)	-0.288**	-0.342***	0.017	0.183	0.170		
Fibre (%)	0.014	-0.031	-0.141	-0.009	0.186	0.124	
ME	0.999***	0.730***	-0.144	-0.345***	-0.289**	-0.252**	0.019

[1]Gas = Total gas production after 48hr (ml gas/g DM); DMD = Dry matter digestibility (%); DM = dry matter (%); CP = Crude protein (%); Fat = Crude fat (%); Fibre = Crude fibre (%); ME = Metabolizable energy (MJ/Kg DM); Coefficient of determination (R^2) and level of significance test **=P<0.01; ***=P<0.001

(ii) Comprehensive in vitro analysis of urea and molasses pre-treated Maize stover

4.2.2 Nutrient and chemical composition

Table 29: The effect of urea and urea plus molasses pre-treatment on nutrient and chemical composition of maize stover

Nutrient/chemical composition	Treatments			SEM[1]	*P* value
	Control	Urea	Urea+molasses		
NDF, g/kg DMI	831[a]	827[a]	643[b]	8.6	<0.001
NDS	169[b]	176[b]	357[a]	8.6	<0.001
ADF	744[a]	605[ab]	543[b]	13.4	0.024
Hemicellulose	87.4[b]	222[a]	100[b]	7.5	0.015
ADL	131[a]	64.7[b]	112[ab]	9.3	0.041
TN	7.6[c]	11.8[b]	15.7[a]	0.36	<0.001
EE	85.8	106	95.7	15.8	0.073

NDF, neutral detergent fiber; NDS, neutral detergent soluble; ADF, acid detergent fiber; ADL, acid detergent lignin; TN, total nitrogen; EE, ether extract. Units = g/kg DM, [1]Standard error of means.

Results (Table 29) showed the effect of pre-treatment of maize stover using urea and urea plus molasses on nutrient and chemical composition. Urea and urea plus molasses treatment of maize stover had similar ($P > 0.05$) effect and significantly decreased ($P < 0.05$) NDF content compared with the control. The control and urea treated maize stover had similar effect ($P > 0.05$) on NDS, though urea plus molasses significantly (P<0.05) increased NDS. Pre-treatment of maize stover with urea plus molasses significantly decreased ($P < 0.05$) ADF compared treatment with urea and the control. Hemicellulose content significantly increased ($P < 0.05$)

with urea treatment compared to urea plus molasses treatment and control that had similar ($P > 0.05$) effect. Pre-treatment with urea significantly ($P < 0.05$) ADL compared to urea plus molasses treatment and the control (Table 29). Total nitrogen (TN) was significantly less ($P < 0.05$) in the control, but increased with urea treatment, and further, with urea plus molasses treatment. Effect of treatment was not significant ($P > 0.05$) on ether extracts (Table 29).

Ruminal fermentation characteristics

Results (Table 30) showed the effect of urea and urea plus molasses pre-treatment on the *in-vitro* ruminal fermentation characteristics of maize stover. Pre-treatment with urea plus molasses significantly increased ($P < 0.05$) % DMD, Ammonia (NH_4^+) concentration (mM – micro Mols), and Total volatile fatty acids (VFA, mM). However, treatment with urea and urea plus molasses had no significant ($P > 0.05$) effect on the PH. Urea and urea plus molasses treatment had a significant ($P < 0.05$) effect on molar proportions of individual VFAs with the exception of Valerate ($P > 0.05$). Molar proportion of Acetate significantly ($P < 0.05$) decreased in urea plus molasses treated, but was similar ($P > 0.05$) in the control and urea treated. However, molar proportion of Butyrate significantly ($P < 0.05$) increased in urea plus molasses treated, but was also similar ($P > 0.05$) in the control and urea treated.

Table 30: Effect of urea and urea plus molasses pre-treatment on *in vitro* ruminal fermentation characteristics of maize stover

Ruminal fermentation characteristics	Treatments			SEM[1]	*P* value
	Control	Urea	Urea+molasses		
DMD (%)	35.4^{c}	42.6^{b}	61.2^{a}	0.89	<0.001
NH_4^+(mM)	7.28^{b}	7.10^{b}	10.3^{a}	0.36	0.006
pH	6.61	6.57	6.63	0.07	0.795
Total VFA (mM)	55.6^{c}	63.4^{b}	72.1^{a}	4.31	0.005
Molar proportion of individual VFAs (mol/100mol)					
Acetate	72.2^{a}	71.2^{a}	67.9^{b}	0.52	0.009
Butyrate	3.98^{b}	3.57^{b}	5.17^{a}	0.28	0.036
*Iso*butyrate	0.39^{b}	0.37^{b}	0.51^{a}	0.03	0.054
*Iso*valerate	0.38^{b}	0.40^{b}	0.64^{a}	0.05	0.033
Propionate	22.7^{b}	24.1^{a}	25.4^{a}	0.33	0.011
Valerate	0.36	0.30	0.41	0.03	0.088
Acetate to propionate ratio	3.19^{a}	2.96^{b}	2.68^{c}	0.06	0.008
R_NH_2, mol/100mol VFA	130^{a}	126^{b}	121^{c}	1.00	0.007

[1]DMD, dry matter degradation; VFA, volatile fatty acids; R_NH_2, estimated net H_2 production relative to the amount of total VFA produced. [1]Standard error of means

Molar proportions of Isobutyrate and Isovalerate significantly (*P < 0.05*) increased in urea plus molasses treated, but was similar (*P > 0.05*) in the control and urea treated. Similarly, molar proportion of Propionate significantly increased in urea plus molasses treated compared to the control and urea treated (P > 0.05). The ratio of Acetate to Propionate was significantly higher (*P < 0.05*) in the control, and lower in urea plus molasses treated compared to urea treated. Similarly, estimated net hydrogen produced relative to the amount of total VFAs produced (R_NH_2) was significantly higher (*P < 0.05*) in the control and lower in urea plus molasses treated compared to urea treated (Table 30).

Gas production

Table: The effect of urea and urea plus molasses pre-treatment on *in vitro* gas production in maize stover

In vitro gas production	Treatments			SEM[1]	*P* value
	Control	Urea	Urea+molasses		
Total gas, mL/g DM	122[c]	144[b]	166[a]	4.40	<0.001
Total gas, mL/g DDM	344[a]	341[a]	272[b]	14.70	0.041
k_{GP}, /h	0.013	0.015	0.017	0.006	0.800
72h CH_4,mL/g DDM	42.0[a]	42.9[a]	31.7[b]	2.25	0.044
k_{CH4} /h	0.046	0.050	0.056	0.014	0.790
72h H_2, mL/g DDM	0.08	0.09	0.06	0.013	0.273
k_{H2} /h	0.101	0.109	0.118	0.043	0.930

[1]k_{GP}, the fractional rate of total gas production; $k_{CH4,}$ the fractional rate of CH_4 production; k_{H2}, the fractional rate of H_2 production.[1]Standard error of means, DDM, digestible dry matter

Results (Table 31) showed tha effect of urea and urea plus molasses pre-treatment on in vitro gas production in maize stover. Total gas produced per dry matter (mL/g DM) was significantly higher ($P < 0.05$) in urea plus molasses treated, but lower in the control compared to urea treated. However, total gas produced per digestible dry matter (mL/g DDM) was significantly higher ($P < 0.05$) in the control and urea treated compared to urea plus molasses treated. As shown in Fig. 40, there was a steady increase in total gas production in maize stover up to 72 hours of *in-vitro* incubation with urea and urea plus molasses. Methane gas produced per digestible dry matter after 72 hours of *in vitro* incubation (72h CH_4 mL/g DDM) was significantly higher ($P < 0.05$) in the control and urea treated compared to urea plus molasses treated. Urea and urea plus molasses pre-treatment had no significant influence ($P > 0.05$) on the fractional rate of total gas production per hour (k_{GP}/h), the fractional rate of methane gas production (K_{CH4}/h), Hydrogen gas produced per digestible dry matter after 72 hours of *in vitro* incubation (72h H_2 mL/g DDM) and the fractional rate of hydrogen gas production per hour (k_{H2}/h).

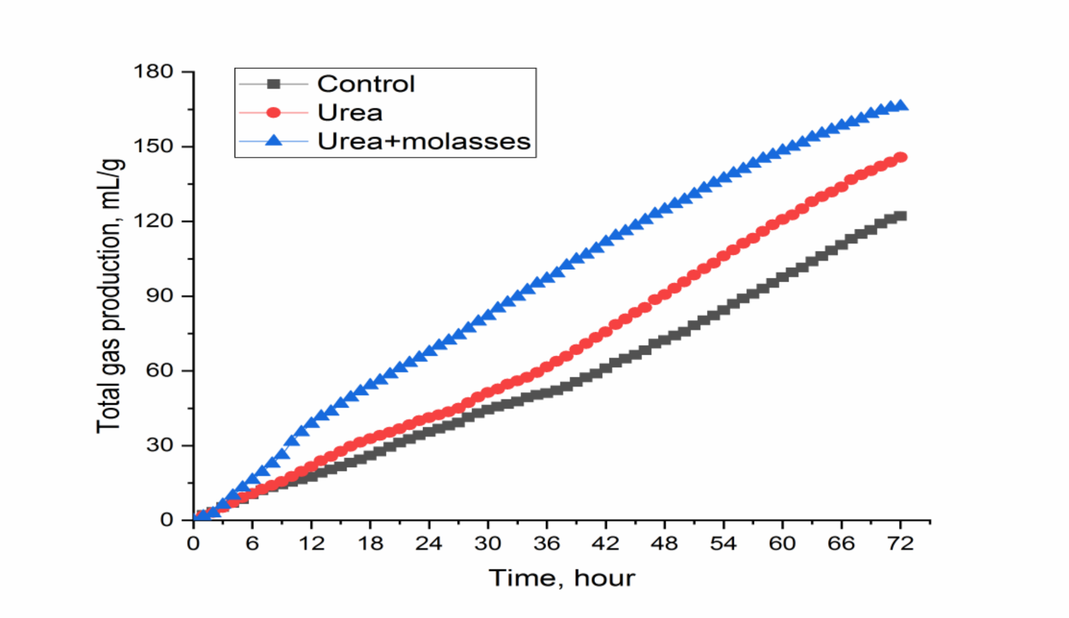


Figure 40: Variation in the total gas production during the 72 h *in vitro* ruminal incubation of maize stover pre-treated with urea and urea plus molasses

Gene copies of selected microbes

Table 31: The effect of urea and urea plus molasses pre-treatment on Gene Copies of selected rumen microbial groups (Log_{10} copies/g DM *in vitro* rumen contents)

Gene copies of selected Rumen Microbes[1]	Treatments			SEM[1]	*P* value
	Control	Urea	Urea+molasses		
Fungi	7.27	7.11	7.08	0.534	0.471
Bacteria	9.73	9.80	9.79	0.114	0.566
Protozoa	7.46	7.69	7.82	0.244	0.201
Methanogen	8.70[ab]	8.62[b]	8.77[a]	0.036	0.015
Methanobacteriales	7.44	7.36	7.61	0.233	0.336
Metanobrevibacteria	7.39	7.37	7.61	0.254	0.389
Methanomicrobiales	5.63	5.73	5.74	0.205	0.647
Prevotella spp.	9.26	9.27	9.30	0.119	0.788
R. albus	6.13	6.11	6.06	0.172	0.718
R. flavefaciens	6.18	6.24	6.19	0.526	0.920
F. succinogenes	8.21	8.05	8.39	0.366	0.663
S. ruminantium	8.82	9.15	9.05	0.376	0.419

[1]16SrRNA gene copies were measured for bacteria and methanogens, 18SrRNA gene copies were measured for protozoa and Prevotella spp., and the multiple alignments of 18SrRNA and ITS1 gene copies were measured for fungi. [2]Pooled standard error of means.

Results (Table 32) showed the effect of urea and urea plus molasses pre-treatment of maize stover on gene copies of selected rumen microbial populations. Urea and urea plus molasses pre-treatment had a significant effect ($P \leq 0.05$) on the 16SrRNA gene copies of total Methanogens. These were higher in urea plus molasses treated and less in urea treated compared to the control. However, the 16SrRNA gene copies of specific Methanogens, namely Methanobacteriales, Metanobrevibacteria and Methanomicrobiales were similar ($P \geq 0.05$). Similarly, urea and urea plus molasses treatment had no significant effect on gene copies of other rumen microbe's populations considered in this study (Table 32).

4.2.3 Feeding value of urea and molasses pre-treated maize stover to Friesian cows

Table 33 presents the nutritive value of napier grass, which was the basal feed for farmer feeding practice (FFP), maize stover and two test diets for the validation feeding trials. Total gas production after 48h fermentation was lower in dry maize stover compared to napier grass, UMS and MUMS.

Table 32: The nutritive value of Napier grass, dry maize stover and pre-treated urea and urea plus molasses maize stover feed blocks for validation feeding trials

Diet	GP 48h	DMD	DM	Ash	CP	Fat	Fibre	ME
Napier grass	229.68	61.85	89.13	17.32	9.42	2.8	29.4	8.12
Dry Maize stover	154.01	41.32	93.00	9.16	3.70	0.12	15.00	5.53
UMS	221.35	47.76	91.89	9.75	6.69	5.35	27.80	7.81
MUMS	228.67	47.67	92.38	9.18	10.77	8.27	29.33	8.10

GP = Total Gas Production at 48 hours; DMD = Dry Matter Digestibility (%); DM = Dry Matter (%); Ash = % Ash; CP = Crude Protein (%); Fat = Crude fat (%); Fibre = Crude Fibre (%); ME = Metabolizable Energy (MJ Kg DM); MUMS = Urea plus Molasses pre-treated maize stover; UMS = Urea pre-treated maize stover

Dry matter (%DM) was almost similar across the four feeds (Table 33). However, DMD and Ash content were higher in napier grass compared to dry maize stover, UMS and MUMS. Crude protein content was higher in MUMS and napier grass, but lower in dry maize stover compared to UMS. Crude fat content was lower in dry maize stover and napier grass, but higher in MUMS compared to UMS. Crude fibre and ME content were lower in dry maize stover, but higher in MUMS and napier grass compared to UMS.

Table 33: Effects of FFP, UMS and MUMS feed blocks on changes in dry matter intake, live body weight gain and milk yield of Friesian dairy cows at farm level

Parameter	Feeds			SEM	*P-value*
	FFP	UMS	MUMS		
DMI kg/cow/day	10.26[a]	11.18[b]	11.42[c]	0.22	0.002
Milk yield L/cow/day	11.70[a]	13.34[b]	13.51[c]	0.74	0.012
DMI increase kg/cow/day (%) from initial DMI	-	4.60	5.70	0.60	0.001
% Milk increase from initial milk production	-	38.50	40.50	0.13	0.001
LBW gain from initial weight (%)	-	5.10	6.50	0.11	0.001
Cost/kg DMI USD	0.04	0.01	0.02	0.02	0.721
Cost/Litre Milk USD	0.03	0.02	0.02	0.03	0.840

[ab=] Means with different superscript letters were significantly different (P < 0.05); DMI, Dry Matter Intake; FFP, Farmer Feeding Practice; UMS, Urea treated Maize Stover; MUMS, Molasses plus Urea treated Maize Stover; LBW, Live Body Weight; SEM, Standard Error of Means

Table 34 presents the effects of farmer feeding practice (FFP), urea treated maize stover (UMS) and molasses plus urea treated maize stover (MUMS) feed blocks on the dry matter intake (DMI) and milk yield of Friesian dairy cows. Dry matter intake (DMI) and milk yield per cow per day were significantly higher (P < 0.05) with MUMS and UMS compared to FFP. The increase (%) in in DMI between UMS and MUMS was significant (P < 0.05) and 4.5 - 5.7% above the FFP. Similarly, the increase (%) in milk yield per cow per day above the initial production with FFP was significant (P < 0.05) and above 40%. Live body weight gains (%LBW) was significantly higher (P < 0.05) with UMS and MUMS compared to FFP. The cost (USD) of DMI per kg feed and milk yield per litre was not significantly different (P > 0.05) between FFP, UMS and MUMS. However, overall, the cost of DMI per kg feed and producing a litre of milk was slightly lower with MUMS and UMS compared to FFP.

4.2 Discussion

4.2.4 Information flow on breeding and feeding and how this affects decision making in face of seasonality

Evidence from this study has shown that location (country), seasons, agro-ecological zones, breed types and production systems, either individually or as interactions, are important drivers of farmer-led breeding and feeding approaches on smallholder dairy farms in Kenya and Tanzania. This was because differences in these factors were reflected in farm household characteristics and performance of dairy cows in terms of reproductive indices, milk production, live body weight, body condition score, morphometric linear body measurements and feeds (sources and utilization).

Farm household characteristics, mainly years of schooling and dairy farming experience of the household head influenced milk production and calving interval. Therefore, smallholder dairy farmers with more years of schooling and dairy farming had more experience in decision making regarding milk production and reproductive performance. These farmers also would be in a better position to undertake long term stable investments in improving milk production and reproductive performance. Land size and land use for crops and livestock production varied by country and agro-ecology, in agreement with Chagunda *et al.* (2016), that land holding size and utilization varies considerably between countries and smallholder dairy farms are notably small.

Effects of country, season, agro-ecological zone, production systems and breed type on milk production and reproductive performance were either direct or indirect. This finding concurred with Ángel Ríos-Utrera *et al.* (2013) that there was a direct and indirect relationship between season effect with calving intervals and milk yield in the sub-tropics due to dynamic climatic changes. This was frequently associated with seasonal fluctuations (quality and quantity) in feeds and fodder availability and usage, disease pattern and changes in management practices.

Past studies have reported on reproductive performance, and calving interval as probably the best index of a dairy cow's reproductive performance and efficiency in smallholder dairy farms (Atuhaire *et al.,* 2014; Duncan *et al.,* 2013; Mayberry *et al.,* 2017). Therefore, the long calving interval, age at first calving and age at first service, in this study, which was observed to be higher in extensive production system as opposed to semi-intensive and intensive production systems was attributed to lack of improved feeding management in this system. Similar findings were reported by Duncan *et al.* (2013) and Oosting *et al.* (2014) that animals are left to graze freely, on usually low quality and quantity pastures, limiting overall performance.

The observed calving interval within highlands and lowlands in Kenya and Tanzania of mean 458.09 SEM = 6.29, was longer than the ideal documented calving interval of 365-380 days (Moran, 2005). The longer calving interval in the dry season than in wet season was expected because cows/heifers that calved during the wet season received adequate feeds in terms of quality and quantity. Therefore, they would recover within a short time for the next reproductive cycle, compared to those that calved during the dry season period when there were inadequate nutrients.

As similarly reported by Bahmani *et al.* (2011) and Duncan *et al.* (2013), year and season effect on calving intervals in the tropics and sub-tropics has been indirect due to dynamic climatic changes which are frequently associated with forage fluctuations, disease pattern and changes in management by the farmers. Further, from this study, lower seasonal (wet and dry) variation (+/-%) in calving interval for local zebu cows than cross bred and pure bred dairy cows was attributed to well adaptability of local zebu to local agro-climatic conditions (Sejian *et al.*, 2013; Thornton *et al.*, 2009). However, due to deliberate efforts or investment by smallholder farmers in feeding management of Holstein-Friesian and Ayrshire purebreds, they had lower calving interval compared to crossbreds and local zebu cows. There was a strong positive association between cow age at first service, cow age at first calving and calving interval, implying that effectively managing these three parameters would result in better reproductive efficiency in smallholder dairy farms, as similarly reported by Bahmani *et al.* (2011) and Tegegne *et al.* (2013).

Milk yield per cow per day, and hence 305-day lactation yield (mean 8.94 litres and 2667.50 litres, respectively), was slightly higher than what has been reported previously in Eastern Africa that ranges from 1.4 – 5.0 litres/head/day (Atuhaire *et al.*, 2014; Duncan *et al.*, 2013; Mayberry *et al.*, 2017; Rufino *et al.*, 2009). Smallholder dairy farmers in Kenya and Tanzania, realized higher milk yields when using pure dairy breeds with higher potential for milk yield than when using the lower potential local zebu dairy breeds. Hence, the local zebu cows produced 6.78 litres of milk per day, compared to Ayrshire cows that produced 10.19 litres per cow per day. However, local zebu cows were more adaptable to local conditions, because of their less variation in performance in response to seasonality effects, as similarly reported by Lukuyu *et al.* (2019); Mujibi *et al.* (2019); and Mwanga *et al.* (2018).

In the present study, slightly more milk yield was realized in highlands as opposed to lowlands agro-ecologies; during the wet compared to the dry season; and within intensive as opposed to extensive system. This was due to more availability and utilization of feeds with relatively high dry matter and nutritive value (improved fodder, legume forage, fodder trees/shrubs and natural pasture, crop residues and other alternative feeds).

Studies have shown that highland areas in both Kenya and Tanzania have a long history of dairy production with improved dairy cattle breeds dating back to the colonial era, coupled with conducive environment (Bebe *et al.*, 2003; Rufino *et al.*, 2009). Therefore, this could have been the reason for the higher milk yields (daily and 305-day lactation) in highlands compared to the lowlands It is also important to note that intensive dairy production system depends on cut and carry supplementary feeding, hence energy conservation for milk production. This is opposed to the extensive system that is mainly grazing on natural pastures and/or crop residues, as similarly reported by Paul (2014). Further, intensive dairy systems have higher farmer-led investment in feeding as opposed to grazing only in extensive systems.

Season variation (+/-%) in daily milk yield from dairy cows was slightly higher during the dry season period compared to the wet season period. This was mainly due to feed scarcity in the dry season, where livestock were allowed free grazing in cropping farm lands after harvesting and supplemented with concentrates (cereal and agro-industrial waste/by products) when available. During the wet season period, there was a tendency for dairy cattle to "starve in a green" as more land was allocated to crop production and less to forage and fodder production in smallholder dairy farms. Therefore, findings from this study showed that, seasonality due to rainfall variability was evident in continued year-round seasonal fluctuation in daily (and hence 305-day lactation) milk yield. This seasonal fluctuation was higher for improved dairy cows compared to local zebu cows within highlands and lowlands in Kenya and Tanzania.

Differences in milk yield and reproductive performance observed in this study were often results of differences in micro-climatic conditions including rainfall, temperature, humidity, and management practices. These factors influenced feed and water availability (quantity and quality) and usage. According to Duncan *et al.* (2013), sub-optimal milk production and reproductive performance are driven by low daily milk yields, short lactations (6–8 months) and long calving intervals (18–24 months). Therefore, increasing farmers' experience and information knowledge flows, as evidenced by this study, can improve milk yield and reproductive efficiency of dairy cows over time, through reducing age at 1st service, age at 1st calving and calving interval. This could be achieved through adopting innovative interventions that aim to improve and optimize the effects of seasons (wet and dry), agro-ecology, production systems, bio-physical, cultural and socio-economic environment of smallholder dairy farmers in Eastern Africa.

Few studies have been conducted in Eastern Africa, where multiple recordings of LBW, BCS and morphometric (linear) body measurements were taken on a dairy cattle population within the context location (country), agro-ecology, seasons, production systems and breed types. Therefore, evidence from this study showed that these factors had a profound influence on LBW, BCS, morphometric (linear) body measurements and subsequent milk yield and reproductive performance. According to Wangchuk *et al.* (2017), comparative measurements of morphometric traits can provide evidence of breed relationships and size and in some cases can be used to predict an animals' LBW. Even though LBW and morphometric body measurements in this study were higher for improved breeds (Ayrshire, Holstein-Friesian, Ayrshire cross and Friesian cross) as opposed to local zebu, they were still consistent with what has been reported from studies in Eastern Africa (Goe *et al.,* 2001; Lesosky *et al.,* 2012; Lukuyu *et al.,* 2016; Tebug *et al.,* 2018).

Ayrshire breed had higher LBW (mean 424.82 SEM = 19.05 kg), as opposed to Holstein-Friesian breed (mean 411.69 SEM = 13.07 kg). This finding contrasted with what has been previously reported for improved (pure) breeds (Lukuyu *et al.,* 2016, 2019). Further, morphometric body measurements were higher in Ayrshire breed, followed by Holstein-Friesian compared to the crossbreeds. This observation implied that based on LBW, and in the face of seasonality and prevailing farmer environment and management factors, Ayrshire showed to be well adapted improved breed in smallholder dairy farms, compared to other improved breeds.

From the present study, the proportion of Friesian cross (21.27%) and Ayrshire cross (21.12%) was still higher in smallholder dairy farms compared to Ayrshire (16.92%) and Holstein-Friesian (13.63%) breeds. This could have been attributed to past government efforts of introducing Ayrshire and Holstein Friesian in cross breeding programmes for improving milk production as similarly reported by Duncan *et al.* (2013) and Lukuyu *et al.* (2019).

The proportion of local zebu breed had decreased in smallholder dairy farms compared to improved crossbreeds, and they were also still the small breed with lower LBW (mean 266.70 SEM = 70 kg) and morphometric linear body measurements. Hence, the local zebu breed still had a place in smallholder dairy farming systems, as similarly reported by Bebe (2004), Ilatsia *et al.* (2012), Lesosky *et al.* (2012), Lukuyu *et al.* (2019), Nyamushamba *et al.* (2017) and Rewe *et al.* (2015). Differences between feeding practices for local zebu versus improved breeds in intake of green fodders and concentrates, further, illustrates their importance in smallholder dairy production, as similarly reported by Khan *et al*. (2012).

Local zebu cows were fed sub-optimally to a maximum limit of 1 kg concentrate daily, usually cereal by products of farmer's own source. In contrast, improved cows were supplied with concentrate in amount 2-3 times higher than local cows, which was composed of cereal by products such as maize bran and germ, rice polish, wheat bran and hauls of legumes and oil cakes. However, according to Moran (2005), dairy cows must be able to consume up to 4% of their live weight as dry matter each and every day for optimum performance (milk yield and reproduction), which was not evident in this study.

Body condition score (BCS) on a 5-point scale across different breeds from this study was 3.15 and ranged between 3.10 – 3.30, against a considered average of 3.00 reported by Saunders Comprehensive Veterinary Dictionary (2007). In our case, the cows appeared smooth over the spine, ribs, and pelvis and the skeletal structure could be easily palpated. The hooks and pins were still discernible, with a moderate, rather deep depression between the pelvis and rib cage, hooks and pins, and around the tail-head. Findings showed that dairy cows across the different breeds we considered in this study within high and low altitude areas in Kenya and Tanzania were in perfect body condition to meet performance needs (milk yield, growth and reproduction). However, as stated by Bastin and Gengler (2013), monitoring changes in body condition through an efficient BCS management strategy and scoring system is probably of greater value than identifying absolute, snapshot measures of body condition.

The present findings also showed that BCS did not vary with breed and age of dairy cows. Hence, changes in BCS may not generally be expected with changes in the other environment and management factors (country, agro-ecological zones, seasons, and production systems). Rather, BCS is a subjective measure of the nutritional status, the amount of metabolizable energy stored in the live animal, and is recognized by animal scientists and producers as being a useful trait to customize feeding strategies and manage dairy cattle health and fertility (Alphonsus *et al.,* 2010; Buttchereit *et al.,* 2011; Lawrence *et al.,* 2014; Roche *et al.,* 2009; van Straten *et al.,* 2009).

Country, seasons, agro-ecological zones, breeds and production systems, either individually, but more as interactions had an influence on LBW and morphometric body indices of dairy cows. LBW, BL, BH and HG of dairy cows decreased during the dry season months (with less or no rainfall) as opposed to the wet season months. These four traits are closely correlated (Lesosky *et al.,* 2012; Tebug *et al.,* 2016), and therefore, it is expected that seasonal changes in water availability, feed quality and quantity during the wet and dry seasons affect LBW which in turn affects the other morphometric body indices.

Body height (BH), body length (BL), height of withers (HW), thigh circumference (TCM) and neck girth (NG) varied and were either shorter or longer depending on country and agro-ecology.

This finding was similarly observed by Kugonza *et al.* (2011) that morphometric body dimensions of Ankole cattle in the five counties that were studied clearly differed. This was possibly because cattle in those areas had become sub populations, or because of variations in feed resource and water availability and associated general climatic conditions. Other authors have stated that these comparative differences in measurements of morphometric traits can also be useful for distinguishing animal breeds and strains by providing evidence of breed relationships and size and in some cases can be used to predict an animals' LBW (Alphonsus *et al.*, 2010; Bozkurt, 2006; Lesosky *et al.*, 2012; Tebug *et al.*, 2016).

The observed slightly higher values of LBW in highlands compared to lowlands agro-ecologies could be attributed to slightly better agro-climatic conditions in the highland areas and colonial history of dairy production from European settlers (Lukuyu *et al.*, 2016, 2019). Therefore, available land was better utilized for crops and livestock production (hence more feed resource availability) in Tanzania highlands and Kenya highlands compared to the Kenya lowlands and Tanzania lowlands. Similarly, slightly higher LBW in intensive and semi-intensive systems compared to extensive system, implied that dairy cows in intensive and semi intensive systems were confined or semi confined with cut and carry and supplementation as main feeding systems. The extensive systems comprised, mainly, of free grazing with little or no supplementation with other feed resources. Further in extensive systems, a considerable amount of energy for maintenance would be spent on locomotion and harvesting feed (hence higher energy cost for growth – weight gain), as opposed to intensive and semi intensive systems (Cañas C *et al.*, 2003; Leon-Velarde & Quiroz, 1999).

Local zebu cows had the least season (wet and dry) change (+/-) in LBW, compared to improved breeds. This was because local zebu cows were hardy and well adopted to the prevailing local agro-climatic conditions in Eastern Africa, hence the minimal seasonal change in LBW. Ayrshire and Ayrshire crossbreed were also relatively well adopted to the local agro-climatic conditions compared to those with Holstein-Friesian and Friesian crossbreed, hence the notable differences in seasonal LBW change. From this study, there was, therefore, higher year-round fluctuation in LBW with seasonal changes (variation) in long-term mean (LTM) monthly rainfall for the improved dairy cows, compared to local zebu across in Kenya and Tanzania.

Live body weight, BCS and morphometric body measurements have been used to aggregate different animal types, as they can be used to account for feed requirements of different animals and are therefore reflective of their varying resource requirements (Henderson *et al.*, 2016).

Therefore, accurate estimation of LBW and other body indices, from this study, was important for many purposes such as determining feed ration amounts, sale prices and for ensuring the correct therapeutic dosing of animals, as similarly reported by Lesosky *et al.* (2012). Live body weight (LBW) from this study was 401.70 SEM = 16.28 kg for improved breeds and 266.70 SEM = 7.89 kg for local zebu cows. However, based on the standard livestock unit for feed ration and therapeutic recommendation amounts for smallholder dairy cows in Eastern Africa, the recommended LBW is 350 kg for improved breed types and 250 kg for local zebu (Lesosky *et al.,* 2012; Marshall *et al.,* 2019). Further, according to Moran (2005), the standard measure for one TLU is one (cattle) with a body weight of 300 kg. Therefore, from this foregoing assessment, smallholder dairy cows, and especially the improved types, are under-dosed and sub-optimally fed based on LBW, resulting into the continuous year round variation in performance (milk yield and reproduction).

This study adopted a different approach and looked at the influence of country (location), agro-ecology, production systems, breeds, seasons and rainfall seasonality on herd dynamics and cow replacement investment decisions by smallholder dairy farmers that form an important aspect of breeding management. However, numerous studies have extensively reported on breeding and mating systems in sub Saharan Africa (Chagunda *et al.,* 2016; Duncan *et al.,* 2013; Kariuki *et al.,* 2017; Marshall *et al.,* 2019; Mueller *et al.,* 2015; Ojango *et al.,* 2019; Philipsson, 2003; Rewe *et al.,* 2009; Rewe *et al.,* 2011), and more recently (Mwanga *et al.,* 2018). Seasonality due to rainfall variability greatly influenced herd dynamics in terms of herd entry and herd exit, which eventually affected milk yield and reproductive performance.

Sseasonal changes in herd structure were also reflected in the multiple roles/uses of dairy cattle in smallholder farms that is milk production, income, insurance, manure production and work. According to Oosting *et al.* (2014), and similar to findings of this study, decreasing herd size will occur only if the benefits outweigh the costs of losing non-production functions. For example, artificial fertilization, short- and long-term financial institutions and mechanization should become available reliably and at low cost to enhance smallholder dairy farmers' investment in herd dynamics. Further, regulatory measures (taxes and quota) could reduce the benefits of keeping many animals. From this study, and in contrast to findings by Mwanyumba *et al.* (2015), the exit factors in herd dynamics (deaths, sales/gift-outs) were almost similar to the entry factors (births, purchases/gift-ins). This was not very favourable for herd re-building and maintenance. Therefore, policy makers in the two countries, and Eastern Africa as a whole, should intervene to smoothen year round dairy cattle cycles and keep track of the herd dynamics.

Dry season months were characterized by low rainfall across the two countries, resulting into decreased proportion of cows, heifers and female calves in the smallholder dairy herd. The proportion of bulls and castrated adult males was higher during the rainfall months in both countries. This was because of the use of these animals as oxen in smallholder dairy farms for cropping activities, mainly land preparation, weeding, harvesting, transportation and processing). Findings showed that in both Kenya and Tanzania, smallholder dairy cows (improved and local zebu breeds), naturally mate to mainly calve down during the rainfall, hence cropping season months when there is abundant locally available natural feed resources and water supply. This births scenario can be exploited in planned mating systems using artificial insemination (AI), through synchronization to ensure that the animals calve down during the rainfall as opposed to the dry season months, when there is abundant feed and water supply. Most deaths occurring during the rainfall season months in the two countries could be attributed to build up of pest and diseases, while from November to December could have been due to end year festivities and other socio-cultural activities.

Across both countries, purchases and gift-ins were mainly targeted at cow replacement and strengthening the productive and reproductive herd, while voluntary culling through sales and gift-outs were mainly for meeting specific family obligations/needs. It is important to point out for this study that the year round seasonality effects of rainfall on year round herd entry (births and purchases/gift-ins) and herd exit (deaths and sales/gift-outs) were strongly reflected in the previous, current and future investment decisions by smallholder dairy farmers on cow replacement by influencing cow and heifer herd dynamics across the high and low altitude areas of Kenya and Tanzania.

Herd dynamics and breeding practices targeted at smallholder dairy farmers from this study, took into account the differences in their production systems, preferences, production objectives, bio-physical, cultural and socio-economic environment and their knowledge of breed characteristics (Chagunda *et al.,* 2016; Marshall *et al.,* 2019; Murage & Ilatsia, 2011). Similarly, as stated by Philipsson (2003), **b**reeding decisions fulfilled the needs of the smallholder dairy farmers. Therefore, smallholder dairy farmers across the high and low altitude areas of Kenya and Tanzania typically made their breeding and feeding investment decisions in a reasoned way, on the basis of their experiences, traditional knowledge and whatever other information is available to them. Firstly, they would assess the alternative choices, develop a set of uncertain outcomes associated with each alternative investment decision (previous or past, present or current and future investment), then finally use their personal subjectivity to choose their line of action. For these smallholder farmers in Kenya and Tanzania, such cow replacement investment decisions were usually carried out in an informal (implicit) rather than formal (explicit) manner.

The choice of cow replacement investment decisions varied depending on the location (country) agro-ecological zones, seasons, production systems, type of the breed and also knowledge on animal husbandry of the farmer and his or her interest in breeding and feeding management. It follows that, the country, agro-ecology, seasons and production systems influenced overall herd dynamics (herd entry – births, purchases and gift-ins and herd exit – voluntary and involuntary culling through sales, gift-outs, deaths). These factors also influenced the farmer-led choice of cow replacement investment decisions to increase dairy cow herd size, decrease dairy cow herd size, keep dairy cow herd size stable, keep dairy cow herd size stable and increase or decrease dairy cow herd surplus. Seasonality driven changes in herd dynamics and farmer-led investment in cow replacement resulted into changes in breed type, composition, size and structure with resultant change in herd demographic rates, and reflected the biological aptitudes of animals (growth, fertility, health), their characteristics (age, sex, physiological status) and their interaction with environmental variables.

These environment (non-genetic) variables, as previously discussed, referred to any factor that affected production and reproduction performances, except those from genetic sources and comprised location, agro-ecological zones, seasons, production systems in terms of the natural resources which are exploited (e.g., fluctuations in feed and water supplies), animal health – diseases, pests and the managerial ability of herd owners. The seasonal changes in herd dynamics and cow replacement were also influenced by the past/previous, present/current and future farmer-led investment decisions in herd dynamics, which were due to biophysical, economic, socio-cultural environment and policies across high and low altitude areas of Kenya and Tanzania.

4.2.5 Current pattern of year-round seasonality driven changes in feed sources, availability and utilization

There existed various types of locally available feed resources including fodder shrubs and legumes, pasture grasses, weeds gathered from cropping areas, crop by-products and residues, agro-industrial by-products and home compounded rations or purchased concentrates. As similarly reported by (Moran, 2009), an adequate year-round supply of livestock feed is crucial to improving the livelihoods of millions of smallholder dairy farmers across the developing world.

However, the quantity (and quality) of feeds and fodder availability and utilization showed seasonal fluctuations with year-round rainfall variability, as similarly reported by Muia (2000). Findings from this study, further, showed year round variation in feed and fodder sources and usage during the dry and rainfall (wet) season periods. This finding agreed with other authors who have reported acute shortage of feed supply during the dry season, which is also of very poor quality (Moran, 2014). These seasonal changes in nutrition (feed and fodder availability and utilization) resulted in low production and reproductive performance, slow growth rate, loss of body condition and increased susceptibility to diseases and parasites, as similarly reported by Moran (2005).

Smallholder dairy farmers buy concentrates feeds as a baseline feed strategy and to overcome periods of low forage production (Baudron *et al.*, 2013), evidenced by the inverse relationship with improved fodder and natural grass from this study. However, for smallholder systems in Kenya and Tanzania, results were in line with Velarde-Guillén *et al.* (2017), who stated that it is feasible to sustain or increase milk yields by decreasing concentrates in diets of milking cows in small-scale dairy systems as the proportion of quality forages in the diet increases.

The significant inverse relationship between the different types of feed and fodder further, implied that an increase in one feed and fodder type, resulted into a tandem decrease in the other type and vice versa. While, the significant positive relationship implied that an increase in one feed and fodder type, resulted in a tandem increase in the other feed and fodder type, and vice versa. Green and dry crop residues came from farming activities as waste/by products during cropping and after harvesting respectively. Concentrate feed is expensive, hence improvement in quantity and quality of improved (planted) fodder, legume forage, fodder trees/shrubs and pasture, will lead to a reduction of its allocation and/or re-allocation in feeding. Year round variation in feeds and fodder sources (quality and quantity) and usage within high and low altitude areas in Kenya and Tanzania was mainly due to rainfall variability, with exception of concentrate feeding.

Decline in forage legume fraction affects the overall efficiency of fodder and pasture utilization as shown in this study. However, mixed pastures of fodder, grasses and legumes improve voluntary intake, dry matter digestibility, live weight gain and overall milk yield and reproductive performance (Mayberry *et al.,* 2017). Crop residues from dual-purpose crops including rice, wheat, sorghum, pearl millet, oilseeds, etc., were by far the most important source of feed, and accounted for 40-60% of the total dairy cattle feed on a dry matter basis, as similarly reported by Parthasarathy Rao and Hall (2003) and Paul (2014). However, there was considerable variation in availability and utilization of crop residues from dual-purpose food crops by type (green or dry) across highlands and lowlands of Eastern Africa. Similar findings were reported by Parthasarathy Rao and Hall (2003), that the availability of feed on a dry matter basis from the above groups of crop residues has varied during the last two decades.

Natural pastures, if properly utilized, were the largest and cheapest basal feed for dairy cattle and other livestock. However, due to a decline in area under fallow lands, pasture and common lands, the availability of grasses had declined as shown in this study. Increasing population pressure on existing arable lands had led to encroachment of the area under common property resources, as also reported by Atuhaire *et al.* (2014). Therefore, from this study, the quantity (and quality) of grasses from the above sources also declined due to over-grazing, and lack of proper maintenance.

Hence, the improvement of natural pastures by manipulation of grazing pressure, use of appropriate species (including mixed herds), controlled burning and clearing and control of woody weeds was always the basis for better yields. As with all improvement, this could only be done effectively where the land and its management could be controlled, similarly reported by Kugonza *et al.* (2011), a scenario not common on smallholder dairy farms in Eastern Africa. Evidenced from this study, year-round feed planning and budgeting, coupled with effective utilization of the available feeds and fodder (Khan *et al.,* 2012), based on site/region specific seasonal availability trends, appear to be the necessary steps to alleviate the nutritional problems of dairy animals. Different supplementation strategies (Duguma *et al.,* 2016) could be applied depending upon the type, accessibility and price of supplementary feeds and fodder in specific sites/regions to overcome seasonality driven milk fluctuations in Eastern Africa.

4.2.6 Evaluation of "best-bet" interventions for overcoming seasonality driven milk fluctuations in smallholder dairy farms

Crop residues from dual-purpose crops, particularly from coarse cereal and leguminous crops, were by far the most important feed source available to smallholder dairy farmers in highlands and lowlands of Kenya and Tanzania. These crop residues were fibrous parts of crops that remain after those edible to human beings have been removed, as similarly reported by Atuhaire *et al.* (2014). On average about 50–60% of total local feed resource in smallholder farms in Kenya and Tanzania was obtained from crop residues. This was similar to findings by Maleko *et al.* (2018); Negesse (2019); and Onyango (2018). This study found considerable variation in the quality of urea and urea plus molasses pre-treated stover and straws in terms of nutritional and chemical composition such as dry matter digestibility metabolizable energy content, etc., as similarly reported by Atuhaire *et al.* (2014) and Mahesh and Mohini (2014). Some of crop residues evaluated were rice straw, sorghum stover, sunflower hulls/husks, maize stover, beans and pigeon pea haulms, collected across high and low altitude areas of Kenya and Tanzania,

The choice of supplementing stovers/straws with forages and concentrates has previously been reported to have a positive impact on animal productivity (Kashongwe *et al.,* 2017; Ngongoni *et al.,* 2007), while chemical treatment with urea and urea plus molasses had proven positive effect on digestibility and milk yield in dairy cows. Fibre is essential in ruminants for rumination, saliva flow, rumen buffering, health of the rumen wall and high butterfat in milk (Atuhaire *et al.*, 2014; Sheikh *et al.*, 2018). The fibrous cell wall, after comprehensive *in vitro culture* of maize stover, consisted of hemicelluloses, cellulose and lignin, some of which may be digested by the rumen microbes (Sheikh *et al.,* 2018). High cell wall content increases rumination time and is associated with a decreased efficiency of conversion of metabolizable energy to net energy (Sheikh *et al.,* 2018)**.** From this study**, t**he rumen had a wide-range of fibrolytic microbial groups that degrade fibre. Fungi, protozoa and fibrolytic bacteria (i.e. *Ruminococcus albus***,** *Ruminococcus flavefaciens* and *Fibrobacter succinogenes***)** are active fiber degraders (Wang & Mcallister, 2002). These rumen microbes were enhanced in this study through pre-treatment of the crop residues with urea and urea plus molasses.

Comprehensive *in vitro culture* was performed on maize stover as a “best bet” least cost dry season animal feed due to the fact that maize is a staple food crop grown where the study was performed. Further, maize stover also showed significant treatment effect compared to the other crop residues. The pH of rumen fluid was not altered among the treatments, and the values were stable at pH 6.50 to 6.70. This ruminal pH range was within the range of 6.5 to 7.0 reported by Wachirapakorn *et al.* (2016); and Wanapat *et al.* (2017), as optimum level of pH in the rumen for microbial digestion of fibre and protein when fed mostly on roughages.

The ruminal NH_4^+ concentrations observed in the present study ranged from 7.10 to 16.4 mM/L. This result was similar to findings by Wachirapakorn *et al.* (2016), who reported a range from

13.6 to 17.6 Mm/L. Ruminal NH_4^+ is an important nutrient in supporting efficient rumen fermentation (Wachirapakorn *et al.*, 2016; Wanapat *et al.*, 2017). The NH_4^+ values for rumen fermentation tended to increase with urea plus molasses treated maize stover compared to urea alone and control (Bannink *et al.,* 2016) estimated the stoichiometry of VFA production in the rumen of lactating cows and found many factors that affected the concentration and proportions of VFA, such as DM intake, dietary composition, digestibility, and the utilization rate of substrate by rumen microorganisms.

The total VFA, acetic acid, propionic acid, butyric acid proportions and acetic acid to propionic acid ratio amongst the treatments showed significant differences (P < 0.05) in VFA concentrations or molar proportions of VFA, similar to findings by Wachirapakorn *et al.* (2016). The total VFA concentrations in all of the treatments ranged from 0.30 to 72.50 mM and were lower than those reported by Maneerat *et al.* (2013); Wachirapakorn *et al.* (2016); and Wanapat *et al.* (2017). However, the proportions of acetate, propionate and butyrate in this study were in agreement to findings by Sheikh *et al.* (2018). The proportions of volatile fatty acids (acetate, propionate and butyrate) were influenced ($P < 0.05$) by both urea and urea plus molasses pre-treatment.

Generally, improving the nutritive value of feed resources, especially crop residues using urea and urea plus molasses was important to smallholder dairy farmers in utilizing the crop residue feed resource effectively. Pre-treatment of crop residues such as maize stover with urea and urea plus molasses resulted into significant improvements in all the nutrient and chemical composition (total gas production, CP, ME, Ash, EE, Fat, Fibre) and fermentation products (volatile fatty acids, propionate, butyrate, and ammonia). These results imply that urea and urea plus molasses pre-treatment enhances the nutrient utilization of dairy cows, particularly protein utilization, and improves rumen fermentation and milk production. Moreover, the use of urea and urea plus molasses pre-treated feed is easy to practice by smallholder dairy farmers who raise animals using available local feeds and low quality roughages.

Following improvements of chemical and nutritive value crop residues, especially maize stover, through pre-treatment with urea and urea plus molasses from *in vitro culture*, effects on efficiency of utilization (feeding value) as “best bet” for on-farm dairy cattle feeding was needed. Therefore, a feeding trial was designed to test and validate urea and urea plus molasses pre-treated maize stover for feeding value at farm level. Results demonstrated that the feeding of urea and urea plus molasses pre-treated maize stover feed block improved dairy cattle performance in terms of dry matter intake, milk yield and growth rate (live body weight gain). These results were supported by similar works carried out by Eslami *et al.* (2011); Maneerat *et al.* (2013); Wachirapakorn *et al.* (2016); Wanapat *et al.* (2017). The explanation for these improved performance could be that urea in the maize stover based feed blocks boosted the non-protein nitrogen level of the crop residues and perhaps could have provided alkali effect when compacted, which helped to break down the ligno-cellulose bond of the crop residues (Kashongwe *et al.,* 2017; Kashongwe & Migwi, 2014) . In addition, the feeding of pre-treated urea plus molasses feed block generally allowed for synchronized supply of nutrients to microbes resulting in the synergy between nutrients demand of rumen microbes and the release of adequate levels of the nutrients bringing stability in the rumen ecosystem for optimal fermentation (Sheikh *et al.*, 2018).

The nutritive values of the feeds used for feeding validation trials implied that MUMS and UMS specifically, but also the dry maize stover were appropriate for feeding to cope with feeds scarcity during the dry season period when napier grass was low in quantity and quality. The observed lower milk yield from animals fed maize stover alone than from those feed blocks and Napier grass was in agreement with those reported by Khan *et al.* (2015); Parthasarathy Rao and Hall (2003) and Smith (2002). Furthermore, pre-treated crop residue feed blocks could be used for dry season supplementation in smallholder dairy cattle intensive feeding systems for a number of reasons.

Firstly, the feed blocks, as expressed by farmers through focus group discussion (FGD) were balanced and one would expect improved supply of nutrients. Secondly, the feed blocks reduced feed wastage thus were efficient in delivery of nutrients. Thirdly, by feeding feed blocks the expenditure on labour with respect to feeding was reduced. Fourthly, on level of technology (compacted urea and urea plus molasses feed block) satisfaction, 36% farmers were highly satisfied while 64% were satisfied with feeding value. Fifthly, dairy cows fed on UMS and MUMS feed blocks increased in body weight, looked healthy, ate to their fill, drunk enough water (3 times more than usual amounts of water), laid down to rest, had an upward milk yield trend and an observed increase in milk cream in all the units where on farm trials were carried out. Lastly, farmers explained that daily cow milk yield moved from as low as 9 litres per cow per day to an average of 13 litres daily when cows were fed with the feed blocks. When the blocks were finished and cows re-introduced to Napier grass, the average milk yield dropped back to the initial amounts.

These farmer perceptions were supported by Atuhaire *et al.* (2014) who demonstrated that feeding the compacted feed blocks reduced labour with respect to feeding by 30-40%. In this case, it took 20-30 minutes to feed 20 animals as opposed to hours of feeding the same animals, with drudgery being experienced in cutting, collecting and transportation of huge loads from roadsides. The observed trend of animals fed on UMS and MUMS producing milk yields slightly higher than those fed on FFP confirmed the findings by Kashongwe *et al.* (2017) who suggested that urea and urea plus molasses pre-treated blocks should be used as supplementary feeding diets during the dry season diets to cope with feeds scarcity rather than for higher yields.

CHAPTER FIVE

CONCLUSION AND RECOMMENDATIONS

5.1 Conclusion

Seasonality due to rainfall variability was the main driver of continuous year-round fluctuation in milk production and reproductive performance in smallholder dairy farms in Kenya and Tanzania. These seasonality effects were also evident in the deliberate efforts or investment by smallholder farmers in dairy cattle feeding and breeding management approaches.

Farmer-led innovative management approaches to reduce the effects of the dry season period, mainly feed and water shortage, could shorten age at first service, age at first calving, calving interval, herd structure and dynamics, while increasing reproductive performance, live body weight and milk yield in smallholder dairy farms.

Year round variation in feeds and fodder sources, availability (quality and quantity) and utilization across high and low altitude areas of Kenya and Tanzania was mainly determined by rainfall variability. Hence, efforts should be directed towards development of alternate climate smart feeding systems which make better use of region specific year-round local feed resource availability based on rainfall pattern and prevailing agro-climatic conditions.

Seasonal variation in the use of crop residues was because of the fact that land for which production of human food and livestock feed competes. Therefore, despite the improvements in nutritive and chemical composition of crop residues through various processing methods such as physical and chemical pre-treatment, their efficient utilization to desirable extent was still awaited.

Urea and urea plus molasses pre-treated crop residue based feed blocks, as “best bet” feeding intervention, improved the milk yield and growth performance of dairy cattle, reduced expenditure on labour with respect to feeding. The cost of producing milk was reduced and they contributed to increase in dry matter intake. Therefore, they were a practical feed resource for supplementary feeding during the dry season period, when only low quality and quantity forages were available.

The benefit provided by easier storage of feed blocks makes it possible to supply uniform quality of the feed throughout the year, with lesser price fluctuation, as against the large price fluctuation and irregular supply of crop residues and other feed ingredients in different seasons. This could also have an impact on stabilizing milk prices, irrespective of seasons, and could produce milk of uniform quality. Better performance of the animals obtained on feeding the crop residue feed blocks would obviously bring better returns to the farmer.

Seasonal variation in production and reproductive performance levels amongst dairy cattle breed types across high and low altitude areas was indicative of potential for improvement under selection and improved smallholder farmer-led feeding and breeding decisions.

Profitable breeding and feeding approaches in smallholder dairy farms across in Eastern Africa could be achieved better by adopting innovative interventions that aim to improve and optimize the non-genetic (environmental) factors such as changes in seasons, agro-ecology, production systems, bio-physical, cultural, socio-economic environment and favorable policies.

5.2 Recommendations

Non-genetic animal factors, which were mainly environment and management factors had the most prominent effects on production and reproduction, and should be considered in developing new strategies/interventions for dairy cattle production improvement. This will facilitate, maintain and sustain adequate resource allocation in terms of nutrients, energy and developmental time for enhanced animal performance.

Seasonal availability and utilization of feed and fodder can only be prevented through strategic increase in shelf life of available local feeds and fodder resources, where this can prevent seasonal milk fluctuations. Milk yield per cow per day was a major determinant of 305-day lactation milk yield in smallholder dairy farms. This is in turn determined by the morning and evening milk yield, which ultimately influences milk for home use, sale and calf rearing in smallholder dairy farms. Therefore, improved breeding is no substitute for better feeding in smallholder dairy farms.

Evaluation of the nutritive value of feeds and fodder, especially dry season feed resources, would be important to enhance their proper utilization. Research should be directed towards the development of alternate feeding system which make better use of region specific local feed resource that are available throughout the year based on the environment, rainfall pattern and prevailing climatic conditions.

Land devoted for green forage production is not expected to expand beyond its present level, and crop residues are produced without additional allocation of land and water. Therefore, there is an urgent need for the efficient utilization of nutrients through further studies on crop residues, as these are predicted to contribute significantly to the East Africa feed budget in future. Furthermore, grain redesigning with duly incorporating forage quality traits in plant breeding under ‘food-feed crops research’ has the potential to sustain the future dairy production to meet the growing global demand for dairy products as well as to partially mitigate feed scarcity and hence seasonal milk fluctuation problem.

With the advent of crop residue based feed block technology, it is possible to set up feed banks nearer to feed deficit areas. Because of easy handling, transportation and storage of the crop residue based feed blocks, the technology could improve preparedness against natural calamities, and save animals from hunger and death during these emergency situations. The crop residue total mixed ration (TMR) blocks can even be air lifted to the remotest places to avert disasters.

The value of crop residue feed blocks could be improved continuously through extended research, trying different supplements, newer feed additives, ant helminths and herbal extracts to improve their overall nutritional quality. However, it has to be ensured that the non-nutrient additives are used within the specified limits, so that they do not cause any major dilution of macro- or minor-nutrients in the feed blocks, which could reduce nutritional quality of the blocks.

The new knowledge gained with this study on feeding approaches and responses to non-genetic factors can be incorporated into a holistic model of optimization of dairy cow performance and thereby be one among other tools for optimizing the production economy for the smallholder dairy farmers in Eastern Africa.

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APPENDICES

Appendix 1: Focus Group Discussion Checklist for FEAST Tool

Preliminary scoping exercise with local stakeholders (Reconnaissance)

- Visit to the area meeting key local stakeholders including agriculture officials and key farmers to get a general understanding of the livestock production system
- Identify target livestock systems and farmers.
- Invite a representative group of approximately 15 men and women farmers to a **½ day** meeting to assess the constraints and opportunities for improving livestock feeding systems. This meeting will consist of a participatory diagnosis with farmers and other stakeholders and visits to local farms to ground truth the earlier discussions and provide an opportunity for further discussion

Participatory Diagnosis

1. Introduction

- **Objective:** Provide a clear picture of who we are, what is our purpose in being here, what we would like to do and how long it will take. Introduce both visitors and farmers; explain the purpose and the process of meeting including any potential long term or short term benefits for the participants; give an estimate how long it will take to complete the meeting.

2. General description of farming and livestock system

- **Objective:** Obtain a general picture of the farming and livestock system so we can ask more detailed questions during the meeting. Make sure we understand the answers and ask for clarification if something is not clear. Be sure to remind participants to include landless farmers when determining averages. Will ask farmer to give a general picture of the farming and livestock system including:
    - range of farm sizes,
    - household sizes,
    - farm labour availability,
    - annual rainfall pattern,

- irrigation availability,
- seasonal patterns, and the
- types of animals raised by households.

3. General description of the livestock production system in the area

- **Objective:** Understand the main purpose of livestock in the farming system, and explore how farmers feed and manage livestock. Will ask farmers about:

    - the types of animals raised (% of households raising these animals and average herd/flock sizes)
    - the purpose of raising these animals (e.g. draught, income, fattening, calf production)
    - the general animal husbandry (including; management, veterinary services and reproduction).

4. What are problems, issues, opportunities within the livestock system?

- **Objective:** Find out if feed is likely to be a major factor limiting animal production, if this is recognized by farmers and what the farmers see as potential solutions. Will ask the farmers to:

    - list the major problems and issues affecting livestock productivity,
    - identify any possible solutions to the identified problems,
    - use pair-wise rankings to determine which are the most important problems identified by farmers.
    - Discuss whether smallholder dairy farmers make deliberate decisions to feed (includes water) their dairy cattle breeds for milk yield or reproduction in the face of seasonality
    - identify socio-political, cultural, economic and bio-physical aspects working to counter, meeting the biological requirements (for milk yield and reproduction) of dairy cattle
    - discuss and determine whether the decisions by the smallholder dairy farmers on feeding and breeding to overcome seasonal fluctuation in productivity (milk yield and reproduction) determined by the complexities and interactions

between the farmer, bio-physical, socio-political, cultural, environmental and economic factors and the need to maximize profitability?

Appendix 2: Household Survey Questionnaire: Kiswahili

DODOSO-KAYA KWA WAFUGAJI WADOGO WA NG'OMBE WA MAZIWA						
TAREHE						
Jina la Mhojaji						
Alama-kificho ya mhojaji						
Alama Kificho ya Nchi/Wilaya	*Alama-kificho 1 = Mbulu, 2 = Karatu, 3 = Kakamega, 4 = Siaya*					
Jina la Tarafa/Kata						
Jina la Kijiji						
Namba za Kijiografia (GPS) ya Kaya au Mahojiano		**LATITUDO**		**LONGITUDO**		
A) Namba kificho ya ukanda wa kilimo-mazingira		*Alama-kificho 1 = Nyanda za Juu, 2 = Nyanda za Kati, 3 = Nyanda za Chini*				
B) Jina na namba ya simu ya mhojiwa						
C) Mahusiano ya mhojiwa na mkuu wa kaya						

Alama-kificho	*1= Mkuu wa kaya*	*2 = Mwenza*	*3 = Mwana/Mtoto*	*4 = Ndugu wengine*		
D) Mfumo wa uzalishaji wa ng'ombe wa maziwa wa wafugaji wadogo						
Mfumo wa uzalishaji	**Asillimia leo/sasa**	**Asilimia mwaka mmoja uliopita**	**Asilimia miaka mitano iliyopita**			
Kutafuta malisho/Kuacha wanyama wajitafutie chakula/Kuwalisha malishoni						
Kuwalisha majani na kuwaacha watafute						
Kuwalishia bandani tu						
Mwingine (ainisha)						
E) Ushirika/Shirika/Uanachama kwenye kundi la wakulima: Je wewe ni mwanachama?						
Kama ndiyo, ni mhusika yupi wa kaya (Tafadhali tumia alama-vificho za wahojiwa kutokana na uhusiano						

wako na mkuu wa kaya)						
F) Msimu - Mwezi au majira ya mvua						
Ni msimu gani wakati wa mahojiano haya?	**Msimu wa Mvua**	**Kiangazi**	**Kawaida**			
Mtawanyiko wa mvua kuanzia Januari hadi Disemba (Alama - 0 hadi 5)						
Mwezi	**Januari**	**Februari**	**Machi**	**Aprili**	**Meyi**	**Juni**
Kiasi cha mvua (Alama 0 hadi 5)						
Mwezi	**Julai**	**Augusti**	**Septemba**	**Oktoba**	**Novemba**	**Disemba**
Kiasi cha mvua (Alama 0 hadi 5)						
SEHEMU 1: TAARIFA ZA KIUJUMLA KAYA						
1.1 Idadi ya watu ndani ya kaya		**Idadi ya wanawake**				
1.2 Idadi ya wanakaya			**Idadi ya wanakaya wenye umri**			

wenye umri zaidi ya 60			**chini ya miaka 15**			
1.3. Taarifa za mkuu wa kaya		*Alama-vificho*				
Jinsia		*1=Mwanaume, 2=Mwanamke*				
Hali ya ndoa		*1=Ameowa/Ameolewa, 2=Hajaowa/Hajaolewa,* *3=Katalikiwa/Katengana, 4=Wanaishi pamoja,*				
Umri (miaka)		*5=Mjane, 9=Mengine*				
Hatua ya juu kabisa ya elimu		*1=Hakuna, 2=Chekechea, 3=Msingi, 4=Upili au Sekondari, 5=Elimu ya Juu*				
Miaka ya kuwa shuleni		*Chuo cha Elimu 6=Chuo Kikuu, 7=Vingine*				
Shughuli ya msingi		*1=Mwanafunzi, 2=Mkulima, 3=Msaidizi wa nyumbani/shambani,* *4=Mwajiriwa serikalini,*				
Miaka aliyokuwepo/aliyoishi kijijini		5=Mwajiriwa sekta binafsi 6=Kajiajiri (siyo kilimo), 7=Mengine				
SEHEMU YA 2: MALI NA SHUGHULI ZA KAYA						

2.1 Tafadhali elezea kwa undani kiasi cha kipato kwa asilimia mnachopata kwa shughuli hizi:						
Chanzo cha kipato cha kaya	**Asilimia sasa**	**Asilimia mwaka mmoja uliopita**	**% 5 years ago asilimia miaka mitano iliyopita**			
Uzalishaji wa mifugo						
Uzalishaji wa mazao						
Biashara ya mifugo						
Biashara ya mazao						
Ajira nje ya kilimo						
Biashara binafsi (siyo kilimo)						
Kutumiwa fedha						
Nyingine						
JUMLA						
2.2. Umejishughulisha na shughuli za uzalishaji maziwa kwa muda gani?				Miaka		
2.2.1 Je ulishawahi pata mafunzo yoyote juu ya uzalishaji maziwa?			*Alama-kificho:*	*1=Ndiyo,*	*2=Hapana*	

2.2.1.1 Kama ndiyo tafadhali ainisha						
2.2.2 Je unajishughulisha na uzalishaji wa maziwa kama biashara au kwa kujikimu tu?			*Alama-kificho:*	*1=Biashara,*	*2=Kujikimu*	
2.3 Ni watu wangapi umewaajiri?						
Vitengo vya waajiriwa shambani	Jinsia	**Idadi ya waajiriwa**	**Ujira kwa mwezi**	**Malipo ya fadhila**		
Waajiriwa wa wakati wote	Wanaume					
	Wanawake					
Waajiriwa wa sehemu ya muda	Wanaume					
	Wanawake					
Kazi za familia	Wanaume					
	Wanawake					
2.4 Tafadhali toa taarifa juu ya uwezo wa kuwa na ardhi na kuitumia						

Jina la shamba	Ukubwa wa shamba kwa ekari/hekari/au vipimo vingine	Umiliki wa ardhi (alama-kificho)	Matumizi ya ardhi kwa sasa (ardhi ya kaya) (alama-kificho)	Ukubwa wa ardhi inayotumiwa na kaya kwa ekari/hekari/vipimo vingine		
1						
2						
3						
4						
Alama-vificho						
Umiliki wa ardhi		***Matumizi ya ardhi***				
1= Inamilikiwa na familia, 2=Imekodiwa (bila malipo), 3=Imekodishwa (kwa malipo)		*0=Ardhi isiyotumika/konde, 1=Ulimaji wa mazao, 2=Ulishaji wa wanyama/lishe*				
4=Imekodiwa (kwa malipo), 5=Ardhi binafsi, 6=Ardhi ya jumuiya, 9=Mengine			*Miti ya lishe, 3=Miti ya matunda/bustani, 9=Mengine*			
2.5 Je unamiliki aina hii ya mzao wa ng'ombe wa maziwa?…;Na kwanini unafuga aina hii ya mzao?…						

na kwanini hasa unapenda au kutopenda aina hizi za mzao?						
Mizao	Sasa (Alama-vificho 1 = Ndiyo, 2 = Hapana)	Miaka 5 - 10 iliyopita (Alama-vificho: 1 = Ndiyo, 2 = Hapana)	Sababu ya kubadilisha mzao (Alama-vificho1)	Kwanini unapendelea kufuga uzao huo	Ulijuaje kuhusu mzao (Alama-vificho 3)	
Ng'ombe wa kienyeji wa maziwa - wananyonyesha						
Ng'ombe wa kienyeji - wasionyonyesha (wanaokaribia kujifungua)						
Ndama wa kienyeji wa maziwa (Umri zaidi ya miezi 6 hadi mwaka anayenyonya)						
Ndama wa kienyeji wa maziwa (umri chini ya miezi 6) jike						

Ndama wa maziwa wa kienyeji (umri chini ya miezi 6) dume						
Ng'ombe wa kisasa wa maziwa - anayenyonyesha						
Ng'ombe wa kisasa wa maziwa -asiyenyonyesha (wanaokaribia kujifungua)						
Ndama wa kisasa wa maziwa (umri kati ya miezi 6 hadi mwaka anayenyonya)						
Ndama wa kisasa wa maziwa (chini ya umri wa miezi 6)- jike						
Ndama wa kisasa wa maziwa (umri chini ya miezi 6) - dume						

Madume yaliyohasiwa (umri zaidi ya miaka 2)						
Madume yaliyohasiwa (umri kati ya miezi 6 na miaka 2)						
Alama-vificho1: 1=Inahimili magonjwa, 2=Inahimili ukame, 3= Uzao mzuri, 4=Ukuaji wa haraka, 5=Ina soko zuri, 6= Ulezi bora wa ndama						
7=Uzalishaji bora wa maziwa; 8=Uwezo mzuri wa kustahimili msongo; 9=Uwezo mkubwa wa kula chakula; 10=Uwezo mdogo wa kula chakula ; 11. Uzao bora						
Malengo: 12=Uwezo wa kuvuta vitu vizito; 13=Ufahari katika jamii; 14=Kuuza ziada; 15=Sababu za kidini; 16=Kwa ajili ya kula; 17=Utamaduni/Mila; 18= Rangi/Mwonekano						
20=Uzalishaji mdogo wa maziwa; 21=Kiwango cha juu cha maziwa; 22=Kiwango kidogo cha maziwa; Ukubwa wa mwili 9=Ukubwa wa mwili (kubwa/ndogo);						
23=Mengine (ainisha)						
Alama-vificho 2: 1. = Imerithiwa/Zawadi; 2. = Msaada toka mradi (wa Serikali, Shirika lisilo la kiserikali, Ushirika, Kikundi cha Kusaidiana) ;						
3. = Imenunuliwa toka kwenye shamba kubwa la ng'ombe; 4. = Imenunuliwa kutoka shamba la serikali; 5. = Imenunuliwa toka shamba la mkulima mdogo;						

6 = Imenunuliwa toka kwenye mnada wa ng'ombe; 7. =Imenunuliwa toka kwa mkulima binafsi au mfanyabiashara; 8. = Mkopo toka kwa mradi; 9. = Imetokana na mahari;						
10 =Dume au ndama wa kukodiwa; 11. = Limepandishwa na uzao wa kisasa; 12. = Mengine (ainisha) _______________________						
Alama-vificho 3: 1. Ushauri toka mtoa huduma za kupandisha kisasa; 2.Sababu za kihistoria/uzoefu; 3. Kila mtu anafuga uzao huu; 4. Huduma za wataalamu;						
5. Urithi/Zawadi; 6. Kupitia maandiko/Vyombo vya habari; 7. = Msaada toka kwa mradi (wa Serikali, Shirika lisilo la kiserikali, Ushirika, Vikundi vya kusaidiana);						

8. Vyanzo vingine, ainisha [_________]						
SEHEMU YA 3: TAARIFA-KINA ZA UMILIKI WA NG'OMBE KWA WAFUGAJI WADOGO WA NG'OMBE WA MAZIWA						
3.1 Elezea juu ya muundo wa ng'ombe wako wa maziwa ndani ya miezi 12 iliyopita; Na vipimo vya maumbile ya ng'ombe kwa ng'ombe mmoja kwa kila swali						
Aina ya ng'ombe wa maziwa	**Aina ya uzao**	**Idadi inayomilikiwa na kaya**	**Umri wa wanyama (miaka/miezi)**	**Uzito wa ng'ombe mzima/hai**	**Urefu**	
Ng'ombe wa kienyeji wa maziwa - wananyonyesha						
Ng'ombe wa kienyeji - wasionyonyesha (wanaokaribia kujifungua)						
Ndama wa kienyeji wa maziwa (Umri zaidi ya miezi 6 hadi mwaka anayenyonya)						
Ndama wa kienyeji wa						

maziwa (umri chini ya miezi 6) jike						
Ndama wa maziwa wa kienyeji (umri chini ya miezi 6) dume						
Ng'ombe wa kisasa wa maziwa - anayenyonyesha						
Ng'ombe wa kisasa wa maziwa -asiyenyonyesha (wanaokaribia kujifungua)						
Ndama wa kisasa wa maziwa (umri kati ya miezi 6 hadi mwaka anayenyonya)						
Ndama wa kisasa wa maziwa (chini ya umri wa miezi 6)- jike						
Ndama wa kisasa wa						

maziwa (umri chini ya miezi 6) - dume						
Madume yaliyohasiwa (umri zaidi ya miaka 2)						
Madume yaliyohasiwa (umri kati ya miezi 6 na miaka 2)						
Aina ya ng'ombe wa maziwa	**Alama ya hali ya mwili (kipimo 1 hadi 5)**	**Kimo cha nundu (sentimeta)**	**Unene/mzingo wa moyo (sentimeta)**	**Unene/Mzingo wa tumbo (sentimeta)**	**Mzingo wa paja (sentimeta)**	
Ng'ombe wa kienyeji wa maziwa - wananyonyesha						
Ng'ombe wa kienyeji - wasionyonyesha (wanaokaribia kujifungua)						
Ndama wa kienyeji wa maziwa (Umri zaidi ya miezi 6 hadi mwaka						

anayenyonya)						
Ndama wa kienyeji wa maziwa (umri chini ya miezi 6) jike						
Ndama wa maziwa wa kienyeji (umri chini ya miezi 6) dume						
Ng'ombe wa kisasa wa maziwa - anayenyonyesha						
Ng'ombe wa kisasa wa maziwa -asiyenyonyesha (wanaokaribia kujifungua)						
Ndama wa kisasa wa maziwa (umri kati ya miezi 6 hadi mwaka anayenyonya)						
Ndama wa kisasa wa maziwa (chini ya umri wa						

miezi 6)- jike						
Ndama wa kisasa wa maziwa (umri chini ya miezi 6) - dume						
Madume yaliyohasiwa (umri zaidi ya miaka 2)						
Madume yaliyohasiwa (umri kati ya miezi 6 na miaka 2)						
SEHEMU YA 4: MAAMUZI JUU YA UZALISHAJI WA NG'OMBE WA MAZIWA: UTENDAJI KATIKA UZAAJI NA UZALISHAJI WA MAZIWA						
4.1 Nini mkakati wako wa sasa wa kuongeza uzao						
Kuongeza idadi ya ng'ombe wanaozaa	*Alama kificho: 1=Ndiyo, 2=Hapana*		Kuongeza ziada (kwa kununua)			
Kupunguza idadi ya ng'ombe wanaozaa	*Alama kificho: 1=Ndiyo,*		Kupunguza ziada (kuuza)			

	2=Hapana					
Kudumisha idadi ya ng'ombe wanaozaa	*Alama kificho:* *1=Ndiyo,* *2=Hapana*		Kudumisha ziada ya ng'ombe waliopo			
4.2 Unawatambuaje wanyama wako?						
	Ng'ombe wakubwa	**Ng'ombe jike hajazaa**	**Madume**	Ndama		
Nawatambua kwa majina, mwonekano au mwenendo						
Mhuri wa moto						
Mfumo wa utambuzi wa mnyama mmojammoja						
Mfumo maalumu wa utambuzi wa wanyama						
4.3 Tafadhali tuambie kuhusu utendaji wa kuzaa wa ng'ombe wako wa maziwa ndani ya miezi 12 iliyopita						

Ng'ombe wa maziwa - jina au kitambulisho	**Aina ya uzao**	**Umri wa ng'ombe (miaka/miezi)**	**Hali ya ng'ombe, 1 = Anajiandaa kuzaa, 2 = Ana mimba, 3 = Ananyonyesha**	**Umri alipopewa huduma kwa mara ya kwanza (miezi)**	**Umbali kati ya mzao wa kwanza na wa pili nk**	
1 =						
2 =						
3 =						
4 =						
Ng'ombe wa maziwa - jina au kitambulisho	**Idadi ya ndama**	**Kiasi cha maziwa (asubuhi)**	**Kiasi cha maziwa (jioni)**	**Maziwa yanayoliwa kwenye kaya**	**Maziwa yanayonyonywa na ndama**	
1 =						
2 =						
3 =						
4 =						

<table>
<tr><td colspan="6">SEHEMU YA 5: UPATIKANAJI WA MAJI NA MATUMIZI YAKE KWA AJILI YA NG'OMBE WA MAZIWA</td><td></td></tr>
<tr><td colspan="4">5.1. Je maji safi na ya kutosha hupatikana kwa ajili ya ng'ombe wako wa maziwa?</td><td></td><td></td><td></td></tr>
<tr><td colspan="3">5.2. Kama HAPANA, je ni mara ngapi unawapa maji ng'ombe wako wa maziwa?</td><td></td><td></td><td></td><td></td></tr>
<tr><td></td><td>Alama-kificho: 1=Mara moja kwa siku, 2=Mara mbili kwa siku, 3=Mara tatu kwa siku, 4=Nyingine (ainisha)</td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td>Chanzo cha maji</td><td>Ni wanyama gani wanapewa maji? (Alama kificho 1)</td><td>Nani anawapa maji? (Alama kificho 2)</td><td>Hupatikana kwa msimu 1 = Ndiyo, 2 = Hapana</td><td>Umbali hadi kwenye chanzo cha maji</td><td>Je kiasi kinatosha kwa ng'ombe wanaonyonyesha?</td><td></td></tr>
</table>

1= Huletwa shambani						
2= Kisima kilichopo shambani						
3= Maji ya mvua						
4= Maji ya mabomba						
3= Mto/mkondo uliopo karibu						
4= Mengine (ainisha)						
Ni wanyama gani wanapewa maji? Alama-kificho 1: 1=Wote 2=Wanaonyonyesha, 3=Wanaokaribia kujifungua, 4=Ndama,						
5=Ambao hawajawahi kuzaa, 6=Wanaopandikiza/wanaozalisha, 7=Wengine?						
Nani anawapa maji?: Alama-kificho 2: 1=Mkuu wa kaya, 2=Mwenza, 3=Binti, 4=Mtoto wa kiume, 5=Mfanyakazi, 6=Wengine (ainisha)						
Kiasi cha maji kinachotolewa: Alama-kificho 3: 1=Kunywa hadi kutosheka kwenye beseni; 2=Ndoo (lita 10); 3= Lita 20; 4=Chombo (Lita 50); 5=Chombo (Lita 80); 6=Vingine						
Je kiasi kinatosha kwa ngombe wanaonyonyesha?						
SEHEMU YA 7: MAAMUZI JUU YA MALISHO YA NG'OMBE WA MAZIWA: UZALISHA WA MAZAO NA CHAKULA						

CHA WANYAMA NA UNUNUZI WA CHAKULA						
CHA WANYAMA						
7.1. Uzalishaji wa mazao (mazao-biashara, mazao-chakula, mazao ya matunda na mbogamboga)						
Jina la zao	Ukubwa wa shamba (Hekari/Ekari/Vipimo vya kienyeji/vingine)	Uzalishaji/Kiasi(Kilo kwa hekari kwa mwaka)				
1=						
2=						
3=						
4=						
5=						
6=						
7=						
8=						
7.2. Uzalishaji wa chakula cha ng'ombe - Majani hai, majani makavu, malisho, mshudu						

Cha kupandwa (majani makavu/majani hai/mashudu)	Ukubwa wa shamba (Hekari/Ekari/Vipimo vya kienyeji/vingine)	Uzalishaji/Kiasi(Kilo kwa hekari kwa mwaka)				
1=						
2=						
3=						
4=						
5=						
6=						
7=						
8=						
7.3. Chakula cha kununua - majani hai, majani makavu, malisho, mashudu; virutubisho vya kibiashara na mazao ya kilimo						
Chakula cha kununua (Majani makavu/Majani hai/Kibiashara)	Ukubwa wa shamba (Hekari/Ekari/Vip	Uzalishaji/Kiasi(Kilo kwa hekari kwa mwaka)				

	imo vya kienyeji/vingine)					
1=						
2=						
3=						
4=						
5=						
6=						
7=						
8=						
8.0. MAAMUZI YA WAFUGAJI WADOGO WA NG'OMBE WA MAZIWA JUU YA ULISHAJI: KUENDANISHA ULISHAJI NA AINA YA UZAO						
8.1. Upatikanaji wa msimu wa chakula (Kalenda ya ulishaji) - Makadirio ya upatikanaji wa chakula kwa msimu kwa kila chanzo kilichotajwa kuanzia Januari hadi Disemba						
kwa kuangalia kipimo cha toka 0 hadi 5 (wakati 0 = hakuna na 5 = upatikanaji mkubwa)						
Aina ya vyakula	**Januari**	**Februari**	**Machi**	**Aprili**	**Meyi**	**Juni**
Mabaki ya mazao -						

makavu						
Mabaki ya mazao - mabichi						
Nyasi mbichi - za asili						
Nyasi mbichi - zilizoboreshwa/za kisasa mfano za Rhodesia						
Mibaazi mibichi						
Miti na vichaka						
Virutubisho						
Aina ya vyakula - mwendelezo	**Julai**	**Augusti**	**Septemba**	**Oktoba**	**Novemba**	**Disemba**
Mabaki ya mazao - makavu						
Mabaki ya mazao - mabichi						
Nyasi mbichi - za asili						
Nyasi mbichi -						

zilizoboreshwa/za kisasa mfano za Rhodesia						
Mibaazi mibichi						
Miti na vichaka						
Virutubisho						
8.2. Mikakati ya ulishaji inayotumiwa na mfuga ng'ombe wa maziwa wakati wa msimu wa mvua na kiangazi (ukame)						
	Alama kificho: 1=Ndiyo, 2=Hapana			*Alama kificho: 1=Ndiyo, 2=Hapana*		
Aina ya ng'ombe wa maziwa	**Mkakati wa ulishaji - msimu wa mvua**			**Mkakati wa ulishaji - msimu wa ukame**		
	Malisho	**Malisho ya kukata na kubeba**	**Malisho ya nyongeza**	**Malisho**	**Malisho ya nyongeza**	
Ng'ombe wa kienyeji wa maziwa - wananyonyesha						
Ng'ombe wa kienyeji -						

wasionyonyesha (wanaokaribia kujifungua)						
Ndama wa kienyeji wa maziwa (Umri zaidi ya miezi 6 hadi mwaka anayenyonya)						
Ndama wa kienyeji wa maziwa (umri chini ya miezi 6) jike						
Ndama wa maziwa wa kienyeji (umri chini ya miezi 6) dume						
Ng'ombe wa kisasa wa maziwa - anayenyonyesha						
Ng'ombe wa kisasa wa maziwa -asiyenyonyesha (wanaokaribia kujifungua)						
Ndama wa kisasa wa						

maziwa (umri kati ya miezi 6 hadi mwaka anayenyonya)						
Ndama wa kisasa wa maziwa (chini ya umri wa miezi 6)- jike						
Ndama wa kisasa wa maziwa (umri chini ya miezi 6) - dume						
Madume yaliyohasiwa (umri zaidi ya miaka 2)						
Madume yaliyohasiwa (umri kati ya miezi 6 na miaka 2)						
Angalizo: malisho yanahusisha malisho ya asili, malisho ya kukata na kubeba yanahusisha mabaki ya mazao na malisho yaliyoboreshwa: Nyongeza inahusisha						
virutubisho, mibaazi, miti na mazao-kilimo ya viwandani						
8.3. Mifano ya ulishaji (Machaguo ya ulishaji) yanayotumiwa na wafugaji wakati wa msimu wa						

mvua						
Aina za vyakula	**Kitengo cha ulishaji wa ng'ombe wa maziwa (Alama-kificho 1)**	**Namna ya ulishaji (Alama-kificho 2)**	**Kiasi kinacholishwa**	**Kipimo cha kiasi (Alama-kificho 3)**		
Mabaki ya mazao - makavu						
Mabaki ya mazao - mabichi						
Nyasi mbichi - za asili						
Nyasi mbichi - zilizoboreshwa, mfano Rhodesia						
Mibaazi mibichi						
Miti na vichaka						
Marobota ya nyasi mbichi						
Marobota ya nyasi kavu						

Virutubisho						
Vyakula vya kutengenezwa nyumbani						
Alama-vificho 1: 1=Ng'ombe wote wa maziwa; 2=Ng'ombe wanaonyonyesha; 3=Ng'ombe wasionyonyesha (wanaokaribia kuzaa); 4=Ng'ombe ambao hawajazaa;						
5=Ndama; 6=Madume; 8=Wengine (ainisha)						
Alama-vificho 2: Kulishwa vibichi; 2=Kulishwa vikavu; 3=Nyongeza						
Alama-vificho 3: 1=Kilo; 2=Robota; 3=Mkungwe; 4=Lita; 5=Mpungu; 6=Ndoo; 7=Gunia (kilo 25, kilo 50, kilo 90-tiki inayohusu); 8=Vingine (ainisha)________________						
**** Vyakula vya kutengenezwa nyumbani - taja viungo vilivyomo na kiasi chake____**						
8.4. Mifano ya ulishaji (Machaguo ya ulishaji) yanayotumiwa na wafugaji wakati wa msimu wa ukame						
Aina ya vyakula	**Kitengo cha ulishaji wa ng'ombe wa maziwa (Alama-**	**Namna ya ulishaji (Alama-kificho 2)**	**Kiasi kinacholishwa**	**Kipimo cha kiasi (Alama-kificho 3)**		

	kificho 1)					
Mabaki ya mazao - makavu						
Mabaki ya mazao - mabichi						
Nyasi mbichi - za asili						
Nyasi mbichi - zilizoboreshwa, mfano Rhodesia						
Mibaazi mibichi						
Miti na vichaka						
Marobota ya nyasi mbichi						
Marobota ya nyasi kavu						
Virutubisho						
Vyakula vya kutengenezwa nyumbani						
Alama-vificho 1: 1=Ng'ombe wote wa maziwa; 2=Ng'ombe wanaonyonyesha; 3=Ng'ombe wasionyonyesha (wanaokaribia kuzaa);						

4=Ng'ombe ambao hawajazaa;						
5=Ndama; 6=Madume; 8=Wengine (ainisha)						
Alama-vificho 2: Kulishwa vibichi; 2=Kulishwa vikavu; 3=Nyongeza						
Alama-vificho 3: 1=Kilo; 2=Robota; 3=Mkungwe; 4=Lita; 5=Mpungu; 6=Ndoo; 7=Gunia (kilo 25, kilo 50, kilo 90-tiki inayohusu); 8=Vingine (ainisha)_________________						
**** Vyakula vya kutengenezwa nyumbani - taja viungo vilivyomo na kiasi chake____**						
SEHEMU YA 9: GHARAMA ZA UZALISHAJI KWA WAFUGAJI WADOGO WA NG'OMBE WA MAZIWA						
9.1 Tafadhali ainisha kwa kina gharama tofautitofauti za uzalishaji unazopata katika ufugaji wa ng'ombe wa maziwa						
Gharama za pembejeo za uzalishaji	**Vitu**	**Hununuliwa wapi?**	**Nani alilipia (Alama-kificho)**	**Jumla ya gharama**		
Gharama za kulisha						
Gharama za uzalishaji mazao						
Gharama za uzalishaji lishe na nyasi						

Afya ya mnyama						
Gharama za kazi						
Umeme						
Gharama za ardhi (kama ya kukodishwa)						
Gharama za nyumba (kama ya kupanga)						
Vipuri/Spea						
Gharama za maji						
Gharama za mafuta						
Nyingine						
Alama-kificho						
Hununuliwa wapi? *1=Duka la karibu, 2=Chama cha Ushirika cha Wakulima, 3=Mganga wa wanyama wa karibu, 9=Mengine*						
Nani alilipia=Mwenyewe (kwa hela), 2=Mwenyewe (kwa mkopo), 3=Serikali, 9=Mengine						
Muda unaohusiana na jumla ya gharama 1=Siku, 2=Wiki, 3=Mwezi, 4=Mwaka						
SEHEMU YA 10: MIUNDOMBINU						
10.1 Upatikanaji wa vitu vifuatavyo (1 = mbaya sana, 9 =						

mzuri sana)						
Uzio						
Nyenzo za kuwahudumia wanyama						
Vyanzo vya maji						
Majengo/Vivuli						
Magari						
Mashine na vifaa vingine						
Vifaa vya kulishia wanyama						
SEHEMU YA 11: TAARIFA MBALIMBALI						
11.1 Vyanzo vya taarifa na uaminifu wa vyanzo na taarifa						
Aina	Chanzo kikuu (Alama-kificho)	Uaminifu wa chanzo				
Matendo ya kawaida ya uzalishaji						
Matumizi ya ushauri						

Masuala ya afya ya wanyama						
Masoko						
Bei						
Kiwango cha mazao						
Uwezo wa kufuatilia						
Uratibu wa hatari						
Alama-kificho 1 =Mtaalamu wa serikali, 2= Gazeti, 3=Shirika binafsi, 4=Maneno ya kusikia, 5=Hakuna 9= Mengine						
Alama-kificho (Namba 1 = si ya kutegemea , 9 = Ya kutegemea sana)						
11.2 Je biashara yako ya ng'ombe wa maziwa imebadilika vipi ndani ya miaka 5						
Wanyama wameongezeka						
Uzalishaji toka kwa wanyama umeongezeka						
Matumizi zaidi ya teknolojia kama uzalishaji wa kisasa						
Ufugaji wa wanyama wengine						

Utanuzi wa biashara (mfano kuzalisha vayakula na kuchinja kwa biashara)						
Kujikita kwenye biashara ya ng'ombe wa maziwa (kuzalisha kwa ajili ya wafugaji wakubwa)						
Mengine						
11.3 Vikwazo						
Panga vikwazo hivi kwa umuhimu wake (1 = muhimu sana, 5 = si muhimu sana)						
Kubadilikabadilika kwa bei						
Uzalishaji wa kiwango cha chini						
Kupata/kufikia masoko						
Kupata mkopo						
Kupata pembejeo						
Kupata taarifa						
11.4 Hatari						
Panga vihatarishi hivi kwa umuhimu wake (1 = muhimu sana, 5 = siyo muhimu sana)						
Hali ya hewa						

Magonjwa						
Upatikanaji wa pembejeo						
Kutolipwa						
Wizi/Rushwa						
Uvamizi dhidi ya ng'ombe na wanyama wakali						

Appendix 3: Household Survey Questionnaire: English

SMALLHOLDER DAIRY HOUSEHOLD SURVEY QUESTIONNAIRE						
DATE						
Name of Enumerator						
Enumerator code						
County/District (code):	*Codes: 1 = Mbulu, 2 = Karatu, 3 = Kakamega, 4 = Siaya*					
Sub-County/Ward (code):						
Village (code):						
GPS Coordinates of Household/Interview Location - GPS Reading		**LATITUDE**		**LONGITUDE**		
A) Agro-Ecological Zome (code)		*Codes: 1 = Highlands, 2 = Midlands, 3 = Lowlands*				
B) Respondent's name						
Respondent's relationship to household head						
Codes	*1= Household head*	*2 = Spouse*	*3 = Child*	*4 = Other relative*	*4= Other member*	
D) Smallholder dairy cattle production systems						

Production System	**% today/Currently**	**% 1 years ago**	**% 5 years ago**			
Paetoral/Free range/Grazing						
Semi Zero Grazing/Semi confined						
Intensive Zero grazing/Confined						
Other (Specify)						
E) Cooperative/Organization/Farmer group Membership/Affiliations: Are you a member?				*Code:*	*1=Yes, 2=No*	
If yes, which household members *(Please use codes for respondent's relationship to household head above)*						
F) Seasonality - Rainfall Season of the month/year						
What is the season at time of survey	**Wet**	**Dry**	*(Tick appropriate)*			
Rainfall Distribution from January to December (Score - 0-5)						
Month	**Jan**	**Feb**	**March**	**April**	**May**	**June**

Rainfall Score (0-5)						
Month	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
Rainfall Score (0-5)						
SECTION 1: GENERAL HOUSEHOLD INFORMATION						
1.1 Number of people in household		Number of Females			Number of Males	
1.2 Number of HH members above 60 years of age			Number of HH members below 15 years of age			
1.3. Household Head Information		*Codes*				
Gender		*1=Male, 2=Female*				
Marital status		*1=Married, 2=Single, 3=Divorced/separated, 4=Living together,*				
Age (years)		*5=Widow/widower, 9=Other*				
Highest level of education or schooling		*1=None, 2=Pre-primary, 3=Primary, 4=Secondary, 5=Tertiary/*				
Years of schooling		*College, 6=University, 7=Other*				
Primary activity		*1=Student, 2=Farmer, 3=House/farm help,*				

		4=Government/				
Years in village		parastatal employee, 5=Private sector employee,				
		6=Self-employed (non-farm), 7=Other				
SECTION 2: HOUSEHOLD ASSETS AND ACTIVITIES						
2.1 Please detail the percentage of income received from following activities:						
Household Income Source	**% today**	**% 1 years ago**	**% 5 years ago**			
Livestock production						
Crop production						
Livestock trading						
Crop trading						
Off-farm employment						
Own business (non-farm)						
Remittances						
Other						
TOTAL						
2.2 How long have you been engaged in dairy farming activities?				years		

2.2.1 Do you have any training in dairy farming activities			*Code:*	*1=Yes*	*, 2=No*	
2.2.1.1 If yes, specify						
2.2.2 Do you engage in dairying as a business or for subsistence			*1=Business,*	*2=Subsistence*		
2.3 How many employees do you employ?						
Category of farm employees	Gender	**Number of employees**	**Monthly wage rate**	**Payments in kind**		
Full-time employees	Male					
	Female					
Part-time employees	Male					
	Female					
Family Labour	Male					
	Female					
2.4 Please provide information on access to land and land use						
Plot ID	Size of each plot Acres/Hectares (ha)/Local Unit	Land ownership (code)	Current land use (for land used by HH) (code)	Size of land under use by HH Acres/Ha/ Local Unit		

	(Specify)					
1						
2						
3						
Codes						
Land ownership		***Land use***				
1= Family owned, 2=Rent in (no payment), *3=Rent out (payment),*		*0=Idle/fallow, 1=Crop cultivation, 2=Livestock* *grazing/fodder/*				
4=Rent in (payment), 5=Freehold title, *6=Communal land, 9=Other*			*fodder trees, 3=Fruit trees/gardening,* *9=Other*			
2.5 Do you own the following breed types of dairy cattle…; And why do you keep these breeds…And why do you						
specifically prefer or not prefer to have these breed types (Breed Preference)						
Breeds	Now or currently (Codes: 1=Yes, 2=No)	5-10 years ago (Codes: 1=Yes, 2=No)	Reason for change of the breeds kept (codes1)	Why do you prefer to keep the breeds (Codes 1)	Source of Foundation /Starting stock (Codes 2)	How you got to know about the breeds (Codes 3)

Local dairy cows - lactating						
Local dairy cows - non-lactating (dry)						
Local dairy heifers (> 6 Months old- < 1st Calving)						
Local dairy calves (< 6 months old) - Female						
Local dairy calves (< 6 months old) - Male						
Improved dairy cows - lactating						
Improved dairy cows - non-lactating (dry)						
Improved dairy heifers (> 6 Months old- < 1st Calving)						
Improved dairy calves (< 6 months old) - Female						
Improved dairy calves (< 6						

months old) - Male						
Bulls or castrated males (> 2 years						
Bulls or castrated males (> 6 months old-< 2years)						
Codes1: 1=Disease resistant, 2=Drought resistant, 3= high Fertility, 4=Higher growth rate, 5=Demanded by buyers/sellers, 6=Better mothering						
ability; 7=Higher milk production; 8=high adaptability/stress resistant; 9=Higher feed consumption; 10=Lower feed consumption; Better breeding						
purposes: 12=Draft power; 13=Social Status; 14=Selling surplus; 15=Religious reasons; 16=Own consumption; 17=Culture/tradition; 18=Colour/						
appearance; 20=Lower milk production; 21=Higher quality milk; 22=Lower quality milk; Body size 9=Body size (big/small); 23=other (specify)						
Codes 2: 1. = Inherited/Gift; 2. = Project support (Govt, NGO, COOP, Self Help Groups); 3. = Bought from large-scale private dairy farm;						
4. = Bought from Government farm; 5. = Bought from smallholder farm; 6 = Bought from cattle market; 7. = Bought from individual farm or trader;						
8. = Loan from project; 9. =						

Obtained as dowry; 10 =through borrowed/rented bull on heifer/cow; 11. = Upgrading of Zebus using AI (through AI on						
Heifer/ cow);12. = Other (specify) ________________________						
Codes 3: 1. Advice from the AI service provider; 2.Historical reasons/ experience; 3. Everybody around keeps those breeds; 4. Extension advice;						
5. Inheritance/gifts; 6. Literature/media; 7. = Project support (Govt, NGO, COOP, Self Help Groups); 8. Other source of info specify [__________]						
SECTION 3: DETAILS OF SMALLHOLDER DAIRY CATTLE OWNERSHIP						
3.1 Please specify the dairy herd structure in the past 12 months; and Measurement of animal body parameters for at least 1 (one)						
animal for each category						
Dairy cattle type	**Breed type/genotype**	**Total number owned by**	**Age of the animal**	**Livel body weight (Kgs)**	**Body Height**	**Body Length (cms)**

		household	(yrs/months)		(cms)	
Local dairy cows - lactating						
Local dairy cows - non-lactating (dry)						
Local dairy heifers (> 6 Months old- < 1st Calving)						
Local dairy calves (< 6 months old) - Female						
Local dairy calves (< 6 months old) - Male						
Improved dairy cows - lactating						
Improved dairy cows - non-lactating (dry)						
Improved dairy heifers (> 6 Months old- < 1st Calving)						
Improved dairy calves (< 6 months old) - Female						

Improved dairy calves (< 6 months old) - Male						
Bulls or castrated males (> 2 years						
Bulls or castrated males (> 6 months old-< 2years)						
Dairy cattle type	**Body Condition Score (scale 1-5)**	**Height of Withers (cms)**	**Heart Girth (cms)**	**Paunch Girth (cms)**	**Neck Girth (cms)**	**Thigh circumference (cms)**
Local dairy cows - lactating						
Local dairy cows - non-lactating (dry)						
Local dairy heifers (> 6 Months old- < 1st Calving)						
Local dairy calves (< 6 months old) - Female						
Local dairy calves (< 6 months						

old) - Male						
Improved dairy cows - lactating						
Improved dairy cows - non-lactating (dry)						
Improved dairy heifers (> 6 Months old- < 1st Calving)						
Improved dairy calves (< 6 months old) - Female						
Improved dairy calves (< 6 months old) - Male						
Bulls or castrated males (> 2 years						
Bulls or castrated males (> 6 months old-< 2years)						
SECTION 4: DAIRY CATTLE BREEDING DECISIONS: REPRODUCTIVE PERFORMANCE AND MILK PRODUCTION						
4.1 What is your current breeding (growth/expansion) strategy						

Increasing breeding herd	*Code: 1=Yes, 2=No*		Increasing surplus (Purchase)		*Code: 1=Yes, 2=No*	
Decreasing breeding herd	*Code: 1=Yes, 2=No*		Decreasing surplus (offtake)		*Code: 1=Yes, 2=No*	
Keeping breeding herd stable	*Code: 1=Yes, 2=No*		Keeping surplus stable		*Code: 1=Yes, 2=No*	
4.2 How do you identify your animals?						
	Mature cows	**Heifers**	**Males/Bulls**	Calves		
Now them by name, looks or patterns					*Code: 1=Yes, 2=No*	
Brand mark or tattoo					*Code: 1=Yes, 2=No*	
Individual animal identification					*Code:*	

system					*1=Yes,* *2=No*	
Formal animal identification system (traceability system)					*Code:* *1=Yes,* *2=No*	
4.3 Please provide information on the reproductive performance of your dairy cows in the last 12 months						
Dairy cow - name or identification	**Name of Breed type/genotype**	**Age of cow (yrs/months)**	**State of cow, 1=dry; 2=pregnant; 3=lactating**	**Age at 1st Service (months)**	**Age at 1st Calving (months)**	**Calving Interval (months)**
1 =						
2 =						
3 =						
Dairy cow - name or identification	**Number of calvings**	**Milk yield (Morning)**	**Milk yield (Evening)**	**Milk-home consumption**	**Milk-sales and Price/litre**	**Milk-Calves**
1 =						

2 =						
3 =						
SECTION 5: DAIRY CATTLE WATER AVAILABILITY AND USE						
5.1. Is water (clean in sufficient amount) always available to your dairy cattle? *Code:*				*1=Yes,*	*2=No*	
5.2. If NO, then how frequently do you water your dairy cattle						
	Code: 1=Once a day, 2=Twice a day, 3=Three time a day, 4=Other (specify)					
Water Source	**Which animals are watered (codes1)**	**Who waters the animals (Codes 2)**	**Seasonal availability 1=yes, 2=no**	**Distance to source (kms)**	**Amount of water provided (codes3)**	**Adequate for lactating cows?**
1= Carted to farm						
2= On farm well/borehole						

3= Rain water						
4= Piped water supply						
3= Closest river/stream						
4= Other (specify)						
Which animals are watered by source? Codes1: 1=All 2=Lactating cows, 3=Dry cows, 4=Calves, 5=Heifers, 6=Breeding males, 7=Other?						
Who waters the animals? Codes2: 1=Household head, 2=Spouse, 3=Daughter, 4=Son, 5=Labourer, 6=Other (specify)						
Amount of water provided: **Codes 3:** 1=Ad libitum on trough; 2=Bucket(10 lts); 3= Jerrian(20 lts); 4=Container(50 lts); 5=Container(80 lts); 6=other						
Is the Water provided for lactating cows adequate? *Code:*			*1=Yes,*		*2=No*	
SECTION 7: DAIRY CATTLE FEEDING DECISIONS: CROP AND FODDER PRODUCTION INCLUDING PURCHASED FEEDS						
7.1. Crops Production (Includes cash crops, food crops, Horticultural crops and vegetables)						
Crop Name	Acreage (Ha/acres/ Local	Yield/Quantity (KgDM/ha/yr)				

	unit__________ _)					
1=						
2=						
3=						
4=						
5=						
7.2. Feeds Production - Includes Forage; Fodder; Pastures; Crop residues						
Planted (Includes Fodder/Forage/Crop residues	Acreage (Ha/acres/ Local unit__________ _)	Yield/Quantity (KgDM/ha/yr)				
1=						
2=						
3=						
4=						
5=						

6=						
7.3. Purchased Feeds - Includes Forage; Fodder; Pastures; Crop residues; Commercial concentrates and Agricultural by products						
Purchased Feeds Name (Fodder/Forage/Commercial)	Acreage (Ha/acres/ Local unit__________ _)	Yield/Quantity (KgDM/ha/yr)				
1=						
2=						
3=						
4=						
5=						
6=						
8.0. FEEDING DECISIONS BY SMALLHOLDER DAIRY FARMERS: MATCHING FEED RESOURCES TO GENOTYPES						
8.1. Seasonal feed availability (Feed calendar) - Estimation of seasonal feed availability for feed resources mentioned above from January -						

December based on a scale of 0 - 5 (where 0=none and 5=highest availability)						
Feed Types	**January**	**February**	**March**	**April**	**May**	**June**
Crop residues - dry						
Crop residues - green						
Grass forage - natural pasture						
Grass forage - improved i.e Rhodes						
Legume forage						
Trees and shrubs						
Concentrates						
Feed Types- *Continuation*	**July**	**August**	**September**	**October**	**November**	**December**
Crop residues - dry						
Crop residues - green						
Grass forage - natural pasture						
Grass forage - improved i.e Rhodes						
Legume forage						
Trees and shrubs						

Concentrates						
8.2. Feeding strategy employed by the dairy farmer for feeding dairy cattle during wet and dry seasons						
	Code: 1=Yes, 2=No			*Code: 1=Yes, 2=No*		
Dairy cattle type	**Feeding strategy - Wet season**			**Feeding strategy - dry season**		
	Pasture	**Cut and carry**	**Supplementation**	**Pasture**	**Cut and carry**	**Supplementation**
Local dairy cows - lactating						
Local dairy cows - non-lactating (dry)						
Local dairy heifers (> 6 Months old- < 1st Calving)						
Local dairy calves (< 6 months old) - Female						
Local dairy calves (< 6 months old) - Male						
Improved dairy cows -						

lactating						
Improved dairy cows - non-lactating (dry)						
Improved dairy heifers (> 6 Months old- < 1st Calving)						
Improved dairy calves (< 6 months old) - Female						
Improved dairy calves (< 6 months old) - Male						
Bulls or castrated males (> 2 years						
Bulls or castrated males (> 6 months old-< 2years)						
Note: Pasture comprises natural pastures for grazing; Cut and carry comprises fodder i.e Napier grass, etc, crop residues and improved pastures						
i.e. boma rhodes; While Supplementation includes concentrates, forage legumes, fodder trees and agro-industrial by products						
8.3. Practical feeding scenarios (feeding options or rations) employed by dairy farmers for their dairy cattle						

during the Wet season						
Feed Types	**Dairy cattle category fed (Codes 1)**	**Feeding regime (Codes 2)**	**Quantity fed**	**Units of quantity (Codes 3)**	**Price (Complete price as fed)**	
Crop residues - dry						
Crop residues - green						
Grass forage - natural pasture						
Grass forage - improved i.e Rhodes						
Legume forage						
Trees and shrubs						
Conserved feeds - Silage						
Conserved feeds - Hay						
Concentrates						
Homemade mixed ration**						
Codes 1: 1=All dairy cattle; 2=Lactating cows; 3=Non-lactating cows (dry)-mature; 4=Heifers; 5=calves; 6=males - bulls; 8=other (specify)____						

Codes 2: Feed as fed (fresh); 2=Fed on dry matter (DM) basis; 3=Supplementation						
Codes 3: 1=Kilogram; 2=Bale; 3=Mkungwe; 4=Litre; 5=Mpungu; 6=Ndoo; 7=Sack (25kg, 50kg, 90kg-tick); 8=other (specify)________________						
**** Homemade ration** - State ingredients and quantities___________________________________						
8.4. Practical feeding scenarios (feeding options or rations) employed by dairy farmers for their dairy cattle during the dry season						
Feed Types	**Dairy cattle category fed (Codes 1)**	**Feeding regime (Codes 2)**	**Quantity fed**	**Units of quantity (Codes 3)**	**Price (Complete price as fed)**	
Crop residues - dry						
Crop residues - green						
Grass forage - natural pasture						
Grass forage - improved i.e Rhodes						
Legume forage						
Trees and shrubs						
Conserved feeds - Silage						

Conserved feeds - Hay						
Concentrates						
Homemade mixed ration**						
Codes 1: 1=All dairy cattle; 2=Lactating cows; 3=Non-lactating cows (dry)-mature; 4=Heifers; 5=calves; 6=males - bulls; 8=other (specify)____						
Codes 2: Feed as fed (fresh); 2=Fed on dry matter (DM) basis; 3=Supplementation						
Codes 3: 1=Kilogram; 2=Bale; 3=Mkungwe; 4=Litre; 5=Mpungu; 6=Ndoo; 7=Sack (25kg, 50kg, 90kg-tick); 8=other (specify)________________						
**** Homemade ration** - State ingredients and quantities____________________________________						
SECTION 9: COSTS OF PRODUCTION ON SMALLHOLDER DAIRY FARMS						
9.1 Please detail the different costs of production incurred by dairy cattle operations						
Production input costs	**Physical units**	**Where purchased**	**Who paid for this (code)**	**Total cost**	**Time linked to total cost**	
Feeding expenses						
Crop production expenses						
Fodder and pasture production						

expenses						
Animal health						
Labour costs						
Electricity						
Land costs (rental)						
Housing costs (rental)						
Spares						
Water cost						
Fuel cost						
Other						
Code						
Where purchased *1=local general store, 2=farmers' cooperative, 3=local veterinary, 9=other*						
Who paid for this*1=Yourself (cash), 2=yourself (credit), 3=Government, 9=Other*						
Time linked to total cost *1=Day, 2=week, 3=month, 4=year*						
SECTION 10: INFRASTRUCTURE						
10.1 Rate quality/availability of the following (1=poor, 9=very good)						

Fences						
Animal handling facilities						
Water sources						
Buildings/sheds						
Vehicles						
Machinery and other equipment						
Animal feeding facilities and equipment						
SECTION 11: MISCELLANEOUS INFORMATION						
11.1 Sources and reliability of information						
Type	Main sources (code)	Reliability of source (code)				
Production practices						
Input use						
Animal health issues						
Markets (physical)						
Price						

Product standards						
Traceability						
Risk management						
Code 1=Extension officer/government, 2=Newspaper, 3=Third party, 4=word of mouth, 5=None 9= Other						
Code (rank 1=not reliable. 9=very reliable)						
11.2 How has your dairy cattle business changed over the last 5 years						
more animals in herd/flock						
higher productivity of animals						
greater use of technology (breeding, AI, etc)						
diversification of herd (raising of other types of animals						
diversification of business activities (raising feed, slaughter for business purposes)						
specialization of dairy cattle activities (e.g., breeding for larger farmers)						
Other						
11.3 Constraints						

Rank the following constraints in order of importance (1=most important, 5=least important)						
Variability in prices						
Low productivity levels						
Access to markets						
Access to credit						
Access to inputs						
Access to information						
11.4 Risk						
Rank the following risk factors in order of importance (1=most important, 5=least important)						
Climate						
Disease						
Availability of inputs						
Non-payment						
Theft/corruption						
Predation						

Appendix 4: Daily milk yield record form

OBSERVATIONAL STUDY: DAILY MILK YIELD RECORD FORM									
District		**Village ID:**				**Enumerator ID:**			
Cow ID:		**Farm ID:**				**Farmers name:**			
Month		**Lactation Number**				**Date Calved**			
Date	**Milk Produced by the Cow (litres)**		**Milk given to Calves (litres)**		**Milk Sold or Delivered to Coop (litres)**		**Milk Price/litre**	**Remarks**	
	AM	**PM**	**AM**	**PM**	**AM**	**PM**			
1st									
2nd									
3rd									
4th									
5th									
6th									
7th									
8th									
9th									
10th									
11th									
12th									
13th									

14th								
15th								
16th								
17th								
18th								
19th								
20th								
21st								
22nd								
23rd								
24th								
25th								
26th								
27th								
28th								
29th								
30th								
31st								

Comments:

-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-
-	-	-	-	-	-	-	-	-

-	-	-	-	-	-	-	-	-

Appendix 5: Observational Study: Daily cow production records

Farmer name ………………………. ID ………………. Location ……………………

S. No………………

Cow name ………… TAG No. ………………. Breed ……………… Date of

Birth.………… SIRE …................

DAILY MILK PRODUCTION PERFORMANCE Month

…………………………………….

MILK PRODUCTION RECORD (Kg/Litres)					FEED SUPPLIED (Kg)	
Date	1st Milking	2nd Milking	3rd Milking	Daily Total	Daily Total	Gross Total
1						
2						
3						
4						
5						
6						
7						
8						
9						
10						
11						
12						
13						
14						
15						
16						
17						

TOTAL						

MONTHLY MILK PRODUCTION PERFORMANCE (In Kg and Ksh)

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Production													
Price/kg													
Income													
Expenses													
Profit/Loss													

Monthly Expenses: Vet costs, Feeds, Labour, Transport, Electricity etc.

ROUTINE PRACTICES RECORD

	Vaccination		Deworming		Other practices		Identification		
Date	Vaccine	Disease(s)	Worm Tests	Drug	Extra Teat(s) removal	Dehorning	Method	Position	No.(code)

HISTORICAL COW PERFORMANCE RECORD

Lactation	1	2	3	4	5	6

Date calved						
Av. Monthly Production (Kg)						
Peak Month yield(Kg)						
Peak Daily Yield (Kg)						
Days in Milk						
Lactation Yield						
Remarks						

Comments…………………………………………………………………………………………

……………………………………………………...

....

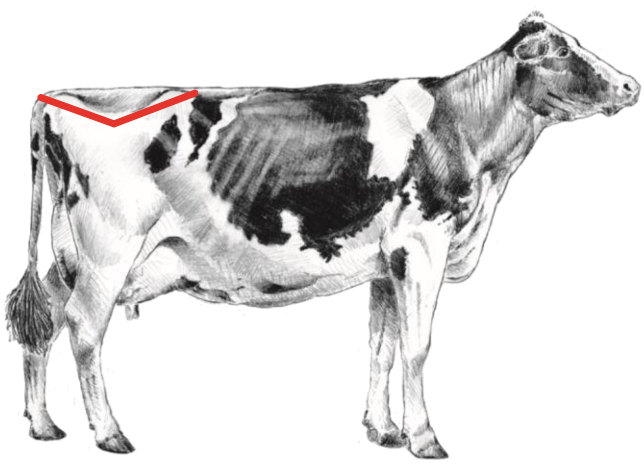
Appendix 6: The 5-point body condition scoring system – ELANCO Animal Health

Body condition scoring (BCS) refers to the relative amount of subcutaneous body fat or energy reserve in the dairy cow. BCS is an important management tool for maximizing milk production and reproductive efficiency while reducing the incidence of metabolic and other peripartum diseases.

Most body condition scoring systems use a 5-point scoring method with quarter-point increments

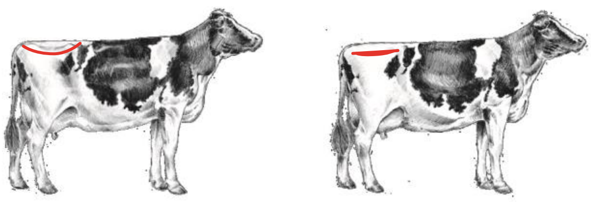
This system concentrates its accuracy toward the mid-range scores (2.50 to 4.00), which includes most cows. This mid-range is the most critical for making management decisions. Scores outside this range indicate significant problems (1.00 denotes a very thin cow, while 5.00 indicates an excessively fat cow). Exact scoring of BCS extremes is less critical. BCS is not an indication of energy balance. You should monitor changes in body condition over time.

Begin by viewing the cow's pelvic area from the side. Check the line formed from hooks to the thurl to the pins to determine if it is angular (V-shaped) or crescent (U-shaped). This is the most difficult part of the scoring process, especially if the cow is near the 3.00 or 3.25 score.



≤ 3.00: Flattened V

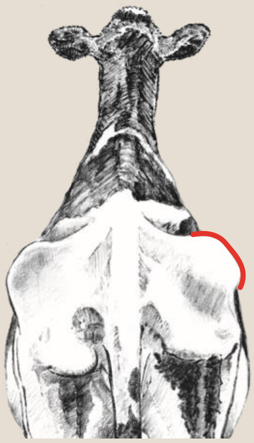
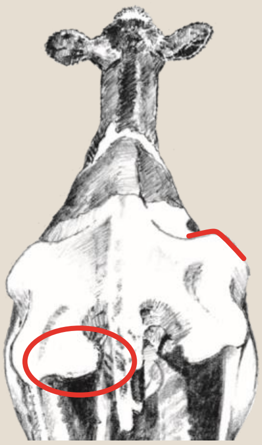
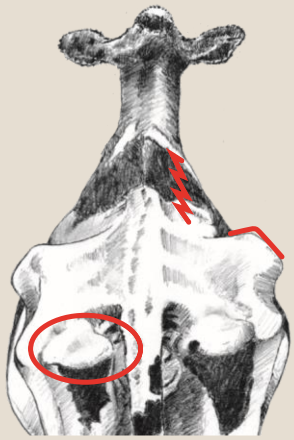
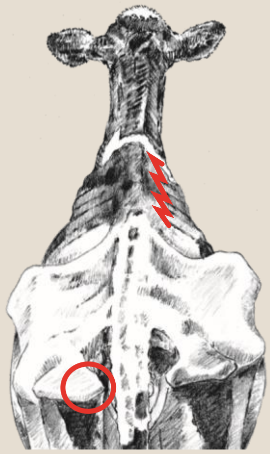
If the line forms a flattened V, then BCS ≤ 3.00. Move to the rear of the cow to view the hooks, then pins and short ribs to determine BCS to the precise quarter point. Use the guide drawings below.



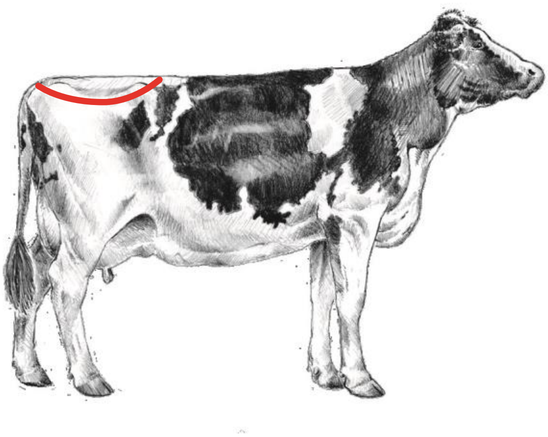
≥ 3.25: Flattened U

Turn this page over for more information.

> 4.00: Straight line

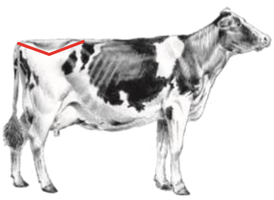
3.00	2.75	2.50	2.25
			
Hooks rounded	Hooks angular More prominent padding on pins	Pins and hooks angular Fat pad slightly palpable on point of pins	No fat pad on pins Visible corrugations halfway between tip and spine of short ribs

2.00: Corrugations visible three-fourths of the way from tip to spine	< 2.00: Thurl prominent Saw-toothed spine



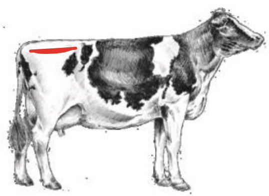
≥ 3.25: Flattened U

If the line forms a crescent or a flattened U, the BCS ≥ 3.25. Observe the sacral and tailhead ligaments next, as in the guide drawings below.



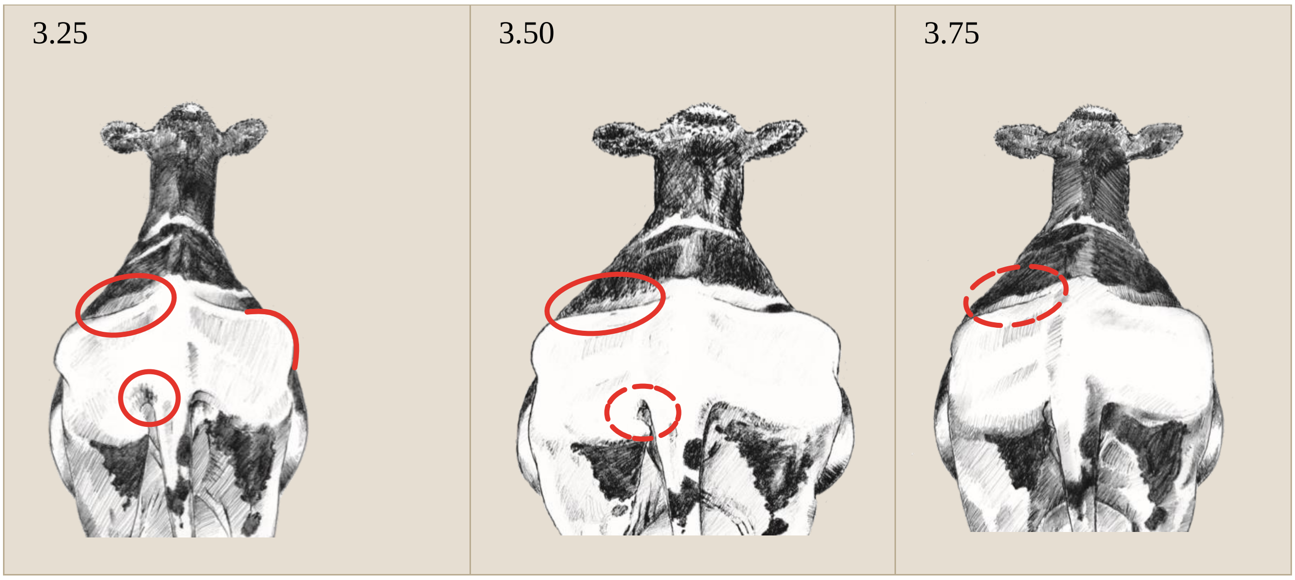
≤ 3.00: Flattened V

See reverse side.

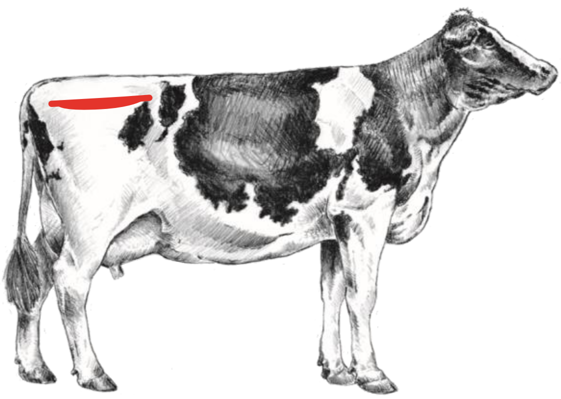


> 4.00: Straight line

See below.



Sacral and tailhead ligaments both visible	Sacral ligament visible Tailhead ligament barely visible	Sacral ligament barely visible; Tailhead ligament not visible



> 4.00: Straight line

If the line is nearly straight, the BCS > 4.00. Use the following indicators to determine the quarter-point value.

4.00: Flat thurl
Sacral and tailhead ligaments not visible

4.25: Tip of short ribs barely visible

4.50: Flat thurl
Buried pins

4.75: Hooks barely visible

5.00: All bony protrusions well rounded

Elanco

AI 10752

BCS	3.0	2.75	2.5	2.25	2.0	< 2.0
Pelvic area	V	V	V	V	V	V
Hook bones	rounded	angular	angular	angular	angular	angular
Pin bones	padded	padded	angular, fat palpable	angular, no fat palpable	angular, no fat palpable	angular, no fat palpable
Ribs	corrugations non visible	corrugations non visible	corrugations non visible	corrugations visible 1/2 way between tips and short ribs	corrugations visible 3/4 way between tips and short ribs	corrugations visible 3/4 way between tips and short ribs
					thurl non prominent	thurl prominent

BCS	3.25	3.5	3.75	4.0	4.25	4.5	4.75	5.0
Pelvic area	U	U	U	U	U	U	U	U
Tailhead ligament	visible	barely visible	not visible	not visible	not visible	not visible	not visible	not visible
Sacral ligament	visible	visible	barely visible	not visible	not visible	not visible	not visible	not visible
Thurl	non flat	non flat	non flat	non flat	flat	flat	flat	flat
Tips short ribs	visible	visible	visible	visible	barely visible	barely/not visible	barely/not visible	barely/not visible
Pin bones	visible	visible	visible	visible	visible	buried	buried	buried
Hook bones	visible	visible	visible	visible	visible	visible	barely visible	barely/not visible
								all bony prominences well bounded

Appendix 7: Feed sample Analysis Protocols

Dry matter and Ash

Materials: Crop residue samples, Aluminum weighing pans, Forced-air oven, Muffle furnace.

Procedure

1) Aluminum pans will be dried in oven at 100°C for 15 to 30 min

2) Pans will be cooled in desiccator, weighed and recorded.

3) 2g of samples will be weighed into the empty pans and record weight of pan plus sample

4) Dry pan plus sample in oven at 100°C for 12 h or overnight

5) Cool in desiccator, weigh back, and record weight

6) Place pans plus samples in muffle furnace and ash at 500°C for 3 h

7) Cool in muffle for at least 8 h, then in a desiccator, weigh back, and record weight

Calculations:

Pan plus sample weight (before drying) - Pan weight = Sample wet weight

Pan plus sample weight (after drying) - Pan weight = Sample dry weight

% DM = (Dry weight/Wet weight) x 100

Pan plus sample weight (after ashing) - Pan weight = Sample ash weight

%Ash (dmb) = (Ash weight/Dry weight) x 100

In vitro System, procedure:

Reagents for McDougall's artificial saliva (mixture of four parts McDougall's to one part ruminal fluid).

1. 9.8 g $NaHCO_3$/L
2. 7.0 g $Na_2HPO \cdot 7H_2O$/L or use 3.71 g anhydrous/liter
3. 0.57 g KCl/L
4. 0.47 g NaCl/L
5. 0.12 g $MgSO_4 \cdot 7H_2O$/L
6. 4% (wt/vol) $CaCl_2$ solution: 4 g $CaCl_2$/100 mL

***Buffer solution preparation**:*

The first five chemicals will be mixed in 500 mL of water and stir until dissolved.

Remainder of water (500ml) will then be added. Before using, 4% $CaCl_2$ solution (use 1 mL of the 4% $CaCl_2$ solution per 1 L) will also be added. The McDougall's solution, after the addition of the 4% $CaCl_2$ solution, will be placed into the 39^0C water bath and bubble in CO_2 gas until the pH of the McDougall's solution reads 6.85.

Stepwise procedure

1. 5g of each sample will be weighed out and placed into a labeled 50-mL centrifuge tube.

2. To this tube, 28 mL of the McDougall's solution will be added after McDougall's solution has been pre-warmed in 390C H_2O bath. Then 7 mL of ruminal fluid (can alter quantity, but use 4:1

ratio of buffer to ruminal fluid) will be added. Place ruminal fluid on stir plate to avoid settling. (Ruminal fluid will be strained through four layers cheesecloth before use and if possible, ruminal fluid will be obtained from at least two animals).

3. The tube will be flushed with CO_2 (gently so sample is not blown out) and inverted several times to suspend the sample, then place tubes into a rack, and place the rack into a 39^0C water bath.

4. Also, at least four blanks will be included (tubes containing **no** sample and 35 mL of the McDougall's to ruminal fluid mixture).

5. Then, the tubes will be incubated for 48 h or 72 h for comprehensive *in-vitro* culture

6. The gas production and concentration of gases (H_2 and CH_4) are automatically measured and recorded by the in vitro system and the connected gas chamber (GC). This is done at intervals depending on the pressure of gases in the fermentation bottles before it is released.

7. After 48 h of incubation, tubes will be removed from the water bath. Centrifuged for 15 min at 2,000rpm and suction off the liquid by vacuum. At this point, one may freeze samples until they can be filtered.

8. After the completion of the digestion, samples will be filtered using the modified Buchner funnel and ashless filter paper.

10. Filter paper containing the sample will be dried in an aluminum pan for 12 to 24 h. Record weights.

11. Ash each sample and record the weights. Ash at 500°C for 4 h.

Appendix 8: Feeds Nutrient Analysis Results

Feed	Class of Material	Dry Matter (%)	Moisture content (%)	Estimated Protein (%)	Energy MJ of ME/kg
Bone meal	Concentrate	75.00	25.00	6.00	8.33
Brewers waste	Concentrate	22.00	78.00	26.40	11.54
Calf pellets	Concentrate	85.00	15.00	13.00	9.25
Cassava tuber meal	Concentrate	84.00	16.00	30.00	15.70
Commercial dairy meal	Concentrate	86.00	14.00	12.00	7.74
Cottonseed cake	Concentrate	92.00	8.00	21.80	8.37
Fish meal	Concentrate	92.00	8.00	64.30	9.04
Maize bran	Concentrate	85.40	14.60	9.40	7.74
Maize flour	Concentrate	90.00	10.00	11.20	13.97
Maize germ	Concentrate	88.00	12.00	22.60	8.08
Pig finisher	Concentrate	86.00	14.00	15.00	9.20
Poultry litter	Concentrate	87.00	13.00	22.00	8.33
Soya bean meal	Concentrate	90.00	10.00	47.00	12.40
Sunflower seed cake	Concentrate	94.00	6.00	36.00	12.50
Wheat bran	Concentrate	88.00	12.00	17.80	9.04
Wheat pollard	Concentrate	90.00	10.00	16.00	15.10
Banana leaves	Crop residue	12.20	87.80	9.90	8.95
Banana pseudostem	Crop residue	5.10	94.90	2.40	8.95
Banana thinning’s	Crop	13.00	87.00	6.40	8.79

	residue				
Bean leaves	Crop residue	89.00	11.00	8.50	9.20
Courgette leaves	Crop residue	20.00	80.00	12.00	10.20
Dry Fodder sorghum	Crop residue	89.00	11.00	7.50	8.90
Kitchen waste	Crop residue	20.00	80.00	12.00	7.74
Maize (green thinning's)	Crop residue	25.00	75.00	6.20	8.28
Maize cobs	Crop residue	90.00	10.00	3.00	7.50
Maize stover (dry)	Crop residue	85.00	15.00	3.70	9.16
Maize stover (green at harvest)	Crop residue	13.00	87.00	7.70	9.20
Maize stover (soaked overnight)	Crop residue	20.00	80.00	3.70	9.16
Maize stover (soaked overnight/salt)	Crop residue	20.00	80.00	3.70	9.16
Maize waste (spoilt grain)	Crop residue	86.00	14.00	10.20	13.22
Sugar cane tops	Crop residue	30.50	69.50	5.90	8.37
Sweet potato vines	Crop residue	25.00	75.00	19.20	8.08

Coach grass	Grass	30.20	69.80	8.80	8.20
Cut grass	Grass	28.00	72.00	10.00	8.16
Kikuyu grass	Grass	20.00	80.00	12.00	9.50
Napier grass (>6 ft)	Grass	24.00	76.00	5.00	8.79
Napier grass (1 ft)	Grass	12.10	87.90	9.20	9.12
Napier grass (2 ft)	Grass	12.60	87.40	7.40	9.00
Napier grass (3 ft)	Grass	13.40	86.60	7.00	9.00
Napier grass (4 ft)	Grass	14.40	85.60	6.50	9.00
Napier grass (5 ft)	Grass	15.50	84.50	6.20	8.95
Napier grass (6 ft)	Grass	18.70	81.30	6.00	8.95
Napier grass -overgrown (>6ft)	Grass				
Rhodes grass	Grass	90.00	10.00	6.30	8.20
Star grass	Grass	30.00	70.00	11.00	8.16
Maclick super	Other	96.00	4.00	0.00	8.20
Mineral salt	Other	96.00	4.00	0.00	0.00
Molasses	Other	75.00	25.00	35.00	12.20
Lupins	Protein grain	86.00	14.00	34.00	14.20
Columbus/Sudan silage	Silage	45.00	55.00	10.80	4.77
Maize silage	Silage	32.00	68.00	8.00	10.50
Napier silage	Silage	28.00	72.00	7.50	9.00
Calliandra leaves	Tree fodder	25.00	75.00	26.30	9.00
Leucaena leaves	Tree fodder	28.00	72.00	23.00	8.40
Sesbania leaves	Tree fodder	28.00	72.00	28.20	7.74
Kales	Vegetable	20.00	80.00	12.00	9.25
Vegetables	Vegetable	11.00	89.00	33.00	12.50

Weeds	Weeds	25.00	75.00	10.00	8.16

Appendix 9: *In vitro* Analysis results for crop residues

Crop Residue	Additive	Period	Gas_48 hrs	DMD (%)	DM (%)	ASH (%)	CP (%)	FAT (%)	FIBRE (%)	ME
Bean	Urea	21	282.17	49.68	88.48	9.59	8.06	11.10	41.20	9.80
Bean	Urea	90	279.81	47.98	91.44	9.72	7.23	4.40	38.20	9.71
Bean	Urea and Mol	90	266.64	55.06	92.60	9.14	12.30	0.60	42.50	9.36
Bean	Molasses	45	269.27	55.45	90.31	10.31	9.75	12.70	28.50	9.41
Bean	Urea and Mol	21	278.96	54.95	90.75	9.60	11.40	0.50	38.20	9.74
Bean	Urea and Mol	90	269.11	54.68	92.82	8.38	12.10	0.30	40.30	9.43
Bean	Molasses	21	275.33	57.75	90.74	8.35	8.34	9.50	31.00	9.58
Bean	Molasses	45	281.71	62.78	90.87	10.17	8.38	2.20	39.50	9.79
Bean	Urea	21	253.14	50.83	88.48	17.99	6.86	12.90	37.30	8.84
Bean	Urea	45	232.51	48.85	89.70	8.47	8.14	0.50	40.30	8.19
Bean	Urea	90	237.85	54.53	91.83	9.46	8.62	4.50	34.30	8.37
Bean	Urea and Mol	45	270.91	52.95	90.31	8.22	13.20	11.20	31.90	9.51
Bean	Urea and Mol	90	217.54	55.52	90.98	8.43	10.50	0.50	33.60	7.74
Maize	Molasses	90	206.52	41.94	90.98	11.41	7.84	4.50	27.50	7.34
Maize	Urea	90	188.59	38.86	89.45	10.61	6.83	5.20	34.80	6.75
Maize	Urea and Mol	90	205.54	44.70	91.15	10.08	11.40	15.60	28.00	7.36
Maize	Molasses	21	221.00	39.81	91.60	8.67	5.24	1.40	28.30	7.78

Maize	Molasses	90	121.40	52.88	92.44	9.37	6.65	3.80	30.70	4.56
Maize	Urea	90	148.03	51.40	91.60	9.55	5.71	1.40	35.90	5.41
Maize	Urea and Mol	21	221.53	45.18	92.12	8.24	10.60	1.10	29.20	7.87
Maize	Urea and Mol	90	258.93	53.13	93.87	9.23	10.30	8.10	30.80	9.08
Maize	Molasses	45	336.48	56.40	92.53	9.53	7.02	11.70	24.70	11.55
Maize	Urea	21	237.17	46.44	92.18	8.72	4.79	3.90	35.60	8.30
Maize	Urea and Mol	45	234.81	46.56	92.02	10.09	9.45	0.50	25.60	8.28
Maize	Urea and Mol	90	269.80	54.71	92.20	8.36	9.07	3.30	30.80	9.41
Pigeon pea	Molasses	45	301.76	50.19	91.74	5.39	6.33	5.00	34.00	10.42
Pigeon pea	Urea	21	289.53	54.43	91.92	4.46	7.56	0.30	28.80	10.03
Pigeon pea	Urea	90	267.08	45.28	91.25	4.99	7.92	3.40	33.40	9.31
Pigeon pea	Urea and Mol	45	294.59	54.97	93.06	4.67	9.10	9.80	32.30	10.22
Pigeon pea	Urea and Mol	90	289.67	68.45	90.95	4.68	7.89	4.50	29.00	10.04
Pigeon pea	Molasses	90	283.23	50.09	91.56	6.54	6.80	1.70	26.90	9.82
Pigeon pea	Urea	45	348.63	61.37	91.87	4.37	7.95	0.50	39.40	11.96
Pigeon	Urea	90	236.88	46.54	91.53	5.26	8.50	3.60	29.40	8.34

pea										
Pigeon pea	Urea and Mol	21	257.30	54.99	92.72	4.51	8.95	6.70	27.60	9.01
Pigeon pea	Urea and Mol	45	288.60	56.88	91.18	4.82	8.23	5.10	26.60	10.01
Pigeon pea	Urea and Mol	90	215.99	50.93	93.11	20.08	4.11	5.60	27.50	7.60
Pigeon pea	Molasses	21	280.32	32.01	92.61	4.87	6.51	4.10	25.20	9.72
Pigeon pea	Molasses	45	244.48	48.87	92.81	7.20	7.34	1.70	30.90	8.57
Pigeon pea	Urea	21	273.78	51.12	91.39	4.10	7.21	5.90	26.10	9.52
Pigeon pea	Urea	45	277.16	49.51	91.79	5.01	7.81	7.20	34.50	9.64
Pigeon pea	Urea and Mol	45	268.02	50.48	92.75	4.82	7.84	0.30	33.80	9.34
Rice straw	Molasses	21	223.59	42.92	92.02	19.60	5.97	0.70	26.90	7.87
Rice straw	Molasses	45	222.45	42.34	92.20	20.35	4.71	1.30	25.80	7.82
Rice straw	Molasses	90	196.61	53.61	92.51	18.94	3.80	3.90	30.70	6.97
Rice straw	Urea	90	263.15	50.24	92.05	5.18	8.12	10.80	27.80	9.19
Rice straw	Urea and Mol	21	197.34	54.89	92.83	18.13	4.47	11.80	25.80	7.00
Rice straw	Urea and Mol	45	225.11	44.13	92.50	20.44	5.11	14.90	28.60	7.91
Rice straw	Urea and Mol	90	194.08	52.09	93.42	20.43	4.62	15.10	32.10	6.89

Rice straw	Molasses	90	209.23	44.67	92.48	19.23	4.29	9.40	28.70	7.38
Rice straw	Urea	21	200.26	43.60	92.56	19.23	5.34	1.00	26.20	7.10
Rice straw	Urea and Mol	45	279.41	49.17	90.10	5.31	8.25	6.60	26.60	9.72
Sunflower	Molasses	45	148.75	32.98	93.19	10.84	11.60	17.60	35.80	5.52
Sunflower	Molasses	90	207.75	39.38	91.58	10.91	11.10	5.10	35.30	7.43
Sunflower	Urea	45	95.44	27.92	91.59	11.09	13.60	12.50	32.80	3.81
Sunflower	Urea	45	208.30	39.06	90.21	9.55	14.10	6.60	23.10	7.48
Sunflower	Urea and Mol	90	186.34	41.82	90.92	10.03	14.10	14.10	34.20	6.77
Sunflower	Molasses	21	186.79	34.84	92.60	10.62	11.40	9.90	30.70	6.75
Sunflower	Molasses	90	170.87	34.50	92.23	10.39	11.80	11.30	35.40	6.24
Sunflower	Urea	21	120.19	30.32	91.86	12.00	12.50	0.80	30.70	4.60
Sunflower	Urea	45	138.16	25.14	92.44	10.94	13.50	17.40	40.60	5.20
Sunflower	Urea	21	125.75	25.40	91.00	10.64	13.50	7.00	35.60	4.79
Sunflower	Urea and Mol	45	178.13	38.37	92.33	8.38	13.40	5.10	14.70	6.50
Sunflower	Urea and Mol	90	190.23	37.49	91.02	10.14	13.80	2.70	22.90	6.89
Sunflower	Molasses	21	154.89	35.04	92.38	10.62	10.80	1.30	33.80	5.70
Sunflower	Molasses	45	201.35	42.09	90.74	12.86	11.50	7.00	24.70	7.22
Sunflower	Molasses	90	211.08	34.68	92.57	10.58	12.00	8.20	39.90	7.55
Sunflower	Urea	21	141.30	31.82	92.72	10.13	12.80	10.10	29.40	5.29
Sunflower	Urea	45	125.96	12.19	92.31	10.97	14.40	16.80	31.40	4.81
Sunflower	Urea	90	150.92	31.70	92.17	10.67	12.10	10.60	25.70	5.59
Sunflower	Urea and	21	170.44	41.25	90.84	57.43	13.40	7.80	32.10	6.25

	Mol									
Sunflower	Urea and Mol	45	182.90	39.35	90.89	11.70	14.10	7.10	29.80	6.66
Sunflower	Urea and Mol	90	178.41	34.92	91.13	9.61	13.80	11.00	44.10	6.51
Sorghum	Urea	21	192.78	49.17	91.45	10.56	13.10	1.20	25.40	6.97
Sorghum	Urea	45	212.66	52.17	92.10	8.81	11.90	0.80	28.30	7.60
Sorghum	Urea and Mol	45	201.12	47.34	91.55	8.39	14.90	0.50	27.50	7.26
Sorghum	Urea and Mol	90	223.26	47.61	90.96	8.11	13.90	7.30	25.10	7.97
Sorghum	Molasses	21	227.71	49.73	92.38	9.17	0.00	0.00	0.00	7.92
Sorghum	Urea	21	303.54	52.06	90.45	8.09	14.40	0.80	27.40	10.58
Sorghum	Urea	45	197.62	52.63	91.16	13.69	7.78	11.60	26.90	7.05
Sorghum	Molasses	90	285.24	59.26	92.10	9.16	7.10	4.40	26.70	9.89
Sorghum	Urea	21	262.85	54.53	91.71	8.63	12.90	4.40	28.20	9.24
Sorghum	Urea	45	270.21	55.49	91.96	9.45	11.40	2.90	32.70	9.46
Sorghum	Urea	90	249.73	54.58	91.88	8.79	11.30	5.20	32.30	8.79
Sorghum	Urea and Mol	21	264.40	53.28	89.91	6.94	13.20	1.30	27.20	9.30
Sorghum	Urea and Mol	45	233.00	52.13	92.05	8.12	16.70	9.30	26.10	8.32

Appendix 10: SIMLESA project forage types selected by the volunteer host farmers in Mbulu and Karatu for intensification trials

DISTRICT	**MBULU**							**KARATU**						
VILLAGE	**Hydom**			**Dongobesh**			**Tumati**	**Rhotia**			**G-Arusha**		**Ayalabe**	
FORAGE (Pasture and Fodder Types)	Loti Elisha	Filimon Joseph	Mama Emmanuel	Joseph Tarimo	Emmanuel Hosea	Henry Merichadi	Samweli Timoteo	Samweli Sehwa	Joseph	Marietha Yqamara	Samweli Paul	Titus Tseama	Leopold Francis	Marco
ILRI 16837														
KK2														
KK2/Vicia vilosa														
KK2/Desmodium														
KK2/Mucuna														
KK1														
ILRI														

16835/Vicia vilosa														
Bracharia/Desmodium														
ILRI16835														
Bracharia														
ILRI 16837/Desmodium														
Dolicos Lablab														
Vicia vilosa														
Cowpea														
ILRI 16835/Cowpea														
Mucuna														
Bracharia/Lablab														
Desmodium														

ILRI 16835/Desmodium														
KK1/Desmodium														
ILRI 16835/Mucuna														
Rhodes grass (Boma)														

RSEARCH OUPUTS