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Enhancing on-farm fodder availability and utilization for sustainable dairy production in the smallholder farming systems of western usambara highlands, Tanzania

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ENHANCING ON-FARM FODDER AVAILABILITY AND UTILIZATION FOR SUSTAINABLE DAIRY PRODUCTION IN THE SMALLHOLDER FARMING SYSTEMS OF WESTERN USAMBARA HIGHLANDS, TANZANIA

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ABSTRACT

Dairy cattle farmers in Tanzania experience a huge decline in milk production due to insufficient feed supply to their animals particularly during the dry seasons. This poses a great challenge to sustainability of smallholder dairy farming systems (SHDFSs) in the country. The aim of this study was to evaluate fodder resources availability, utilization practices and seasonal variations; as well as to assess potentials for improving pasture production and utilization in the SHDFSs of Western Usambara Highlands (WUHs), Tanzania. Integrated approaches were used in this study including review of literature, household and farm surveys, planting and evaluating suitability of four *Pennisetum purpureum* Schumach varieties (local Napier, Bana, Ouma and Kakamega 2) in improving ruminant feed availability. In addition, an experiment was conducted during a dry season to assess the potential of graded levels of homemade supplementary ration (HSR) consisting of *Calliandra calothyrsus* leaf-meal, maize bran, molasses and mineral-vitamin premixes on dairy cattle milk productivity. Results indicated that fodder scarcity was the major challenge during the dry season (July-October). On-farm fodder resources contributed most of the cattle diet. Natural pasture and Napier grass were the most important feeds in wet season and maize stover in dry seasons. Processing and supplementation of poor roughages with protein-energy concentrates were unpopular. Milk yields were 5.57 and 3.01 litres/cow/day in the wet and dry seasons respectively. The findings also demonstrated that Ouma and Kakamega 2 can be promoted in the WUHs for forage use due to higher biomass production. HSR improved the dry season milk yields significantly ($P<0.001$). Nonetheless, simulated year-round daily milk yields indicated that 4 and 6 kg HSR/cow/day would double the milk yields. There was overall significant difference ($P=0.02$) in the income to cost ratios (ICR) across the HSR levels. However, the ICR for 4 and 6 kg HSR/cow/day did not differ significantly ($P<0.05$). In conclusion, the supplementation level of 4 kg HSR/cow/day to the fibrous basal diets is suitable for profitable milk yields in the WUHs. It is therefore, recommended to increase fodder production and adopt proper supplementation practices to meet sustainable dairy production in the WUHs and elsewhere with similar environment.

Key words: Dairy cattle feeding, Smallholder dairy farming, Napier grass, feed supplementation, Milk yield, Milk quality, Methane emission.

DECLARATION

I, **David Dawson Maleko** do hereby declare to the Senate of the Nelson Mandela African Institution of Science and Technology that this thesis is my own original work and that it has neither been submitted nor being concurrently submitted for degree award in any other institution.

David Dawson Maleko **Date**

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CERTIFICATION

The undersigned certify that they have read the thesis titled "**Enhancing on-farm fodder availability and utilization for sustainable dairy production in the smallholder farming systems of Western Usambara Highlands, Tanzania**" and recommend for examination in partial fulfillment of the requirements for the degree of PhD in Life Sciences of the Nelson Mandela African Institution of Science and Technology.

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DEDICATION

This work is dedicated to the Almighty God for his Everlasting Love and Blessings.

Glory be to Him.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

LIST OF APPENDICES

LIST OF ABBREVIATIONS AND SYMBOLS

ADF	Acid Detergent Fibre
ANOVA	Analysis of Variance
ASARECA	The Association for Strengthening Agricultural Research in Eastern and Central Africa
AOAC	Association of Official Analytical Chemists
˚C	Degree of Centigrade
CARP	Community Action Research Project
CDR	Climate Data Records
CF	Crude Fibre
CLM	Calliandra Leaf Meal
CP	Crude protein
DCFBs	Densified Complete Feed Blocks
DM	Dry matter
EE	Ether Extract
FAO	Food and Agriculture Organization
GHGs	Green House Gases
Ha	Hectare
HFP	Hydroponic Fodder Production
Hh	Household
HSR	Homemade Supplementary Ration
ICR	Income to Cost Ratio
ILRI	International Livestock Research Institute
InvDMD	*In vitro* Dry Matter Digestibility
InvOMD	*In vitro* Organic Matter Digestibility
Kg	Kilogram
LEDAPS	Landsat Ecosystem Disturbance Adaptive Processing System
LSR	Leaf to stem ratio
OM	Organic matter
MAFF	Ministry of Agriculture, Fisheries and Food, Department of Agriculture and Fisheries
MB	Maize Bran
ME	Metalizable Energy

MFB	Multinutrient Fodder Block
MLF	Ministry of Livestock and Fisheries
MP	Molasses Powder
MVP	Minerals and Vitamins Premix
NDF	Neutral Detergent Fibre
NDVI	Normalized Difference Vegetation Index
NIR	Near Infra-Red
NIRS	Near-infrared spectroscopy
NM-AIST	Nelson Mandela African Institution of Science and Technology
NRC	National Research Council
PCA	Principal Component Analysis
SHDFSs	Smallholder Dairy Farming Systems
SUA	Sokoine University of Agriculture
TALIRI	Tanzania Livestock Research Institute
TSHZ	Tanzania Short horn Zebu
WUHs	Western Usambara Highlands

CHAPTER ONE

INTRODUCTION

1.1 Background of the problem

Africa has a low level of livestock protein consumption averaging at 17% of the recommended safe level intake that amounts to 58 g per person per day (The Food and Agriculture Organization of the United Nations (FAO), 2011). This insufficient protein intake might have resulted to the 40 – 60% of the sub-Saharan Africa's children to be mentally retarded or with impaired growth (The United Nations Children's Emergency Fund (UNICEF), 2007). Milk is of great importance particularly in the rural communities of Africa as a source of macro and micronutrients that improve the nutritional status of individuals and populations (FAO, 2013). It is an important nutritional resource for the wellbeing of the people and the young suckling animals (de Leew *et al.*, 1999; Randolph *et al*., 2007). It is also one of the pathways out of poverty for millions of people in these communities (FAO, 2013). In Africa demand of milk and milk products will continue to increase from their current levels as a result of population increase, economic growth, and urbanization (Tschirley *et al.*, 2015). The projected increase in dairy products demand will be due to rise in human population from the current 7.7 to 9.7 billion people coupled with increased per capita consumption (Herrero & Thornton, 2013; The United Nations "UN", 2019). Thus, enhancing sustainable livestock production including increasing milk yield is indispensable if Africa including Tanzania is to combat the long-term persisting food insecurity problem. Moreover, FAO (2011) forecasted that by 2050 the world average dairy consumption will raise to over 58% from the current consumption levels (84.9 kg/capita/year). Intensive production systems in arable lands including smallholder dairying under mixed farming systems is expected to contribute significantly towards achieving the projected dairy product demands. Steinfeld *et al*. (2006) reported that rain fed mixed production systems contributed to about 54% of the total 594.4 million tonnes of milk that was globally produced between 2001 and 2003.

Dairy farming in the tropics is a production system that focuses on converting the plenteous roughages to milk amongst other important resources including meat, leather and manure. McDermott *et al*. (2010) described smallholder dairy farms as small farms often comprising of less than 5 ha land that keep 1 to 5 dairy cows that are often improved breed (Holstein, Friesian or Ayrshire mixed with local breeds) whilst the rest of the herd comprise of few heifers or calves. Feeding system is normally “cut and carry” of fodder mainly from natural pastures, small plots of planted pastures and crop residues such as of maize, rice, beans and sorghum. The commonly established pasture is Napier grass (*Pennisteum purpureum*). Moreover, average milk production per farm under smallholder dairy farming systems (SHDFSs) is about 10 kg per day of which 25% is for home consumption and the rest is for sale to mainly neighbours and to a limited extent to traders and processors. Smallholder dairy production is important to the world rural economies in which it increases access to animal protein and household income including empowering women through sell of surplus milk (FAO, 2011).

In Tanzania, dairy farming has been mainly adopted by smallholder farmers in densely populated high rainfall areas including highlands whereby crops, few livestock and trees are integrated in limited units of land. Most smallholder farmers rely on on-farm resources for feeding their livestock that often fluctuate seasonally both in terms of quantity and quality (Kavana & Msangi, 2005). Pasture is always plenteous during wet season often exceeding animal requirements but scarce in dry season. At times of fodder scarcity most smallholder farmers are forced either to underfeed the animals or purchase fodder and concentrates. The latter option is rather unaffordable to most poor smallholder dairy farmers who normally tend to underfeed their animals resulting to decline in milk productivity (Lukuyu *et al.*, 2015).

Most smallholder dairy farmers have adopted a number of technologies for improving productivity including crossbreeds of dairy cattle, control of diseases through vaccination, deworming and dipping/spraying of acaricides and pasture establishment though in small scale. However, productivity is still poor in terms of milk yield, calving rate, growth rate, body size, and delayed maturity. For example, the average milk production per improved cow (Friesian-Boran cross) under smallholder conditions in Tanga region is 4 and 8 litres in dry and wet seasons, respectively (Cadilhon *et al.*, 2016). Whilst, the recommended milk production potential for improved dairy cattle breeds in East Africa is between 15 and 20 litres per cow per day (Lukuyu *et al.*, 2015). Inadequate supply of good-quality animal feeds is amongst the major hindrances for constant year round high milk production in Tanzania and East Africa at large (Njarui *et al.*, 2011; Swai & Karimuribo, 2011; Kabirizi *et al.*, 2013).

Nonetheless, Cadilhon *et al.* (2016) reported that Tanga Fresh Limited which is the largest operating milk processor in Tanzania has ability to absorb 60 000 lts of milk per day but receives only 50 000 and 30 000 lts per day in wet and dry seasons, respectively. This low milk productivity is in converse to milk requirement that is increasing in Tanzania concurrently with human population increase at about 3% per annum, and the emerging of middle income class (National Bureau of Statistics (NBS), 2013). It is therefore, imperative to come up with innovative technologies and practices that will enhance sustainable milk production and improve social welfare.

1.2 Statement of the problem

The most limiting factor for increased milk production in East and Southern Africa is mainly low levels of energy and protein in the animal diets especially during dry seasons (Romney *et al.,* 2003). During dry seasons grasses and dried crop residues such as maize stover have low nutritional value, digestibility and acceptability (Ogle, 1990). Hence, necessitating supplementation which is not a common practice to most smallholder dairy farmers, major bottleneck being higher prices of concentrates such as maize bran, sunflower seedcake and molasses (Kaliba *et al.,* 1997; Romney *et al.,* 2003). Nevertheless, the culture of forage production and preservation in terms of hay or silage for feeding during dry seasons is not common. Also, where leguminous fodder trees, pasture and crop residues are plenteous available in wet season there is no strategic feeding that include proper reserving for future use. There is evidence that among the contributing factors for low adoption of improved technologies is the existing tendency of most technologies to be developed and tested on-station and with limited emphasis to suite smallholder needs and local environments (Peters & Lascano, 2003; Moran, 2005; Lukuyu *et al.,* 2011; Owen *et al.,* 2012).

Dry season decline in milk yields due to inadequate supply of good quality feed is prevalent in Tanzania SHDFSs (Swai & Karimuribo, 2011; Cadilhon *et al.,* 2016). Therefore, there was a need to find solutions for enhancing on-farm fodder availability and proper dairy cattle feeding for improving year-round milk production.

1.3 Rationale of the study

This work aimed at contributing into generating new information on innovative feed production and feeding strategies for closing dry season feed gaps in smallholder dairy farms. This included promotion of fodder production, processing and use of on farm grown leguminous fodder tree leaves to replace locally unavailable and expensive protein concentrates. Reduction of overreliance to bought-in animal feeds is deemed to be essential for reducing production costs and environmental pollution (Ogle, 1990; Bwire & Wiktorsson, 2002). This information is of paramount importance to a number of stakeholders including policy makers for helping in planning and designing proper intervention strategies for facilitating sustainable smallholder dairy productivity in Tanzania.

1.4 Objectives

1.4.1 General objective

The overall objective of this study was to improve the nutrition of dairy cattle in the smallholder farms through development and application of innovative and sustainable animal production and feeding technologies for optimization of on-farm feed resources. The major intent was to improve milk production for enhanced household income and food security among the smallholder dairy farming communities.

1.4.2 Specific objectives

(i) To evaluate the current dairy cattle feeding practices and their limitations to dairy productivity under smallholder farming systems in the Western Usambara Highlands, Tanzania;

(ii) To assess the effect of season change on quantity and quality of different on-farm feed resources in the smallholder dairy farming systems in the Western Usambara Highlands, Tanzania;

(iii) To test innovative fodder production and feeding strategies for improving dairy cattle productivity among smallholder farmers of Western Usambara Highlands, Tanzania;

(iv) To assess the effect of the innovative feeding strategies on the year round dairy cattle productivity using a LIFE-SIM simulation model.

1.5 Research questions

(i) What are the current dairy cow feeding practices among the smallholder farms of West Usambara Highlands, Tanzania? Are the rations quantity and quality sufficient?

(ii) To what extent seasons affect the quantity and quality of different on-farm feed resources in the West Usambara Highlands' smallholder farms, Tanzania?

(iii) Can innovative fodder production and feeding strategies improve on-farm dry season feed resources availability and dairy cattle productivity in the smallholder farms of West Usambara Highlands, Tanzania?

(iv) What is the potential year-round milk productivity of dairy cows under different feeding scenarios?

1.6 Significance of the study

Dairy cattle convert low quality feed materials to products which are useful to humans (milk, meat, manure and leather). Farming of these animals has become popular in developing countries such as Tanzania and it is among the major means for improving food security and income in the smallholder dairy farming communities and mainly rural households. However, less profitability is commonly reported in enterprises involving dairy cattle farming in recent years. This situation is mainly caused by decline in feed supply particularly during dry seasons leading to decline in milk production and hence poses a great challenge to sustainability of smallholder dairy production systems in countries such as Tanzania. Interventions for improving feed supply are highly needed to enhance sustainability and profitability particularly in the SHDFSs. This study was designed to contribute solutions for curbing dry season dairy cattle feed scarcities and this was done through: (a) review of the strategies for combating dry season feed scarcities in the SHDFSs including those in the Western Usambara Highlands (WUHs) of Tanzania, (b) assessing seasonal fodder resources variations in a selected SHDFS, (c) designing and carrying out on-farm experiments for improving sustainable forage production under smallholder farming environments, and (d) optimizing the utilization of local protein and energy concentrated feed resources in terms of milk yield and quality, and financial profitability. The findings of this study are envisaged to be beneficial to a range of stakeholders including dairy farmers, practitioners and policy makers and for facilitating informed decisions.

1.7 Delineation of the study

The study is delimited to the followings:

(i) The research focused on improving dry season on-farm fodder availability (quantity and quality) and utilisation for sustainable dairy cattle productivity in the smallholder production systems of Western Usambara Highlands in North Eastern Tanzania.

(ii) Four varieties of Napier grass were evaluated as feed for ruminants through planting trials that were set in the Western Usambara Highlands in North Eastern Tanzania. Possibility to explore on forage conservation in form of silage and feeding the ensiled Napier grass to dairy cattle could generate useful information for enhancing sustainable dairy production in smallholder farming systems.

(iii) The experiment on assessing the effects of dry season supplementation of *Caliandra calothyrus* leaf-meal mixed with maize-bran on dairy cattle milk production was conducted for only 45 days during dry season. The possibility to conduct it for a longer period (both dry and wet seasons) together as involving a significant large number of smallholder dairy farmers (men and women) would generate useful information for enhancing adoption.

CHAPTER TWO

LITERATURE REVIEW

2.1 Dairy cattle feed resources in smallholder farming systems

Dairy cattle feed resources include natural pasture that comprises of grasses and forbs naturally growing in farms in form of weeds. On-farm feed resources also include established pasture such as Napier (*Pennisetum purpureum*) and Guatemala (*Tripsacum laxum*) grasses, fodder trees such as Calliandra (*Calliandra calothyrsus*), mulberry (*Morus alba*), leucana (*Leucaena leucocephala*) and *Acacia spp*. Grasses and fodder trees can be grown within the farm boundaries, contour strips or in plots and are the major feed resources for livestock. Crop residues obtained from seasonal crops such as maize, beans and rice are also important feed resources for dairy cattle. Although crop residues are of low nutritional quality they play an important nutritional and feeding role for dairy cattle and other livestock.

2.1.1 Pasture as livestock feed

Natural pasture including herbs (grasses and forbs) and fodder trees is the most plenteous and cheapest source of feed for ruminants in tropical countries (de Leew *et al.,* 1999). The grassland cover for the African continent is about 51% and in Tanzania grasslands, shrublands and woodlands together cover 42.5% (Mayaux *et al.,* 2004). Over 90% of the ruminant livestock in Africa are reared in rangelands where grass is a key feed resource (FAO, 1991). Despite the key role of natural pasture in supporting ruminant livestock seasonal immense variations in both quantity and quality (nutritive value) of the herbage is amongst major setback towards its reliability for sustainable milk production (Stobbs & Thomson, 1975; Ramírez-Rivera, 2019). Decline in protein quantity and digestibility during dry season preclude its reliability for dairy cattle production due to insufficient nutrient supply that are needed for maintenance and production (Van Houtert & Sykes, 1999). For tropical grasses, when the CP levels drops below 7%, animal voluntary intake of DM is depressed and leads to loss of body condition (Whiteman, 1980). In contrary to grasses, the CP content of most legumes including fodder trees and shrubs such as *Acacia, Gliricidia* and *Leucaena* species remains over 15% even in dry season (Estell *et al.,* 2012). However, the recommended inclusion of leguminous fodder in ruminant diet should not exceed 30% due to presence of anti-nutritional factors such as tannins and lectins which in most cases lower levels of animal productivity in terms of milk and meat (Wang *et al.*, 1996). Thus, seasonal low levels of CP in many pasture based tropical animal production systems is crucial cause of low animal production (FAO, 1991). Another constraint is the ongoing rapid conversion of natural grasslands into croplands or protected areas, thus limiting availability of natural pasture to ruminant livestock under extensive production systems (Herrick *et al.,* 2012).

Due to aforementioned constraints of natural pastures practices and technologies for improving year round pasture availability are normally advocated. These practices and technologies include over-sowing of natural pasture with superior pasture species, establishment of improved pasture, promotion of fodder trees and legumes, effective use of crop residues and forage conservation. Napier, Guatemala, buffel grass (*Cenchrus ciliaris*) and Rhodes grass (*Chloris gayana*) are among high yielding fodder grass species that are highly promoted to improve livestock feed availability in tropics. However, availability of pasture seeds and prolonged droughts are still major hindrances towards wide adoption of pasture production technologies (Baruch, 1994; Rusdy, 2016). This implies that efforts for investigating on efficient ways for enabling smallholder farmers to access and produce pasture seeds or planting materials locally are necessary.

2.1.2 Crop residues as livestock feeds

Mixed crop-livestock farming systems constitute the main economic activity for more than 80% of the population of developing world, contributing about 50% of world cereal production, 34% of world beef production and about 30% of world milk production (Blümmel *et al.*, 2009). In East Africa, the rapid increase of both human and livestock populations within limited land has put high pressure on the dominant mixed crop-livestock systems towards meeting the competing demands for human food and animal feeds (De Groote *et al.*, 2013). McDowell (1988) reported that crop residues including maize, beans and rice straw contributed 35 to 45% of the livestock feed demand and about 25% of the energy required by ruminants in Kenya. In Tanzania, agro-pastoralism is a dominant production system in which crop residues mainly maize stover and beans haulm play important role of energy provision to ruminant livestock especially in dry season. However, straw based crop residues are characterized by low levels of nutrients with CP of about (260 g/Kg DM) and ME of 7.5 MJ/Kg DM. Also, macro minerals in particular such as P and Ca tend to be low, thus necessitating supplementation (Chenost, 1986). According to Moran (2005), tropical fibrous crop residues have inherently low acceptability, palatability and digestibility due to high fibre content (>18%).

Treatment of crop residues increases acceptability, palatability, and digestibility of straw-based feeds and thus it is an important feed management activity. Treatment by spraying molasses and urea on feeds followed by ensiling is recommended for increasing intake. Treatment of crop residues with a Nitrogen (N) source such as urea or ammonia is reported to increase the N content of the material by 0.5 -1.5%. Eventually, enabling the rumen microbes to synthesize protein more efficiently due to increased N availability (FAO, 1985). Moreover, Preston (1995) reported that ammonia treatment on cereal crop residues increased organic matter digestibility by 5-10% units and *ad libitum* intake by 25-50%.

Orskov (1993) recommended rate of 5% of urea when treating crop residues. The author showed that lesser rates are ineffective and increasing the rate to 7% gave insignificant results. However, higher rates pose higher risks of ammonia toxicity which is lethal to cattle. Despite high use of crop residues as feed for livestock in Tanzania, proper handling including harvesting and storage for dry season use is still limited, most farmers still neither chop nor treat fibrous straws. Thus, on-farm interventions to enhance effective crop residue use for enhancing livestock productivity are worth undertaking.

2.2 Forage conservation practices and technologies

Conservation of excess forage for future use (dry season or winter) in form of hay, silage, leaf meal or straws is a widespread practice in the developed world but still evolving in most developing tropical countries including Tanzania. Generally, labour demand (low mechanization level), transport costs, limited storage facilities and low awareness level are reported to contribute to limited adoption of forage conservation technologies in the developing world (Peters & Lascano, 2003; Owen *et al.*, 2012).

2.2.1 Hay

Hay is a cut grass and dried to about 15% water content for future use. Leafy grass species with thin stem such as *C. gayana*, *C. ciliaris* and *Cynodon spp.* are most suitable for hay making as they are simple to cure. It is recommended that grass for hay making should be cut at the blooming stage and on dry weather to avoid molding (Gallaher & Pitman, 2000). According to these authors, harvesting at this stage is deemed appropriate based on the fact that the pasture has already accumulated ample biomass and its nutritive value is still high. The dry grasses can be stored in dry places in a loose form but baling is always recommended in order to facilitate easy handling and optimization of storage space.

Hay making is not a common practice under SHFSs of Tanzania despite previous interventions such as promotion of making and using of simple hay-making box (Massawe & Mruttu, 2005). Currently hay making is mainly practiced in farms managed by the livestock research and training institutions, and some commercial dairy farms (Kizima *et al.,* 2013). In a few places including Njombe region in southern highlands of Tanzania for instance, establishment of Rhodes grass and hay making is gaining popularity due to long-term interactions between farmers and pasture researchers (Sundstøl, 2013). Hence, popularization of this practice through overcoming the adoption barriers and devising appropriate solutions will reduce dry season feed stresses.

2.2.2 Silage

Silage is a chop and anaerobically fermented succulent forage plant (60-80% moisture content) preserved in airtight conditions for future use (Horrocks & Vallentine, 1999). Silage might be considered as an alternative to hay. This is because hay making from growing thick-stemmed and succulent grass species such as Napier and Guatemala grass, and crops such as maize (*Zea mays*) and *Sorghum spp* in wet and cold environments is practically impossible. Alternatively, silage making that begins with cutting of green grasses at early stages with only 12-15% DM followed by wilting to about 30% DM and chopping to small cuttings normally less than 3 cm. Thereafter, ensiling the chopped forage under anaerobic conditions to preserve as silage is considered to be the best option (Moran, 2005). Silage making provide opportunities to store surplus forages even during wet season and allow pasture re-growth. Silage making is not a common practice in Tanzania and this situation leads to considerable loss of valuable forage resources in wet areas (Mtengeti *et al.,* 2013). Under smallholder conditions; Moran (2005) recommended making of silage using plastic containers, earth silos or nylon bags and use of locally soluble fermentable carbohydrate additives and proteins such as maize bran (5-10%) or molasses (3-5%) and legume leaves such as alfalfa (*Medicago sativa*).

2.2.3 Leguminous fodder trees leaf meal

Leaf meal is a product of dry leaves made from protein-rich fodder legumes such as *Leucaena, Calliandra, Sesbania, Gliricidia* and *Acacia* species for supplementing poor roughages especially during dry seasons. It is recommended that leaf meal should not exceed 30% of daily ration of the ruminant livestock diet due to their inherent toxicological effects (Wang *et* *al.*, 1996). Franzel *et al.* (2007) reported that about 61% of the dairy farmers in Tanga region use leucaena leaf meal as a protein source to supplement their stall-fed dairy cows. Unfortunately, packaging or processing of the leaf meal into blocks or pellets for maximizing animal intake, nutrient concentration and transport/handling is not well established.

Kakengi *et al.* (2001) reported that milk yield in grazing dairy cattle supplemented with *L. leucocephala* leaf meal, cotton seed hull and maize bran at a proportion of 2.6, 1.8 and 1.8 kg DM/day increased by 6.7 lt/cow/day in the semiarid Western Tanzania. Therefore, it is imperative to promote the use of leaf meals through innovative technologies for improving production and feeding. This is based on the fact that leaf meal can be easily and locally produced at relatively lower costs than purchased oilseed based protein concentrates including sunflower and cotton seedcakes which are expensive and unaffordable to most smallholder dairy farmers.

2.3 Agricultural byproducts as concentrate feeds

These are concentrated source of energy or protein to livestock and they contain less fibre (below 18%). These are important for supplementing poor roughages that contain insufficient amounts of proteins, energy and other essential nutrients and which cannot meet the physiological demand of highly producing dairy cow (McDonald *et al.,* 2011). The commonly used plant-based protein concentrates are mostly agricultural byproducts including cotton seed cake, soya bean cake, copra cake, simsim, sunflower cake, groundnut cake/meal, cashew nut cake. Protein concentrates of animal origin including fish meal, blood meal and meat meal, also exist but are not commonly used in dairy cattle feeding due to higher costs, animal health and unacceptability (smelly) reasons. Energy concentrates are mostly of cereal grains and cereal by-products origin including maize bran, wheat bran, wheat pollards and rice polishing (Moran, 2005). Mineral and vitamin concentrates are also used in feeding of dairy cows to ensure adequate supply of essential minerals to meet maintenance, reproduction and production requirement of the animals. The most essential mineral elements include calcium, phosphorus, sodium and iron, copper, iodine and selenium. Vitamins include A, D, B1, B2, B6 and B12 that are very limited in poor roughages (McDonald *et al.*, 2011). Plaizier *et al.* (1999) reported a 1.5 lt/cow/day increase in milk yield in smallholder farms of rural Morogoro when the dairy cattle were supplemented with Urea molasses mineral blocks. In general, concentrates are of paramount importance and enable dairy cows to achieve their maintenance and production requirements. However, over feeding can lead to bloating, acidosis and economic losses (McDonald *et al.,* 2011), and therefore it should be avoided. Also, feeding of dairy animals with plant-based cereals and beans products which are essentially needed by humans increasingly becoming questionable due to food security and environmental concerns (Herrero *et al*., 2010).

The tradition of over-relying on imported soybean in the developed world for feeding dairy cows where they can produce up to 40 lt/cow/day of milk is increasingly being discouraged, and a move towards use of locally produced concentrates is being advocated (Blümmel *et al.,* 2009; Herrero *et al.,* 2013) to minimize production costs. Conversely, in the developing countries including Tanzania there is underutilization of concentrates leading to dairy cattle to fail to meet their milk production potential (Geerts, 2014). This suggests a need to investigate on economic, social, healthy and environmental friendly local resources for protein, energy and minerals to improve dairy productivity in Tanzania.

2.4 Promising feed technologies in the Eastern Africa smallholder dairy farming systems

2.4.1 Multi-nutrient feed blocks

Multi-nutrient fodder blocks (MFBs) are compounded feeds which are molded into blocks of various sizes depending on target species and technology used. These contain/comprise of energy, protein, vitamins, minerals and other essential nutrients (Walli *et al.,* 2012). Multi-nutrient fodder blocks can be manufactured as Densified Total Mixed Ration Blocks (DTMRBs) also called Densified Complete Feed Blocks (DCFBs). The Densified Total Mixed Ration Blocks have been shown to have a potential for supplying balanced feeds to dairy cows and other livestock in the tropical regions (Owen *et al.,* 2012). The application of pressure to compress the blocks reduces bulkiness and increases density hence nutrient concentration. Also, blocks reduces bulkiness of loose roughages that are difficult to handle, expensive to transport and consumes large storage space (Walli *et al.,* 2012). The technology of making DTMRBs has been commercialized in India and the manufacturing factories exists in different states under the dairy cooperative unions. In India, DTMRBs have reported to increase milk yield to over 14% and reduce feed costs by 34% (Walli *et al.,* 2012).

In East Africa, MFBs technology was tested in some farms in Uganda, Kenya, Burundi and Tanzania whereby a 10% milk yield increase is reported (Association for Strengthening Agricultural Research in Eastern and Central Africa (ASARECA), 2013). Despite this success, efforts towards developing this technology in Tanzania with emphasis of use of on-farm resources are still essential. The ASARECA trials amongst other ingredients used 15% cotton seedcake, 30% molasses and 6% calliandra leaf meal. In Tanga region, where the use of leucaena leaf meal is reported to be prevalent (Franzel *et al.,* 2007; Mangesho *et al.,* 2017), efforts towards optimizing the opportunity by incorporating it into MFBs are worth undertaking towards improving the nutrition of dairy cows.

2.4.2 Hydroponic fodder

Hydroponic fodder production (HFP) is a technology that involves growing of cereal and legume seeds under controlled moisture and nutrient solutions without the need of soil. The green shoots and root mats are harvested within few days (less than 10 days) for feeding livestock. The HFP systems are gaining popularity in some tropical countries including India, Kenya and Ethiopia where it has shown to improve nutritive value of cereal and legume seeds including maize, barley and oats. Hydroponic fodder production is reported to increase the digestibility of the nutrients in ration comprising of low quality roughage which could contribute towards increase in milk production between 8 and 13% (Naik *et al.*, 2014; Naik *et al.*, 2015). Moreover, increase by 36% DM and 2-4% CP of the original barley seed was reported by Tranel (2013). Furthermore, Tranel (2013) elucidated that the initial investment cost of basic HFP system was 2795 United States Dollar (USD) for a 16 tray unit, labor inputs of 9 minutes per tray and seed costs of 0.12 USD per pound. However, these costs might be higher for developing world smallholder farmers, thus innovating on making use of locally available material in system design is inevitable. Investigation on use of seeds from local legume and cereal species instead of using imported barley and oat is essential for reducing seed costs.

For example, Shayo *et al.* (2001) reported a well-established traditional practice of producing green malt of germinating finger-millet seeds on damp burlap bags in thick layers of up to 10 cm for 2-3 days at 25-30^{o}C in northern Tanzania. Whereby, the green malt is dehydrated through sun-drying, ground and fermented to produce traditional liquor materials. Nonetheless, Tiisekwa *et al.* (2000) reported that maize, finger-millet and sorghum grains are germinated on polythene films covered by mats that are moistened to form malt in many parts of Tanzania were they are locally grown for food and traditional brew. Therefore, there is a potential for building upon this local knowledge of germinating cereal seeds under soilless conditions through inducing skills for HFP using locally available materials to produce hydroponic fodder for improving dairy nutrition. This might be worth undertaking where conventional green fodder cannot be grown successful, for example in densely populated urban and peri-urban areas where land is very scarce. However, economics and biomass aspects of HFP enterprise need to be keenly investigated before government and firms promote the HFP wider adoption in a given locality (Tranel, 2013). This implies that apart from grass and crop residues based feeds that grown directly on the soil, hydroponic technologies also have potential for improving dairy nutrition.

2.5 Dairy cattle nutritional requirements

According to the National Research Council (NRC) (2001) for the dairy cow to meet the energy requirements for maintenance, activity e.g. chewing and walking, milk production, pregnancy and gaining condition needs a diet comprising of at least 10 MJ/kg DM of ME. The total DM intake in form of forages and concentrates requirement per day of dairy cow needs to be between 3 to 4% depending on its live body weight, lactation stage and body condition. Generally a CP value ranging from 10 to 16% is recommended. Also, dairy cattle need fibre which is essential for preventing rumen acidosis especially for animals being fed grains or cereal and associated starch-rich by-products. Fibre fractions in the diet need to be about 30% NDF, 19% ADF or 17% CF (Moran, 2005). Grasses are more fibrous than legumes and as grass matures the concentration of hard to digest or indigestible plant cell-wall materials including lignin, cellulose and silica also increases. Determinations of digestibility (DM and OM) of fibrous forage resources is essential indicator of potential nutrients availability to ruminants fed forage based rations. For example, a forage grass either being green/fresh, in form of hay or silage is only considered of good quality when the dry matter digestibility is at least 65% (NRC, 2001).

Furthermore, dairy cows need other macro and micro elements in the diet including the major minerals such as Ca, P, Mg, K, Na, S, and Cl (g/ Kg DM), micro-minerals such as Co, Cu, Fe, I, Mn, Zn, Se and Mo as well as vitamins. Macro minerals are essential for maintenance and production and needed in large amount compared to micro minerals. Although micro minerals are required in smaller amounts, they are needed for effective animal performance. Most of the minerals are supplied by forages but for high producing animals they must be supplemented in forms of mineral licks or through in-cooperating in appropriate amounts during compounding of dairy meals. As for vitamins, A (retinol) is essential for proper animal sight, D plays a very important role in Ca and P immobilization and storage in the bones to prevent milk fever.

Vitamin E is important for strengthening the immune system of the animal. Vitamin deficiency can be a problem for full housed stall fed cattle but uncommon to dairy cattle grazing in green forage (McDonald *et al.,* 2011).

It is a practice of most farmers to provide grasses to their animals which are nutritionally poor and lack many nutritional elements particularly minerals and vitamins. It is therefore important to supplement the animals with feed resources which can provide the lacking elements. Supplementation depends on several factors and the major aim is to sustain higher milk yield. Before supplementation is done managers should consider the physiological state of the animal such as whether the animal is lactating or lactating pregnant is important. Moreover, milk responses to supplementary feeding depend on stage of lactation, the amount and quality of supplements that most of the times are unknown to smallholder dairy farmers. For some elements e.g. protein, the requirements for dairy cows depend on body size, milk production, stage of pregnancy and weather, On the other hand, water is vital for maintenance and productivity of dairy cattle in which 70 to 75% of its live weight is water and about 87% of milk is water (NRC, 2001). A dairy cow weighing 350 kg live weight requires about 60 to 70 litre of water per day for maintenance, and 4 to 5 litre for each litre of milk produced (Moran, 2005).

Therefore, assessing the nutritive values of locally available feed resources is essential for informing effective basal forage feeding and ideal ration supplements.

2.6 Dairy farming in the interface of climate change

Carbon dioxide, methane and nitrous oxide are among the greenhouse gases (GHGs) of primary concern when it comes to anthropogenic driven climate change and global warming (International Panel for Climate Change (IPCC), 2014). Despite the crucial role of livestock sector in food security and livelihood support to the rural poor in developing world yet it contributes substantially to the global GHGs emissions (Steinfeld *et al.,* 2006). Livestock including dairy cattle contributes about 12% of the total global anthropogenic based GHGs emissions (Havlík *et al.*, 2014). Enteric fermentation and gas eructation, as well as manure excretion (faecal and urine) are the major sources of methane and nitrous oxide gas emissions (Moss *et al.,* 2000). Cut and carry of fodder including crop residues with minimal retention/mulching, as well as poor manure management practices are major sources of GHGs emissions and soil nutrient loss in SHFSs (Rufino *et al.,* 2006). On the other hand, GHGs emissions related to deforestations, wildfires and soil degradation are attributed to milk production under extensive agro-pastoral (mixed) production systems. Whereas, reliance on imported concentrate feeds (e.g. cereals and soybeans) with high GHGs emission coefficients is a downside of the intensive commercial dairy production systems (Herrero *et al.,* 2013).

Milk production systems in the Eastern Africa contributes significantly to GHGs emission due to large number of animals and large land sizes that are inefficiently used in striving to meet the milk demand (Herrero *et al.,* 2008). Sustainable intensification through optimal on-farm production and utilization of feed resources offers a promising future for climate change adaptation as well as for mitigation in SHFSs (Havlík *et al.,* 2014; Brandt *et al.,* 2019). For example, the practice of growing tree fodder legumes in the smallholder farms apart from providing nutritious feeds to livestock also sequesters carbon both below and above the ground (Dawson *et al.,* 2014). Brandt *et al.* (2019) observed that intensifying dairy production in Eastern Africa through improving forage quality and concentration supply has potential for improving milk yields by 44-51%. Also, these authors quantified that simultaneously the intensification will decrease the intensity of GHGs emissions from the current 2.4 ± 0.1 to 1.6 ± 0.1 kg CO_2 equivalents per kg of milk.

A number of studies have indicated that improving feed quality and proper feeding improves feed conversion efficient to valuable products such as milk and meat *inter alia* reducing GHGs emissions (Moss *et al.,* 2000; Herrero *et al.,* 2013; Havlík *et al.,* 2014; Herrero *et al.,* 2016). For example, improving protein content of poor roughage basal feeds fed to ruminants through provision of fodder legumes or concentrates decrease methane emissions (Moss *et al.,* 2000). Options for adaptations and mitigations of climate change in SHFSs include effective on-farm pasture production and utilization e.g. grasses and leguminous fodder trees (Muir *et al.,* 2014). Also, selection of crop species including varieties and hybrids capable of producing optimal yields of good quality food and feeds in given climatic conditions are among the adaptation strategies (Chagunda *et al.,* 2015). However, limited farmland sizes, lack of investment capital, low technical knowhow and high labour costs have been challenges for adoption of smart climate change adaptations and mitigations technologies under the SHFSs (Thomas & Sumberg, 1995; Toth *et al.,* 2017). Therefore, investigations on how to produce optimal milk yields with minimal GHGs emissions are vital undertakings for fostering the sustainability of SHFSs.

2.7 Role of simulation models in dairy farming decisions

Simulation models are mathematical or graphical representation of the real world 'entities' (e.g. weather, time, soil, animals, feeds, money) and 'activities/processes' (e.g. feeding, digesting, growth, milk synthesis, excretion, transporting and marketing) and their logical interactions with a given system (Ören, 2011; Ifenthaler, 2012). Normally computer program(s) are used in the systems modeling environment. Simulation models are important tools for informing management decisions in agricultural production systems including dairy farming (Tedeschi *et al.,* 2014). Simulation models have shown not to be 100% accurate in predicting the impacts of different management decisions or scenarios (Table 1). However, they are still useful for enlightening and forecasting the unforeseeable effects/futures and with capability of considering both human controllable and uncontrollable factors (Tedeschi, 2006). For example, the current concerns for ensuring that food production do not compromise the current and future environmental, socio-economic and political integrity can be addressed through production systems modeling (Havlík *et al.,* 2014). At farm level, models can assist the manager or farm advisor on the best feeding, breeding and marketing strategies for enhancing sustainable productivity and profitability (León-Velarde *et al.,* 2006; Rufino *et al.,* 2009).

There a number of modeling platforms for optimizing dairy productivity ranging from individual animal, herd, regional to global models (Tedeschi, 2006). However, the major challenge with most simulation models when it comes to smallholder production systems has been data scarcity (Thornton & Herrero, 2001). Poor record keeping and weak institutions culminating to limited agricultural advisory services are among the causes of data scarcity (Minoe *et al.,* 2003). In addition, lack of financial capacity for purchasing equipment for performing routine yet accurate on-farm direct measurements of various farm productions attributes (quantity and quality) further complicates the matter. Farm attributes such as soil, feed, animal physiology (feed intake, digestion, excretion and reproduction), animal products (e.g. milk and meat), water availability and weather conditions are necessary for proper decision making. Farm level to regional decisions such as what feed types (quantity and quality), breeding program (natural or artificial), population control (culling or cropping) up to product management (sell raw, process or where to sell and at what prices) requires reliable data and information. Scarcity of data and given ability of simulation models to emulate the system and generate data for helping informed decision making are making them attractive.

Table 1: A list of selected simulation models for predicting cattle performances under different feeding regimes.

Model (Reference)	Inputs	Outputs	Mean prediction error
RUMINANT (Herrero *et al.*, 2002; Herrero *et al.*, 2013; Shikuku *et al.*, 2017)	Animal data (breed, weight, age, parity etc.) and feed type, quantity and quality (ash, fat, carbohydrate and protein concentrations)	Milk and meat, manure production, N excretion, and methane emissions	Model has a feed intake prediction error of 7% (± 4.72 g/kg $BW^{0.75}$)
LIVSIM or LIVestock SIMulator (Rufino *et al.*, 2009)	Animal data (Breed parameters, calving rates and mortality rates) and Feed (quantity and quality)	Lifetime productivity parameters (milk yields, body weight changes, birth and mortality rates)	Normalized root of the square mean errors of feed intake ranges between 7% and 9% at low and high feeding levels, respectively.
LIFE-SIM (León-Velarde *et al.*, 2006; Mugerwa *et al.*, 2013; Katiku *et al.*, 2014)	Animal data (breed, weight, sex and age), feed (quantity and quality) and environment (temperature, precipitation, humidity and wind)	Milk yields, manure amount, enteric, methane emission, nitrogen and production costs	Model errors between observed and simulated data range from 7% to 11%.
e-Cow (Baudracco *et al.*, 2012)	Animal data, pasture and herbage dry matter intake (HDMI)	Milk yields, potential HDMI and live weight change	Model predicted HDMI with an error ranging from 9.1% to 9.8%
DairyMOD (Johnson *et al.*, 2016)	Animal data, pasture and herbage mass	Milk yields, potential pasture and supplement intakes, and body weight characteristics	Correlation coefficient of 0.91 (91%) between pasture intake and predicted responses' data

Modified from Tedeschi *et al.* (2019).

In particular, simulation models that require minimum data but yet generate useful information are gaining popularity (Claessens *et al.*, 2012; Shikuku *et al.*, 2017). For example, methane emissions can be modeled with the Ruminant model; the model simulates methane emissions in response to feed intake and nutrient supply of a particular ruminant production system (Herrero *et al.*, 2002). LIFESIM model has indicated to be effective in predicting milk yields, costs and benefits, manure excretion and methane emissions in Latin and East Africa smallholder dairy production systems (León-Velarde *et al.*, 2006).

However, apart from input data scarcity impingement to the widespread use of some livestock simulation models in the developing world; inability to access expensive commercial user licenses and datasets is another challenge. In addition, each simulation model has strengths and limitations related to precision/reliability, specificity and technological requirements. Model specifications can include computer capacity requirements, scope of applicability e.g. simulation period (daily, seasonal to decadal), climate, region (temperate or tropical), production systems (beef, dairy, extensive or intensive) to animal number i.e. individual animal or herd (Tedeschi *et al.,* 2019).

Therefore, a part from usefulness of the simulation models the choice for what kind of model to use must consider a number of factors. These factors include availability of input data, expected outputs, model precision and relevance of the results for a given environment.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Description of the study area

The study was conducted in the Western Usambara Highlands (WUHs) located at latitudes 4°38'S and 4°53'S and longitudes 38°14'E and 38°22'E (Fig. 1). The WUHs are found in the administrative district of Lushoto, Tanga region, north-eastern Tanzania. Elevation of the WUHs ranges between 1200 m and 1800 m above sea level (a.s.l) or an average of 1498 m a.s.l resulting in a tropical savanna climate (Rubel and Kottek, 2010).

The WUHs experiences bimodal rainfalls in which long rains fall occur between March and June, while the short rains fall takes place between late October and December. The average annual precipitation is around 1100 mm, while average temperature is 17 °C (Fig. 2). This climate supports production of various crops including maize, banana, beans, fruits and vegetables. Moreover, the WUHs are an ideal area for intensive mixed smallholder farming involving crop and highly productive livestock species such as dairy cattle and goats. The total number of cattle in 2017 was reported to be 85 846 of which 22 846 were dairy cattle. The dairy cattle are predominantly crosses of Friesian or Ayrshire dairy breeds and indigenous cattle breeds namely Tanzania Shorthorn Zebu (TSZ). The population of other livestock species in the district included: 79 614 goats, 68 573 sheep, 3634 pigs and 435 000 chickens (Source: Lushoto District Council, 2017).

The commonly established fodder grass species in the district include Napier and Guatemala. The aforementioned grass species are widely grown around farm borders and along contour strips. Apart from fodder provision these grass species also reduce soil erosion and surface runoff in steep slopes (Mwango *et al.*, 2014). Three wards in the WUHs namely Shume, Ngulwi and Mbuzii were selected for this study based on the highest adoption of dairy cattle farming (Fig. 1).

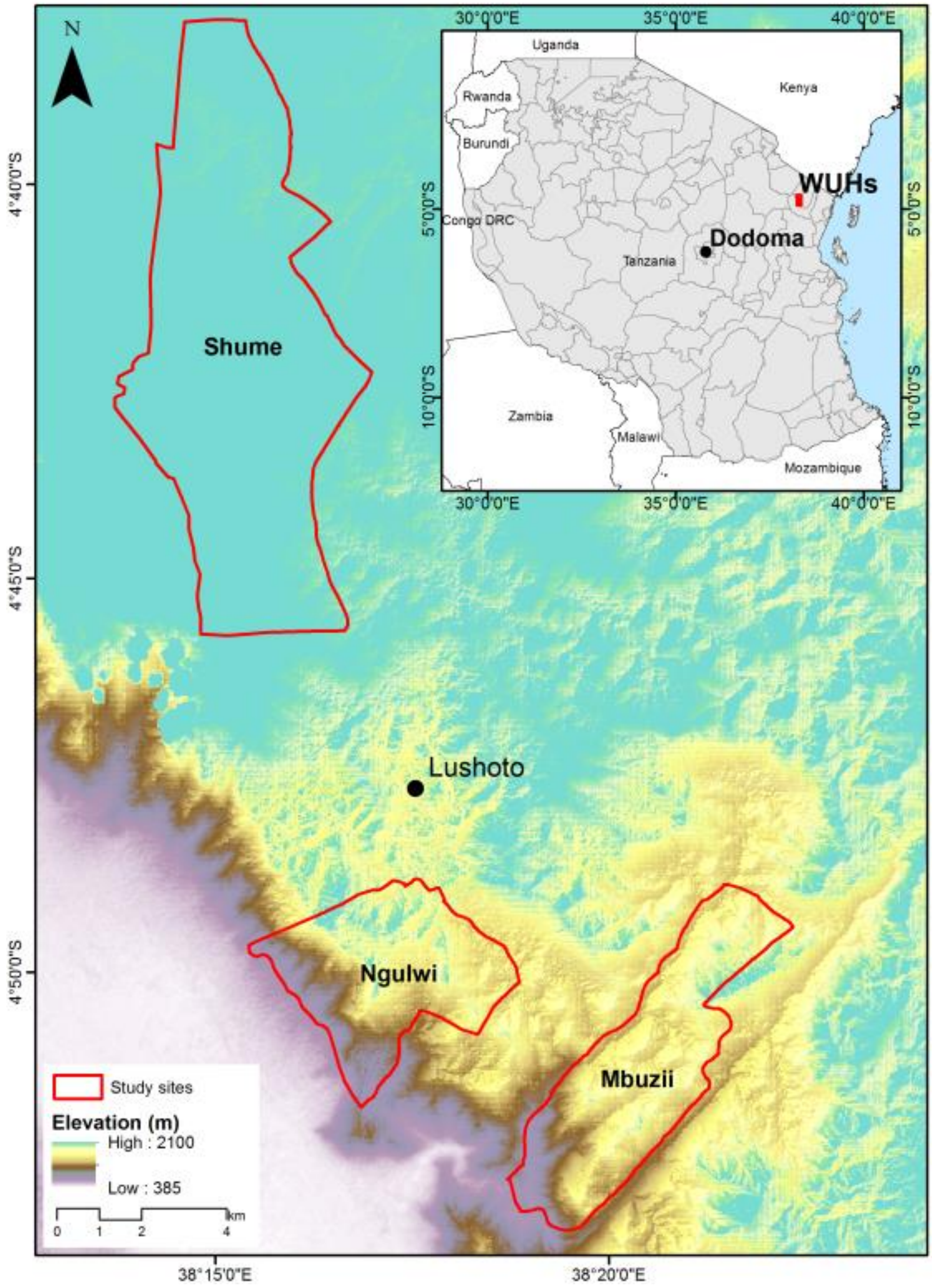

Figure 1: A section map of Lushoto District, Tanga, Tanzania showing the study sites (Shume, Ngulwi and Mbuzii Wards) in WUHs; the base map consists of an ASTER GDEM V1

The monthly precipitation and temperature data for the period ranging between 2006 and 2016 was obtained from Lushoto district council. The ground meteorological station is located at latitude 04°47’28.48”S and longitude 38°17’09.39”E and elevation of 1483 m a.s.l.

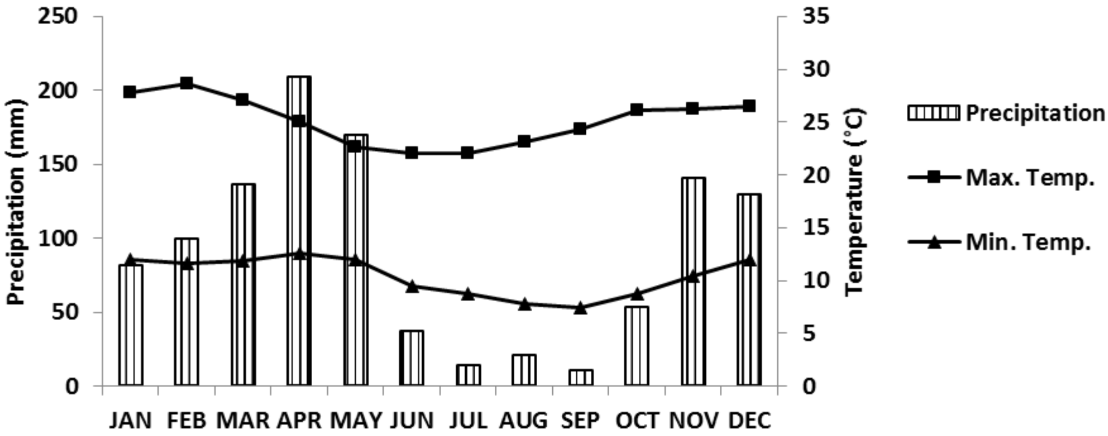

Figure 2: Average monthly precipitation and temperature between 2006 and 2016 of Western Usambara Highlands, Tanga, Tanzania (Source: Lushoto District Council, 2017)

3.2 Reconnaissance survey

The actual baseline study was preceded by a reconnaissance survey which was conducted in March 2016 followed by comprehensive household survey in September 2016. The reconnaissance survey aimed at introducing the study to the local communities and authorities, as well as to enable the researcher to get acquainted to the study sites environments. This was done through consultative meetings with governance bodies including district councils, village councils and dairy farmers’ associations. A simple checklist for assessing the existing dairy cattle feeding practices, feed availability and milk production status was developed and administered to 24 smallholder dairy farmers from 8 villages (Appendix 1). This information was essential for enabling further understanding of the research gaps and identifying areas of key research focus.

3.3 Seasonal variations in fodder resources availability and practices of dairy cattle feeding

3.3.1 Smallholder dairy farming household survey

A cross-sectional design was employed in this study whereby a structured questionnaire (Appendix 2) was administered to respondents, representing 150 households (hh) picked from the three wards. The questionnaire was first pre-tested in five smallholder dairy farming hh before the actual hh survey. In the study wards, a total of five villages (the smallest administrative units) were selected for conducting hh interviews. The villages were Viti and Hambalawei (Shume ward), Ngulwi and Bombo (Ngulwi ward) and Mbuzii village (Mbuzii ward). Moreover, the criteria for enrolling hh into the study included possession of at least one dairy cow and dairy farming experience of minimum 3 years. The hh satisfying the aforementioned criteria were randomly selected using the village residence list obtained from the village government offices. The maximum number of hh enlisted for the survey was 30 based on the criteria developed by Angelsen *et al.* (2011). According to these authors, in a village with 100 to 500 hh a sample size of 25 to 30 hh is adequate for meeting the assumptions of basic statistical tests.

3.3.2 Farm surveys, quantification and chemical analysis of fodder resources

The above ground dry matter (DM) biomass yield (DM Kg/ha) of natural and improved pastures (grass, herbaceous legumes and forbs) were estimated according to the procedures described in Crowder and Chehhda (1982). Briefly, systematic random sampling techniques were employed in which a line transect was established across fodder plots/fields, and along fodder lines for Napier and Guatemala grass strips, and natural grasses in public lands. The length of the line transect was defined by farm or strip size (length and width) in which the total distance across the centre of the farm or strip was divided by 3 to generate 3 spots where a 0.25 m^2 quadrant metal frame was placed for destructive sampling. Within the quadrant frame the forage was cut using a sharp bush knife at 5 cm above the soil surface. Thereafter, the harvested forage was weighed to get the total fresh weight. Sub-samples of about 0.5 Kg (fresh weight) was packed in labeled paper carrier bags then weighed immediately to get sample fresh weight. Thereafter, the sub-samples were transported to the laboratory where they were oven dried at 80 °C to constant weight for DM content determination. In addition, mixed fodder samples (average 500 g) were collected at 15 farms (three farms in each of the five study villages) in both dry (October 2016) and wet (May 2016) seasons for analyses of nutritive values. The maize stover DM yields were estimated in similar farms following the procedures described by (Mussa, 1998).

The DM samples were subjected to a nutritive value analysis at the analytical animal nutrition laboratory of Sokoine University of Agriculture (SUA) located in Morogoro, Tanzania. The analyzed nutritive values included firstly the CP, EE, and Ash according to the procedures found in AOAC (1990). Secondly, In vitro DM digestibility (InvDMD) and *In vitro* organic matter digestibility (InvOMD) were determined according to Tilley and Terry (1963). Neutral detergent fibre (NDF) and acid detergent fibre (ADF) were analyzed according to the Van Soest *et al*. (1991). Whereas, minerals were determined using the UNICAM 919 Atomic Absorption Spectrometer (AAS) for Calcium (Ca), and PU 8620 UV/VIS/NIR Spectrophotometer for Phosphorus (P) in accordance with AOAC (1990). Moreover, Metabolizable energy (ME) was calculated by the formula (Equation 1) according to Ministry of Agriculture, Fisheries and Food, Scotland (MAFF) (1975).

$$ME = \frac{\left(InvDMD \times (100 - Ash\%)\right)}{100} \times 0.15 \qquad (1)$$

3.3.3 The NDVI time series analysis and land cover classification

To obtain high quality time series, for the generation of the vegetation indices and input feature for the land cover classification, a smoothing and gap filling algorithm as proposed by Vuolo *et al.* (2017) was applied. This method utilizes the entire Landsat Ecosystem Disturbance Adaptive Processing System (LEDAPS) Climate Data Records (CDR) archive (i.e. TM, ETM+ and OLI) to generate bi-monthly cloud free time series of Landsat like Earth Observation (EO) products, at 30 meter spatial resolution and covering 6 spectral bands (R, B, G, NIR1, NIR2 and SWIR). Cloud free input data (applying the QA band) covering the period from 2008 to 2016 were used to create a temporal stack, per pixel displaying the seasonal dynamics and were smoothened using the state of the art Whittaker smoother (Atzberger & Eilers, 2010). Thereafter, a series of templates was created and each individual pixel was assigned a template. For generating the output available smoothed high quality pixels were used, when the pixel is flagged by the cloud mask or no observation is available, it was substituted with a value derived from the template (seasonal dynamics). This method allows for bi-monthly reflectance outputs, mostly free from clouds, cloud shadows or the SLC-off striping effects.

The Normalized Difference Vegetation Index (NDVI) as proposed by Rouse *et al.* (1974) is the most applied vegetation index for remote sensing (Equation 2). Its application and benefits are well documented and uses information from the near infra-red (NIR) and visible (VIS) wavelengths (Carlson & Ripley, 1997; Fensholt et *al.*, 2006; Klisch & Atzberger, 2016). Its effectiveness for fodder and biomass monitoring in combination with livestock keeping has been described by Kawamura *et al.* (2005) and Todd *et al.* (1998).

$$NDVI = \frac{(NIR - VIS)}{(NIR + VIS)} \quad (2)$$

The smoothed and gap filled time series were used in which two images of the wet (April 2017) and dry (October 2016) season were used as input. These two images, including the NDVI stack were used as input features in a Random Forest Classifier (RF) presented by Breiman (Breiman, 2001) and implemented in the R package “Random Forest” by Liaw and Wiener (2002). The RF is a high performance state-of-the-art machine learning algorithm based on an ensemble of decision trees and numerous papers describe its successful applications (Immitzer *et al.*, 2012; Ng *et al.*, 2016a, 2016b; Meroni *et al.*, 2017).

The classification results were validated by applying a 10-fold cross validation (Kohavi, 1995), where the reference dataset was split in training (90%) and validation (10%), while a validation polygon was only used a single time and repeating the process ten times. The classification and validation was automated by using a script developed in the open source statistical software R Version 3.2.3 (R Core Team, 2015). A time series analysis was performed on extracted NDVI values of 2009-2016. Based on the land cover classification the two main land cover types (smallholder farms and bushland/forest) were selected for comparison. Thereafter, ten random points per class within each study site were generated and its NDVI values compared for the period between 2009 and 2016.

3.4 Forage growth, yield, nutritional characteristics and farmers' assessment of four Napier varieties

3.4.1 The Napier grass varieties used in this study

Matured healthy stem cuttings for Ouma and Kakamega 2 were obtained from the Tanzania Livestock Research Institute (TALIRI) located in Tanga city, Coastal Tanzania. While those of Bana grass were sourced from Magadu Dairy Farm (MDF), a facility of the Department of Animal, Aquaculture, and Range Sciences (DAARS) at SUA. Moreover, the local Napier (LN) stem cuttings were obtained from smallholder farms in the study area.

3.4.2 Experimental design and plant establishment

Two on-farm experiments were set, including one in lowland and another on upland sites within the study area. This aimed at ensuring that the trials capture influence of altitude on performances of the experimental plants if any. The lowland site was located at latitude 4°49′ 45″ south and longitude 38°18′ 25″ east and at an altitude of 1206 m above sea level (a.s.l) in Bombo village. The upland site was set at latitude 4°40′ 10″ south and longitude 38°15′ 28″ east and at an altitude of 1779 m a.s.l in Hambalawei village. Planting was done in 21st December 2016. A Completely randomized block design (CRBD) was adopted whereby the improved Napier varieties (Pp cv Ouma, Pp cv Kakamega 2 and Pp cv Bana) as well as the LN (control) were replicated thrice. Twelve (12) plots were prepared in each site making a total of 24 plots. The plots had dimensions of 4 x 3 m^2, spaced 1m apart and there was a 1m wide path around the block boundary. In each plot, three contour furrows spaced 0.5 m a part and with a length of 4 m, 0.5 m width and 0.4 m depth were dug.

The furrows were prepared through a sunken seedbed technique commonly called *Tumbukiza* method literally meaning planting in pits/furrows. The *Tumbukiza* method has been proved superior in enhancing Napier grass biomass yields, soil moisture and nutrients retention and reducing soil erosion (Orodho, 2006; Nyambati *et al.*, 2011). In brief during furrows preparation; the topsoil about 15 cm depth was mixed with pit composited dry cattle manure and returned to the furrow at the manure application rate of 5 kg/m^2. The subsoil (below 15 cm depth) was not returned to the furrows.

Within the furrows two Napier stem cuttings about (30-45 cm long) were planted in two 25 cm apart parallel lines at a planting space of 50 cm along the furrow length. At least two nodes were inserted into the soil leaving a single internode at about 45^o angle slanted to the ground. Also, dry *Grevilia robusta* tree leaves that were abundantly available were spread into the furrows at a thickness of about 10 cm as mulch. Due to rainfall inadequacy at the onset of the experiment, the furrows were irrigated twice a week at an interval of 3 days within the first three weeks to facilitate robust establishment. Weeding was done manually once.

3.4.3 Farmers' assessment of the established fodder grasses

On-farm assessment of the five fodder grass varieties was done by 30 smallholder dairy farmers both women and men at the demonstration sites when the grasses were considered matured for forage use (Plate 1). Researchers and extension officers facilitated the farmers in developing criteria for evaluating both quality and prospective biomass yield of the grasses. The criteria included leaf colour, leafiness, growth vigour (height and stem thickness), potential biomass, and leaf and leaf sheath hairiness. A score scale of 0 to 10 was agreed upon with 0 being less important/few or non-existence whilst 10 being most important/dominant. For leaf color (yellowish close to 0, pale green around 5 and dark green close to 10. For hairiness/tillering 0 means no hair/tiller while close 10 very hairy/many tillers. Potential biomass and growth vigour included 0 very small to 10 very high. A checklist was designed and each farmer moved around the plots and facilitated to fill in. The mean scores for each fodder variety were computed and shared to all participating farmers and a discussion for common consensus was done. In addition, in April 2017 a total of 80 farmers, Lushoto district livestock officials being led by the District Executive director (DED) were invited to visit the fodder demonstration plots for awareness creation and sensitization on establishment of improved forages.

3.4.4 Forage growth characteristics and sampling

Field measurements and sampling were done in April 2017 when the plants were considered mature for forage use (110 days post planting). At the time of field measurement each of the two planted stem cuttings established a bunch of tillers (Plate 1). Number of tillers per bunch was counted in three inner bunches of each plot. In each bunch, three tillers including the tallest, medium and shortest were used for measurement of growth characteristics. The recorded parameters include plant height, leaves per plant, leaf length, leaf width, internodes per tiller, basal diameter and leaf area index (LAI). The fourth leaf from the tiller's tip was used for measuring leaf length and width measured at the center. Number of leaves and visible internodes were counted for each measured tiller. The basal diameter of the tiller was measured at the lowest internode by means of a Vernier caliper. The leaf area index (LAI) was measured by Samsung Galaxy S4 Smartphone installed with the Pocket-LAI app (a Smartphone App developed for estimating plant LAI) through non-destructive techniques (Francone *et al.*, 2014). A 0.25 m^2 quadrant metal frame was used for destructive sampling in which it was placed once at the center of each of the three furrows within a plot. Within a quadrant, the forage was cut at about 15 cm stubble height and total fresh weight was measured. Thereafter, leaves excluding the leaf sheaths were stripped off the culm/cane and both the stem and leaves' fresh weight was measured separately. Leaf and stem sub-samples of about 0.3 kg were packed, labeled and taken to the laboratory for analysis. The leaf to stem ratio (LSR) was computed by dividing the leaf to stem dry matter yields.

3.4.5 Laboratory analysis of forage samples

The forage sub-samples were oven dried at 80 ^oC to constant weight and thereafter ground to pass through a 2 mm sieve. The analyzed nutritive values include dry matter (DM) crude protein (CP), crude fat (EE), neutral detergent fibre (NDF), acid detergent fibre (ADF), ash and mineral element (Ca and P) percentage content. Near-infrared spectroscopy (NIRS) techniques as described by Corson *et al.* (1999) were used in analyzing the nutritive values at the Tanzania Veterinary Laboratory Agency (TVLA), Dar es Salaam, Tanzania. While the *in vitro* DM digestibility (InvDMD) and in vitro organic matter digestibility (InvOMD) were estimated using the 2-stage technique of Tilley and Terry (1963). A 0.5 g of ground forage sample was incubated in rumen liquor obtained from a fistulated dairy steer maintained on a mixture of fresh Napier and natural grass hay at SUA. The InvDMD and InvOMD analysis was done at the Animal Nutritive Analytical laboratory of SUA, Morogoro, Tanzania.

(A) (B) (C) (D)

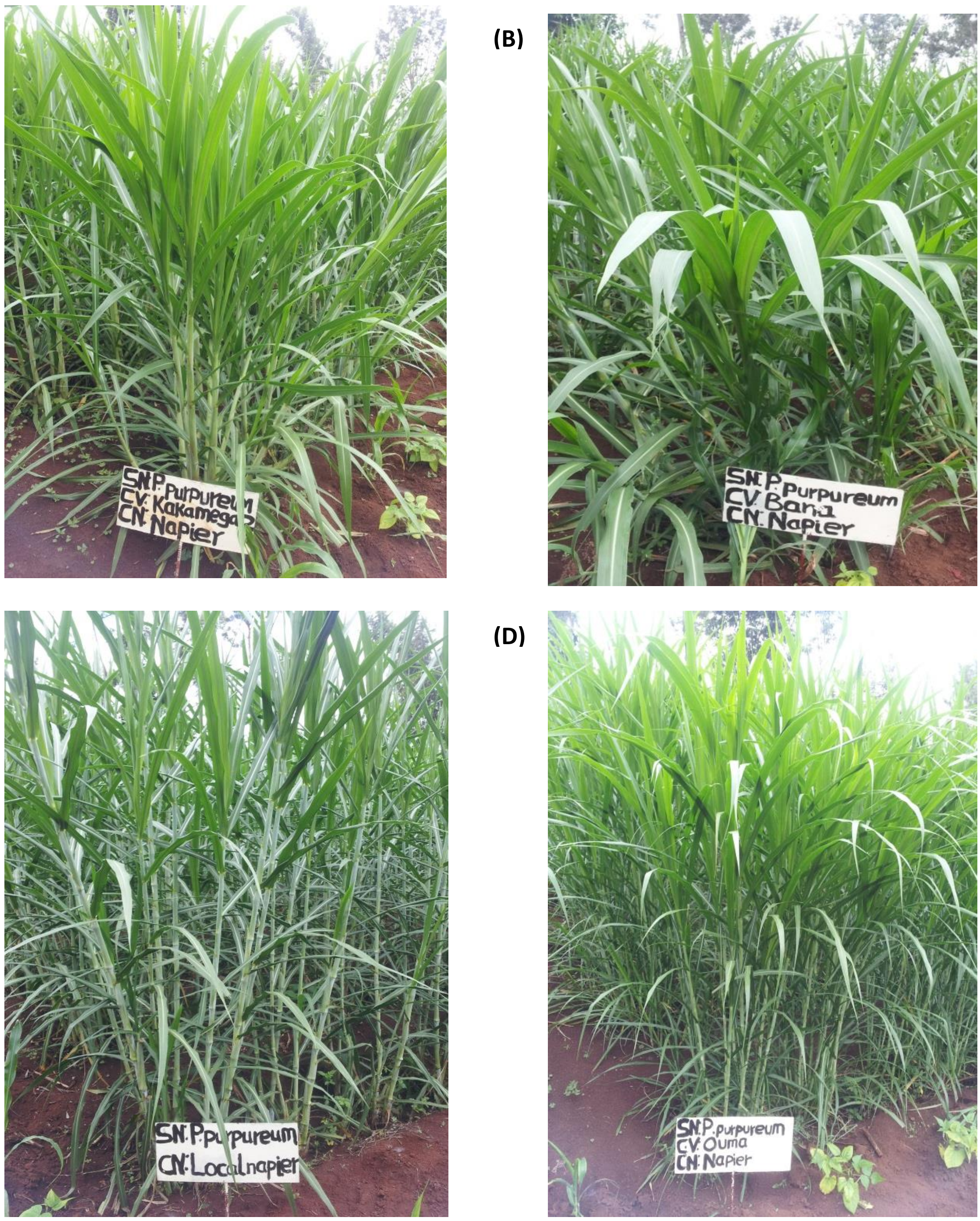

Plate 1: Napier grass varieties on the 110th day post planting at the study site. (A) Kakamega 2, (B) Bana, (C) Local Napier and (D) Ouma

3.5 The effects of dry season supplementation of *Caliandra calothyrus* leaf-meal mixed with maize-bran on dairy cattle milk production

3.5.1 Basal feeds used in this study

The basal feeds were mainly crop residues and established pasture purchased from smallholder farms in the villages around Irente farm, whereby they were cut and carried for stall feeding. The availability of the basal feeds was in the order of dry maize stover > Guatemala grass > Napier grass > natural pastures > sugarcane tops. However, the availability of basal feeds was opportunistic in nature and with limited control of quality. The natural pastures mainly *Cynodon* and *Setaria* grass species often mixed with weeds and herbaceous legumes were gathered within the farm. Basal feed samples were collected and analyzed for nutrient compositions (Table 2) through NIRS techniques described by Corson *et al.* (1999). The fibrous basal feeds had both low CP (%) and ME (MJ/kg DM) values necessitating supplementation for effective milk production.

Table 2: Nutrient composition of the most common basal feeds that were fed to the experimental animals

Basal feed type	n	CP	CF	Ash	ADF	NDF	IVDMD	ME(MJ/kg DM)
Dry maize stover	2	6.77±0.54	1.00±0.06	7.09±2.47	49.06±1.36	73.47±1.51	52.47±9.88	7.33±1.57
Napier grass	4	10.48±1.02	1.80±0.49	8.01±1.11	40.10±2.07	65.21±2.51	59.95±4.63	8.28±0.72
Guatemala grass	2	11.79±0.50	1.67±0.23	7.63±0.23	45.86±1.20	69.15±1.29	54.39±0.76	7.54±0.09
Natural pastures	7	8.78±4.69	1.66±0.33	7.03±1.93	34.06±4.52	56.77±5.68	56.09±2.88	6.82±0.46
Sugarcane tops	2	5.68±0.35	1.32±0.04	4.98±0.23	33.48±1.62	55.57±2.35	74.71±1.97	10.65±0.26

n= Number of samples; CP = Crude protein (%); CF= Crude fat (%); ADF = Acid detergent fibre (%); NDF = Neutral detergent fibre (%); IVDMD = In vitro dry matter digestibility; ME (MJ/kg DM)= Metabolizable energy (MJ/kg dry matter)

3.5.2 Supplementary concentrate feeds used in this study

A homemade/on-farm supplementary ration (HSR) comprising of 56% maize bran (MB), 40% *C. calothyrsus* leaf meal (CLM), 2% mineral vitamin premix (MVP) and 2% molasses powder (MP) was formulated (Plate 2). The associated price of this supplementary ration was 620 Tsh./kg as fed and nutrient concentrations are shown in Table 3 (Analyzed by NIRS techniques). Maize bran a co-product of maize grain was selected based on the fact that maize cultivation and maize grain processing are common practices in Lushoto. Maize is among the staple food in Lushoto thus guaranteeing the availability of maize bran (Maleko *et al.*, 2018). The *C. calothyrsus* leaf meal was incorporated as a protein source and had a CP of 25.2. *C. calothyrsus* is widely grown at Irente Biodiversity farm and in nearby smallholder farms

(Plate 2). Leaf meal was prepared through cutting and sun drying of small branches of *C. calothyrsus* during the dry season. Sun drying was done immediately after cutting for 2-3 days on plastic sheets placed on ground followed by sorting the sticks off dry leaves (Plate 2). Commercial MP and MVP were purchased from the accredited local dealers. Molasses powder was important for improving energy and palatability of the supplementary ration. Mineral vitamin premix was essential for enhancing concentration of mineral elements and vitamins that are essential for milk production. As it is indicated in Table 3 the formulated HSR had a CP of 22.3 and ME of 10.73 MJ/kg DM. According to Herrero *et al.* (2013) the metabolizable energy between 9.5 and 12.5 MJ/kg DM is considered to be high enough for stimulating optimal cattle milk outlet under mixed tropical farming systems.

Table 3: Nutritive value of the Calliandra leaf-meal mixed with maize-bran homemade/on-farm supplementary feed ration for lactating dairy cattle

Variable	DM (%)	CP **(%)**	CF **(%)**	Ash **(%)**	ADF **(%)**	NDF **(%)**	IVDMD **(%)**	ME (MJ/kg DM)	Ca **(%)**	P **(%)**	Mg **(%)**	K **(%)**
Proportion	89.20	22.30	4.70	9.10	22.40	32.74	73.34	10.73	1.24	0.29	0.34	0.77

3.5.3 Experimental design, treatments and care of the lactating dairy cows used in this study

Completely randomized design was employed in which a total of 16 lactating cows were used in this study. There were three (3) levels of HSR of CLM-MB-MVP-MP based concentrate and farmers feeding practice (control). Hence, there were four (4) treatments (T1 – T4): T1 = 2 kg/cow/day, T2 = 4 kg/cow/day, T3 = 6 kg/cow/day and T4 = 1 kg/cow/day maize bran (control). Four cows were randomly allocated in each of the 3 HSR levels making a total of 12 cows and the rest 4 cows being control. These were tested to determine the optimal feeding strategy in terms of milk production and economic returns under the WUHs farm conditions.

The selected animals were crossbred of Friesian x Tanzania Short-horn Zebu (TSZ) in their third or fourth parity with mean live weight of 359.38 ± 38.10 kg obtained from a single farm. The animals were weighed prior to commencing the study and biweekly thereafter. During the same period, the body condition score (BCS) of each animal was assessed using a score ranging from 1 (very thin) to 5 (very fat) and animals had a mean BCS of 3.31±0.05. Animals were housed in a well-constructed cowshed with stone walls, concrete floor and corrugated iron roof. The cowshed was cleaned daily to ensure comfort of animals and hygienic conditions. Partial grazing was practiced during mid-days. The experimental period was 55 days which was the peak of dry season during September and October 2018 with the first 10 days set aside for acclimatization to the experimental diets and 45 days for data collection. Supplementation was done twice a day during morning and evening milking (0700 and 1600 hours). Animals had access to adequate amount of drinking water and basal feeds provided in troughs. Mineral leak blocks were hanged in the cowshed and animals had ample access. Health care including proper prophylaxis e.g. vaccination and health management were provided by a veterinary expert contracted by the farm. Prior the actual feeding, the experimental cows were dewormed once using Ivermectin injection and sprayed with acaricides on weekly basis.

3.5.4 Milk sample collection and nutrient composition analysis

The cows were hand milked twice daily at 0700 and 1600 hours with individual cattle milk yields being recorded at each milking. Before milking the teats and udder were cleaned with water and a towel followed by smearing teats with a milk salve lubricant. Milk was sampled once per week and immediately assessed for milk protein, fat, lactose and solids non-fat components using a portable Ultrasonic Milk Analyzer Model Master LM2 (Milkotester, Bulgaria).

3.5.5 Simulated impacts of the supplementary feeding strategies on the dairy cow milk productivity

The Dairy Simulation Model under the Livestock Feeding Strategies Simulation models (LIFE-SIM) Version 8.1 was used to simulate the effects of different supplementation strategies (scenarios) on crossbred dairy cattle performance at WUHs. The effects of supplementation strategies on milk yields, incomes, costs, methane emissions and manure excretion were evaluated. The LIFE-SIM model has six data inputs including (a). Animal (age, body weight and condition, lactation numbers, milk protein, fat and solid not fats composition), (b). Pasture and forage (dry matter availability, digestibility and protein contents), (c). Supplement feed (nutrient composition and amount offered to animal) (d) Weather conditions (Temperature, humidity and wind) (e). Feeding strategy (scenarios), and (f). Economic information (feed costs and milk farm gate price). The model is described in detail in León-Velarde *et al.* (2006).

(A)

(B)

(C)

(D)

Plate 2: (A) Calliandra shrub along the farm boundary in smallholder farm in the WUHs, (B) leaf meal preparation, (C) leaf meal storage, and (D) a dairy cow feeding the supplementary homemade ration at Irente Biodiversity Farm, WUHs, Tanzania

3.6 Data analysis

Descriptive statistics including frequencies, means and percentages were generated. Moreover, the independent t-test also found in IBM SPSS 21 was used to test the effect of fodder seasonality and feeding related parameters including fodder availability and milk yields (wet and dry seasons). One way analysis of variance in IBM SPSS 21 was used to test the effect of location (wards) on some selected parameters (family, farm and cattle herd size).

Correlations between number of cattle per farm and family sizes or versus household farm sizes were also done using IBM SPSS 21.

Statistics for the above ground growth morphological characteristics, biomass yields and nutritional contents of the four experimental Napier varieties were computed using the STATISTICA 8.0 software package (Weiß, 2007). The 2 x 4 factorial ANOVA considering two sites and four Napier varieties was employed to test the overall effects and interactions between sites and varieties. The following model was used: Yijk = μ + Vi + Sj + (VS)ij + eijk. Where; μ = overall mean, Vi = effects of the v^{th} variety, Sj = effects of the s^{th} site, (VS)ij = effects of the interaction between the v^{th} variety and the s^{th} site and eijk = error term. The Fisher's Least Significant Difference post hoc test was used to do the pairwise comparison of the means. The means were considered to be statistically significant different when $P<0.05$. The principal component analysis (PCA) was used for explanation and visualization of the observed variations among the growth and yield parameters.

The general linear model (GLM) under MINITAB® 18 computer based statistical program was used to assess the effects of supplementary ration, lactation phase and experimental week on milk quantity and quality (Lesik, 2018). The following model was used: Yijk = μ + Si + Lj + Wk + (SLW)ijk + Eijk. Where; Yijk is milk yield /nutrient composition of the i^{th} supplementary ration, in j^{th} lactation phase fed i^{th} ration on the k^{th} week. μ = overall mean, Si = effects of the i^{th} supplementary ration, Lj = effects of the j^{th} lactation phase, Wk effects of k^{th} week (SLW)ijk = effects of the interaction between i^{th} supplementary ration, j^{th} lactation phase and the k^{th} week and Eijk = error term. Moreover, One Way ANOVA was used to test the effect of supplementary rations on simulated milk yields, income, production costs, methane emission and manure excretion. Tukey's Post Hoc test was used to perform all the pairwise comparisons to test the effects among the supplementary rations at $P = 0.05$.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Results

4.1.1 Introduction

The aim of this study was to improve the nutrition of dairy cattle in the smallholder farming systems of Western Usambara through optimization of production and utilization of on-farm feed resources for improved milk yields. This involved conducting a baseline study which aimed at assessing the smallholder dairy cattle feeding practices (Specific objective 1). Specific objective 2 assessed the availability and seasonal variations of dairy cattle on-farm feed resources in the study site. The baseline study indicated that dry season fodder scarcity and improper dairy cattle feeding are huge challenges in the smallholder dairy farms at the study site. The biomass quantity of on-farm fodder resources was low due to small farmlands. Also, the nutritive quality was found insufficient to meet the requirement of dairy cattle for optimal milk production especially during the dry season. Therefore, strategies aiming at enhancing sustainable on-farm fodder production and optimal feeding strategies were deployed at the study site (Specific objective 3). These involved setting of on-farm planting experiments that evaluated the performance (yield and nutrition) of four Napier grass varieties as feed for ruminants. Also, assessed effects of dry season supplementation of *C. calothyrus* leaf-meal mixed with maize-bran on dairy cattle milk productivity and profitability. Specific objective 4 evaluated the impacts of feeding/supplementary strategies on milk production, profitability and enteric methane gas emissions per litre of milk produced. The results for each specific objective are presented in detail below:

4.1.2 Characteristics of the smallholder dairy farms, fodder types and fodder sources, and feeding practices

(i) Characteristics of the smallholder dairy farms

The household survey involved interviewing of 150 smallholder dairy farmers from 3 wards at the study site. About 42 and 58% of the respondents were female and male, respectively. Most of the respondents were married (90%) and had primary education (88.7%). Crop cultivation and livestock keeping in the same farm (mixed farming) was the primary occupation (95.3%) of the heads of households (Table 4).

Table 4: Demographic characteristics of the surveyed households

Demographic characteristics		Ward			Total (N=150)
		Shume	Ngulwi	Mbuzii	
Gender	Female	18.7% (28)	15.3% (23)	8% (12)	42% (63)
	Male	21.3% (32)	24.7% (37)	12% (18)	58% (87)
Marital status	Single	0	0	0.7% (1)	0.7% (1)
	Married	38% (57)	36% (54)	16% (24)	90.0% (135)
	Widow	2% (3)	4% (6)	3.3% (5)	9.3% (14)
Education level	Primary	34% (51)	38% (57)	16.7% (25)	88.7% (133)
	Secondary	1.3% (2)	1.3% (2)	0.0%	2.7% (4)
	College	1.3% (2)	0.0%	0.0%	1.3% (2)
	Adult education	2% (3)	0.0%	0.7% (1)	2.7% (4)
	No formal education	1.3% (2)	0.7% (1)	2.7% (4)	4.7% (7)
Age	18 to 45	16% (24)	10% (15)	6% (9)	32.0% (48)
	46 to 60	16.7% (25)	20.7% (31)	7.3% (11)	44.7% (67)
	Above 60	7.3% (11)	9.3% (14)	6.7% (10)	23.3% (35)
Primary occupation	Mixed farming (crop and livestock)	36.7% (55)	38.7% (58)	20% (30)	95.3% (143)
	Crop production	2% (3)	0	0	2% (3)
	Business	1.3% (2)	1.3% (2)	0	2.7% (4)

Note: Number of respondents is enclosed within the brackets

The average family size consisted of six individuals comprising of parents, children and relatives. The farm sizes were small averaging 1.3 ha and the number of cattle was about three per farm (Table 5). Also, the number of cows per farm was less than two in the surveyed household. Despite the fact that family and farm sizes size are known to be important factors that influence herd size and uptake of forage technologies such as pasture establishment. In this study, there was no significant correlation between number of cattle per farm and family sizes or versus household farm sizes.

Table 5: Family size, farm size and cattle number per farm of the smallholder dairy farms at the study site

Parameter	Ward			Min. statistics	Max. statistics	Overall mean ± SE	P value
	Shume	Ngulwi	Mbuzii				
Family size	6.25	6.18	4.90	2.00	14.00	5.95 ± 0.18	0.02
Farm size (ha) per household	1.48	1.20	1.27	0.20	8.10	1.32 ± 0.10	0.42
Total number of cattle per farm	3.20	2.98	2.27	1.00	12.00	2.93 ± 0.13	0.03
Number of cows per farm	1.47	1.63	1.23	1.00	6.00	1.49 ± 0.08	0.15

SE Standard error, P value is the probability for statistical significant difference at 95% confidence limit (P = 0.05)

(ii) Fodder types and sources

Five main types of fodder found in the WUHs are: (a) natural pastures both grasses and legumes, (b) established pastures (Napier and Guatemala grasses), (c) crop residues mainly maize, beans and vegetable residues, (d) fodder trees including mulberry (*Morus alba*), leucaena (*Leucaena spp*) and avocado (*Persea americana*), as well as (e) crop weeds. Napier and Guatemala grasses were mainly found at farm boundaries and contour strips and their cover was estimated to be only 8.4 to 12.5% of the total household farmland. In addition, only 6% of the respondents were found to have set aside pasture plots often less than 0.125 ha. Natural pastures were restricted to fallowed farms and uncultivated public lands such as play grounds, steep and rocky hills, riparian areas, forest reserves and along the roadsides. Weeds were mainly found in farms with maize (*Zea mays*), beans (*Phaseolus vulgaris*) and round potatoes (*Solanum tuberosum*). The most common weed species included *Commelina bengalenisis*, *Bidens Pilosa*, *Galinsoga parviflora*, *Ageratum conyzoides* and *Tegetus minuta*. Planting of herbaceous forage legumes was very uncommon while multipurpose fodder trees were limited to farm boundaries of few farms.

Dairy cattle fodders were obtained from six sources namely crop fields, road side areas, uncultivable lands, open areas, forest reserves and fallowed lands. In particular, this study found out that most of the smallholder dairy farmers (53.4%) in the study sites were mainly sourcing fodder from their own farm or neighboring farms with few (2.8%) source from fallow lands (Fig. 3). In addition, respondents from Mbuzii (76.5%) and Ngulwi (23.5%) wards reported to source natural pastures from uncultivable stony and rocky areas during the dry season.

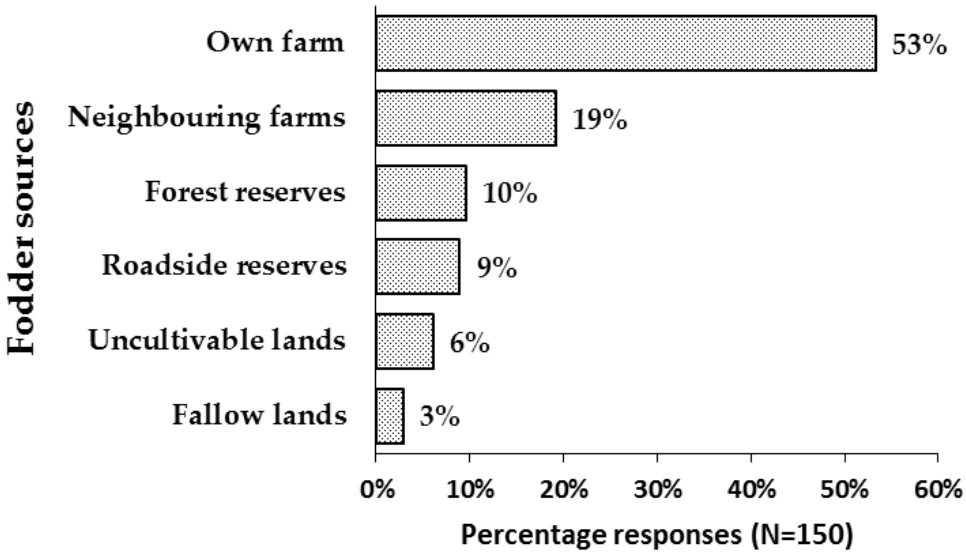

Figure 3: Fodder sourcing areas by smallholder dairy farmers in WUH, Tanzania

Roadside reserves and open areas including play grounds were reported to provide fodder to dairy cattle through either cutting for stall feeding or tethering. Roadside reserves fodder sourcing was more prominent at Mbuzii ward (40.7%), followed by Ngulwi (35.5%) and least at Shume (23.7%). The practices of promoting vegetation cover including fodder species for controlling erosion and improving road safety was also common. Fodder sourcing from fallow lands was mainly reported at Shume (50.0%) and Mbuzii (37.5%) wards, while at Ngulwi (12.5%) this practice was unpopular. Forest reserves, in particular forest plantations were among important sources of fodder at the Shume ward. It was reported that farmers are allowed to grow seasonal crops and collect fodder in areas where trees were felled or newly planted in forest plantations (Fig. 3). Fodder sourcing from fallow lands was minimal due to few numbers of fallow fields. Fallow lands were limited to hillsides or areas where crop was prone to wildlife damage.

(iii) Feeding practices

Zero grazing (cut and carry of fodder) was the dominant dairy cow feeding system as confirmed by 86.7% of our respondents. Other dairy farms' feeding systems included tethering and field grazing reported by 11.3% and 2% of the respondents, respectively. About 52.8% of the respondents reported were supplementing poor roughages with a small amount of maize bran (less than 2 Kg/day) and mineral pre-mixes during milking. High costs and unavailability of supplementary dairy meals and agro-industrial by-products were the major constraints towards adequate feeding to dairy cattle (Fig. 4). Only 37.6% of the respondents reported chopping forages before feeding to dairy cattle. None of the respondent reported to add molasses or treating dry crop residues with urea or alkali (e.g. sodium or calcium hydroxide) to improve intake.

Land scarcity, inability to construct large barns, limited agricultural advisory services and low milk prices (ranging from 0.27 – 0.45 USD/litre) were among major constraints contributing towards effective dairy cattle feeding (Fig. 4). In addition, unaffordability of farm machinery such as forage choppers, balers and feed mixers were among other constraints (Fig. 4). While, good climatic conditions (67.3%) and fertile soils (54%) capable of supporting various fodder species (both grasses and legumes) were identified as positive contributors to dairy cow feeding.

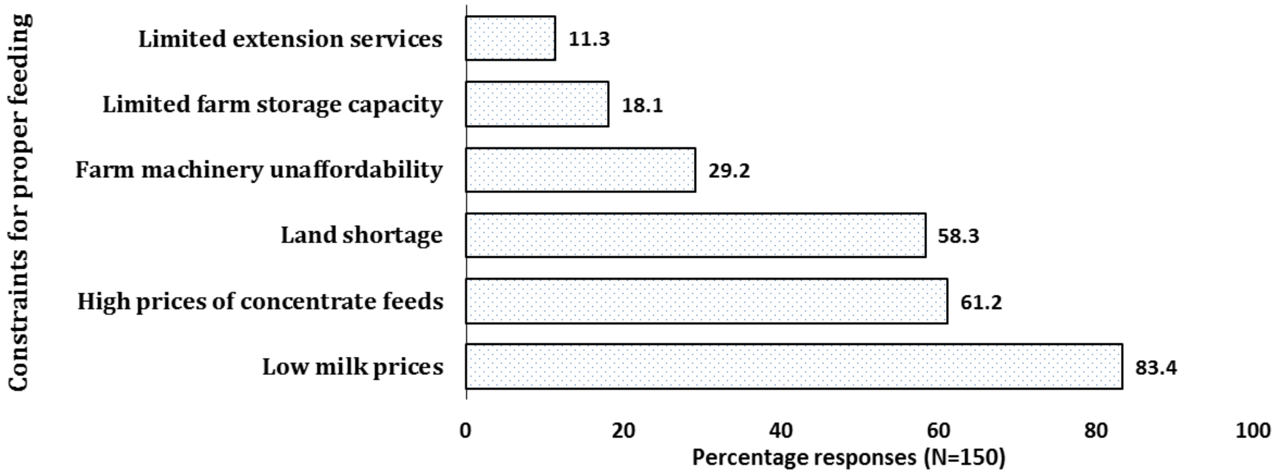

Figure 4: Constraints towards adoption of effective dairy cattle feeding practices among smallholder dairy farmers, WUHs, Tanzania

4.1.3 Seasonal variations in quantity and quality of fodder resources

(i) Fodder types, availability and quality in wet and dry seasons

Crop residues in particular maize stover was accentuated as the key important dry season livestock feed (Fig. 5a). About 86.6% of the respondents reported dry season (July to October) fodder scarcity as a major challenge. It was further revealed that with the advance of the dry season the availability of both pastures and crop residues declined (Fig. 5b). The maize stover yield for the 2016-2017 long rain cropping season (November to June) was estimated at 4013.8 Kg DM/ha. In addition, it was observed that during dry season unusual livestock feeds including sedges (*Typha latifolia* and *Cyperus exaltatus*) and vegetable residues (cabbage, broccoli, cauliflower and carrot) are fed to dairy cattle (Fig. 5a). During the wet season (March to May) on farm fodder both natural and established pasture was reported to be plentiful (Fig. 5b). Note that between March and June, pasture is highly available (growing season) and June to August crop residues availability tends to increase (harvesting season).

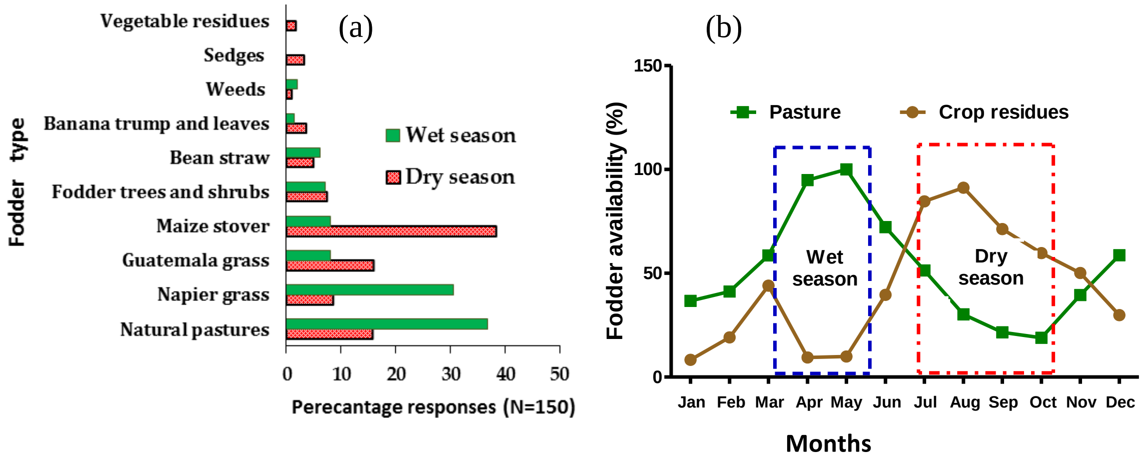

Figure 5: Seasonal dairy cattle fodder availability (a), and annual profile of pasture and crop residues availability (b) to dairy cattle in WUHs (N=150)

Nonetheless, about 80.1% of the respondents reported higher costs in terms of labour and time for feeding dairy cows especially during dry seasons. Whereby, during dry season farmers reported to walk longer distances in search of fodder on uncultivable stony hill areas for Mbuzii and Ngulwi while at Shume farmers sourced fodder from forest reserves. Consequently, the decreased amount of feed offered to dairy cattle resulted in an eventual decline in milk production during the dry season (Table 6). A number of coping strategies to dry seasonal fodder shortage were identified (Table 7), in which, searching and sourcing fodder anywhere within a farmer's reach was the major strategy

Table 6: Seasonal variations in fodder sourcing distance, gathering time and milk yields, WUHs, Tanzania, 2016

Parameter	Season	Min. Statistic	Max. Statistic	Overall mean ± S.E	P value
Fodder sourcing distance (Km)	Wet	0.01	3.50	0.67 ± 0.08	< 0.001
	Dry	0.10	5.00	1.64 ± 0.15	
Fodder gathering time (hrs)	Wet	0.10	3.00	0.74 ± 0.07	< 0.001
	Dry	0.25	4.00	2.02 ± 0.13	
Amount of fodder offered (Kg/cow/day)	Wet	31.00	69.40	45.23 ± 2.79	0.003
	Dry	19.50	53.00	33.60 ± 2.33	
Milk yield (litre/cow/day)	Wet	2.00	12.00	5.56 ± 0.19	< 0.001
	Dry	0.00	7.00	2.97 ± 0.12	

Table 7: Proportion (%) of respondents using different coping strategies to alleviate dry season fodder scarcity in the three study wards

Parameter	Ward			Overall mean
	Shume	Ngulwi	Mbuzii	
Source fodder from distant locations	28.46	36.90	47.38	37.58
Purchase feeds	23.29	29.26	21.06	24.54
Feed unusual feedstuffs	23.29	17.81	10.53	17.21
Sale some animals (destocking)	20.70	11.45	10.53	14.23

Regarding quantity, established pasture (Napier and Guatemala) had the highest dry matter yields of tonnes (tDM) per hectare ranging from 2.26 ± 0.30 to 13.72 ± 1.10 tDM (Table 8). In addition, seasonality was found to affect the CP and ME contents among other nutrients of the fibrous feed offered to dairy cattle. Both CP and ME content of the fodder declined while DM, NDF and ADF content increased during the dry season. The variations were statistically significant different between seasons (P<0.05) (Table 9).

Table 8: Estimated average yield (tDM/ha) of different on-farm feed resources during wet and dry seasons in the study area

Fodder type	Wet season fodder yield			Dry season fodder yield			SEM	P-value
	Shume	Ngulwi	Mbuzii	Shume	Ngulwi	Mbuzii		
Guatemala grass	6.4^{c}	4.1^{d}	3.4^{d}	13.7^{a}	11.2^{b}	3.5^{d}	0.45	<0.001
Napier grass	5.5^{b}	6.1^{a}	5.8^{ab}	2.3^{e}	3.5^{d}	4.6^{c}	0.13	<0.001
Natural pasture	2.1^{a}	0.6^{c}	0.8^{b}	0.4^{d}	0.6^{c}	0.6^{c}	0.06	<0.001
Weed	1.3^{a}	0.2^{c}	0.4^{b}	0.1^{d}	0.06^{d}	0.1^{d}	0.04	<0.001

Mean in the same row with different superscripts differs significantly (P < 0.05)

Table 9: Effects of season on nutritive values of mixed fodder samples from smallholder dairy farmers' feeding pen in WUHs, 2017

Parameter (%)	Wet season	Dry season	P value
	Mean ± S.E	Mean ± S.E	
DM	28.52 ± 0.95	46.08 ± 2.88	0.001
CP	10.08 ± 0.36	7.81 ± 0.46	0.01
NDF	53.15 ± 1.48	62.38 ± 2.12	0.01
ADF	36.10 ± 1.41	41.32 ± 0.98	0.005
EE	1.56 ± 0.13	1.66 ± 0.21	0.69
Ash	8.70 ± 0.55	8.20 ± 0.79	0.61
Ca	0.46 ± 0.04	0.47 ± .033	0.79
P	0.22 ± 0.02	0.23 ± 0.20	0.68
IVDMD	43.63 ± 1.14	34.6 ± 1.26	<0.001
IVOMD	50.12 ± 1.35	43.50 ± 0.93	<0.001
ME(MJ/KgDM)	5.98 ± 0.16	4.76 ± 0.16	<0.002

(ii) Land cover and climatic influences on fodder resources distribution at the landscape

The land cover classification (Fig. 6) had ana overall accuracy of 67% and consists of six classes: Smallholder farms, irrigated farmlands, build-up and soils, bushland, transition between bushland and forest, and forest. The mapping results revealed that Mbuzii (72.6%) and Ngulwi (51.4%) consist of mostly smallholder farms, followed by Shume (23.3%) with 61.2% covered by forest. Based on the land cover classification, a number of points for both the Smallholder farms class and non-agriculture classes (i.e. bushland/forest) were selected and used these to extract NDVI values from the time series, then per study site mean NDVI values were created (plotted left of the land cover maps). Note that the agricultural areas consistently have lower values compared to the more natural bushland/forest areas. The NDVI time series indicated that live green vegetation (cover and bareness) was varying within years (wet and dry seasons) whereby during wet seasons it was higher and declining during dry seasons. It also indicated years were vegetation vigour was low due to limited rains for example 2010 - 2011 (NDVI < 0.4) and years with rainfalls above average (2014 - 2015) with NDVI > 0.6 (Fig. 6).

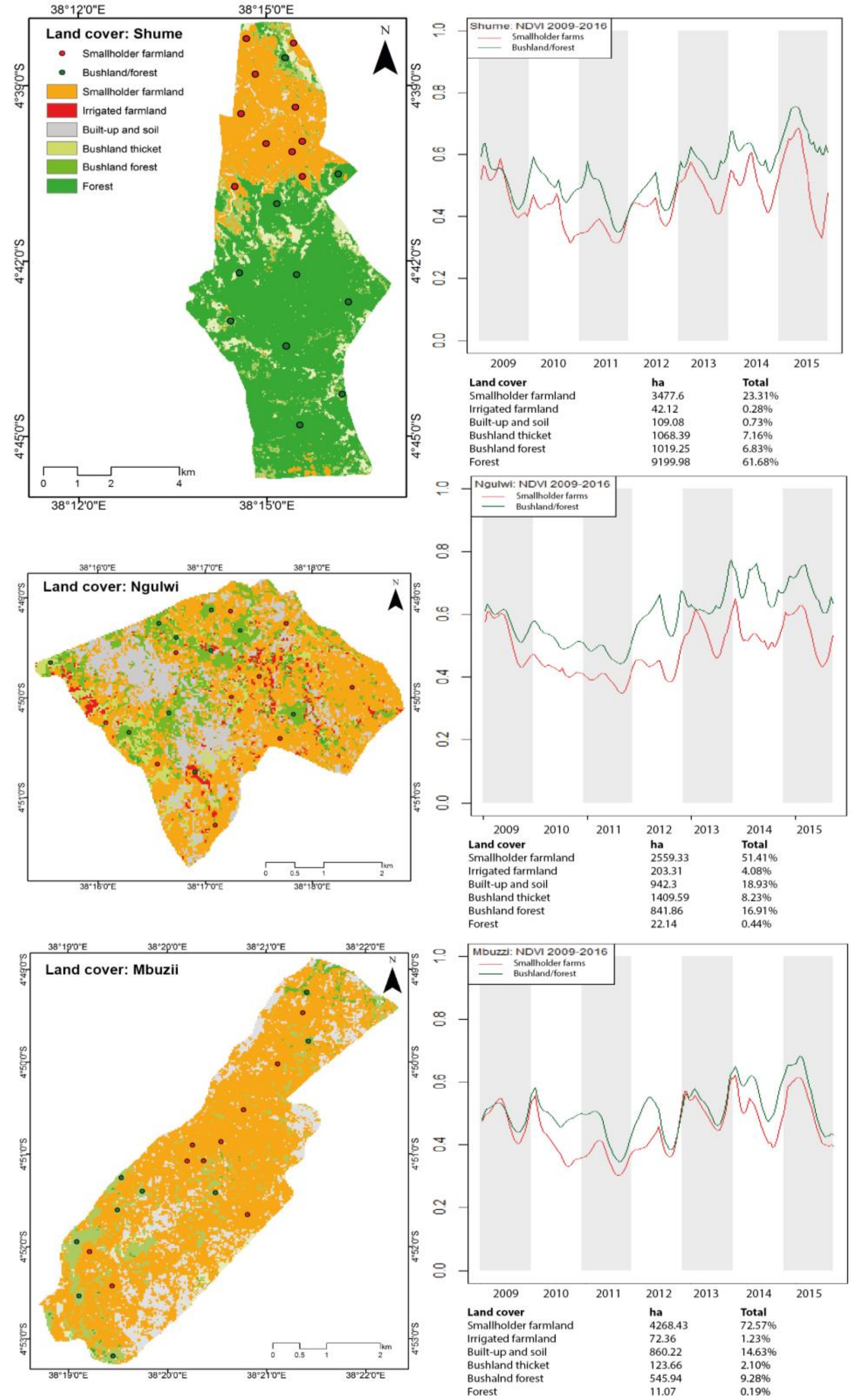

Figure 6: Land cover classification of Shume (top), Ngulwi (middle), and Mbuzii (bottom), extracted points (smallholder farmlands/SDFS: red, bushland and forest: green), statistics (ha and percentage of total land cover) and mean time series of NDVI values of smallholder farmlands and non-agriculture

4.1.4 Forage growth, yield and nutritional characteristics of four varieties of Napier grass (*Pennisetum purpureum* Schumach) in West Usambara highlands

Three forage varieties of Napier grass (Bana, Ouma and Kakamega 2) were grown and compared against the local Napier variety as feed for ruminants. These three Napier varieties were evaluated in the WUHs under smallholder farming conditions in order to ascertain their potential for improving on-farm fodder availability to dairy cattle. Forage growth, yield and nutritional characteristics were the parameters assessed and the results are presented below.

(i) Forage growth characteristics

The above ground forage growth characteristics of the four Napier varieties are presented in Table 10. In general, there was a significant difference in the mean plant height of the four Napier varieties (P<0.001) while site did not have a significant effect (P=0.936). The mean plant height of Kakamega 2 and Ouma did not differ significantly (P>0.05). The mean number of tillers per bunch was in the order of Ouma > Kakamega 2 > LN > Bana and varied significantly between varieties and sites (P<0.001). All two-way comparisons of the mean tiller number per bunch were significantly different (Fisher's LSD test, P<0.05). The basal tiller diameter varied significantly between varieties (P<0.001) but site did not have a significant effect (P=0.889). Bana had the thickest basal tiller diameter and Ouma the thinnest. However, there was no significant difference between the mean tiller basal diameter of Kakamega 2 and LN (Fisher's LSD test, P>0.05).

The mean number of leaves per tiller varied significantly between varieties (P=0.015) but not sites (P=0.114). The Kakamega 2 variety had the highest mean number of leaves per tiller followed by LN while were lowest (11.17 and 11.46 respectively) in Bana and Ouma varieties. Nevertheless, no significant differences (P>0.05) in the number of leaves per tiller was found between Bana and Ouma. Concerning mean leaf length, there was no significant difference among varieties (P=0.322), however differed significantly between sites (P<0.001). The mean leaf width varied significantly between varieties (P<0.001) and sites (P=0.006). Bana had the widest leaf blades while Ouma and LN the narrowest. No significant difference (Fisher's LSD test, P>0.05) was found between the mean leaf blades width of Ouma and LN.

The number of internodes per tiller varied significantly between varieties (P<0.001) and sites (P<0.001). The mean number of internodes per tiller was in the order of LN > Kakamega 2 > Ouma > Bana. All two-way comparisons of the mean number of internodes per tiller were significantly different (Fisher's LSD test, P<0.05). The mean LAI varied significantly between varieties (P<0.001) but not sites (P=0.086). The mean LAI was found to be in the order of Ouma > Kakamega 2 > LN > Bana. All two-way comparisons of the mean LAI for the Napier varieties were significantly different (Fisher's LSD test, P<0.05).

The interaction between variety and site was only significant for plant heights, tillers per bunch in number of leaves per tiller while for the rest of variables it was insignificant (Table 10).

Table 10: Effects of variety and site on the growth characteristics of four Napier varieties

Variable	Variety				S.E.M	P-value		
	Bana	Kakamega 2	Ouma	LN		Var.	Site	Var. x Site
Stem height (cm)	145.44[c]	177.15[b]	185.72[b]	210.81[a]	2.88	<0.001	0.936	0.019
Tillers per bunch (no.)	9.96[d]	18.17[b]	28.87[a]	16.33[c]	0.53	<0.001	<0.001	<0.001
Basal stem diameter (cm)	2.19[a]	1.81[b]	1.18[c]	1.73[b]	0.34	<0.001	0.889	0.646
Leaves per stem (no.)	11.17[b]	13.50[a]	11.46[b]	12.65[ab]	0.30	0.015	0.114	0.029
Leaf length (cm)	89.48[a]	84.74[a]	85.72[a]	86.28[a]	1.01	0.322	<0.001	0.621
Leaf width (cm)	3.69[a]	2.74[b]	2.33[c]	2.46[c]	0.05	<0.001	0.006	0.067
Internodes per stem (no.)	4.46[d]	7.28[b]	6.34[c]	8.72[a]	0.19	<0.001	<0.001	0.103
LAI (dimensionless)	2.23[d]	3.37[b]	3.82[a]	2.69[c]	0.08	<0.001	0.086	0.520

Variable means followed by same superscript letter within the same row are not significantly different (P>0.05); S.E.M = standard error of the mean; Var. = Variety

(ii) Forage biomass production

The forage biomass production of the four Napier varieties in terms of leaf and stem DM%, leaf and stem DM yields (kg/ha), total biomass yield (kgDM/ha) and LSR are presented in Table 11. The leaf DM% did not vary significantly among the varieties (P=0.057) but differed significantly between sites (P=0.035). Bana had the lowest leaf DM% and there was no significant difference among the rest of varieties (P>0.05). The stem DM% differed significantly among the varieties (P<0.001) but not between sites (P=0.422).

The leaf DM yield did not vary significantly among the varieties (P=0.141) but varied between sites (P=0.003). The stem DM yield varied significantly between varieties (P=0.009) and sites (P=0.009). Among the four varieties; LN and Kakamega 2 had the highest stem DM yields. The forage biomass DM yield varied significantly among the varieties (P=0.025) and between the sites (P=0.003). Among the four varieties; LN and Kakamega 2 had higher (P<0.05) stem DM yields than Ouma and bana. The LSR differed significantly among the varieties (P=0.014) and between the sites (P=0.02). The LSR of Kakamega 2, Ouma and LN did not differ significantly (P>0.05). Also, the LSR of Bana and Ouma were statistically similar (P>0.05).

The interaction between variety and site was only significant for the LSR (P=0.029) while for the rest of variables it was insignificant (P>0.05).

Table 11: Effects of variety and site on the yield performance of four Napier varieties

Variable	Variety				S.E.M	P-value		
	Bana	Kakamega 2	Ouma	LN		Var.	Site	Var. x Site
Leaf DM%	17.44[b]	22.06[a]	22.87[a]	21.81[a]	0.75	0.057	0.035	0.808
Stem DM%	8.29[d]	10.63[cd]	14.7[ab]	11.98[bc]	0.54	<0.001	0.422	0.514
Total DM%	12.87[b]	16.34[ab]	18.78[a]	16.90[ab]	0.84	0.105	0.364	0.972
Leaf DM yield (kg/ha)	4901[b]	7909[a]	6527[ab]	6496[ab]	477	0.141	0.003	0.648
Stem DM yield (kg/ha)	4053[b]	8642[a]	6341[ab]	7539[a]	535	0.009	0.009	0.192
Total yield (kgDM/ha)	8954[b]	16551[a]	12868[ab]	14035[ab]	955	0.025	0.003	0.426
LSR	1.39[a]	0.987[b]	1.19[ab]	0.89[b]	0.064	0.014	0.020	0.029

Variable means followed by same superscript letter within the same row are not significantly different (P>0.05); S.E.M = standard error of the mean; Var. = Variety

(iii) Nutrient concentrations

The selected nutritional values as forage for ruminants of the four Napier varieties were determined and presented in Table 12. In general, neither variety (P=0.829) nor site (P=0.649) had significant effect on the CP concentration. All two-way varietal comparisons of the mean CP were not significantly different (Fisher's LSD test, P>0.05). NDF and ADF did not vary significantly between the varieties and sites. The pairwise comparisons revealed that LN had the highest NDF (66.63%) and ADF (39.40%) while Ouma had the least 62.93 and 35.83%, respectively. The concentrations of EE, Ash, Ca and P did not differ significantly between varieties but that of Ash and P differed significantly between sites (P< 0.05). The InvDMD did not differ significantly between varieties (P=0.085) and sites (P=0.793). However, the pairwise comparisons indicated that Ouma had the highest InvDMD (60.84%) followed by Bana (55.55%) and Kakamega 2 (55.28) while LN the least (52.09%). The InvOMD varied significantly between varieties (P=0.03) but not between sites (P=0.69). The ME did not differ significantly across the varieties (P=0.109) but varied significantly between sites (P=0.004). No significant interaction between variety and site was observed among all the nutritional value parameters (Table 12).

Table 12: Effects of variety and site on nutritional values of four Napier varieties

Variable	Variety				S.E.M	P-value		
	Bana	Kakamega 2	Ouma	LN		Variety	Site	Variety x Site
CP%	9.73^{a}	10.40^{a}	9.98^{a}	9.58^{a}	0.31	0.829	0.649	0.912
NDF%	63.70^{ab}	65.24^{ab}	62.93^{b}	66.63^{a}	0.55	0.084	0.231	0.620
ADF%	36.88^{ab}	36.60^{ab}	35.83^{b}	39.40^{a}	0.55	0.094	0.187	0.409
EE%	1.95^{a}	1.90^{a}	2.05^{a}	2.04^{a}	0.08	0.889	0.900	0.260
Ash%	8.62^{a}	9.35^{a}	9.38^{a}	7.96^{a}	0.37	0.174	0.001	0.632
Ca%	0.24^{a}	0.26^{a}	0.29^{a}	0.21^{a}	0.02	0.349	0.466	0.476
P%	0.13^{a}	0.19^{a}	0.15^{a}	0.19^{a}	0.01	0.191	0.001	0.219
IVDMD%	55.55^{ab}	55.28^{ab}	60.84^{a}	52.09^{b}	1.21	0.085	0.793	0.429
IVOMD%	59.22^{ab}	58.33^{ab}	65.87^{a}	55.41^{b}	1.27	0.030	0.690	0.677
ME(MJ/KgDM)	7.92^{ab}	7.85^{ab}	8.57^{a}	7.42^{b}	0.18	0.109	0.004	0.413

Variable means followed by same superscript letter within the same row are not significantly different (P>0.05); S.E.M = standard error of the mean

(iv) Correlations for forage growth and yield parameters

The correlation matrix of forage growth and yield parameters are presented in Table 13. In general, leaf yield, stem yield and overall biomass yield had strong positive relationship between each other. Leaf to stem ratio had weak negative relationship with internodes per stem. Stem height had weak positive relationship with tillers per bunch and internodes per stem, but negatively related to leaf width and basal stem diameter. Leaves per stem were positively associated to number of internodes per stem. Internodes per stem had weak negative relationship with leaf width. Tiller numbers per bunch were found to have strong negative relationship with basal stem diameter and leaf width. Leaf width had strong positive relationship with basal stem diameter while it has weak negative relationship with LAI. Basal stem diameter was found to have negative relationship with LAI.

Table 13: Correlations between forage growth parameters in four Napier varieties

	Leaf yield (kgDM/ha)	Biomass yield	LSR	Stem height	Leaves per stem	Internodes per stem	Tillers per bunch	Leaf length	Leaf width	Basal stem diameter
Biomass yield (kgDM/ha)	0.94*									
Stem yield	0.78*	0.95*								
LSR	0.19	-0.12								
Stem height (cm)	0.14	0.17	-0.1							
Leaves per stem (no.)	0.05	0.08	-0.2	0.19						
Internodes per stem (no.)	-0.03	0	-0.25*	0.26*	0.37*					
Tillers per bunch (no.)	-0.03	0.02	-0.2	0.24*	0.06	0.18				
Leaf length (cm)	0.05	0.11	-0.1	-0.02	-0.15	-0.14	-0.02			
Leaf width (cm)	-0.04	-0.08	0.17	-0.42*	0.03	-0.31*	-0.55*	0.03		
Basal stem diameter (cm)	-0.07	-0.1	0.14	-0.31*	0.05	-0.16	-0.64*	0	0.64*	
LAI	0.06	0.09	-0.1	0.17	0.16	-0.05	0.38*	-0.07	-0.25*	-0.31*

*Correlations marked with * are significant (P < 0.05)*

The principal component analysis (PCA) results indicated cumulatively Principal Component 1 (PC1) and Principal Component 2 (PC2) explained 47.47% of the observed varietal differences. Furthermore, the results of the principal coordinate analysis (PCO) indicated that PCO1 and PCO2 explained about 70% and 12% of the observed varietal variations, respectively. Hence, affirming that Bana grass exhibited relatively different from the rest of the observed varieties both in terms of biomass growth characteristics and yield components (Fig. 7, Appendices 4 and 5). It also indicated that Kakamega 2 and LN had a lot of similarities.

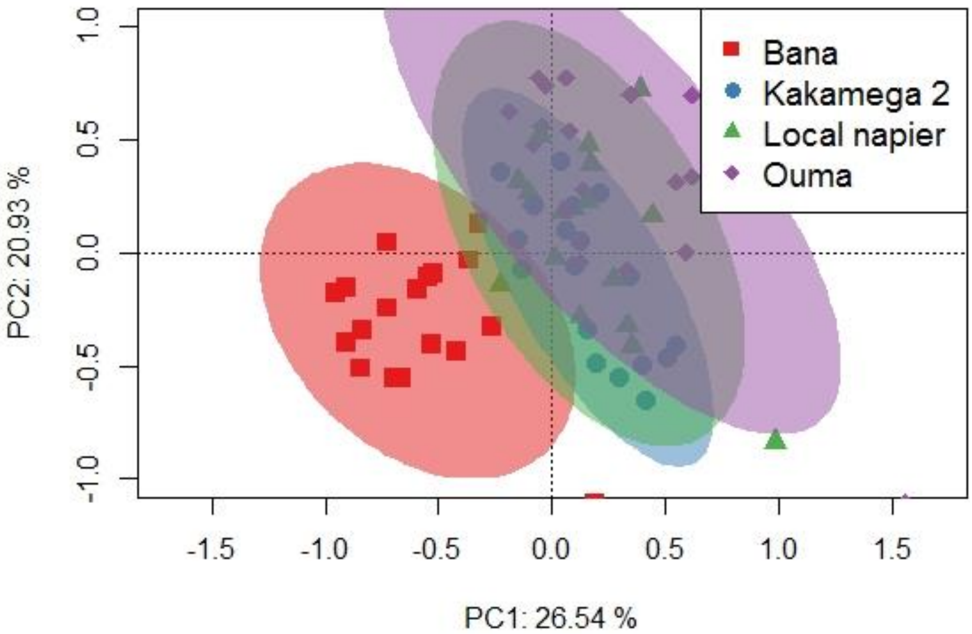

Figure 7: Principal component analysis plot showing the relationship between the four Napier varieties

In addition, the correlation coefficients of the Eigen vectors for the 12 assessed parameters are indicated in Table 14. This depicted that the biomass yield components had strong correlations among each other, basal stem diameter and leaf width were positively correlated (bolded in Table 14). However, number of tillers per bunch had strong negative correlations with basal stem diameter and leaf width (bolded in Table 14). In addition, the ordination plot for the correlations between Eigen vectors for the 12 assessed variables in the four experimental Napier varieties is presented in Fig. 8. Whereby, it was depicted that yield components (leaf, stem and total biomass) had strong positive correlation among each other. Basal stem diameter and leaf width had strong negative correlation to number of tillers per bunch (Fig. 8).

Table 14: Principal component analysis correlation matrix of Eigen vectors for the first 6 axes

Variable	1	2	3	4	5	6
Leaf yield	**0.6313**	**0.6756**	0.0968	-0.3139	0.0893	-0.0119
Stem yield	**0.7646**	**0.5795**	-0.0565	0.1851	-0.0684	0.1364
Biomass yield	**0.7435**	**0.6619**	0.0166	-0.0531	0.0063	0.0704
LSR	-0.35	0.1626	0.3513	-0.7229	0.2282	-0.2967
Stem height	0.5165	-0.2666	-0.1632	-0.1354	0.3008	-0.4308
Leaves per stem	0.2184	-0.0829	-0.7476	-0.1589	-0.2576	-0.3383
Internodes per stem	0.296	-0.3431	-0.6353	0.0167	0.3721	0.1097
Tillers per bunch	**0.5182**	**-0.5905**	0.2561	-0.0231	-0.126	0.0476
Leaf length	0.0588	0.2	0.308	0.6648	0.1673	-0.5633
Leaf width	**-0.5891**	**0.554**	-0.1922	0.0254	-0.2702	-0.0804
Basal stem diameter	**-0.5877**	**0.5289**	-0.3551	0.0294	-0.0851	-0.0924
LAI	0.4004	-0.29	0.139	-0.1301	-0.729	-0.2057

Note: The bolded numbers indicate strong correlation coefficients

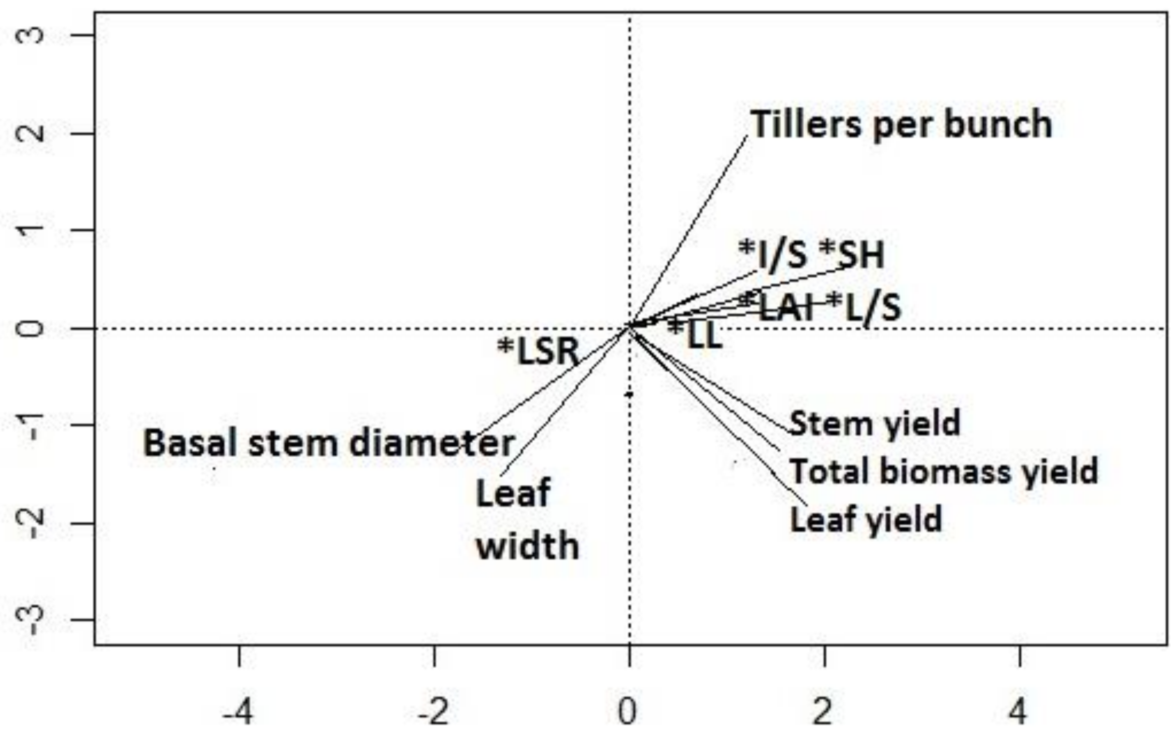

Figure 8: Principal component analysis plot showing the relationship between the 12 variables for the four Napier varieties

Note: I/S=internodes per stem, SH=stem height, LAI=leaf area index, L/S=leaves per stem, LL=leaf length, LSR=leaf to stem ratio, and * = abbreviation

(v) Farmers' assessment of the established grasses

According to the farmers' assessment Ouma and Kakamega 2 scored the highest and bana grass the least. The scores were attributed to higher potential biomass yield, high leafiness and tillering and hairiness values. Local Napier was the most hairy, followed by Kakamega 2 and bana while Ouma was the least hairy (Table 15). The farmers indicated higher preference to Ouma than Kakamega 2 and bana grass due to higher tillering, greenness and leafiness. The higher stem thicknesses and broader leaves of bana grass were highly appealing to farmers but its shorter height was a demerit.

Table 15: Mean scores of the farmers' evaluation of four fodder grasses in terms of quality and quantity in WUHs, Tanzania

Evaluation criterion	Bana	Ouma	Kakamega 2	Local Napier	S.E.M	P value
Greenness	6.0[c]	8.5[a]	6.2[c]	4.0[b]	0.25	<0.001
Leafiness	6.3[b]	7.4[a]	6.2[b]	4.3[c]	0.20	<0.001
hairiness	3.9[c]	0.9[d]	6.7[b]	8.2[a]	0.34	<0.001
Tillering	3.8[c]	8.1[a]	6.6[b]	4.4[c]	0.24	<0.001
Growth vigour	4.0[c]	5.7[b]	7.0[ab]	6.5[ab]	0.21	<0.001
Potential biomass yield	3.4[b]	6.4[a]	6.4[a]	6.1[a]	0.24	<0.001

S.E.M means standard error of the mean

4.1.5 Effects of dry season supplementation of *Calliandra calothyrsus* leaf-meal mixed with maize-bran on dairy cattle milk productivity in Western Usambara Highlands

This experiment was designed to supplement crossbred lactating dairy cows with graded levels of *C. calothyrsus* leaf-meal mixed with maize-bran for 45 days during the dry season between September and October, 2018. The major aim was to discern the optimal supplementation strategies for optimizing milk productivity and profitability using locally produced protein-energy rich feed resources.

(i) Animal conditions, milk yields and milk quality

The body weight and BCS was not affected by any of the analyzed variables ($P > 0.05$) (Table 16). The level of CLM-MB-MVP-MP supplementation was found to have an effect on milk yields ($P < 0.001$) (Table 16; Fig. 9). The un-supplemented cows yielded consistently low milk compared to the supplemented ones (Fig. 7). Moreover, interactions between SL and LP, and between LP and EW had significant effects on milk yield ($P < 0.05$). Milk fat, protein, lactose and SNF composition were affected by SL (P < 0.05) (Table 16). Nonetheless, LP and interactions between SL and LP had effects on milk protein content (P = 0.003 and P = 0.02, respectively) (Table 16).

Table 16: Effects of graded protein-energy rich supplementary feed on milk yield and composition among lactating crossbred cows during the dry season at the study site

Variable	Supplementary level (kg/cow/day)				S.E.M	P value						
	0	2	4	6		SL	LP	EW	SL x LP	SL x EW	LP x EW	SL x LP x EW
BW(kg)	366[a]	346[a]	368[a]	357[a]	4.22	0.36	0.07	0.95	0.36	0.99	0.99	0.99
BCS	3.15[a]	3.33[a]	3.45[a]	3.30[a]	0.05	0.08	0.58	0.47	0.11	0.61	0.34	0.68
MY (litre)	2.73[d]	4.48[c]	5.59[b]	6.13[a]	0.08	<0.001	0.18	0.22	<0.001	0.20	0.02	0.08
Fat (%)	3.77[c]	3.88[c]	4.24[b]	4.98[a]	0.09	0.001	0.09	0.55	0.08	0.78	0.43	0.73
Protein (%)	2.91[b]	3.15[a]	2.96[ab]	3.17[a]	0.04	0.002	0.003	0.73	0.02	0.15	0.14	0.31
Lactose (%)	3.86[a]	3.94[a]	3.59[b]	3.81[a]	0.03	0.01	0.09	0.11	0.27	0.49	0.16	0.47
SNF (%)	6.99[a]	7.25[a]	6.55[b]	6.95[a]	0.06	0.001	0.53	0.45	0.17	0.80	0.91	0.88

Variable means that do not share a similar superscript letter within the same row are significantly different. P values in italics indicate statistical significance (P < 0.05). SEM stands for the overall standard error of the mean, BW body weight, BCS body condition score, MY milk yield, SL supplementation level, LP lactation phase, SL x LP, SL x week, LP x week, SL x LP x week – interactions between the independent variables

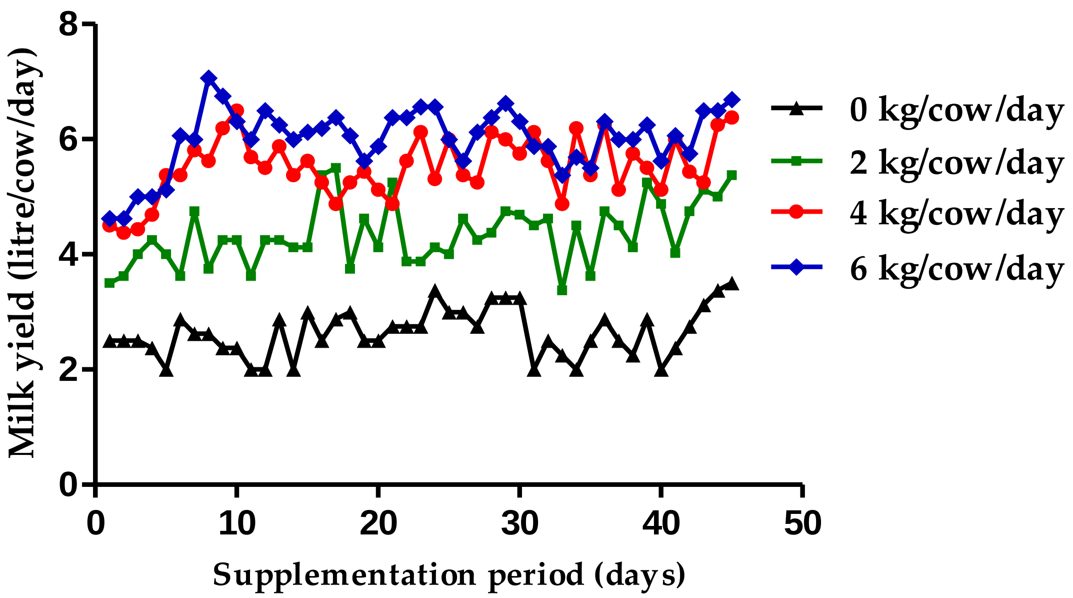

Figure 9: Effects of graded CLM-MB-MVP-MP supplementary concentrate feed during dry season on milk production trends of lactating crossbred dairy cows for 45 days

(ii) Simulated impacts on milk yields, income and production costs

Supplementation was found to improve milk production significantly (P = 0.02) both in terms of per lactation and per day milk yields (Table 17). Similarly, supplementation level was found to have an effect on potential milk production (litre/lactation) (P = 0.017). However, simulated milk productions and associated milk yield per cow per day for both supplementation of 4 and 6 kg/cow/day did not differ significantly (P > 0.05) (Table 17). Furthermore, the lactation curves revealed that the simulated milk yields were below the theoretical production potential (15 – 20 litres/cow/day) of the Friesian – Zebu crossbred cows (Fig. 10). Supplementation was found to increase both gross income and total production costs per lactation substantially (P = 0.018 and P = 0.042, respectively) (Table 17). Production cost per litre of milk, which was highly influenced by milk yields, differed significantly across all the supplementation levels (P < 0.001). Whereby, the production cost per litre of milk was highest for un-supplemented followed by supplemented cows in the order of 2 kg/cow/day > 6 kg/cow/day > 4 kg/cow/day. Consequently, the income to cost ratios were affected and being in the order of 6 kg/cow/day > 4 kg/cow/day > 2 kg/cow/day > 0 kg/cow/day (P = 0.019) (Table 17).

Table 17: Simulated bio-economic effects of graded supplementary concentrate feed on lactating crossbred Friesian cows fed with maize stover, Napier grass, Guatemala grass and natural pasture in WUHs, Tanzania

Variable	0 kg/cow/day	2 kg/cow/day	4 kg/cow/day	6 kg/cow/day	SEM	P Value
Simulated milk production (litre/lactation)	1341^c	2194^b	2937^a	3001^a	234	0.02
Milk yield per cow per day (litre)	4.10^c	6.57^b	8.80^a	9.06^a	0.70	0.019
Gross income (x 1000 Tsh./cow/lactation)	1343^b	2194^b	2937^a	3025^a	235	0.018
Total cost (x 1000 Tsh./cow/lactation)	2482^b	2772^a	2772^a	2772^a	1.61	0.042
Gross margin (x 1000 Tsh./cow/lactation)	-1139^d	-578^c	166^b	253^a	28.31	0.021
Price of milk (Tsh./litre of milk)	1000	1000	1000	1000	NA	NA
Production cost per litre of milk (Tsh.)	2010^b	1293^a	973^a	1020^a	125	<0.001
Income to cost ratio	0.54^b	0.79^{ab}	1.06^a	1.09^a	0.21	0.019

**Tsh. means Tanzania shillings; 1 USD ≈ 2250 Tsh. at the time of this study. SEM stands for standard error of the mean while NA stands for not applicable. Means that do not share a similar superscript letter within the same row are significantly different*

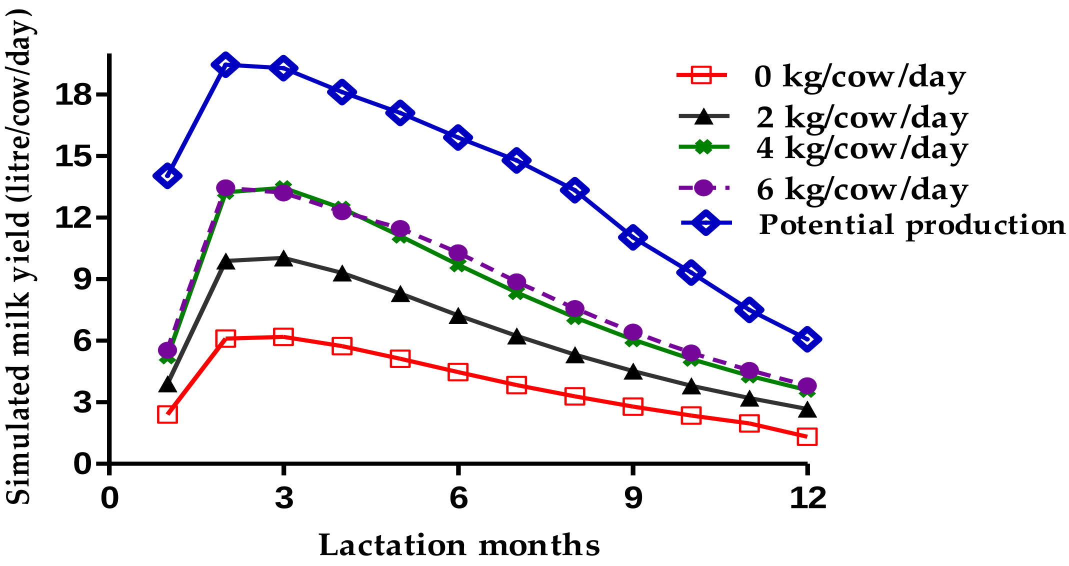

Figure 10: Simulated milk yields and potential milk production of lactating crossbred Friesian cows under supplementation

(iii) Correlations between observed and simulated milk yields

The observed average milk yields (real responses) during the 45 days dry season experimental feeding period was correlated to the simulated year-round average daily milk yields (LIFE-SIM output). It was found out that the observed and simulated milk yields have strong positive correlation (Pearson's $R^2 = 0.973$, $P < 0.001$) (Fig. 11 a). Moreover, simulated milk yields at all supplementary feeding levels were consistently higher than the observed (Fig. 11 b).

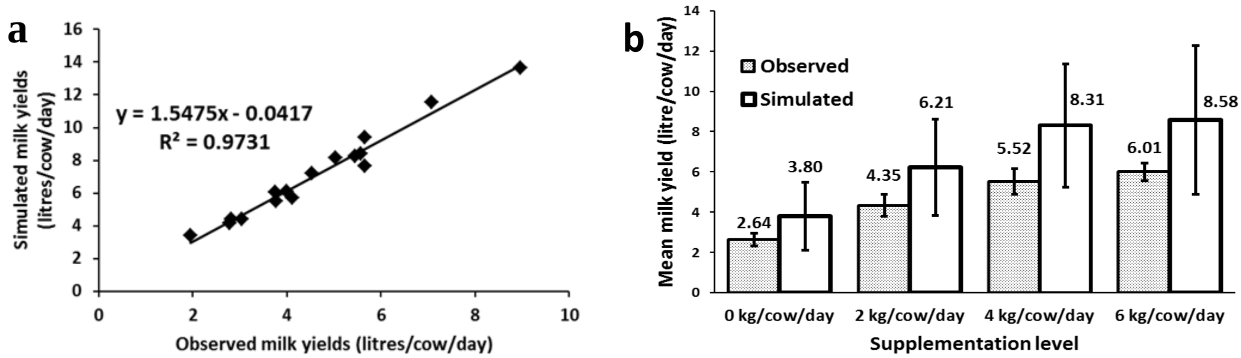

Figure 11: Correlations between mean observed and simulated milk yields (a), and comparisons between mean observed and simulated milk yields (b)

(iv) Simulated impacts on methane emission and manure excretion

The level of supplementation had effect on both methane emissions per cow per year and per unit of milk produced (P = 0.031 and P = 0.006, respectively). Whereby, methane emission (litre /cow/year) was least for un-supplemented cows and increased gradually with increasing level of supplementation (Table 18). Methane emission per kg of milk produced was highest in un-supplemented cows and was in order of 2 kg/cow/day > 6 kg/cow/day >4 kg/cow/day (Table 18). However, manure excretion (kgDM/cow/year) was not significantly affected by supplementation level (P = 0.976).

Table 18: Simulated methane emission and manure excretion as affected by graded supplementary concentrate fed to lactating crossbred Friesian cows at the study site

Variables	0 kg/cow/day	2 kg/cow/day	4 kg/cow/day	6 kg/cow/day	SEM	P Value
Methane emission (litre/cow/year)	195.64[b]	220.97[ab]	224.90[ab]	236.03[a]	5.81	0.031
Methane emission per kg of milk (litres)	0.13[b]	0.095[a]	0.072[a]	0.079[a]	0.01	0.006
Manure excretion (kg DM/cow/year)	1258.30[a]	1223.59[a]	1253.46[a]	1251.10[a]	27.13	0.976

Means that do not share a similar superscript letter within the same row are significantly different

4.2. Discussion

In this section, the results from the baseline study are discussed in sub-section 4.2.1. The results for the on-farm experiment for evaluation of the performances of four (4) Napier varieties as feed for ruminants are discussed in sub-section 4.2.2. The experimental results for the dry season supplementation of *C. calothyrsus* leaf-meal mixed with maize-bran to lactating crossbred dairy cows, and associated simulated impacts on milk productivity, economics and enteric methane emissions are discussed in sub-section 4.2.3.

4.2.1 Seasonal variations in availability of fodder resources and dairy cattle feeding practices

(i) Land cover classification and 2009 – 2016 climate data (time series) and implications to fodder availability

There was a good agreement between the climate record and the NDVI time series. The occurrence of droughts in 2010 and 2011 and a drop in vegetation vigor can be clearly noted (Fig. 6). Also, the effect of season change on the dairy production was observed through the decline in milk production by 29.3% in 2011 but raised again by 19.9% in 2012.

When analyzing the mean NDVI time series and more precisely the difference between the SDFS/ smallholder farms and the non-agriculture (bushbland and forest) a difference was observed. Relatively higher mean NDVI values were noticed in non-agriculture areas. The higher abundance of non-agriculture (i.e bushland, forest) at Shume (75.67%) is thought to have reduced fodder and fuel wood demand pressure on SDFS. In Ngulwi (25.14%) and Mbuzii (11.57%) the non-agricultural areas are fairly marginal and utilization of these lands reflects in the NDVI.

As the study sites are located in a region which is affected by cloud cover frequently and within a continent which has poor storage infrastructure (Wulder *et al.,* 2016), there was very little high quality satellite data available. Also, limitations of spatial resolution (Landsat 7 Satellite Imagery) reduce the effectiveness of the land cover analysis (the estimated accuracy of the output was 67%).

The SDFS are typified by its high heterogeneity and mix of crops. These subtle vegetation changes can not detected by the Landsat sensors and also influenced our GPS reference points, which often were clustered within a couple of pixels. Nevertheless, ground surveys revealed that the seasonal crop farming practices left most of the SDFS landscape bare during dry season with exception of few scattered trees and perennial grasses in farm margins and contour strips. Henceforth, being in agreement with the observation that reserved dry crop residues are essential dry season livestock feed resource in the WUHs.

(ii) Milk production and implications to sustainability

The reported smaller landholdings and low milk productivity implied that most farmers were practicing subsistence small scale dairy production. The smaller landholdings coupled with low milk prices were deemed to discourage intensification of dairying in the WUHs. The observed tendency of most smallholder farmers' land in WUHs to be devoted to household food crop production is in concurrent with Waithaka *et al.* (2006) opinions. Waithaka *et al.* (2006) opined that household food security is the major determining factor for land use decisions among smallholder farmers.

Moreover, the reported milk yields under this study were far less than those reported by Cadilhon *et al.* (2016) who reported 8 and 4 litres/cow/day for wet and dry season, respectively. Reasons for low milk productivity apart from being caused by poor feeds were also attributed to other factors including inferior crosses of dairy cattle breeds, diseases (mastitis and helminthiases) and poor general management. Whereby, most farmers mentioned poor cattle breeds as the major driver for low milk yields and demanded for superior dairy cattle breeds. Nonetheless, the finding that in WUHs fodder fluctuates seasonally both in terms of quantity and quality, with eventual variations in seasonal milk production implies that fodder/feed is important driver for milk production. Henceforth, even if the cattle breeds will be improved and diseases controlled the year-round proper feeding of dairy cattle is still crucial if sustainable high milk production is to be achieved in WUHs (Chagunda *et al.*, 2015).

(iii) Fodder production and implications to sustainability

The small farm sizes averaging 1.32 ha/hh coupled with the non-existence of pasture plots may contribute to inadequate year-round fodder at farm level. For example, most smallholder dairy farmers reported a practice of making arrangements with nearby farmers who do not keep livestock to collect fodder and crop residues from their farms in exchange for money, manure or labour. The key role of crop residues in particular maize stover as dry season dairy feed was justified by its higher yields of about 4013.84 Kg DM/ha. However, lack of processing and its high fibrous nature might have attributed to dry season decline in milk productivity. Thus, capacity building to smallholder dairy farmers towards proper harvesting, storage, processing and feeding of maize stover will be imperative to enhance sustainable dairy production in WUHs.

Despite higher diversification of fodder sources, on-farm production was reported to be the most reliable compared to other sources including reserved, uncultivable and fallowed lands. This is due to direct control of the farmer to fodder resources within his/her farm, while other sources such as roadsides, reserved and uncultivable land are opportunistic in nature. Fore stance, at Mbuzii ward dry season pasture in communal rangelands were reported to be unreliable due to wildfires. Whilst, at Shume ward pasture access in forests was limited only to newly harvested or planted areas and access permits are required. Crop cultivation and cut and carry of pasture in forest plantations aim at reducing grass weeds that poses wildfire risks. The importance of forest reserve fodder source is in agreement with large shrub-forest cover (75.67%) in the Shume ward (Fig. 6).

Heemskerk (2016) estimated that yearly about 1800 Kg DM of natural pasture per farm is sourced from public lands for livestock feeding under zero grazing in WUHs. This is in compromise with the sustainability of cattle dairying in WUHs given the fact that human and livestock population is increasing within the limited lands. Also, the sharp decline in milk production in 2011 due to drought despite the presence of forests and bushlands implies that natural areas supply a limited amount of fodder. Additionally, this indicates that the resilience of the WUHs' SDFS is in compromise if adequate on-farm feeds are not produced and stored for feeding at times of scarcity. Henceforth, initiatives for improving on farm fodder production and adhering to carrying capacity are inevitable if SDFS in the WUHs is to be sustained.

Farm surveys revealed that Napier and Guatemala grass had highest yields both in the dry and wet seasons compared to natural pasture and weeds. The importance of Napier grass for feeding dairy cows was highly emphasized by the smallholder dairy farmers in which it was testified that upon feeding Napier grass the milk yields increases two-fold. Orodho (2006) also highlighted that Napier is the best fodder grass in the East Africa highlands for improving dairy nutrition. However, Guatemala grass was avoided based on low response in milk yields and it was testified that it is fed only during dry seasons. This implies that promotion of Napier grass and further research on locally high yielding and nutritive varieties is worth undertaking in the WUHs to cater for both wet and dry seasons.

(iv) Seasonal variations in fodder nutritive values and implications to sustainability

Dairy cow requires feed of at least 10 MJ/Kg DM of ME to meet the energy requirements for both maintenance and effective production (NRC, 2001). Whilst, the observed ME values under this study for both dry and wet seasons were about 5 MJ/Kg DM implying that the observed low milk yields might have been caused by low ME values. In addition, the dry season CP value of about 8% observed under this study is less than the recommended range of 10 to 16% (NRC, 2001) that may further compromise milk production.

The current study reported higher fibre contents compared to the recommended of 30% NDF and 19% ADF (NRC, 2001). The higher fibre contents in fodders result to low digestibility as well as low IVOMD and IVDMD values. Henceforth, these nutritive results imply that dairy cows in the study sites will not meet their productivity potential in both wet and dry seasons unless feed is improved. For example, one farmer reported an average of 10 litres of milk/cow/day in dry season after supplementing with energy source, minerals and a practice of night feeding. This is also supported by an observed average milk yield of 15 litres/cow/day after provision of 6 kg supplementary concentrate per milking cow per day in a commercial farm located in the WUHs.

4.2.2 Forage growth, yield and nutritional characteristics of four Napier varieties

(i) Forage growth characteristics

The four Napier varieties varied in growth parameters including stem height, tiller numbers, leaf sizes and LAI. These variations were comparable to Nyambati *et al.* (2010), Halim *et al.* (2013) and Khairani *et al.* (2013) who reported wide range of variations of growth parameters among Napier grass varieties. The differences observed under the current study could be based on variety characteristics and adaptation potentials to the cooler and wet conditions of WUHs. Ouma variety consistently produced higher number of tillers per bunch followed by Kakamega 2 and LN while Bana was the least. According to Lafarge and Loiseau (2002) tiller production is vital for perennial grasses to sustain forage production through replacing plant parts that are lost through ageing, grazing or cutting. All varieties except Bana achieved the recommended harvesting height of 150 cm within 110 days in WUHs. Hence, suggesting that Bana grass exhibit slow growth rate under attitudinal and climatic conditions of WUHs. In addition, Bana was outcompeted by the other varieties whereby it had the least number of leaves and internodes per tiller. However, in terms of basal tiller diameter and leaf width; Bana outperformed all varieties indicating that it invested more on stem thickness and leaf size rather than other parameters such as tiller density and height. Similarly, Nyambati *et al.* (2010) recorded broader leaves and shorter stems in Bana grass relative to other 12 Napier cultivars compared in Western Kenya.

The LAI was significantly higher in Ouma followed by Kakamega 2 and LN while Bana had the least. According to Kubota *et al.* (1994) stem elongation and erection is essential for enhancing canopy light penetration and hence photosynthesis efficiency in 4 carbon (C4) grasses. Hence, the low LAI in Bana variety might be attributed to the low tiller density and the observed slightly decumbent growth habit while the rest of grasses exhibited erect stem growth. Nevertheless, the measured LAI values (2.2-3.8) in this study were well below those obtained by Kubota *et al.* (1994) who reported LAI of 12.4 in Napier sward aged 75 days and with over 2m canopy height. Comparable LAI results ranging from 1.7 to 4.1 were reported by Guenni *et al.* (2005) worked in five Brachiaria grass species in a tropical environment. The lower LAI values of this study compared to those of previous studies might be attributed to the methodological differences (Confalonieri *et al.,* 2013). Similarly, Francone *et al.* (2014) observed that PocketLAI provided low LAI values in comparison to those of commercial instruments namely LAI-2000 and Accu-PAR Ceptometer. Nevertheless, based on growth morphological characteristics Bana did not perform well in the WUHs in comparison to Ouma, Kakamega 2 and LN varieties.

(ii) Forage biomass production

The DM yield results for Kakamega 2, LN and Ouma varieties under the present study are in conformity to those reported by Halim *et al.* (2013). Under Halim *et al.* (2013) recorded DM yields for a single cut were 12 640, 14 420 and 15 840 kg/ha for tall Napier varieties namely Red Napier, Common Napier and King grass, respectively. The current findings are also in agreement with Nyambati *et al.* (2010) who reported an average yield of 13.5 tDM/ha per cutting for eight Napier varieties in Western Kenya. However, in this study Bana grass which is a tall Napier variety was found to have contrasting DM yields (8954 kg DM/ha) comparable to those of dwarf Napier varieties (Halim *et al.*, 2013). In particular, Halim *et al.* (2013) reported single cutting DM yields of 8000 and 8720 kg DM/ha for Australian Dwarf and Dwarf 'Mott' Napier varieties, respectively. In contrary to this study, Nyambati *et al.* (2010) recorded an average of 16.2 tDM/ha for Bana in 8 cuttings under Nitrogen and Phosphorus fertilizer application. The significantly higher DM yields of Kakamega 2 and Ouma which were comparable to that of LN indicated that they are suitable for enhancing forage production in the WUHs. The observed low DM yields for Bana indicated that it is not suitable for enhancing forage biomass availability in the smallholder farms of WUHs. However, the recorded higher LSR for Bana indicates that it has potential for enhancing leaf availability which is among the key parameters to be considered for high quality fodder production (Smart *et al.,* 2004). Similarly, Mwendia *et al.* (2008) reported higher LSR for Bana grass (4.98) compared to that of Kakamega1 (2.49) and Kakamega 2 (3.32) in the highlands of Kenya.

(iii) Nutrient concentrations

Both forage yields and nutrient content are essential elements to consider on selection of fodder varieties for livestock production. The major nutrients required by ruminant animals are carbohydrates and proteins. Carbohydrates are essential for energy provision while proteins are required for growth and maintenance with surplus used for production. In the present study, the mean CP concentration of the Napier varieties was 9.9%. This is higher than the values (4.2-6.7%) reported by Gemiyo *et al.* (2017) across 10 Napier accessions under unfertilized conditions in Ethiopia but lower than that reported by Rusdy (2016). It was attributed that such variations were probably based on genotypes, harvesting age and environmental conditions. The CP reported in Napier studies does not meet the dairy cattle requirement according to NRC (2001) where for sustainable production and maintenance feeds need to have CP between 14 and 16%.

The mean ME values in the present study ranged between 7.4 to 8.5 MJ/KgDM and are comparable to 7.1 MJ/Kg DM reported by Turano *et al.* (2016). However, NRC (2001) recommends 10 MJ/Kg DM as minimum ME requirement for dairy cattle. This implies that supplementary protein-energy rich feed sources are required for optimal milk production if the Napier varieties under the study are to be the basal dairy cattle feed in the WUHs.

The concentrations of fibers (NDF and ADF), crude fat (EE) Ash and minerals (Ca and P), are generally concurring to earlier recorded values in Napier grass varieties (Orodho, 2006; Rusdy, 2016; Turano *et al.,* 2016). For example, the NDF values followed within the range of 45-65% which is regarded as roughage feed of moderate quality (Rusdy, 2016). According to NRC (2001) minerals are very essential for ruminant animal reproduction including conception and calving, growth, maintenance and production (e.g. milk, beef and wool). In this study, mean phosphorus (P) concentrations ranged from 0.13 to 0.19% while calcium (Ca) ranging from 0.21 to 0.29%. The observed values under this study are further below the recommended concentrations of 0.36 and 0.43% for P and Ca, respectively. The low concentration observed from the current study may be influenced by edaphic factors, seasons and biomass dry matter proportion as reported elsewhere (Mtengeti *et al*., 2008).

The mean ranges *in vitro* digestibility values under this study were IVDMD (52.1-60.8%) and IVOMD (55.4-65.9). These results are in agreement with Rusdy (2016) who generally revised IVDMD for Napier grass ranging from 55.7 to 81.7% whilst IVOMD ranged from 35 to 66.4%. Moreover, the varietal differences were significant in IVOMD with Ouma being most digestible and LN the least. The observed higher IVOMD of Ouma might be attributed to its low NDF contrary to LN. High NDF contents render low forage digestibility and intake by ruminants due to increased fraction of indigestible structural carbohydrates in the feed ration.

(iv) Correlations of forage growth and yield parameters

In this study, it was observed that tiller numbers per bunch have negative correlations with tiller diameter (r=-0.64) and leaf width (r=-0.55). This can be explained by the tiller density/size compensation theory which states that forage grasses might either adopt a high density of small tillers or low density of bigger tillers as a strategy to maximize canopy light access (Assuero & Tognetti, 2010). Ouma which had the highest number of tillers per bunch had thinnest tillers and leaves. Interestingly, Bana grass which was observed to have broadest leaves and thickest tillers had the smallest number of tillers per bunch. Nevertheless, the stem height tended to be negatively correlated to basal diameter (r=-0.31) and leaf width (r=-0.42). Tiller number tended to be positively correlated to height (r=0.24) and LAI (r=0.38). This observation can be attributed to the fact that all Napier varieties except Bana exhibited erect growth habit and achieved higher heights. This is in agreement to Kubota *et al.* (1994) who affirmed that in Napier grass stem elongation and erection has positive correlation with leaf area index. The observation that LSR had weak negative correlation with stem height (r=-0.1) and internodes per tiller (r=-0.25) might be attributed to the fact that Bana which was the shortest was the most leafy variety.

4.2.3 Effects of the *Calliandra calothyrsus* leaf-meal mixed with maize-bran supplementary feed on dairy cattle milk production

(i) Animal conditions, milk yields and quality

The observed lack of significant influence of HSR supplementation on body condition and weight changes in this current study is attributed to short duration of this experiment. Roche *et al.* (2009) argued that the body condition of a lactating cow apart from feed is determined by interplay of other factors including hormones, lactation stage, gestation period, diseases and physical activity. However, effects of feeding on milk response can be observed within few hours or days upon altering either feed quantity or quality. The observation that increase in supplementation level was concurrent to milk yield increase was in agreement to our prior assumptions.

However, the observed low milk yields for 4 and 6kg HSR/cow/day could be attributed to the poor genetic potential of the cows. The theoretical milk yield of East African crossbred dairy cattle is between 15 and 20 litres/cow/day (Lukuyu *et al.,* 2015). This is owing to the fact that there were no records on genotypes and breeding of the crossbred dairy cows at the study site. At Irente farm and nearby villages, estrous cows received bull services from crossbred Friesian bulls of untraceable origin where artificial insemination was not practiced. Thus, indigenous cattle genotype (*Bos indicus*) might have dominated that of temperate dairy cattle (*Bos taurus*) hence reducing milk production potential. This is also supported by Chagunda *et al.* (2015) who reported milk yields of 7.3 and 11.9 litres/cow/day for cattle with genotypes of 1/2 Friesian x 1/2 Malawi Zebu and 3/4 Friesian x 1/4 Zebu Malawi, respectively.

Nonetheless, the observed significant effect of HSR on milk quality improvement in particular milk fat is in agreement with Paterson *et al.* (1999). These authors reported that Calliandra based diet increased milk butterfat by 10% under the smallholder farming conditions in the Kenyan highlands. Therefore, implying that adoption of HSR feeding strategies has potential for improving both milk yields and quality in the WUHs.

(ii) Simulated impacts on milk yields, income and production costs

Similarly to observed milk yields the simulated milk yields had positive responses to HSR increments. Subsequently, income was also positively influenced by HSR supplementation as income was calculated based on milk sale using existing farm gate price. The finding that feed quality improvement improved both milk production and profitability is consistent with Shikuku *et al.* (2017). These authors projected that milk yields and incomes would increase by 42 and 48%, respectively if households in WUHs would improve dairy cattle diets in terms of energy and protein concentrations.

Nonetheless, low milk yields on un-supplemented or limited HSR supplemented cows were reflected on their higher production costs per litre of milk. This was possibly due to fixed costs including labour, animal health (vaccination and internal and external parasites control) and water which must be incurred regardless of the animal production level. Low farm gate milk prices was observed to be a major bottleneck at the study site whereby income to cost ratios (ICR) indicated that if milk price would increase by even a marginal percent will make dairying more competitive in WHUs. Comparably, Zvinorova *et al.* (2017) reported as low as an ICR of 0.6 and affirmed that incomes did not cover costs in smallholder dairying of Zimbabwe. Previous studies in WUHs (Shikuku *et al.*, 2017; Maleko *et al.*, 2018; Twine *et al.*, 2018), also emphasized on the importance of improving milk prices so that to incentivize farmers to adopt feeding and breeding technologies.

Nevertheless, lack of significance difference between 4 and 6 HSR kg/cow/day the ICRs implied that 4 HSR kg/cow/day is optimal if dairying is to be profitable in the WUHs. A sensitivity analysis was done by increasing the HSR to 8 kg/cow/day, milk yield increased to 9.65 lt/cow/day but the ICR was only 1.16 which is comparable to that of 4 kg/cow/day. Henceforth, this implies that most smallholder dairy farmers in WUHs do not break even due to low milk prices. Nonetheless, these findings suggest that for economic viability farmers should give more attention to high producing cows in their least cost supplementation programmes. Also, it indicates that the farmers' motive for keeping dairy cattle might be over-emphasized by other associated benefits of dairy cattle keeping. These benefits include milk for home consumption, manure for crops fertilization, fuel or sale, and cattle as a household asset.

(iii) Correlations between observed and simulated milk yields

The fact that increase in amount of the supplementary feed ration was found to improve milk yields consistently to the simulated milk yields implies that LIFE-SIM is a reliable tool. This is also in agreement with previous studies under East African smallholder dairy farming environments (Kavana & Msangi, 2005; Ongadi *et al.,* 2010; Katiku *et al.,* 2014). However, under this study the LIFE-SIM model was observed to overestimate the milk yields and this could be attributed to fact that the feeding experiment under this study was conducted during the acute dry season while the model simulates year-round milk production.

Also, according to León-Velarde *et al.* (2006) LIFE-SIM had an allowable error ranging between 7 and 11%. This implies that LIFE-SIM does not predict exact accurate values but just an estimate within an allowable error. Interestingly, the crossbred dairy cattle under this study had theoretical optimal milk yields of 15 - 20 lt/cow/day but were found to produce less milk. This is possibly due to decreased milk production potential of the crossbred dairy cows resulted from the prevailing widespread poor breeding regimes in smallholder dairying systems (Lentes *et al.,* 2010; Chagunda *et al.*, 2015). Henceforth, in concurrent to previous studies this study demonstrates that LIFE-SIM is a useful tool for helping managers, extension personnel and farmers with making decision on optimal feeding strategies. It can also be used to generate information for advising policy makers on planning and designing proper intervention strategies for facilitating sustainable smallholder dairy productivity in East Africa.

(iv) Simulated impacts on methane emission and manure excretion

Methane contributes to about 25% of the 12% livestock related global anthropogenic greenhouse gas (GHG) emissions contributing to the negative consequences of climate change such as prolonged drought recurrences (Havlík *et al.*, 2014). In this study, the increase in protein-rich supplementary feed was observed to enhance enteric methane emission in which un-supplemented cows had the lowest level of enteric methane emission. This is in agreement to previous findings by Ongadi *et al.* (2010) and Mugerwa *et al.* (2013) who urged that the population of rumen microbes including that of methanogenic bacteria which are responsible for enteric fermentation of feeds with methane gas being among the products increases with feed quality improvement. Importantly, feed quality improvement also enhances feed utilization efficiency by the ruminant animal resulting in improved milk and meat yields per unit of feed offered. Also, high milk productivity resulted from supplementation is thought to incentivize farmers to keep small stocks contrary to low productivity which encourages herd maximization with consequent to increased GHGs emissions. Thus, the observed lower methane emission per litre of milk produced in the supplemented cows is thought to abate the overall emitted methane intensity.

Commercial products such as Probiotics and Ionophores capable of enhancing propionic acid synthesis and suppressing acetic and butyric acid in the rumen do exist. Acetic and butyric acids are responsible for enhanced ruminal methane synthesis and eructation. However, these commercial products are rare in the developing world although use of feeding strategies that ensure minimum methane emission per unit of milk or meat produced are advocated (Mugerwa *et al.*, 2013; Havlík *et al.*, 2014). The simulated methane emission in a range of 196 – 236 litres /cow/year was similar to that reported by Grainger *et al.* (2009). The authors measured methane emission of 435 g/day ≈ 222 lt/cow/year from lactating cows grazing ryegrass pasture with grains supplement in Australia. Also, Ejobi *et al.* (2007) had comparable findings of 0.123 kg of methane per litre of milk produced by improved dairy cattle breeds in Uganda. Interestingly, Ejobi *et al.* (2007) also found out that the indigenous Zebu and Nganda cattle had the highest methane emissions per unit of product. Whereby, they generated approximately 1 kg of methane per a kg of milk while Ankole produced 0.566 kg of methane per kilogram of milk. This implies that improving the genotypes of dairy cattle breeds through proper breeding accompanied with proper feeding for optimal milk production will reduce methane emission per litre of milk. Moreover, Kavana and Msangi

(2005) observed that feeding strategy on cross-bred dairy cattle have a direct influence on methane emissions in which they noted methane emissions of 105 and 90 litres/cow/year in two contrasting stall feeding regimes in coastal Tanzania.

The simulated manure excretion (kg DM/cow/year) in this study are comparable to that of Ongadi *et al.* (2010) and Katiku *et al.* (2014) reported manure excretions of 1162 and 1290 kg/cow/year for stall-fed dairy cattle in Kenya. The consistency of the current findings with the previous observations implies that LIFE-SIM is a reliable decision support tool for evaluation of feeding scenarios targeting environmental pollution mitigation in the smallholder mixed dairy farming systems.

CHAPTER FIVE

CONCLUSION AND RECCOMMENDATIONS

The overall aim of this study was to improve the nutrition of dairy cattle in the smallholder farming systems of the Western Usambara highlands (WUHs), Tanzania. Study approaches involved investigation of the existing dairy cattle feeding strategies and effects of seasons on availability of fodder resources in the Western Usambara highlands. It also explored the potentials of improved Napier grass varieties for improving forage production and availability in the smallholder dairy systems of the WUHs. Furthermore, it explored potential use of locally produced protein-energy concentrates for improving year-round milk productivity of dairy cows under poor roughages. The conclusions and recommendations of this study are presented below:

5.1 Conclusion

Cut and carry of fodder to feed animals at stall (zero grazing) was the dominant dairy cattle feeding practice (87% of the respondents) in the WUHs. Inadequate feeding of dairy cattle in terms of both feed amount and nutrition is omnipresent in the WUHs. Whereby, only 53% of respondents reported to supplement the poor roughages with a limited amount of protein-energy concentrate feeds during milking hours. Low milk prices, high prices of concentrate feeds and land shortages (83%, 61% and 58% of the respondents, respectively) were the major constraints towards effective adoption of dairy cattle feeding practices and technologies among the smallholder farmers

Dry season fodder scarcity as it was reported by 87% of the respondents is a major problem in the WUHs. The average amount of fodder offered to dairy cattle was 45 and 34 kg/cow/day during the dry and wet seasons, respectively. The nutritional values of the fibrous feeds also declined during the dry season, whereby, the metabolizable energy and crude protein contents were 6.0 MJ/kg and 10.1% dry matter, respectively during wet season compared to 4.8 MJ/kg and 7.8% dry matter, respectively during the dry season. Dry season feeding of poorly stored and unprocessed dry maize stover was common. Consequently, milk yield drops from 5.6 litres per cow per day in the wet season to 3.0 litres in the dry season

Ouma, Kakamega 2 and local Napier grass performed well in terms of forage biomass production (12-16 t/ha) while Bana the least (≈9 t/ha) in the WUHs of Tanzania. Nutrient concentrations including CP (≈10%) and ME (7.4 – 8.6 MJ/KgDM) was almost similar for the four Napier varieties. However, in terms of *In vitro* digestibility Ouma with IVOMD (65.9%) was superior while local Napier with 55.4% IVOMD was inferior.

The supplementation level of 4 kg HSR/cow/day to the basal diets was optimal for sustaining lactating dairy cow's productivity in terms of high year-round milk yields, profitability and reducing methane emission per litre of milk produced. However, the low milk prices are disincentive for the farmers to supplement lactating dairy cows to their optimal milk production potentials due to the associated low or unprofitable gross margins.

5.2 Recommendations

(i) The practice of growing multipurpose leguminous fodder shrubs/trees including *C. calothyrsus* along the farm boundaries and contour strips should be promoted in order to improve local availability of cheap protein rich feed resources. Also, extension services should be devoted into creating awareness to smallholder dairy farmers on optimal feeding including supplementation strategies using locally produced protein-energy rich feed resources

(ii) Further research for improving handling of maize stover including storage conditions, processing and proper feeding is essential as this was the dominant feed resource that was fed to dairy cattle during the dry seasons in the WUHs. Researches might include developing efficient forage processing machines such as choppers that can be easily adopted by smallholder farmers including women.

(iii) Farmers at the WUHs are advised to adopt Ouma grass based on its high yield, digestibility and handling merits. Further studies on on-farm silage making and animal feeding of the Napier grass varieties are suggested. This is deemed to be essential for generating valuable information for optimizing forage conservation and animal performance in the WUHs and elsewhere with similar conditions. In addition, studies on molecular characterization to discern the genotypes of the WUHs' local Napier variety are advised.

(iv) The 4 kg/cow/day Calliandra-maize bran based HSR is recommended to farmers in the WUHs and other areas with similar environments for increasing both milk productivity and profitability. Also, further exploration on the potentials for improving the formulated HSR into multi-nutrient feed blocks or pellets is suggested. This is an essential step towards commercialization of the formulated HSR for improving its availability and wealth creation among actors along the value chain from producers to consumers.

(v) Clear supportive policy statement for addressing the low milk prices challenge is needed. For example, policy initiatives to support dairy farmers' associations and cooperatives with access to better milk prices and milk value addition. This is deemed to be an essential incentive for the smallholder dairy farmers to adopt forage technologies including fodder production, conservation and proper dairy cattle feeding.

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APPENDICES

Appendix 1: The reconnaissance survey checklist

DAIRY CATTLE SEASONAL FEED AVAILABILITY AND FEEDING STRATEGIES RUFORUM LIVESTOCK CARP PROJECT

District................................. Ward ....Village....................................
Enumerator .... Date.......................................

1. What is the situation of dairy cattle feed availability during wet and dry seasons?

   ....

2. What is the average milk yield, litres per cow per day in your farm? Wet season: ……… Dry season ……………..

3. What opportunities are there for improving dairy cattle nutrition in your farm?

   ....
   ....

4. Do you grow either fodder grasses or legumes within your farm? If yes, what species and how much land (ha) have been allocated?
   ………………………………………………………………………………………
   ………………………………………………………………………………………

5. What strategies are in place for ensuring that your dairy cattle access adequate and quality feed throughout the year?

   ....
   ....

6. What are the major constraints you are facing towards proper dairy cattle feeding?

………………………………………………………………………………………………
……………………………………………………………………………………………..

7. Are there any researchers or other stakeholders who are engaging with dairy cattle feed nutrition improvement within your locality?

   ....
   ....

8. What is the situation of dairy cattle feed availability during wet and dry seasons?

   ....

9. What is the average milk yield, litres per cow per day in your farm? Wet season: ………. Dry season ……………..

10. What opportunities are there for improving dairy cattle nutrition in your farm?

    ....
    ....

11. Do you grow either fodder grasses or legumes within your farm? If yes, what species and how much land (ha) have been allocated?
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………

12. What strategies are in place for ensuring that your dairy cattle access adequate and quality feed throughout the year?

    ....
    ....

13. What are the major constraints you are facing towards proper dairy cattle feeding?
    ………………………………………………………………………………………………
    ………………………………………………………………………………………………

14. Are there any researchers or other stakeholders who are engaging with dairy cattle feed nutrition improvement within your locality?

    ....
    ....

Appendix 2: Structured household questionnaire

HOUSEHOLD QUESTIONNAIRE - RUFORUM LIVESTOCK CARP PROJECT

Enumerator's name... Respondent's name...
Date............................ District...................................... Village name..

Sub-village......................................Mobile No..

Start time...................... End time...................... Questionnaire number………………………

SECTION I: HOUSEHOLD CHARACTERISTICS

1. Name of household head……………………..………………………
2. Age……………………
3. Sex of household head: Male ( ) Female ( )
4. Marital Status: Single ( ) Married ( ) Divorced ( ) Widow/widower ( )
5. Educational Level: No formal education ( ) Adult education ( ) Primary ( ) Secondary ( ) College ( ) others (specify)..
6. Household size – How many people live in your home?

Years	Females	Males
1-17		
18-45		
46-60		
Above 60		

7. Primary occupation
   Crop cultivation only ( ) Mixed farming ( ) Civil servant ( ) Business ( ) others (specify)………………………
8. Do you own land? Yes…………….. No…………………..
9. If yes, how much land do own? Homestead ……………… Acres, Away from home …………Acres
10. Is there communally land in your village? Yes ………….. No ……………… If yes does it provide fodder to your animals? Yes ………….. No ………………
11. What are the three major crops, intercropped crops and give acreage allocated to each for 2015/2016

Crop	Acreage

12. How long have you been practicing dairy farming? ……………. Years
13. What is your main purpose for dairy farming?..

....

....

14.Indicate the numbers of cattle owned

		Breed/ Indicate colour	Number	Use (e.g. breeding, milking)	Source (e.g. bought, inherited, pass on, project
Bulls					
Cows					
Heifers					
Steers					
Calves	Female				
	male				

15. What other livestock do you own? List and give numbers

Species	**Number**

16. How many lactating cows do you have? .... At which lactation stage? 1-3 ( ) 4-7 ( ) >7 ( )

How many are pregnant? …………………….

17. Lactation performances

Season	**Average Litres/cow/day**	**No. of cattle milked per day**	**Sold to**	**Price (Tshs)/litre**	**Amount/day**
Wet season					
Dry season					

18. **Reproductive performance :** Age at first service................, Age at first calving......................, Days open ...., Days dry ………….. After how long did you get next calf/calving interval ....

19. What method do you use for breeding?: Natural [ ] or Artificial insemination [ ], Numbers of services per conception ....

SECTION II: <u>FEEDING PRACTICES, FODDER PRODUCTION AND CONSERVATION</u>

1. How do you feed your animals?

Grazing/feeding system	Season (wet or dry)	Animal Class

2. If you graze your animals, how much land have you set aside solely for this purpose? .... acres

3. Where do you source the fodder for your animals?
……………………………………………………
……….

4. Is a labour a limitation towards feed production and dairy cow feeding? On a scale of 1 – 5; 1= *Not* limiting, 2 less limiting, 3= moderately limiting, 4 = Highly limiting, 5 = Very highly limiting) *Circle the consensus number accordingly*

5. In what form do you feed dry grasses or crop residues? Loose unchopped [ ] Chopped [ ] Chopped + spraying of molasses or mineral salts [ ] others (specify)....................................

6. In what form do you feed green grasses or crop residues? Loose unchopped [ ] Chopped [ ] Chopped + wilted [ ] others (specify)....................................

7. What do you normally do when you have feed shortage in your farm?

Purchase feeds [ ] Sale some animals [ ] Move them to somewhere else [ ] Do nothing [ ] other (specify)………………………………………………………………………………………

8. If purchased, from who.......................... in what form... and at what price (e.g. per luggage/acre)........................

9. Do you supplement your dairy cows with concentrates? Yes [ ] No [ ]

10. If yes what type, amount, price and source of concentrates?

S/N	Type	Amount fed (Kg/day)	Price (Tsh/Kg)	Source
1	Maize bran			
2	Rice polish			
3	Sunflower seedcake			
4	Cotton seedcake			
5	Minerals and vitamins			
6	Copra cake			
7	Molasses			
8	Others (specify)			
9	Others (specify)			

11. If No why? Concentrates are not available [ ], Unaffordable prices [ ] Others (specify)………..
....

12. How many times do you supplement your animals ………….. at what time………to which animal category……………………………………………………………………………………………….

13. What is your feeding routine under zero grazing?

....
....
....
......

14. Do you use any of feed additives? Yes ( ) No ( ) If yes which one……………………………………… for what purpose……………………………………………………………………………………

15. What are the main livestock feed used?

During; wet season..

During; dry season..

16. Do you plant grasses or legumes for stall feeding or grazing your animals? Yes......... No.......... If yes, how much land is allocated for forage production? .... acres

17. Do you grow or conserve indigenous fodder trees in your farm? Yes [ ] No [ ]

If yes where: (a) Around farm boundaries/hedgerows (b) reserved area/fodder bank (c) shed trees (d) Along contour lines (e) alley cropping (f) Other (Specify)...

18. What should be done to enhance pasture production in your farm? (a) Awareness creation (b) Access to inputs e.g. pasture seeds (c) Enhance access to land (d) Improve access to farm machinery (f) Enhance market access (g) Other (Specify)..

19. Which months is rainfall high, which months is the rainfall Low? (Score against the months: 1= no rain, 2 very low, 3= Low, 4 = High, 5 = Very high)

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Rainfall amount												

Which months is fodder is in surplus, which months are fodder very scarce (shortage)? (Score against the months: 1= *Not available, 2 very scarce, 3= Low, 4 = High, 5 = Very abundant*)

Month	**Jan**	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Fodder availability												

20. What do you normally do when you have excess feed in your farm?

Conserve as hay [ ] Conserve as silage [ ], Conserve as leaf meal [ ], Sale [ ] Do nothing [ ]
Others:
(Specify)..
....
....

21. Do you practice any forage conservation; Yes …… No…… If yes which one ………………, describe how ………………………………………………………………………………………., amount Produced........................ (ton/season) and what is the major constraint(s)?
....
....

22. Have you ever purchased any conserved forage? Yes [ ] No [ ]. If yes, which one…………………………………………….. from whom ………………………. .... and at what price..(Tshs/Kg)

23. If have never purchased conserved forage Why? Not available [ ], Unaffordable prices [ ] Others (specify)
....

24. What should be done to enhance forage conservation practices in your farm? (a) Awareness creation (c) Access to farm machinery (d) Access to inputs e.g. silage inoculants (e) Access to fodder markets (f) Others
(specify)...

25. What are the major three challenges are you facing towards pasture production and proper dairy cattle feeding?
…………………………………………..………………………………………………………………

26. What are the major three opportunities for improving pasture production and proper dairy cattle feeding within your locality? ………………………………………………………………………

27. As we conclude what do you think are the major areas of intervention you would like farmers associations, government or development partners to collaborate for improving dairy productivity in your farm?

....
....
....

THANK YOU VERY MUCH FOR YOUR TIME

Appendix 3: Datasheet for the on-farm feeding experiment

Nelson Mandela African Institution of Science and Technology – Dairy cattle Supplementation Experiment at Irente Farm (PhD Project) – Lushoto, Tanga, Tanzania
CARP Project

COW ID **AGE** **PARITY/CALVINGS NUMBER**

Date Calved……../……/201 **Other Calves**

FEEDS NAME 1.…………………………………………2.3.
4. 5. Supplement amount ……………Kg

DATE	MILK QUANTITY AM	MILK QUANTITY PM	BASAL FEED TYPES (Circle accordingly)					REMARKS e.g. HEAT/SICK
1			1	2	3	4	5	
2			1	2	3	4	5	
3			1	2	3	4	5	
4			1	2	3	4	5	
5			1	2	3	4	5	
6			1	2	3	4	5	
7			1	2	3	4	5	
8			1	2	3	4	5	
9			1	2	3	4	5	
10			1	2	3	4	5	
11			1	2	3	4	5	
12			1	2	3	4	5	
13			1	2	3	4	5	
14			1	2	3	4	5	
15			1	2	3	4	5	
16			1	2	3	4	5	
17			1	2	3	4	5	
18			1	2	3	4	5	
19			1	2	3	4	5	
20			1	2	3	4	5	
21			1	2	3	4	5	
22			1	2	3	4	5	
23			1	2	3	4	5	
24			1	2	3	4	5	
25			1	2	3	4	5	
26			1	2	3	4	5	
27			1	2	3	4	5	
28			1	2	3	4	5	
29			1	2	3	4	5	
30			1	2	3	4	5	
31			1	2	3	4	5	

BODY WEIGHT

Week No.	Dates	Kg (Weigh band)	Remarks

Appendix 4: Principal component analysis Eigen values and percent variance of the first 10 axes

Axis	Eigen value	% of Variance	Cumulative % of variance
1	3.185	26.543	26.543
2	2.512	20.933	47.476
3	1.468	12.235	59.711
4	1.163	9.692	69.403
5	1.016	8.463	77.866
6	0.801	6.673	84.539
7	0.686	5.716	90.255
8	0.463	3.86	94.115
9	0.356	2.966	97.081
10	0.315	2.623	99.704

Appendix 5: Principal coordinate analysis Eigen values and percent variance of the first 10 axes

Axis	Eigen value	% of Variance	Cumulative % of Variance
1	3.73E+00	70.711	70.711
2	1.04E+00	19.768	90.479
3	1.49E-01	2.822	93.3
4	1.25E-01	2.365	95.665
5	6.38E-02	1.212	96.877
6	3.44E-02	0.653	97.531
7	2.32E-02	0.441	97.971
8	1.84E-02	0.349	98.32
9	1.43E-02	0.271	98.592
10	1.21E-02	0.23	98.822

Appendix 6: Acceptance letter for the 6th RUFORUM Conference paper, October, 2018, Nairobi, Kenya

RUFORUM
Capacity Building in Agriculture

Regional Universities Forum for Capacity Building in Agriculture (RUFORUM)

Plot 151/155 Garden Hill, Makerere University, Main Campus, P.O. Box 16811 Wandegeya, Kampala, Uganda

Ref. RUBiennial18_Ext. Abstract #439

12 October 2018

Maleko David
Tanzania
malekod@nm-aist.ac.tz

Re: Your Extended Abstract submitted in Response to Call

Your Extended Abstract submission titled "**Field experiences on promotion of forage technologies to the smallholder dairy farmers in Western Usambara Highlands, Tanzania**" has been accepted for publication and presentation at the Sixth Higher Education Week and RUFORUM Biennial Conference scheduled for 22 – 26th October 2018 in Nairobi Kenya. You are expected to make both Oral and Poster presentation.
For details about preparing and presenting posters at the Conference, please check the below link:

https://www.researchgate.net/publication/327729682_Posters_Preparation_Presentation_Guidelines_The_Sixth_African_Higher_Education_Week_and_RUFORUM_Biennial_Conference_21_-_26th_October_2018_Nairobi_Kenya

Regarding the Program for Technical Sessions for Oral presentations and other Plenary Sessions please check www.ruforum.org/Biennial2018
We very much look forward to seeing you in Nairobi, Kenya and we appreciate your contribution to this important event that will bring together key stakeholders in Higher Education in Africa to dialogue on the theme "Aligning African Universities to Accelerate Attainment of Africa's Agenda 2063".

Please note that all participants need to pay conference registration fees ($250 for Students, $350 for RUFORUM Member Universities or $450 for non-RUFORUM Members)

Yours Sincerely,

Dr. Paul Nampala
Chair Scientific Committee
Sixth Africa Higher Education Week & RUFORUM Biennial Conference