Evaluation of sweet potato vines silage as a protein supplement for lactating dairy cows

A thesis submitted in fulfillment of the requirements for Doctor of Philosophy degree in Animal Nutrition and Feed Resources of University of Nairobi

Jesse Kagai Gakige, MSc

Department of Animal Production

Declaration

This thesis is my original work and has not been presented for a degree in any other University.

-- 12th May 2022

Jesse Kagai Gakige, BSc, MSc Date

Department of Animal Production

J80/54611/2019

This thesis has been submitted for examination with our approval as university supervisor(s)

-- 12th May 2022

Prof. C.K. Gachuiri, BSc, MSc, PhD Date

Department of Animal Production

-- 12th May 2022

Prof. John Mburu, BSc, MSc, PhD Date

Department of Agriculture Economics

-- 12th May 2022

Dr. John Goopy, BSc, MSc, PhD Date

ILRI, Nairobi

Dedication.

To my Dad, Zachary Gakigi, you started this good work many years ago, you always believed in education and did your best to make sure we were educated to our level best amidst financial challenges. I am proud to carry forward your legacy of hard work and determination.

Acknowledgements

I wish to first extend my gratitude to the Almighty God for his favors and mercies through this tough journey.

My heartfelt gratitude goes to my supervisors Prof. Charles Gachuiri, Dr. John Mburu and Dr. John Goopy, for the support they have given me in the course of this work. Dr. John Goopy thank you for believing in me even when I had lost faith in myself, thank you for the much-needed support and instructions and making sure I never lacked anything while at Mazingira center.

I would also want to thank my colleagues at Mazingira center, ILRI's capacity development department (CaPDev) and ILRI in general for your kind support throughout the period of my study.

To my field assistants, thank you Nelson Saya and the whole Kenya Agriculture and Livestock Research Organization (KALRO) Kakamega team for the support and assistance you offered during the long animal experiment at KALRO Kakamega research station.

For funding, I am indebted to German Academic Exchange Program (DAAD) for granting me a scholarship, Consultative Group on International Agriculture Research CGIAR research program and German Agency for International Cooperation (GIZ) for the financial support.

To my dear wife, thank you for the support and encouragement you always gave me, especially when I felt discouraged and hopeless. Thank you for your patience throughout this journey. To my dad, thank you for the prayers and encouraging words.

Table of Contents

List of tables

List of figures

Abstract

Dairy production in East Africa is dominated by the smallholder production system, characterized by suboptimal milk production attributed to poor nutrition. Grain-based concentrates can be used to cover the energy and protein deficits arising from forage feeding in rain-fed systems, but this strategy is constrained by grain competition with human and monogastric animals such as poultry, making these feeds very expensive. Sweet potato can serve both as a source of human food (tuber) and animal feed (vines). The objectives of this study were; 1) to determine the effect of harvesting regime on DM yield and nutrient content of sweet potato variety SPK 013, Kenspot 1 and SPK 117, 2) to determine the effect of amount of molasses and storage period on silage quality of sweet potato vines from the three sweet potato varieties, 3) to assess effect of supplementing lactating dairy cows on Napier grass basal diet with sweet potato vine silage on dry matter intake, milk production, milk composition, 4) assessing the economic benefit of feeding sweet potato vines silage as an alternative protein supplement.

The biomass yield of three new orange-fleshed dual-purpose sweet potato varieties were assessed under different harvesting regimes. The three varieties were chosen because they were newly introduced into the market as dual-purpose varieties. The vines were harvested either at intermediate stage (75 days) and again at final stage (150 days) (INT) or at final stage only (150 days) (FIN). Of the three varieties tested, Cultivar SPK013 yielded the most vine in both treatments (7.3 and 5.6 t DM/ha for INT (75 and150 days) and FIN respectively) and tuber at FIN (2 t DM/ha), but lowest tuber yield at INT (0.8 t DM/ha. The intermediate harvesting increased vine yield for all varieties (3.6 vs 2.3, 7.3 vs 5.6 and 5.0 vs 4.2 for INT vs FIN for variety Kenspot1, SPK013 and SOK117 respectively). For cultivar SPK013, intermediate harvesting resulted in a 58% decline in tuber yield (2.0 t DM/ha to 0.8t DM/ha) ($p<0.05$).

Vines from the three varieties were mixed with three amounts of molasses (0, 20 and 40g of molasses/ Kg of vines), and ensiled for 7, 14, 21, 28 and 56 days. The pH and CP content of the silage were monitored. The pH of 0% molasses amount was the highest (4.56) but had the lowest CP (16.25%). Ensilage period significantly affected the quality of silage with CP decreasing from 19.54 to 15.62% at 56d of storage. From the study, molasses amount of 20g per Kg of vines was recommended for both short term and long-term storage.

The efficacy of sweet potato vine silage plus wheat bran (SPVSWB) as a low-cost supplement compared to grain-based commercial dairy concentrate (CDC) was assessed. Multiparous Holstein–Friesian cattle (n = 12) were fed on a basal diet of Napier grass (*Pennisetum purpureum* cv. South Africa) *ad libitum*, plus a fixed amount of either SPVSWB or CDC, (the ration formulated to be both iso-nitrogenous and iso-caloric) during late (LL) and early (EL) lactation.

Daily milk yield was not significantly different ($p>0.05$) between SPVSWB and CDC groups during both LL (6.2 vs 7.5 L/day) and EL (14.2 vs 16.0 L/day). However, the lower cost of production for SPVSWB (23.2 vs 48.7 KES/Kg DM) resulted in margins on milk income over feed (per cow per day) being greater for SPVSWB in both periods (LL: 71 vs 14.5; and EL: 426 vs 400 KES/day). Despite SPVSWB eliciting lower milk production (LL 6.2 and EL14.2 L/day) than CDC (LL7.5 and EL 16.0 L/day), SPVSWB is a cost-effective, accessible alternative to grain-based supplementation in small-holder dairy-farming systems of Kenya. The study recommended 2% inclusion of molasses when making sweet potato vine silage. The silage can be fed in combination with other by-products, for moderate milk production which will result to a lower cost of supplementation compared conventional grain-based supplementation.

1.0 INTRODUCTION

1.1 General introduction

In the continents of Africa and Asia, more than 1 billion people depend on dairy production for their livelihoods (McDermott *et al.* 2010). The dairy sector might play an even bigger role in future where it is estimated to increase by 25% by year 2025, due to increased demand for livestock and livestock products, owing to population growth, urbanization and improved economic power (Muia *et al.* 2011b). This will offer increased market for dairy products from smallholder systems.

In Kenya, dairy farming is mainly practiced by small-scale farmers with unique farming systems where they own over 80% of the dairy cattle, contributing to over 56% of total milk production (Odero-Waitituh, 2017). These small-scale farmers practice mixed farming where they grow temporary and/or permanent cash and food crops as well as raising of livestock (Njarui *et al.* 2016a). In high potential areas, the main food crops in the smallholder farms are maize, beans, sweet potatoes, Irish potatoes and vegetables, while in the highland, cash crops such as coffee, tea and horticultural crops are also grown (Njarui *et al.* 2016a).

The type and number of cattle kept depend on the feed availability. In most cases, smallholder dairy farmers in developing countries own 1-10 lactating cows (VanLeeuwen *et al.* 2012) and are concentrated in high-potential agriculture areas. The animals are confined in zero grazing units and are fed using the cut and carry system (Wambugu *et al.* 2011a) where fodder is harvested from small plots or contour strips meant for soil erosion control. This is due to high rate of population growth leading to less land available for grazing and pasture production (Wambugu *et al.* 2011a).

The average milk production per cow in small scale dairy farms is low (2.8-10.5 l/ d), this being attributed to shortage of suitable feed resources (Richards *et al.* 2015). Due to seasonality of rainfall and dependence on rain fed fodder, the farmers are not able to provide adequate feed all year round (Giridhar and Samireddypalle 2015). This has led to animals being offered low quality pastures and crop residues (Klapwijk *et al.* 2014), which cannot sustain optimal milk production. Supplementation with better quality ingredients is often not possible due to high prices of cereal-based concentrates (Linn and Kuehn 1997), which in most cases are of substandard quality (Richards *et al.* 2016). This leads to high cost of production and low productivity in dairy farming (Mburu *et al.* 2007). It is for this reason that there is need for dairy farmers to consider alternative feeds, which are cheaper and rich in nutrients.

One of such alternative feed is sweet potato (SP) vines, which has demonstrated potential as livestock feed, having relatively high protein content of up to 21.2% and low fibre of 43.9% (Ali *et al.* 2016). The production potential of most of SP varieties is high ranging from 3 - 4 tonnes Dm/ha of tubers and 4.3 - 6 tonnes Dm/ ha of vines, with some of the high yielding varieties harvested up to three times per year yielding up to 125t/ha fresh vines (Khalid *et al.*, 2013). However, as a source of ruminant feed, sweet potato vines (SPV) are only available during harvest and have high moisture content of up to 86.7% (Lam 2016) and thus high perishability. This is further exacerbated by the fact that times of SPV availability may not necessarily be at the time when there is scarcity of animal feeds (Lukuyu *et al.* 2012b), which leads to a wastage of this nutritious feed resource. This calls for preservation of the vines when they are in plenty to ensure constant supply of this feed resource throughout the year.

1.2 Statement of the problem

There has been tremendous increase in demand for milk and milk products over the years. However, the amount of milk produced is not able to meet this demand due to low milk production from the smallholder farmers, who contributes over 56% of the milk consumed in Sub–Saharan Africa. The low milk production levels are caused by two factors, these being; low quality tropical forages and high cost of supplements leading to high cost of feeding. This problem is exacerbated by low milk prices, making dairy farming a low profit venture.

Therefore, there is need for dairy farmers to come up with alternative feeding strategies to reduce the cost of production to survive in the dairying business. These feeding strategies should involve inclusion of feed resources that are readily and cheaply available. One such feed resources is sweet potato vines, which is high in protein content and therefore can be used to feed livestock and is a commonly cultivated crop in the developing countries. However, the crop is highly perishable due to its high moisture content and its availability does not coincide with time of need thus necessitating the need to conserve it through ensiling to guarantee supply throughout the year. Furthermore, the effect on production and cost effectiveness of supplementing cows with sweet potato silage has not been thoroughly explored. This study will contribute to information on suitability of sweet potato vines silage as a potential cheaper protein source to lactating dairy cows, as compared to commercial concentrates.

1.3 Objectives

Main objective

To evaluate the effect of inclusion of sweet potato vines silage in lactating dairy cow diets on performance.

Specific objectives:

1. To determine the effect of harvesting regime on biomass yield and quality of sweet potato vines and effect on DM yield of tubers of varieties SPK 013, Kenspot 1 and SPK 117.
2. To determine the effect of amount of molasses and ensilage period on the sweet potato vines silage quality for varieties SPK 013, Kenspot 1 and SPK 117.
3. To assess effect of supplementing lactating dairy cows with sweet potato vine silage on dry matter intake, milk production and milk composition.
4. To assess the economic benefit of feeding sweet potato vines silage as an alternative protein supplement to grain-based concentrates in lactating dairy cows.

Null Hypothesis

1. Harvesting regime has no significant effect on biomass yield and quality of sweet potato vines and DM yield of tubers of varieties SPK 013, Kenspot 1 and SPK 117.
2. amount of molasses and storage period have no significant effect on sweet potato vine silage quality for varieties SPK 013, Kenspot 1 and SPK 117.
3. Supplementing lactating dairy cows with sweet potato vine silage has no significant effect on dry matter intake, milk production and milk composition
4. Supplementing lactating dairy cows with sweet potato vine silage as an alternative protein supplement has no economic benefit

1.4 Justification

In the recent past, sweet potato vines (SPVs) have gained popularity as protein supplement for ruminants in sub–Saharan Africa (SSA) due to their higher protein content compared to other common fodder crops. Their high nutritive value has led them being categorized as protein-rich forages. The Productive potential of sweet potato varieties range from 3 to 4-tonne DM/ha of root and the foliage production varies from 4.3 to 6.0-ton DM/ha/ crop. They can be harvested three or four times per growing season and can be preserved through ensiling.

There is low use of grain-based concentrates by the smallholder dairy farmers due to their unreliable quality and high cost (Tolera *et al.* 2000) leading to low milk production throughout the lactation period. Purchase of concentrates form the largest share of the variable costs in smallholder zero-grazing dairy system (Lukuyu *et al.* 2011a). SPVs have been reported as potential partial replacement of grain-based dairy concentrates and therefore reducing the cost of supplementation. Due to their high dry matter yield and high protein content, the sweet potato has a potential to make a major contribution to small holder dairy feed requirements. There are surplus sweet potato vines during the rainy season which can be conserved for use during the dry season when good quality forage is in short supply. However, due to high moisture content of the vines, it is difficult to conserve them as hay with ensiling being the most suitable or viable conservation method for dairy farmers.

2.0 LITERATURE REVIEW

2.1 Background

Kenya lies between longitude 34^0 E and 42^0 E, latitudes 5^0 S and 5^0 N of the equator, covering a total area of 580,367 KM^2 with population of about 47.5 million people (KNBS, 2019). Only 17% of this area has potential for rain-fed agriculture with an average annual rainfall of 500-800 mm (Njarui *et al.* 2011a). Agriculture is the backbone of Kenya's economy contributing up to 25% of the GDP, supports up to 75% of the population and is the second largest industry after the service sector (Onyalo 2019).

In Kenya, there is an estimated herd of 3.4 million milking animals (KNBS 2010), most of which are crosses of Friesian–Holstein, Ayrshire, other dairy breeds and local zebus (Muriuki 2011). Smallholder dairy farmers own approximately 80% of the milking animals (Njarui *et al.* 2011a) and produce over 80% of the milk marketed (FAO 2011). In many households, 36% of the milk produced is consumed at home while the rest is marketed, showing the importance of the dairy sector in household nutrition (Njarui *et al.* 2011b).

2.1.2 The Kenyan dairy industry

The Kenya dairy industry can be traced back to 1920's and was mainly dominated by large scale farms owned by white settlers (Muia 2000). The dairy industry contributes upto 14% of the overall agricultural GDP and 4% of the national GDP, while within the livestock sub-sector, it contributes to 40% GDP (KDB 2015). The sector's growth rate has been recorded as 1.5% per annum from 2011 to 2014 (KNBS 2016). The sub-sector is the most developed among the agriculture sub-sectors and plays a major role in nutrition and economic status of many people including farmers, hawkers, processors and consumers (Wambugu *et al.* 2011b). The dairy herd is estimated to produce 5 billion liters of milk annually (State Department of Livestock, 2018). Of the total milk produced, 60% is marketed through formal channels (Thorpe *et al*., 2000), indicating the importance of dairy sector in Kenyan economy as it employs many who derive a regular source of income (Ann *et al.* 2015) .

Compared to other countries in the Sub-Saharan Africa region, Kenya has the largest dairy sector with 70% of the dairy cattle and is the only country, apart from South Africa, that produce enough milk for its consumption and export (Bingi and Tondel 2015). Its per capita milk consumption is 4 to 8 times higher compared to countries in this region (Muia *et al.* 2011a). Compared to other major milk-producing land-based systems in Sub Saharan Africa, lactation yields in Kenya are 3 to 4 times higher due to market-oriented dairy systems (Bingi and Tondel 2015). The Kenyan dairy industry therefore is well established in both production and processing of milk. This could be as a result of government policies that promote market-oriented dairying for smallholder farmers.

2.1.3 Demand for livestock products

It is desired that the human diet should contain milk or milk products, especially for young growing children. This is because milk contains important macronutrients such as energy, fat and protein and micronutrients such as Vitamin A, B_{12} and calcium (Choudhury and Headey 2018). It is for this reason that consumers in the developing countries are increasingly improving their diets through increased consumption of livestock products (Scott 1992). However, a large proportion of population in the developing countries still have inadequate access to milk products due to low productivity from dairy animals and rely on plant-based proteins which are low in some of the micronutrients (Kidoido and Korir 2015).

By the year 2050, global population is projected to exceed 9 billion people (Alexandratos and Bruinsma 2012) which translate to 70% additional food to feed the population. This comes at a time when the developing countries are increasingly converting arable land to cater for urban expansion leading to scarcity in land for food production (Graham-Rowe 2011). Furthermore, global warming is also exerting pressure on the available land and related resources such as water, soil and biodiversity and therefore decreasing agricultural production. The demand for agriculture products in the world is projected to increase by 1.1% yearly from 2007-2050 (Alexandratos and Bruinsma 2012), with changes in diets increasingly leading to consumption of more livestock products.

Due to rapid human population increase in Africa, Bajpai and Swain (2012) projected that dietary consumption of meat will increase from 9.5 to 14 kcal/person/day and 28.3 to 34 kcal/person/day for dairy products between year 2001 and 2030. In Kenya, the population growth is 3% per annum, with gross national per capita income increase by 48.5% between 2011 and 2015 (KNBS 2016). Owing to this rapid population growth, it is reported that within two decades annual milk consumption (per capita) will increase from approximately 110 liters in 2009, to 220 liters by the year 2030 (MoLD 2010). This demands increase in milk production from 4.5 billion liters in 2009 to 12.76 billion liters in the year 2030 (MoLD 2010). To meet these increased demands for livestock products, scientists are expected to come up with technologies that increase productivity efficiency.

2.1.4 Role of livestock in developing countries.

In developing countries, livestock play multiple roles resulting in nonproductive animals being kept for socio-economic and cultural values (Kebreab *et al.* 2005). The main role of livestock is food security where foods of animal origin such and meat and milk are known to be rich sources of protein, energy and essential micronutrients (Ehui *et al.* 1998). Some of the essential micronutrients such as calcium, zinc, iron, and vitamin A are more bioavailable from animal products than other sources (Allen, 2005) with others such as vitamin B_{12} found only in animal foods. It is estimated that by the year 2050, there will be an additional two billion people who will require 50 to 70% increase in food productivity (Smith *et al.* 2013). Crop-livestock systems are reported to contribute to half of the food consumed in the world (Herrero *et al.* 2010) where ruminants depend on grass and crop residue while in return supplying manure to the crops.

Hundreds of millions of people in the tropics depend on animal draught power for cultivation, planting and as a means of food distribution by transporting agricultural produce from the farm to marketplaces (Phaniraja and Panchasara 2009). More than 240 million cattle are reared as work animals with nearly 50% of the cultivated land in the world depending on animal power (Gebru 2001). This is attributed to the relative affordability and flexibility of animal draught power with no input requirements compared to farm machinery.

Livestock play a major role in nutrient recycling where manure from the animals is used to replenish nutrients exported from soil through crop harvesting, leaching and erosion (Kebreab *et al.* 2005). This compensates for lack of access to inorganic fertilizer (Gebru 2001) and helps to maintain variability and environmental sustainability of food production. In addition, some of the forage crops grown for livestock such as Napier grass, lucerne and desmodium help in improving soil organic matter, increase water retention and reducing runoff (Abdullah 2014).

However, one of the major negative roles of livestock is their contribution to greenhouse gas emission with ruminants being the largest sources of enteric methane (CH_4) in the livestock sector, which is produced in their digestive system (Caro *et al.* 2016). These emissions represent loss of feed energy at the expense of meat and milk production (Bell *et al.* 2016). Of the total methane produced in the whole digestive system, 87% is produced in the rumen and 13% in the hind gut (Pinares- Patiño *et al.* 2008). About 95% of the methane produced in the rumen is excreted through eructation, whereas 89% of methane produced in the hindgut is exhaled through the lungs.

The low-quality forages in the tropics lead to high emissions per unit of meat or milk produced (Boadi *et al.* 2002) where grazing has been reported to 0.23 Kg CH_4/animal/d. This translates to a conversion rate of 7.7 to 8.4% of gross energy into methane. Feeding the same cattle with a highly digestible grain diet, methane production was reported to reduce to 0.07 Kg CH_4/animal/d, with a conversion rate of 1.9 to 2.2% of the feed energy to CH_4 (Harper *et al.* 1999). This shows that supplementing cattle fed low quality forages greatly reduces enteric methane production which is a major contributor to climate change.

2.2 Constraints in the smallholder dairy industry

2.2.1 Feed resources

Although the contribution from the smallholder dairy farms to the total milk production is high, the individual animal yields are characterized by sub-optimal milk production (5-8 L/ d) due to sub- optimal milk yields, short lactation periods of 6 to 8 months and long calving intervals of up to 24 months) (Mayberry *et al.* 2017). The average daily weight gain for heifers in these farms is reported to be as low as 0.36 Kg/d (Makau *et al.* 2018) as compared to a reported optimum weight gain of 0.85 to 0.95 Kg/d (Krpálková *et al.* 2014) for heifers fed exclusively on forage diets. This is made worse by the fact that dairy cows' nutritional requirement is high, and in the tropics, it is difficult to secure quality feed resources required to sustain optimal production (Devendra and Leng 2011).

The smallholder dairy systems are often not able to provide enough feed, both quality and quantity, throughout the year as most of the available tropical pastures are poorly managed (Lukuyu *et al.* 2009). These pastures are in most cases low in nitrogen and have low digestibility and thus unable to sustain optimal production without supplementation. Most farmers offer the poorly managed grasses and supplement with cereal-crop residues, which offer minimum nutrients needed for optimal production (Tolera *et al.* 2000).

Due to increased population pressure over the years, land has been sub-divided into small parcels giving priority to crop production rather than fodder production (Muia 2000). This has led to feed shortage for dairy animals, especially during the dry seasons. As the land sizes continue to diminish and as the production systems move from extensive to intensive, ruminants are increasingly fed on human- edible crops such as grains which causes pressure on human food supply (Ertl *et al.* 2015). This situation is aggravated by the fact that commercial supplements are not always available and/or affordable to the smallholder farmers (Njarui *et al.* 2011a). Reduction in fodder production, feeding of poor-quality byproducts and high cost of concentrates has led to low productivity of dairy cattle (Khan *et al.* 2009).

The potential for increased productivity per animal has been improved as a result of decades of genetic improvement through imported semen from high quality bulls (Weigel 2004). However, the improved breeds require high plane of nutrition, a situation that is further constrained by high feeding costs due to global inflation (Ayantunde *et al.* 2005). Furthermore, this intensive selection and breeding of dairy animals has negatively impacted on the health of individual offspring and future generations (Oltenacu and Broom 2010).

Studies have revealed genetic link between increased milk yield in cows and occurrence of health problems such as mastitis, ketosis, ovarian cysts, and lameness (Ingvartsen *et al.* 2001). This correlation is often linked to mobilization of body reserves during early lactation to support nutrient demand for high milk production due to low intake of energy. This situation is worsened by poor body condition at calving when there are minimal body reserves to mobilize, leading to regeneration of functional body tissues such as muscle (Agenäs *et al.* 2006).

2.2.2 Milk marketing and prices

The potential for increased demand for milk is high, with global demand expected to increase by 35% by 2030 (Adesogan and Dahl 2020). This is also supported by the fact that annual demand in the developing countries has increased by nearly 50% in three decades (Handford *et al.* 2016). This increase is driven by population growth, urbanization and increase in purchasing power as a result of off-farm employment in both rural and urban households (Ng'ang'a *et al.* 2010). This expands opportunities for marketing smallholder dairy products across the entire dairy value chain in Eastern Africa and Kenya in particular (Thorpe *et al.* 2000).

In sub–Saharan Africa however, there are a multitude of constraints that contributes to high cost of production and low productivity, leading to low profits and price fluctuations. One of the major constraints is declining farm sizes (Mutavi *et al.* 2016) leading to increased reliance on purchased feeds, both concentrates and forage. The price of these grain-based commercial concentrates is high relative to milk prices lowering economic performance of the dairy farming (Wolf 2012). Changes in milk prices have been caused by the liberalization in the milk market and choice of market outlet (Kaitibie *et al.* 2010). Before the liberalization, milk processing in Kenya was only by a state- controlled firm, but thereafter many other players have emerged, and the government can no longer subsidize the prices of inputs or control prices (Berem *et al.* 2015). The farmers were left with the responsibility to search for markets and the related costs in contractual arrangements with the market outlets (Kaitibie *et al.* 2010). In most of the smallholder farms, there are no alternative sources of income and thus the need for daily cash push farmers to sell their milk through informal market outlets which generate employment as they handle over 60% of the marketed milk in Kenya (Berem *et al.* 2015).

2.3 Nutrient requirements of lactating cow

Proper nutrition is crucial in achieving and maintaining high livestock productivity. The milk production potential of most of dairy animals in the tropics has increased due to adoption of improved breeding programs in the recent years (Oltenacu and Broom 2010). However, there is need to improve feeding regime so as to fully exploit the genetic potential. The low milk production reported for dairy animals in the tropics is mainly due to poor nutritional management where the animals are fed low quality forages and agricultural byproducts that are high in fiber, low in CP, ME and digestibility (Zhu *et al.* 2017).

In the developed countries, the main source of nutrients for dairy cattle is based on cereal grains for energy (An *et al*., 2003). However, in developing tropical countries, there is shortage of animal feeds that have adequate energy and protein and low-quality forages such as crop residues are not only used as the basis of diets but are often the whole diet for ruminants (Duguma and Janssens 2016). In most dairy farms, animals are fed with minimal consideration of the nutrients need which are dependent on stage of lactation (Dulphy *et al.* 1980). Feeding during early lactation requires special consideration due to the low dry matter intake and increased demand for nutrients during this period (Weber *et al.* 2013). In early lactation, effects of low level of feeding are reflected in reduced milk yield, change in milk composition and poor body condition (Sheehy *et al.* 2017). This effect is not only immediate but also present for a while even after the underfeeding is over. Bryant (1982) reported that underfeeding in early lactation resulted to reduced milk yield as well as alteration of milk composition where decrease in 1 Kg DM intake resulted to a decrease in 39 g of milk fat. Roche (2007) reported 8.4% reduction in milk fat for the first five weeks post calving, on feed restricted cows. Furthermore, underfeeding during this period also results in mobilization of body reserves resulting in loss of body condition and as a result delayed resumption of estrous which impacts negatively on calving interval and therefore long-term productivity of the dairy cow.

Nutrition during the dry period is also important as live weight and good body condition score at calving are very critical in the cow's production cycle, more critical than the subsequent change in weight and body score after calving (Roche 2007). According to Treacher *et al*. (1986), cows calving in poor body condition fed well, after calving do not completely compensate for the underfeeding prepartum. Cows with lower live weight and body score at calving produce less milk than those with higher liveweight and better body condition (Grainger *et al.* 1982). Besides, there is also a delay in the resumption of estrous leading to protracted calving interval which undermines long term productivity of the dairy cow. Low milk production has been reported from cows on less than 50% of ME requirements before calving (Roche 2007). This is due to how feed is partitioned in early lactation where a greater portion of nutrients is used for live weight gain at the expense of milk yield (Yearsley *et al.* 2001).

2.4 Dry matter intake

Dry matter intake is a critical aspect in dairy cows feeding and is the most important factor in meeting nutrient requirements of ruminants (Mertens 1994). Ideally, an animal can satisfy its nutrient requirements if it could consume enough of low-quality forages, but practically this is not possible due to physical limitations of the animal and feed factors (Kubkomawa *et al.* 2013). Research by Mertens (1994) found that the value of a feed in animal nutrition is more dependent on the amount consumed than its chemical composition.

There are several factors that affect voluntary dry matter intake in ruminants: metabolic and physical factors. Metabolically, the animal maintains an energy balance by altering its feed intake in relation to its energy requirement (Baile and Forbes 1974). This is done with help of physiological control where neural receptors inform the brain about the nutrition status of the body. Baile and Mayer (1970) reported that propionate and acetate are the main feedback signals for satiety in ruminants. Butyrate is not directly involved in regulation of feed intake because most of it is metabolized to ketones in the rumen epithelia tissue following absorption.

The physical factors include rumen capacity, distention of the reticulorumen, fiber content of the feed and rate of passage of the digesta (Forbes 2000). When ruminants are fed more fibrous feeds, they take longer time to chew and therefore comminute the digesta to fibre particles that are small and dense enough to pass through the reticulo-omasal orifice to create more space to accommodate more feed. They stop eating before they consume enough nutrients required for their production potential (Meijs 1981). This is due to rumen distention which is determined by the size of the abdominal cavity, fetal enlargement for in-calf animals and fat deposition in the abdominal cavity (Forbes 2000). Rumen capacity is dependent on the animal body size because gut size increases almost linearly with body size of the animal leading to higher DMI (Beecher *et al.* 2014). Furthermore, large animals have higher maintenance requirements and thus they have to take more feed than smaller animals (Kleiber 1961). However, maintenance requirements per unit of body weight is reported to decrease with increase in size thus decreasing the feed intake

(Riaz *et al.* 2014).

2.5 Feed resources

Ruminant production in the tropics mainly dependent on native unimproved pastures, crop residues and agricultural by products (Lanyasunya *et al.* 2006a). In areas with relatively large tracts of land, farmers set aside patches of land for grazing (Lukuyu *et al.* 2011a). However, due to increased land pressure and dairy cattle population, most farmers have adopted stall feeding (Njarui *et al.* 2016b) using natural fodder (Kikuyu grass, Star grass and fodder trees) or established fodder (Napier grass) or crop residues (Ongadi *et al.* 2010). Use of maize stover, beans haulms, banana leaves and pseudostems as dry season supplements is a common practice to alleviate nutritional problems of livestock (Nyaata *et al.* 2000). Some farmers purchase fodder as bales of hay or backload of Napier grass to sustain the animals (Thorpe *et al.* 2000).

In East Africa, most common animal feed resources include Napier grass, Kikuyu grass, crop residues, legumes, Rhodes grass, Setaria and other roadside grasses (Nangole *et al.* 2013). Crop by- products form a major portion of the feed resources especially during the dry season. These by- products include maize stover, wheat straw and bean haulms (Lukuyu *et al.* 2011a). Most of these crop residues have low metabolizable energy of 5 to 7 MJ ME/Kg DM and crude protein of 2 to 5% (Smith 2002). In the tropical Kenya, maize stover is the main crop residue used by 94.9% of dairy farmers (Njarui *et al.* 2011a). Majority of the farmers store the stover in open-roof hay barns with few leaving the stover in the field, stacked under trees for gradual collection, leading to loss of nutrients due to weathering and leaf shattering (Syomiti *et al.* 2011).

Most of the available feed resources are of low quality characterized by low protein concentration (less than 8% CP) and low digestibility (less than 55% digestible) leading to reduced ruminal fiber degradation (Sampaio *et al.* 2010b). This leads to low forage intake and eventually low animal productivity (Lazzarini *et al.* 2009). It is therefore evident that low protein content in tropical grasses poses a challenge to any form of intensification in the dairy sector. Protein content in mature grass is related to the pathway of carbon fixation (Brown 1978) and is determined by the initial protein levels at growth, rate of protein content decline over the growth stage and the final leaf stem ratio (Norton and Poppi 1995). In a review of three experiments from two grasses, Crowder (1982) reported an average decline in protein content from 17.2% at 4 weeks to 10.4% in 12 weeks regrowth.

The tropical forages have low bulk density of leaf as compared to the temperate grasses, thus leading to low biomass yield and low intake by animals (Guenni *et al.* 2002). The low biomass yield is as a result of their growth habit, leaf to stem ratio and flowering behavior (Stobbs 1973). They are reported to have C4 photosynthetic pathway which results to higher fiber content as compared to temperate grasses which have C3 photosynthetic pathway (Norton and Poppi 1995). Furthermore, tropical pastures tend to store their storage polysaccharides in form of starch as compared to temperate pastures that store theirs inform of fructosan. Warm temperatures in the tropics also lead to higher growth rates and rapid maturity in the tropical grasses and according to Wilson (1982), this leads to decline in their nutritive quality at a faster rate as compared to the template grasses. This is because when grasses mature and flower, there is transfer of soluble carbohydrates from the stems and leaves to the flowers leading to decline in forage quality (Crowder and Chheda 1982). This also leads to increased lignified cell wall and decrease leaf to stem ratio.

The low CP content of most tropical grasses calls for supplementation of the same with forages or concentrates that are high in protein. There is therefore need to seek alternative low-cost supplementation which can be easily cultivated to improve the nutrient supply to dairy cattle.

In the tropics, feed availability is seasonal due to over-reliance on rain-fed agriculture for production (Njarui *et al.* 2011a). This is in spite of dairy cows feed requirement being constant throughout the year which translates to a surplus forage during the wet season and deficit during the dry season and which impacts negatively on animal's productivity. The extent of the shortage is determined by land size, number of animas and the management systems. Njarui (2009) reported that farmers with small land sizes had only 10% of the land dedicated to feed production. In a survey on feed seasonality in Kenya, 93% of the farmers experienced seasonal feed fluctuation (Njarui *et al.* 2011a) with the worst months being September to October. These feed fluctuations are both in terms of quantity and quality. Even with this scenario, there is low rate of adoption of feed preservation technologies to address these fluctuations (Lukuyu *et al.* 2011b).

In Kenya, fodder shortages are most prevalent between December and April, with peak shortage in the months of February and March, when the animals do not get enough feed to meet their full production potential (Njarui *et al.* 2011a). On the other hand, there is plenty of fodder during the months of April, May, June and November (Lanyasunya *et al.* 2006b). For instance, 66% of farmers surveyed in Central Kenya had excess fodder during these months (Nyaata *et al.* 2000), although 63% of them left the excess fodder in the field until need arose or sold to neighbors. Others used the excess fodder to make compost, mulching or cow beddings (Singh and Kumar 2018).

2.6 Common forage crops

Due to increased land pressure and dairy cattle population, most farmers have adopted stall feeding (Njarui *et al.* 2016b), otherwise also known as zero grazing, using natural fodder (Kikuyu grass, Star grass and fodder trees) or established fodder (Napier grass) or crop residues (Ongadi *et al.* 2010). Use of maize stover, beans haulms, banana leaves and pseudostems and sweet potato vines as dry season supplements is a common practice to alleviate nutritional problems of livestock (Agutu

2018). Some farmers purchase fodder as bales of hay or backload of Napier grass to sustain the animals (Thorpe *et al.* 2000).

In Western Kenya, the average area set aside for fodder production is 30% of the total land in smallholder households (Musalia *et al.* 2007) with Napier grass being the most dominant fodder in this area. Other common forage crops that were found in the farms included desmodium (*Desmodium spp*., both silver and green leaf), Guatemala grass (*Tripsacum laxum*) and Fuzi grass (*Brachiaria ruziziensis*) (Baltenweck *et al.* 2010).

2.6.1 Napier Grass

The main feed resource for dairy animals in Kenya is Napier grass (Ng'ang'a *et al.* 2010). The popularity of Napier grass among the farmers could be attributed to its actions as a soil conservation crop and as a trap plant for management of stem borer pest in maize (Khan *et al.* 2014). This coincides with a survey by Nyaata *et al*., (2000) in central Kenya where it was observed that the main fodder in smallholder dairy farms was mainly Napier grass grown on small plots and on contour strips, which act both as fodder source and biological soil erosion control. The survey showed that 22% of the farmers who grew Napier grass on plots intercropped it with desmodium while 5% who grew Napier grass on contour strips intercropped it with calliandra (*Calliandra calothyrsus)*. Most Napier grass varieties in Kenya have an average DM yield of between 10 - 40 ton/ha/year DM (Nyambati *et al.* 2010). It has an advantage of withstanding repeated cuttings of up to six times in a year producing 50 - 150 tons of fresh herbage per hectare (Mwendia *et al.* 2006). It withstands long periods of drought, recovering rapidly from stagnated growth with the onset of rains (Negawo *et al.* 2017).

Napier grass on average contains 20% DM, 6.5-8% CP, 70% NDF and 48% ADF (Turano *et al.* 2016). It can be fed fresh or as silage and performs well when intercropped with legumes (Magcale-Macandog *et al.* 1998). Napier grass has high structural wall that increases with age as opposed to crude protein and digestibility that decreases (Bayble *et al.* 2007). Even when cut at the recommended height of 1metre, it is of low quality with a mean CP of 80g/Kg which cannot sustain adequate performance in lactating cows without supplementation (Kariuki *et al.* 1998). For instance, average daily gain (ADG) of Friesian heifers fed on Napier grass alone was reported to be 0.34 Kg/day (Kariuki *et al.* 1999) as opposed to the expected ADG of 0.85 to 0.95 Kg/day for heifers exclusively on forages (Krpálková *et al*. 2014).

Height at which Napier grass is harvested has been shown to influence digestibility in dairy animals. A study on the best harvesting age showed that organic matter digestibility reduces as cutting height increases (Zewdu and Baars 2003). This is due to increased fibre content that contributes to decreased digestibility of cell wall constituents. This could also be due to thicker cell wall and reduced leaf to stem ratio. The nutritive value remains unchanged between 76cm and 137 cm height but decreases at 183cm (Mwendia *et al.* 2006).

Napier grass, if well managed, can supply enough animal fodder in the intensive small-scale dairy farming systems (Tessema *et al.* 2010a). Harvesting intervals and cutting height above the ground are the major management practices important for high production and quality of Napier grass (Wijitphan *et al.* 2009). This determines the plant vigor, yield and its persistence within the soil.

These agronomic practices also affect nutritional quality of the Napier grass, where it is reported that cutting at an interval of 45-60days, resulted in higher yields of CP as opposed to increased cutting interval (Lounglawan *et al.* 2014).

Defoliation (cutting) frequency has also been reported to affect the number of tillers per plant, number of leaves per tiller, total number of leaves in the whole plant and leaf length per plant (Tessema *et al.* 2010b). Contrary to the findings by Lounglawan (2014) above, increase in cutting frequency was reported to increase leaf to stem ratio, subsequently increasing voluntary feed intake and CP content (Jorgensen *et al.* 2010). However, the same study reported increase in dry matter yield from 16.4 to 31.7 t/ha as cutting frequency decreased from 60 to 120 days.

2.6.2 Sweet potato

Sweet potato (*Ipomea batatas*), a crop in the family *Convolvulaceae*, is native to Central and South America (O'brien 1972). Due to its versatility and adaptability, it is a common crop in developing countries both in the tropics and sub-tropics (Frankow-Lindberg and Lindberg 2003). It is a tuberous-rooted perennial with adventitious roots which are mostly located within top 25 cm soil (Getachew *et al*., 2000) but mainly grown as an annual crop. Among the most common traditional crops in the tropics, sweet potato is ranked seventh in the world and fifth among the most consumed food crops (Truong *et al.* 2018). It is a crucial food crop in the rural areas (Karuri *et al.* 2017), with high production found in the highlands of East African region (Hotz *et al.*, 2011).

It is commonly cultivated and classified as a famine-relief or a subsistence crop, but this is changing gradually to commercial crop due to increase in demand for food in urban areas (Widodo *et al.* 2015). For food or small-scale marketing, farmers practice piecemeal harvesting of the roots where they dig up a few tubers and leave the rest to continue bulking (Stathers *et al.* 2013). Other farmers grow different varieties with different maturing periods or stagger the planting time so as to have supply of fresh tuber throughout the year (Ngailo *et al.* 2016). However, this strategy does not work in most of the sub-Saharan Africa countries due to prolonged dry periods (Low *et al.* 2020).

In sub-Saharan Africa, sweet potato is grown extensively in the densely populated intensively cultivated regions of East Africa (Low *et al.* 2017b) where it is seen as a food security crop due to its reliable yields and ability to grow throughout the year (Andrade *et al.* 2016). It can adapt well in a wide range of climatic conditions and marginal areas with poor soil conditions (Bioethics 2004). Due to its drought tolerance, farmers rarely loose the total crop harvest and thus they plant it as an insurance (CIP, 1996).

Sweet potato is an important dual-purpose crop grown mainly for human consumption (Kapinga *et al.* 1995), and the crop residue (vines and leaves) fed to animals (Wanapat 2009). As a result, sweet potato has the potential to support livestock production without competing for human feed resources. Yield of sweet potato tubers is comparable to other tuberous crops where it is similar to cassava yield but less than yam (Terry *et al.* 17-23 Aug1986). However, the leaf biomass yield of sweet potato is higher than both, as it can be harvested many times throughout the year (Hong *et al.* 2003). After harvesting the roots for human consumption, most of the vines and non-commercial roots are left in the field and could be used to feed ruminants (Ruiz *et al*., 1981).

2.6.2.1 Sweet potato agronomy

Sweet potato can adapt to wide range of environmental conditions and can thrive in areas with poor soil fertility and inadequate moisture (Bioethics 2004). However, optimum production is achieved when SP is grown on fertile, high organic matter, well drained light textured soils with an optimum pH of between 5.8 and 6.2 (Woolfe 1992). Heavy textured poor-drained soils have poor aeration and are prone to water logging which reduces tuber growth in early stages and can cause rotting in late stages of development (Yooyongwech *et al.* 2017).

Propagation is mainly through vine cuttings or sprouts from the tubers. The cuttings are 300 to 450 mm long and are cut from the apical part of the mature plant and should be from clean planting material free of diseases and pest (An 2004). They are then planted in molds, flat beds or sunken beds. Mold planting is common and is encouraged due to proper drainage thus preventing tuber from rotting, especially where there is high water table (Root 2010). It is also reported to significantly increase tuber yields as compared to flat bed or sunken bed planting (Lugojja *et al.* 2001). This is because the molds offer loose topsoil that encourages growth and bulking of the tubers leading to a 64% increase (Agbede and Adekiya 2009) in tuber yields as compared to flat or sunken bed planting. There is good aeration due to less compaction of the molds which encourages root growth. Sweet potato grown on flat beds are reported to grow excess foliage at the expense of the roots (Busha 2006).

Once planted, sweet potato undergoes three stages of development: initial growth of vines and development of absorbing roots, continuation of growth of vines absorbing roots plus initial development of the tubers and finally rapid development of the tubers (Clark and Wright 1983). Tuber development is reported to occur between 7 and 91 days after planting depending on the variety, soil composition and environmental conditions (Issa 2015). The tubers are ready for harvest between 3 to 8 months depending on the variety (Stathers *et al.* 2013). Due to their delicate skin, harvesting of tubers should be done manually using sharp sticks to avoid bruising the skin that can result to lowered market value or rotting (Ray and Ravi 2005).

2.6.2.2 Chemical composition of sweet potato

The roots, stem and leaves of sweet potato contain a variety of nutrients, some of which are important s for human and animals. Various studies have reported high protein content in vines: 22.1% (Luyen and Preston 2012), 22.9% (Nguyen *et al.* 2012) and 23.1% (Ly *et al.* 2010). The leaves are high in minerals such as Ca, Mg and Na and vitamins such as A, B_{2}, C and E (Sun *et al.* 2014) and have a fibre content of 38% on DM basis (Johnson and Pace 2010). The roots contain low dry matter content (30%) low CP (0.72-1.27% DM) but high in carbohydrates (80 to 90% DM) (Pérez and Fujita 1997). The carbohydrates consist of starch and sugars with minimal pectins and hemicellulose (Woolfe 1992). A medium sized sweet potato tuber (114 grams) is reported to contain 162 calories, 37 grams of carbohydrates 0 grams of fat and 3.6 grams of protein (Tan *et al.* 2007), a calorie yield higher than maize and comparable to cassava.

The nutritive value of sweet potato tuber depends on variety (Rose and Vasanthakaalam 2011). For instance, the white and yellow varieties have lower levels of beta carotenes, a precursor for vitamin A, as compared to the orange-fleshed variety (Kim *et al.* 2011). It is for this reason that researchers have embarked on breeding programs to come up with bio-fortified, orange-fleshed sweet potato varieties that are high in carotenoids (Low *et al.* 2017a).

2.6.2.3 Effect of harvesting regime on sweet potato productivity.

In smallholder farms, there is a daily need for food and feed throughout the year which can be supplied by sweet potato. Dual purpose varieties have the ability to regenerate continually when vines are harvested even before harvesting the tubers at maturity (León-Velarde 2000). Intermediate harvesting of vines (i.e., harvesting halfway through the growing period, then again at maturity) has been reported to improve the animal-feeding value of the SP varieties (An *et al.*, 2003). The effect of this partial harvesting on tuber yield is however dependent on the stage of growth of the plant (Nwinyi 1992) and should be done in time and manner that will not affect the yield and quality of the tubers. This is because tuber development is reported to be influenced by the vegetative part of the sweet potato, where the initial stages of tuber development are characterized by accumulation of carbohydrates in the vines (Mulungu *et al.* 2006). However, this is not always the case as some of the SP varieties with a rigorous vine growth have been reported to have low tuber yield (Mulungu *et al.* 2006).

Roots yield is reported to be reduced by frequent vine harvesting (Nwinyi 1992) because shoot removal while the plant is still growing decreases the supply of photosynthates to the growing roots. The degree of yield reduction however depends on the harvesting intensity and the age of the plant. Gonzales et al. (1977) and Villareal (1979) have shown that harvesting the vines when the plant is young and still growing negatively affects yield and quality of the tubers. There is a severe reduction on marketable roots when the vines were harvested at 45 and 75 days as compared to those harvested at 105 days (Stathers *et al.* 2005). Several studies have recommended different ages at which vines can be harvested without significantly affecting the roots; 90 to 120 days (Lebot

2009), 112 days (Nwinyi 1992) and 140 days after planting (Larbi *et al.* 2007a).

Studies on the effect of vine harvesting intensity on tuber yield have been inconclusive. For instance, removal of 25% or less of the total vines does not significantly affect tuber production as compared to removal of 50, 75 or 100% (Edmond and Ammerman 1971). Dahniya (1980) reported a 31 to 48% reduction when only part of the shoots was removed at the tip as compared to 50 to 62% reduction when the vines were harvested at the base. This information is crucial to the smallholder farmers because harvesting 25% of the vines from one-acre plot can provide seed for planting for another 2 acres thus, increasing yields. In Afar region of Ethiopia, farmers have traditionally harvested the vines with a purpose of influencing the tuber size. They cut the vines to reduce production of huge tubers which, as they claim, have to be split into smaller pieces for them to fit in the cooking pots (Ahmed *et al.* 2012).

However, other studies have reported increase in tuber yield and quality when partial harvesting was done. Griggs and Villareal (1982) reported that frequent harvesting of vines increases the total biomass yield and starch content of the tubers. Lugojja (2001) reported no effect on tuber yield when a single defoliation was performed but repeated defoliation reduced tuber yield significantly. This was attributed to the plant having sufficient time to recover after single defoliation to grow new vines and mobilize reserves towards roots development (Welter 1993). Repeated defoliation does not give the plant enough time to redirect enough assimilates to the plant after each regeneration. Also, the same study by Welter (1993) reported that growth stage at which the vines were harvested did not have any effect on the tuber yield.

The effect of partial vine harvesting on vine biomass yield has also been studied. Kiozya *et al*. (2001) found that forage yields increase with longer cutting interval as this allowed the plant enough time to recover from the previous cutting. Generally, it is known that plant productivity is reduced when the leaves are removed while the plant is still growing. This is attributed to leaves serving as the photosynthesis area and their removal reduces plant growth (Lugojja *et al.* 2001). Sweet potato however can tolerate high levels of defoliation due to its compensatory growth ability (Chalfant *et al.* 1990). Even though a single harvest at maturity may result to high biomass yield of vines as compared to each single harvest during the growth period, it does not result to higher yield than the total yield from all the cuttings from intermediate and final harvesting (Hue *et al.* 2012). This shows that there is a positive relationship between vine biomass yield and cutting frequency (Wanapat and Kang 2015) which was attributed to capture of the leaves before they reached the age of senescence when frequently harvested. It also stimulates faster regrowth of new shoots leading to production of higher quantities of foliage (Hue *et al.* 2012).

For defoliation to negatively affect vine growth, a threshold of 30% defoliation of the total leaves has to be exceeded (Mattson and Addy 1975). Because the sensitivity of plants to defoliation changes with time and stage of development (Lugojja *et al.* 2001; Olorunnisomo 2007), different studies have shown varying effects on vine dry matter yield when harvesting is done at different stages of growth. Viana *et al*. (2011) reported yield of 3.7 to 7.4 t/ha at 150 d after planting as compared to 3.05 to 4.95 t/ha at 163 days after planting. Pedrosa *et al* (2015) reported the same vine yield of 4.2 to 7.9 t/ha at both 150 and 230 days after planting. This indicates that beyond 150 days the vines growth slows, and some leaves are lost.

2.7 Grain based supplementation.

In the developed countries, breeding programs with emphasis on milk production has led to dairy cattle breeds with high milk yield potential. To meet the high demand for nutrients of these high yielding cows, forages alone cannot meet the nutrients requirements for milk production and therefore energy and protein need to be supplied through grain-based concentrates (Tolera *et al.* 2000). Grain based concentrates are expensive, and in some cases of low quality (Lukuyu *et al.* 2011a) and not always readily available in most developing countries. Some developing countries do not even have enough cereal grains even for human consumption (Tolera *et al.* 2000), which raises the question of whether it is ethical to feed grains to livestock (Ertl *et al.* 2015). When animals are fed grains which could directly be consumed by humans, food scarcity can occur. IAASTD (2009) reported that half of the grains produced in the world are fed to animals, a claim supported by Alltech (2012) who reported that in 2011, 70% of grains produced went to feeding livestock.

It has also been estimated that less animal protein is produced (58 million tons of animal) by feeding more plant protein (77 million tons) to livestock (Steinfeld *et al.* 2006). In a sustainable livestock production system, there should be less human-edible food that is fed to animals (Herrero and Thornton 2013). Feed resources that are both locally available and don't fall under conventional human food category, create an opportunity as an alternative in feeding livestock (Apata and Babalola 2012).

2.7.1 Alternatives to grain-based supplementation

The increasing pressure on the use of grains by human population and livestock feed millers has created scarcity and increased the cost of cereal grains. This scenario calls for use of alternative sources of energy and protein that are locally available and not in competition with humans (Apata and Babalola 2012). By-products from processing cereals are often considered as a solution, but their supply is never guaranteed as availability is mainly in urban centers where the processing plants are located. Ideally, animal supplement sources should not compete for land space and should be part of smallholder farming systems. This can be made possible by cultivating plants that act as both food and feed sources in an integrated crop-livestock farming system (Tolera *et al.* 2000). One of the crops fitting this description is sweet potato, which can provide food to human (tuber and in some cases even leaves) and feed to livestock (vines) (Apata and Babalola 2012). When the value of the tuber is taken into account, cost of vine production is much lower than cereal crops.

2.7.2 Potential for sweet potatoes as alternative to grain-based supplementation

Growing demand for livestock products is putting pressure on many developing countries to effectively use the available resources in agricultural sector (Scott 1992). The prospects of increasing the production of cereal grains to meet livestock and human needs is proving impossible, leading to seeking alternative feed sources for livestock (Wilkinson 2011). The need to reduce feeding costs and improve profitability in the smallholder dairy systems require use of alternative cheaper protein and energy sources (Phesatcha and Wanapat 2016).

In the past, there has been efforts to improve dry matter content of sweet potato vines, with some varieties having improved by 25.9 to 35.1% percent (Scott 1992), and orange-fleshed varieties up to 42% (Kapinga *et al.* 2007). Also, due to increased demand for both food and feed in the tropical farming systems, dual purpose varieties have been developed and are proving popular among smallholder rural farmers. These dual-purpose varieties allow several harvestings of the vines for fodder without significantly affecting tuber production (Ahmed *et al.* 2012). This enables provision of animal feed all year-round thus enhancing productivity.

In a study by Etela *et al.* (2009), it was reported that supplementing cows with SPV in early lactation could be sustainable and cost effective, especially when improving dry-season Guinea grass. Meyreles and Preston (1977) reported linear increase (up to 34%) in voluntary DM intake of sugarcane stalks when supplementation levels of SPV in the diet were increased. In the study, simultaneous consumption of SPV did not significantly reduce intake of the sugarcane stalk. The increase in DM intake was comparable to 30% reported by Preston et al. (1976) when rice polishing was used and 34% reported by Silvestre and Hovel (1978) when wheat bran was used. Khalid *et al*. (2013) studied the effect of supplementing with SPV on weight gain and reported the highest gain in seven days (4.6 Kg) in animals on SPV silage as compared to sorghum (0.75 Kg) and clitoria (0.38 Kg).

However, when fed without drying, digestibility of SP vines can be a problem due to trypsin inhibitors leading to reduced nutrient absorption from sweet potato or other feeds consumed together (Stathers *et al.* 2013). Improvements through biotechnology is needed to come up with varieties that are low in trypsin inhibitors (Tsou and Hong 1989). Furthermore, farmers are encouraged to process SP vines before feeding to the animals by sun-drying and cooking the tubers thus improving the feed value by destroying the trypsin inhibitors (Pérez and Fujita 1997).

2.7.3 Effect of concentrate feeding on milk yield and composition

When dairy cows are supplemented with concentrates, the overall feed intake is increased (McEvoy *et al.* 2008). For instance, an increase of 2.9 Kg/cow dry matter intake was reported for cows fed diets high in concentrates as compared those on low amounts (Lawrence *et al.* 2015). Sutton et al. (1987) reported an increase in hay intake of 0.9 Kg DM when cows were fed 9.5 Kg of high fibre concentrate as compared with same amount of a high starch concentrate. However, other studies have contradicted these findings with Gordon (1984) reporting lower intake of silage when supplemented with fibrous concentrate compared with a high starch concentrate. Furthermore, there was a reported increase in substitution of pasture by 0.03 DM/Kg DM for an additional Kg of concentrate offered (Stockdale 2000).

The rate of substitution is influenced by type of supplement fed (McKay *et al.* 2019), quality and level of feeding of both the supplement and the forage, and the physiological state of the animal (Sutton *et al.* 1987). Supplements with high levels of readily digestible carbohydrates tend to reduce rumen pH and fiber digestion due to reduction of microbial activity in the rumen (Dijkstra *et al.* 2012). Substitution effect can also be affected by supplementing with a nutrient that is deficient in the ration, where if a forage is deficient of protein, protein supplementation will increase the forage intake (Cappellozza *et al.* 2021).

When feeding dairy animals with low feed-value tropical forages, supplementation is vital in enhancing digestibility and utilization of nutrients if high level of production is to be achieved (O'Neill *et al*, 2013). Even with high quality forages, it is sometimes difficult to meet the energy and/or protein demand of high producing dairy cows due to the DMI limits of the animals (Beecher *et al.* 2014). Gut limitation is major constraint to intake of adequate levels of digestible nutrients, especially energy to sustain high milk yield in high genetic merit dairy cows. Therefore, there is a need for high nutrient supplementation with concentrates and in some cases even with the use of modified dietary fats such as Calcium salts of long chain fatty acids. To fill this gap, supplementing with energy and protein sources is crucial and is expected to result in increased nutrient intake and subsequently increase production.

Response in milk production when concentrates are fed depends on the basal diet quality, stage of lactation of the animal, production potential of the cow and level and type of concentrate (Dillon *et al.* 1997). Milk response to supplementation is reported to depend on energy balance between demand and supply (O'Neill et al, 2013). However, this response is always much less than the expected due to substitution of the basal diet by the supplement (Sheahan *et al.* 2013). Ideally, when there is no substitution of the basal diet by the supplement, and all extra energy is channeled towards milk production, 1 Kg DM concentrate with approximately 12 MJ ME/kg should lead to a milk increase of approximately 2 Kg. (Bargo *et al.* 2003). However, other studies have reported lower milk yield response rate of between 0.41 and 1.0 Kg of milk per Kg of concentrate fed in the tropics (Woodward *et al.* 2002; Burke *et al.* 2008). Variation in the response is high (up to 63%) which can be attributed to quality of the basal diet and that of the concentrates, reduced forage intake due to substitution effect and partitioning of the extra energy to body tissue synthesis. The response rates increase as the quality of the basal diet decrease, a scenario more evident in the tropics than temperate systems.

The nature and composition of the concentrate has been reported to affect both the milk yield and milk composition, where concentrates with higher fiber produces higher milk yield and higher fat content than the starch-based concentrates (Larsen *et al.* 2013). This could be because starch-based concentrates lower the rumen pH, leading to low digestion and reduced dry matter intake. On the other hand, high fibre diet tends to stimulate acetate type of fermentation in the forestomach and acetate being a lipogenic substrate promotes butter fat synthesis. The genetic merit of the cow is also considered a factor in response to supplemental feeding (Kennedy *et al.* 2002). Cows with superior genetic merit partition their supplemental feed energy towards milk production rather than body reserves in the early lactation. The stage of lactation also affects milk response to supplementation because energy is channeled more to body reserves in the late lactation as compared to early lactation where more of the energy is channeled towards milk production. Furthermore, in early lactation dietary energy intake levels may be inadequate due to factors associated with uterine involution and hormonal levels making the dairy cow to mobilize adipose tissue fat reserves that results in loss in body weight. Recent studies in the USA on the use of Bovine somatotropin (BST), have also shown that this hormone does influence nutrient partitioning in favor of high lactation, especially in dairy cows with high genetic merit for milk production.

Protein type in the supplement is also reported to affect the response of milk production. Rumen undegradable protein (RUP) has been reported to improve yield where milk was reported to increase by 6.5 Kg/d when RUP in a CP diet was increased from 5% to 9% (Amanlou *et al.*

2017). When lactating cows were fed formaldehyde-treated soybean meal, there was an increase of 2.2 Kg/d compared to those fed untreated soybean meal (Throat *et al.* 2016). Also, by varying the levels of RUP in goats' diet, protein and net energy content in milk increased significantly (Chowdhury *et al.* 2002). In these studies, the response was attributed to the fact that rumen undegradable protein increases the flow of protein into the small intestines thus making more protein available for milk synthesis. In other studies, increase in milk yield in response to protein supplementation is attributed to increased dry matter intake (Laudadio and Tufarelli 2010), while others attribute it to improved energy utilization (Kaufman *et al.* 2018). This is supported by the fact that supplementation with RUP is likely to help the dairy cow to surmount the limiting amino acids phenomena that may be limiting efficient utilization of available dietary energy in addition to the endogenous energy mobilized from the animal's adipose tissue which is likely to boost milk production high genetic merit dairy cows. Furthermore, it is also widely accepted that while dairy cows have a capacity to mobilize endogenous energy reserves from the body's adipose tissue to close the metabolizable energy gap, the same cannot be said for the protein because of the dairy cow's limited capacity to mobilize body's protein reserve. In such cases, the limiting amino acids are best supplied through exogenous supplementation with undegradable dietary protein.

In the recent past, consumers are increasingly demanding for food that is healthy and environmentally friendly (Gao *et al.* 2020). Milk quality is becoming a major issue in the developing country's dairy value chain, with consumers' purchasing interest shifting towards safety and nutritional quality of milk (McGarry Wolf *et al.* 2009), specifically milk with low fat content and high protein and unsaturated fatty acids. Furthermore, milk processors are starting to offer milk prices based on total solids, specifically protein and fat (Santos and De Vries 2019), with export markets setting quality standards. This has led dairy sector to step up production not only volumes but also quality. With this emphasis on milk composition in today's dairy industry, any change in feed type or the level of feeding should be followed with understanding on how the milk composition will respond to the changes. If a feed results in a great change in milk composition, then such an effect would be of a great concern to the dairy industry. The composition in milk is the main measure of its quality and any intervention that can alter the composition is crucial in achieving the desired milk quality.

Milk fat and protein content are the major components given attention to when analyzing milk quality. Increased milk protein synthesis is stimulated by increased supply of amino acids in the diet (Safayi and Nielsen 2013). This synthesis requires energy and therefore apart from amino acids, energy availability is crucial. Milk fat is mainly affected by roughage physical properties (fiber) rather than chemical properties (Tafaj *et al.* 2004). In some cases, the type of diet fed to the animal influences milk fat content. For instance, Khalid *et al*. (2013) studied the effect of feeding different silage diets to Nubian goats on milk composition. In their study, SPV silage showed the highest milk fat content (3.81%) as opposed to sorghum (3.37%) and Clitoria (3.49%).

Milk composition can be altered using breeding or nutrition interventions (Samková *et al.* 2012). With genetic manipulation being slow, nutrition can be a quicker way of changing milk composition (Tyasi *et al.* 2015) and thus a better means of meeting the rapidly changing demands in the milk market. This can be achieved by altering the feed itself (amount fed and composition) and meal pattern, as well as other feed factors such as roughage - concentrates ratio which can be used to influence the amount of fat in the milk (Sutton, 1995).

Nutrient composition in the blood is affected by nutrient intake and energy balance and this in turn affects mammary nutrient supply and milk composition (Safayi and Nielsen 2013). After the feed is consumed, the amount of external control is greatly reduced. At this stage, minimal intervention can be achieved only by use of additives to influence rumen functionalities and to some extent absorption.

In an experiment to study the influence of supplementation with soybean meal on milk quality, Gonzalez *et al.*, (2009) reported that fat content was affected by supplementation, with higher values obtained by the group under supplementation (4.77%) as compared to 4.46% for pasture only. In normal circumstances, when the milk production lowers, fat content is expected to increase due to increase in concentration of solid components because of reduced dilution effect (Boland *et al.* 2013). However, in some cases where the supplement is high NDF content, this could lead to increased production of volatile fatty acids leading to high butter fat content (Tafaj *et al.* 2004). Protein content is also reported to be affected by supplementation with high amounts of amino acids in the diets increasing protein content in milk. Gonzalez *et al*. (2009) reported higher percentage of protein (3.67%) for a group of cows supplemented with soybean meal as compared to 3.49% for cows on pastures only. However, the same study reported that there was no difference in lactose content of cows on supplementation (4.28%), and those not supplemented (4.26%). This is because lactose suffers less variation as compared to the other milk components and increases with milk production (Tafaj *et al.* 2004). The age of the animal can also influence its response to the nutrient supply, with older cows having higher milk composition response to increased nutrient supply as compared to first-time lactating cows (Bossen *et al.* 2009).

2.8 Silage making

Ensiling is a process of fermentation to conserve moist green forages which preserves their moisture and nutrient content making them suitable for feeding (Bautista-Trujillo *et al.* 2009). The process of silage making is a relatively easy technique that does not pollute the environment and the products are deemed natural (Filya *et al.* 2000). The ensiled feed is more palatable, and animals can digest the plant fibre and protein more effectively (Dom *et al.* 2011). In the developed countries, silage is highly valued as animal feed with more than 90% of forages produced being conserved as silage (Mohd-Setapar *et al.* 2012).

Traditionally, silage making has been a means of fodder preservation for the large-scale dairy farmers, owing to the machinery, labor and other costs involved. However, development of low-cost ensiling techniques which do not involve heavy machinery has enabled smallholder farmers to practice silage making. In the recent past, silage making has become crucial to smallholder dairy farmers, especially in areas where there is extended dry seasons (Aminah *et al.* 1999) or even when weather conditions are not favorable for cut and carry system of feeding. In small scale farms where family labor is insufficient, silage making reduces the burden of the tedious daily harvesting of Fodder (Aminah *et al.* 1999). Ensiling is also used to transform some unpalatable low-cost by-products into useful livestock feed by changing their chemical nature (Chedly *et al* 1999.). For instance, chicken droppings and rice bran can be used as additives leading to improved crude protein and dry matter conversion rates of the byproducts (Peters *et al.* 2002).

To achieve quality silage, the forage material has to be harvested at the right stage of maturity where the nutrition quality is highest. The forage material should have high water-soluble carbohydrates (WSC) content of 6 to 12% (Giang *et al.* 2004), low buffering capacity and dry matter of 250 to 400 g/Kg. For ensiling to be a success, two objectives must be met; one is to achieve an anaerobic condition and two, is to inhibit undesired microorganisms such as clostridia and enterobacteria (Adesogan and Newman 2010).

Ensiling is done anaerobically by storing the material in airtight silos where preservation is enabled by fermentation of carbohydrates by microorganisms lowering the pH to a level that inhibits the spoilage microorganisms (Mohd-Setapar *et al.* 2012). The storage period has to be long enough for the fermentation process to be completed. This occurs at the time when lactic acid is the predominant acid leading to rapid drop of pH to a maximum level of 4.0. The aim should be to complete the fermentation process in the shortest period possible to retain more nutrients in the silage (Adesogan and Newman 2010).

Silage fermentation process occurs in several stages. The first phase is the aerobic stage that starts immediately the silage is made and depending on the level of compaction, can last a few hours up to 2 days until oxygen is completely depleted from the sealed silo (Adesogan and Newman 2010). The longevity of this stage depends on how the silage was made with the stage taking longer (up to 2 days) in poorly made silage. A significant proportion of nutrients can be lost through aerobic oxidation with substantial amount of heat being generated in the process (Wilkinson 2015). In this stage, the atmospheric oxygen that is trapped in-between plant particles is reduced by respiration and the plants proteins are broken down to amino acids. The oxygen allows biological processes that consume nutrients and energy, producing water, carbon dioxide, heat and ammonia where the heat produced causes increase in temperature leading to DM and quality losses (Borreani *et al.* 2018a). Therefore, to minimize nutrient losses at this stage, the plants should be harvested at the right maturity, chopped to the right particle size, compacted thoroughly to reduce oxygen and silo sealed immediately after ensiling.

After oxygen is exhausted, the silage enters the second phase of anaerobic fermentation where lactic acid bacteria (LAB) start proliferating and become predominant over other acid producing bacteria (enterobacteria, clostridia and yeast) (Calabrò *et al.* 2012). The LAB ferment sugars into organic acids, alcohols, carbon dioxide and nitrogenous compounds (Pahlow *et al.* 2003). The organic acid acids (mainly lactic acid) lowered the silage pH to a level where the undesirable microbes cannot survive. The anaerobic condition in this stage is the main factor that determines the success of the ensiling process (Calabrò *et al.* 2012). Even small amounts of oxygen infiltrated into the silage can inhibit plant cell lysis and trigger growth of aerobic microorganisms (yeast, fungi and aerobic bacteria) thus affecting LAB fermentation (McEniry *et al.* 2011). Under anaerobic conditions, most of the spoilage microorganisms decrease due to low pH caused by increase in lactic acid, leading to a stable silage. This stage can last 3 days up to four weeks until the fermentable sugars are depleted (Adesogan and Newman 2010). The silage can stay stable for as long as there is abscence of oxygen but once the silage is opened during feed out, the aerobic conditions are restored, and this marks the beginning of the last phase. Due to oxygen penetration, yeast and molds that have been dormant during the stable phase are revived and they use up sugars, lactic acids and other nutrients to produce carbon dioxide and heat (Bernardes *et al.* 2021). This amounts to nutrient losses of silage. Molds also produce mycotoxins that can lead to health problems to animals (Ogunade *et al.* 2018). To reduce these losses, the silage should be fed to animals immediately after exposure to air. It is recommended that the feed out rate should be in layers of 8 to 12 inches per day (Adesogan and Newman 2010). Where possible, additives and inoculants that slow down growth of yeast and molds should be added to help improve the quality of the silage.

The main stages of DM loss are during harvesting, fermentation, silage effluent from the silos and exposure to air during feed out stage (Borreani *et al.* 2018a), where in each of these stages, quality deterioration and dry matter loss occur leading to reduced quality of the silage fed, as compared to the ensiled material. During fermentation, extent of DM loss depends on the dominant microbial species where there are increased DM losses in form of carbon dioxide if microorganisms other than LAB play a significant role in fermentation (Sakhawat 2011). Some of the LAB species ferment glucose homofermentatively producing only lactic acid leading to minimal DM losses (Borreani *et al.* 2018a). However, other species of LAB ferment glucose heterofermentatively, producing 1 mol of carbon dioxide per every mole of glucose fermented leading to 24% loss in DM. Good management practices in each stage of silage making can therefore play a significant role in reducing these losses.

2.8.1 Factors affecting silage quality

Respiration and temperature at ensiling

Immediately after the ensiling process, the chopped forage is still metabolically active. This leads to rise in temperature due to respiration aided by the trapped oxygen in the forages (McAllister and Hristov 2000). The rise in temperature is a s result of complete oxidation of the glucose molecules in the plants releasing energy which, in an open field, is dissipated as heat into the atmosphere but in the silo, it leads to rise in temperature (Henderson 1993). The temperature leads to acceleration of respiration exponentially until either the oxygen supply is exhausted, or enzymes are inactivated by low pH. This occurs before the fermentation stage starts. The rise in temperature results to DM and nutrient losses where it has been reported that 10 ^{o}C rise in temperature leads to 1.7% DM loss (Rees 1982). Respiration peaks at 46^{o}C beyond which the enzymes involved are inactivated (Pitt and Muck 1993). If the high temperatures are prolonged, they cause protein denaturation, extensive browning and decreases intake and digestibility of the silage (Wang and Nishino 2013). The DM loss is more if the ensiling process is done during the hot or wet weather (Ashbell *et al.* 2002). The rise in temperature is also detrimental to lactic acid growth where the optimum temperature for lactic acid to thrive is between 27 and 38 degrees (Yamamoto *et al.* 2011).

Silo filling and sealing

The amount of time taken to fill and seal the silo affects silage quality. Slow filling and delayed silo sealing lower the quality due to yeast development which plays an important role in anaerobic deterioration of silages (Henderson 1993). Yeast develops during wilting and in case of air infiltration in the storage period (Weiss *et al.* 2016). Its effect can be minimized by filling the silo in the shortest time possible and sealing it immediately and efficiently. Bruning *et al*. (2018) reported that delaying sealing the silo by 4 days led to 11% DM losses, increase in yeast production and a decline in WSC of up to 65%. This agrees with Gerlach *et al* (2013) who reported a 27.2% increase in losses in organic matter when silage was sealed after one day as compared to immediate sealing. Delayed sealing has also been linked to decreased feed intake due to production of ethyl ester during fermentation (Weiss *et al.* 2016). Immediate sealing sets the start of fermentation stage, leading to rapid drop of pH thus reducing the rate of protein degradation by the protease enzyme (Brüning *et al.* 2018). Plant proteases are most active at pH of between 6 and 7 but below 4 their activity is reduced (Henderson 1993). Proteolysis and amino acid degradation can also be reduced by increasing the plant DM (Yitbarek and Tamir 2014).

2.8.2 Sweet potato vine ensiling

Over the years, silage has been made mainly from grass and fodder maize (Wilkins 2005). However, due to poor quality of tropical grasses, and competition between ruminants and human for maize, these traditional sources of silage are not viable and there setting stage for the exploration of other viable alternatives with sweet potato vines being considered as one such option. Sweet potato vines have been used as an unconventional alternative for silage making (Salehi *et al.* 2014). Another reason for ensiling SPV is to guarantee its availability throughout the year due to its seasonal availability (Mose *et al.* 2006) which may not coincide with the time of feed scarcity. Furthermore, irregular feeding of SPV has been reported to affect milk production where there is lowered milk yield when cows are fed vines irregularly (Peters 2008). This is attributed to low feed intake resulting from a cow used to high palatable feed refusing other feeds until a particular feed is offered. This therefore calls for ensiling the sweet potato foliage as a feed conservation strategy (Cheli *et al.* 2013) to enable constant supply throughout the seasons.

Dom *et al*., 2009 reported that the economics of making SPVs silage are feasible in storing vines for a long time and therefore reducing costs of buying fodder and reducing need for labor in daily feeding chores, especially for women (Dom and Ayalew, 2010). A study by Khalid (2013) concluded that the value of vines and roots are improved by ensiling because fermentation improves their digestibility. A study by Peters (2008) showed potential of SPV silage in improving milk production by up to 1.5 Kg per day. This is due to its ability to raise the level of digestible protein in mixed diets. Replacing 50% of commercial feed with SPV silage proved to be effective in maintaining adequate feed intake, body weight gain and feed conversion efficiency (Giang *et al.* 2004).

However, there are reports of reduced CP when SPVs are ensiled (19.7g/Kg DM) as opposed to drying (22.9 g/Kg DM) (Nguyen *et al.* 2012). An earlier study by Brown and Chavalimu (1985) reported a loss of up to 37g per Kg of silage dry matter as opposed to 15g per Kg DM when SPVs were dried, a loss attributed to the succulent stems of sweet potato vines making them not feasible to dry. Presence of bacteria, mold and other metabolites e.g., mycotoxins in silages are a major concern due to their effect in animal health (Drejer Storm *et al.* 2008). Use of forages as the main dry matter component, as compared to cereal grains, makes the contribution of silage to mycotoxin intake significant (Cheli *et al.* 2013). Mold contamination in silage leads to reduced palatability, reduced nutrition value and feed intake, decreased fertility and susceptibility to diseases. Worldwide, an estimated 25% of crops are affected by mycotoxins (Ashbell *et al.* 2001). These mycotoxins are of economic importance due to their detrimental effects on livestock productivity and plant losses. Some types of mycotoxins such as aflatoxins have a high carryover rate from feed to milk thus leading to high mycotoxin intake in human population (Cheli *et al.* 2013). In a study carried out in the Netherlands, Driehuis *et al*., (2008) reported that relative to compound feed, the contribution of silage to dietary mycotoxins was between 2.9 to 3.5 times higher. The same study reported that fungi and aflatoxins levels are more affected by environmental conditions (high temperatures, low rainfall and drought stress) and agronomic practices than the actual silage-making practices.

The biggest challenge in ensiling SPV is the low dry matter content. Pedrosa et al., (2015) reported vines dry matter of 21%, a figure that was below the recommended DM of 35% required for silage making (Nishino *et al.* 2012). This therefore requires wilting of the vines to achieve the DM requirements. When the DM is increased through wilting, sugars are concentrated in the DM thus increasing concentration of water-soluble carbohydrates (WSC) (Henderson 1993). It also reduces water activity in the plant cells and reduce seepage losses from the silos (Borreani *et al.* 2018a).

Studies have indicated that unwilted herbage may seem more extensively fermented due to high concentration of fermentation products (McEniry *et al.* 2011) but are less well preserved as compared to wilted herbage. This is because wilting increases the dominance of the desired lactic acid bacteria (LAB) and reduces the concentration of ammonia nitrogen which indicates reduction in proteolysis. (Thomas, 2007).

To reduce DM and nutritive losses, the forage should be wilted rapidly by spreading the forage immediately after cutting. Kung *et al*. (2010) suggested that, for forages with high moisture content and low WSC, cutting the forage in the morning maximizes wilting in a shorter period rather than leaving the forage for a longer time to dry. However, this contradicts findings by Morin *et al*. (2012) and Brito *et al*. (2008) who reported an increase in WSC when forages were cut in the afternoon as compared to those cut in the morning. This is attributed to the fact that the plants accumulate carbohydrates during the warm and sunny period of the day due to photosynthetic activity (Brito *et al.* 2008), thus WSC content is relatively higher in the afternoon as compared to early morning (Kaiser *et al.* 2000). Marsh (1978) reported that wilting of forages before ensiling increased voluntary feed intake by 25 to 31% in beef animals. Haigh et al. (1985) reported a lower increase in intake of wilted silage by 19% from 4.7 to 5.6 Kg. Although efficiency of utilization of DM is reduced by wilting (Charmley and Thomas 1987), it does not affect energy utilization. Wilting also enables the silage to stabilize even at high pH of 5 and above. This, according to McDonald *et al*. (1991) is due to suppression of clostridial growth due to the osmotic pressure caused by wilting. However, according to Pedrosa *et al*. (2015), wilting under the open sun increases NDF, ADF and lignin content thus reducing the vine nutritional value. It is also reported to reduce digestibility of the silage, and this is attributed to loss of digestible nutrients due to plant respiration (Charmley and Thomas 1987). Organic dry matter digestibility was reduced by 10 g/Kg when silage material was wilted due to loss of highly digestible nutrients through oxidation and leaching (Haigh and Parker 1985).

Crops ensiled at a DM below 300 g/Kg were reported to have high in-silo fresh weight losses through effluent production (McEniry *et al.* 2011). This is worse if there is high level of compaction at ensiling leading to high pressure exerted on the herbage. Through this effluent, nutritional losses occur and in large scale silos, it may cause environmental pollution of water sources due to high BOD (Weinberg and Ashbell 2003).

Another challenge of ensiling SPV is its low energy content. This can be corrected by mixing sweet potato vines and tubers during ensiling which has been shown to improve the feed energy value of SPV silage (Giang *et al.* 2004). The roots are rich in energy (15.6 MJ ME/ Kg DM) due to high carbohydrates content (80 to 90% DM) while the vines are high in protein (17.1% CP) with 8% starch and 4% sugars (Dominguez 1992). This mixture is reported to contain up to 59.6% carbohydrates which provides a perfect environment for fermentation during ensiling. Giang *et al*. (2004) concluded that ensiling sweet potato vines does not require any additives if sweet potato roots are incorporated at a ratio of 30 to 70%. However, this leads to a slight decrease in DM (5%) which is considered acceptable (Sylvester 2010).

2.8.3 Ensiling additives

The conservation of forage as silage relies on a natural fermentation process under anaerobic conditions. However, some of the forages used may not have enough soluble carbohydrates required for successful fermentation leaving the fermentation process to chance (Kung 2018). Silage additives have been used to cover for some of the risks of insufficient fermentable substrates in silage making process while at the same time improving their nutritive value (Henderson 1993). A good silage additive improves nutrient recovery from the silage by minimizing heating and fungi development (Elferink *et al.* 2000). The additives also increase the efficiency of silage utilization, limit spoilage and improve anaerobic stability, leading to reduced DM losses (Yitbarek and Tamir 2014).

Without the additives, the fermentation occurs as a result of the activity of microorganisms on the crop WSC (Borreani *et al.* 2018a). The presence of WSC and population of these microorganisms is influenced by the type of the crop, growing conditions and the environmental factors at cutting and wilting stage. It is reported that, for successive preservation to occur without using additives, the ensiling material will require WSC levels of about 30 g/Kg DM (Haigh and Parker 1985). The low levels of WSC in SPV therefore calls for silage additives to be used to enhance fermentation process.

Silage additives have been used for decades to improve the ensiling process. It is estimated that out of the 200 million tons of silage made worldwide annually, 9% of the cost involved goes to additives (Weinberg and Ashbell 2003). The choice of the additive product to be used is largely determined by its cost and availability rather than its effectiveness and suitability for the crop being ensiled (Elferink *et al.* 2000).

2.8.4 Categories of silage additives

Fermentation enhancers

Even when good fodder harvesting and ensiling techniques have been followed, fermentation can still be inefficient due to lack of enough water-soluble carbohydrates. The fermentation coefficient depends on the plant's dry matter content and buffering capacity, factors whose relation was characterized by Weissbach and Honig. (1996) as follows.

FC = DM (%) + 8 WSC/BC

where FC is the fermentation coefficient, DM is the forage dry matter content, WSC is the water-soluble concentrates and BC is the buffering capacity of the forage. Using this relationship, it was concluded that forages with fermentation coefficient of less than 35 should be ensiled with additives (Elferink *et al.* 2000). However, the formula does not work for forages with low nitrate content because they are more liable to clostridial fermentation (Spoelstra *et al.* 1988). Due to the high number of lactic acid bacteria required to inhibit clostridial activity (100,000 units/ g fresh crop) (Kaiser and Weiss 1997), LAB inoculants are recommended for such forages.

Fermentation inhibitors

These are used in forages with very low DM and low WSC. They reduce the clostridial spore count thus inhibiting clostridial growth. Most used inhibitors are salts from acids, formic acids and nitrite that reduce clostridial spores in wilted grass by 5 to 20 times (Lättemäe and Lingvall 1996).

Aerobic spoilage inhibitors

Yeast and acetic acid bacteria are known to be the spoilage organisms in silage making. Some volatile fatty acid-based additives (propionic and acetic acids) can be added to inhibit growth and activity of these microorganisms (Weinberg and Muck 1996). This is because propionic and acetic acids have been found to have inhibitory effects on yeast populations (Moon 1983). Others are bacteriocin producing microorganisms such as lactobacilli (*Lactobacillus buchneri*) which degrades lactic acid to acetic acid that in turn suppresses yeast population.

Additives used as nutrients or absorbents

Silage quality is highly dependent on the nutritional quality of the forage ensiled. Sometimes specific nutrients lack or are insufficient in the forages. the quality of these forages is often

improved by adding specific additives high in the lacking nutrients (Borreani *et al.* 2018a). Ammonia and urea are the most common additives used in silages to improve on the crude protein content. Limestone and magnesium sulphate are also used to increase calcium and magnesium. Wheat bran can also be added to SPV silage to improve on energy content and at the same time increasing dry matter content. These additives have no effect on silage fermentation although some such as urea and ammonia have been reported to improve aerobic stability of silage (McDonald 1991).

2.8.5 Sugarcane molasses

The main limiting factor in using additives in silage making in the tropics is the cost and availability (Weinberg and Ashbell 2003). By-products such as sugarcane molasses, which is available and relatively cheap, is one of the additives that can be used as a source of external readily fermentable sugars (Luo *et al.* 2021). Sugarcane molasses is reported to have nutrimental value to cattle and has no anti-nutritional substances such as tannins and polyphenols that may interfere with microbial fermentation. In Netherlands, sugarcane molasses is the most used silage additive (37%) as compared to inoculants (31%) and fermentation inhibitors (29%) (Elferink *et al.* 2000). It is a by-product of sugarcane industries with a dry matter (DM) content of 700 to 750 g/Kg and soluble carbohydrate of 650 g/Kg mainly sucrose (Yuan *et al.* 2015). Molasses is a carbohydrate-rich material added to silages to increase supply of substrate for lactic acid bacteria (Henderson 1993). In legumes and tropical grasses, it must be used in high concentrations (40-50 g/Kg) for it to achieve optimal benefit. However, a considerable proportion of the added carbohydrates may be lost in the first few days after ensiling if the forage being ensiled has low DM content. Its inclusion in animal feeds has been reported to improve silage quality and feed intake by up to 10% (Pettersson 1988). In a study on Leucaena silage, inclusion of molasses at 2% of the crop DM improved its chemical composition and rumen fermentation efficiency (Phesatcha and Wanapat 2016). The study reported that molasses removed some chemical linkages of the hemicellulose in leucaena silage thus improving its solubility in the rumen. In this study, rumen microorganisms were able to degrade plant metabolites such as alkaloids and saponins and utilize them as energy source. Increase of CP (18.4%) has been reported when molasses was added to grass and fermented for 30 days (Khan *et al.* 2006). This was attributed to increased microbial activity due to availability of readily fermentable energy.

2.8.6 SPV Silage quality

Silage quality assessment is approached from two aspects: nutritional characteristics and fermentative characteristics (Cherney and Cherney 2003). In nutritional characteristics, silage making should target to minimize DM losses and a good target for DM of grass silages is around 30% (Cooper and Hutley 2010). This agrees with Titterton (2004) who reported that the recommended DM for traditional crops silages is 21 to 30%. DM is important in silages as it indicates the bulkiness of the feed which affects the rumen fill, passage rate and the subsequent quality of a feed (Brüning *et al.* 2018).

The main fermentative characteristics that determine silage quality include pH, ammonia nitrogen, lactic acid and volatile fatty acids (Cooper and Hutley 2010), with pH indicating the acidity of silage and hence its stability. Its variation in silages is attributed to quality of the fodder, harvesting and ensiling techniques (Titterton *et al.* 2004). A good silage should have high lactic acid content produced by the lactic acid bacteria, as compared to propionic and butyric acid (Kung and Shaver2001), which depends on the levels of water soluble carbohydrates in the ensiling material

(Gerlach *et al.* 2013). Silage is stable at pH of 4.3 – 4.5 (Kung Jr *et al.* 2018).

Ammonia nitrogen is nitrogen that has been fully degraded, and its presence indicates presence of secondary fermentation and hence protein loss (Meeske *et al.* 1999). Its level in silage gives an indication of the extent to which nitrogenous compounds have been degraded or decomposed during the ensiling period (Stark and Wilkinson 1988). Good quality silage should have ammonia nitrogen concentration of below 2% of total nitrogen while poor quality silage having over 20% (McDonald *et al.* 1991).

Lactic acid is a sweet-smelling product that is the principal acid contributing to a successful fermentation process. It lowers the pH and reduces ADF and ammonia nitrogen while reducing yeasts and moulds (Blajman *et al.* 2018) thus improving silage stability. Poor quality silage contains as low as 29.7g lactic acid/ Kg DM (Santos *et al.* 2013), while good quality silage contains more than 170g lactic acid /Kg DM (Meeske *et al.* 1999).

Volatile fatty acids (propionate, acetate and butyrate) are normally produced during secondary fermentation and high levels in silage indicate spoilage. These acids are less desirable because they waste metabolites of microbial origin and therefore not useful to the rumen microbes and represent DM and nutrients loss (Coblentz *et al.* 2016).

However, even after silage meeting all the above qualities, its quality and efficiency of utilization cannot be guaranteed. For instance, there are reported instances where rumen digestibility is affected by polyphenolic compounds in silages (Taboada *et al.* 2010), while other reports show lowered CP utilization (Titterton *et al.* 2004). Bearing this in mind, the feeding value of silages can only best be determined using practical feeding trials.

2.8.7 Factors affecting quality of SPV silage.

Age at ensiling

In the tropics, forages tend to reach their maturity faster (Zailan *et al.* 2018) than in temperate forages. The maturity age of forages is reported to have an effect in aerobic losses of silages (Weinberg *et al.* 2010). As the forages advance in age, they become more fibrous, lignified and less nutritious due to reduced leaf fraction (Mushtaque *et al.* 2010).

Wilting

SPV wilting is crucial to increase forage DM content to 25-30% that is ideal for silage making (Pedrosa *et al.* 2015). It helps to increase concentration of water-soluble concentration and reduce water activity (Borreani *et al.* 2018b). This will also reduce nutrient loss by seepage/effluent loss from the silo, especially during compaction. Rapid wilting with high solar radiation helps in inactivating plant-derived proteases (Hartinger *et al.* 2019) thus stabilizing CP content in SPV silage. It is also reported to increase the utilizable CP at the duodenum, while increasing the rumen undegradable protein fractions (Edmunds *et al.* 2014). Lowered pH and ammonia nitrogen has also been reported as a result of wilting before ensiling (Agarussi *et al.* 2019). However, wilting has also been reported to negatively affect silage quality. It is reported to increase NDF and decrease CP and DM digestibility (Gomes *et al.* 2019).

When wilting SPV, DM losses are likely to occur especially in leaves, affecting quality of the silage (Gomes *et al.* 2019). DM losses of between 9-10% has been reported (Köhler *et al.* 2013).

Additives

Additives are natural or industrial products added into silages to reduce losses or improve stability. Their inclusion is important for improving fermentation and nutrition quality of silages (Liu *et al.* 2020), by enhancing growth of lactic acid bacteria the produces lactic acid. The additives achieve this by being inform of fermentation stimulants or inhibitors, aerobic deterioration inhibitors, nutrients or absorbents in nature (Yitbarek and Tamir 2014). Fermentation stimulants include bacteria culture and carbohydrate sources, fermentation inhibitors include acids and formaldehydes, deterioration inhibitors include lactic acid bacteria and propionic acid, nutrients include urea and ammonia, and absorbents include barley and straw (Henderson 1993).

A by-product of cane processing, molasses, is a widely used additive in silage making (Luo *et al.* 2021). It is a DM of 75% and can be included up to 10% w/w to provide fast fermentable carbohydrates (Yitbarek and Tamir 2014). Molasses is recommended for low DM forages and those with low level of water-soluble carbohydrates but should be used at high concentration of 4-5%, where it is reported to improve silage quality by increasing both lactic acid and protein content (Ni *et al.* 2017).

3.0 MATERIAL AND METHODS

3.1 Effect of harvesting regime on DM yield and nutrient content of sweet potato variety SPK 013, Kenspot 1 and SPK 117.

3.1.1 Study site

The trial was carried out at the Kakamega campus of Kenya Agriculture and Livestock Research Organization (KALRO) (0°17'N, 34° 45'E; annual Rainfall 1971mm; Elevation 1535 m ASL).

3.1.2 Experimental design

A randomized block with a split plot design was used where the three varieties were grown in split plots with each variety replicated three times. The varieties constituted the main plots and days to harvest (75 and 150 days) constituted the subplots.

3.1.3 Plot layout

Plot layout was as shown in Fig 1. The trial area was a single block 17 x 26 m, divided into three rows 3 m wide with 2 m space between each row. Each row featured three plots 3 x 6m with 2 m between plots. Varieties were randomly assigned to three plots each. Subplots (3 x 3 m) for the two harvesting treatments, intermediate (INT) and final (FIN) harvesting of vines were delineated for each of the replicates.

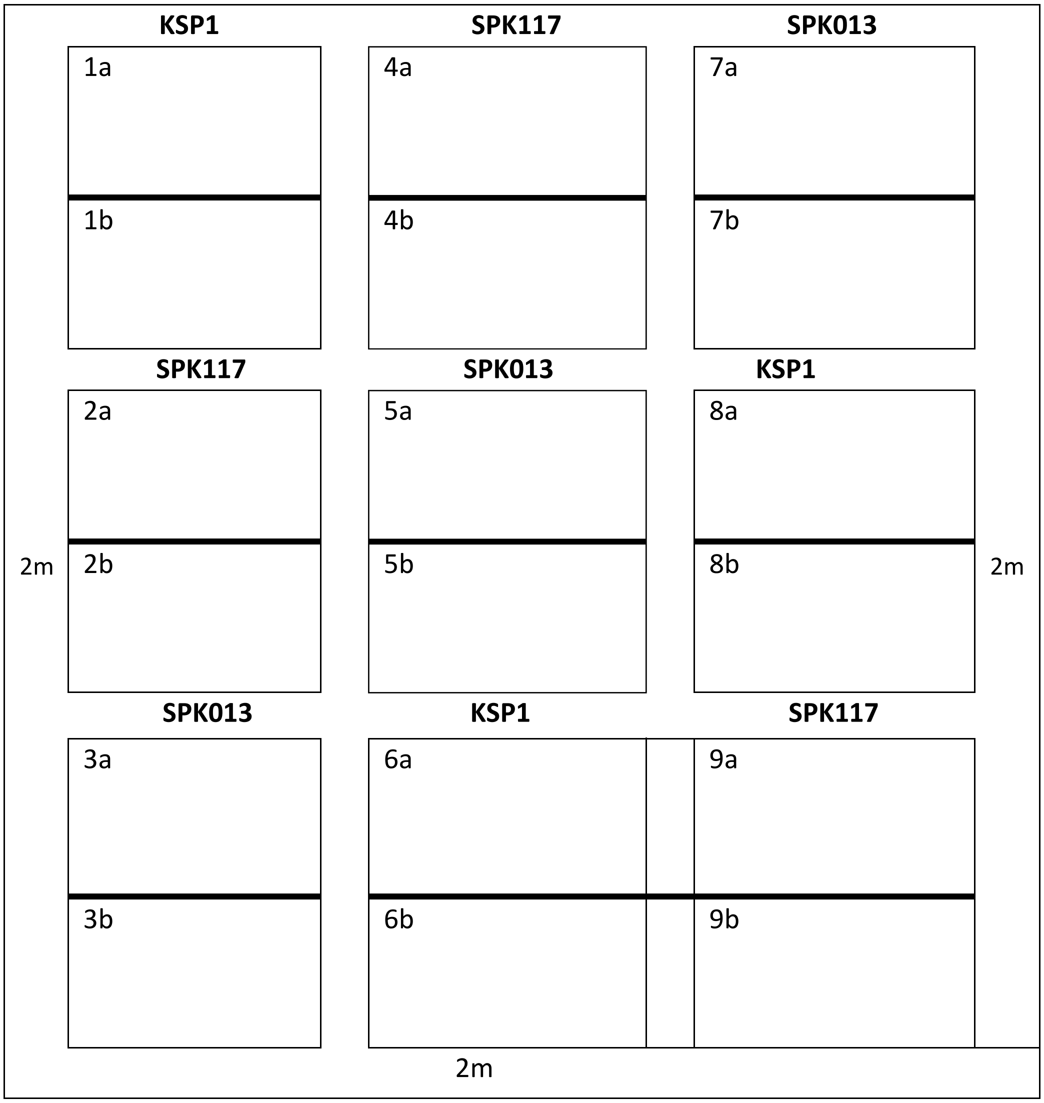

Figure 1. Plot layout

3.1.4 Plot Preparation

Weeds in the experimental plots were cleared and sprayed with a non-selective herbicide (Glyphosate 480 SL) at a rate of 4 liters/ha. They were then ploughed and sprayed a pre-emergence herbicide (Susplo-Emulsifiable SE) one week before planting at a rate of 4 liters/ha to delay emergence of weeds before vines establishment.

3.1.5 Planting

Three dual purpose sweet potato varieties (*Ipomea batatas*; cv.: Kenspot 1, SPK 013, SPK 117) used in this study were chosen due to previous assessment of their suitability for their cultivation by the International Potato Center (CIP) but yield and chemical composition were not part of this earlier, unpublished assessment. Cuttings were sourced from a disease-free breeding farm within the KALRO, Kakamega campus and were planted in the subplots in six rows 0.5 m apart with each row having 15 plants, planted on 30 cm high mounds. Weeds were controlled by hand, two and four weeks after planting.

3.1.6 Harvesting

INT subplots vines were harvested at 75 d post-planting (INT 75 d) using knives ensuring 20 cm of vine was left to regrow. The final harvest was carried out for both INT and FIN treatments at 150days. In this final harvesting, vines were harvested, after which tubers were uprooted.

Total vines yield was recorded during both harvests in each sub-plot. After weighing, the harvested vines were chopped to a length of ~4 cm using a petrol driven chaffcutter and mixed by hand mixing and ~ 200 g sub samples taken from each subplot for dry matter determination and chemical analysis, while the rest were discarded. Tubers were weighed and recorded for each subplot at the 150-d harvest.

3.1.7 Sample preparation

The sub samples from each subplot were frozen at -20^0 C in a deep freezer for further processing. At processing, they were thawed at room temperature, dried at 55^0 C for 72 h, ground through a 1mm screen using a hammer mill (model; MF 10 basic Microfine grinder IKA. Germany) then stored in airtight bottles at -4^0 C for chemical analysis.

3.1.8 Chemical analysis

All samples were analyzed for DM, ash and CP according to the standard analytical procedures (AOAC 1990). NDF and ADF were determined by filter bag technology using ANKOM^{200} fiber analyzer (ANKOM Technology Corp., Fairport, NY), and Ether extract (EE) by method number 1.14R (AFIA 2014).

3.1.9 Statistical analysis

Data on dry matter content, crude protein, ash, ADF and NDF was analyzed using ANOVA of R 3.0.3 statistical program (Team 2013). Differences among means were compared by least-square means method and the level of significance was determined at 0.05.

3.2: Effect of amount of molasses and storage period on the sweet potato vines silage quality for variety SPK 013, Kenspot 1 and SPK 117.

3.2.1 Study site

The experiment was conducted at the Kenya Agriculture and Livestock Research Organization (KALRO) in Kakamega, western Kenya (0°17'N, 34° 45'E, elevation: 1535 m, rainfall: 1971 mm).

3.2.2 Experimental materials

The vines of the three dual purpose sweet potato varieties (*Ipomea batatas*; cv.: Kenspot 1, SPK 013, SPK 117) were obtained from the trial in objective 1. The vines were wilted under the sun for one day and chopped to 20-30 cm length using an engine driven chaff cutter (model J-56 Jawala Singh & Sons, Coraya, Punjab).

3.2.3 Silage preparation

After harvesting vines from the three varieties, they were hand-mixed in equal parts. Three portions of the mixture each weighing 20 Kg were mixed with three amounts of molasses (0, 20 and 40g of molasses/Kg of vines). Each 20 Kg portion of the vines-molasses mixture was then divided into ten, 2 Kg portions. The portions were then compacted by hand in polythene tubes (500 gauge), measuring 12 by 18 cm (Asami Ltd., Nairobi) and sealed. They were labelled and stored in a box and silos opened and sampled in duplicates for 7, 14, 21, 28 and 56 days.

3.2.4 Chemical analysis

pH determination

At each sampling time, the silage bags were opened and samples of 20 and 200 g taken. The 20 g sample was placed into a beaker mixed with 100 ml distilled water and stirred. After 30 minutes storage at room temperature, electrodes of a pH meter were immersed into the solution and the pH readings recorded (AFIA 2014). The 200 g samples were frozen in plastic zip-lock bags at -20^0 C pending analysis. The frozen samples were then thawed at room temperature and dried at 55^0 C for 72 h, ground through a 1mm screen using a hammer mill (model; MF 10 basic Microfine grinder IKA. Germany) and stored in airtight bottles at -4^0 C. Chemical analysis of the samples was determined as elaborated for objective 1.

3.2.5 Statistical analysis

The effect of molasses, storage period and interaction between molasses and storage period on silage quality was evaluated using ANOVA of R 3.0.3 statistical program (Team 2013). Differences between means were compared using least-square means method and the level of significance was determined at 0.05.

3.3 Effect of supplementing lactating dairy cows with sweet potato vine silage on dry matter intake, milk yield and milk composition.

3.3.1 Study site

Kenya Agricultural and Livestock Research Organization (KALRO) at Kakamega research station (0°17'N, 34° 45'E; annual Rainfall 1971 mm; Elevation 1535 m above sea level (ASL)).

3.3.2 Experimental animals and design

The experimental protocol was approved by the Biosafety Animal Use and Ethics Committee, (University of Nairobi) No. FVM BAUEC/2018/161. Friesian cows in mid-late lactation (n = 12; age = 48 – 96 months; live weight = 422 ± 9.4 Kg (mean ± SE); Parity = 2.83 ± 0.24 (mean ± SE)) were selected from a herd at the Kenya Agricultural and Livestock Research Organization (KALRO) at Kakamega research station.

Animals in late lactation were assigned into equal treatment groups, commercial dairy concentrate (CDC) or sweet potato vine silage mixed with wheat bran (SPVSWB) matched for parity and milk production of early lactation stage. The animals had grazed only on unimproved pasture prior to selection, and consequently milk production had been low (4.2 ± 0.1 Kg Day ^{1}). After selection, animals were housed in individual pens in a zero-grazing unit at the KALRO (Kakamega) campus. They were dewormed with anthelminthic (Levamisole Hydrochloride, Norbrook LTD, Nairobi, Kenya), washed with an acaricide (Amitraz 125g, EC, Coopers Ltd, Nairobi, Kenya) and ear tagged as part of standard induction procedures before commencing the trial. The trial was conducted in two distinct tranches: late lactation (LL) commencing about 126 days before estimated parturition and early lactation (EL), commencing 14 days post-partum. Each feeding period was 70 days, which included a 14-day adaption period. Cows in LL were dried off 56 days before expected calving date and during the dry period, animals were fed on *ad libitum* Napier grass (NG) and then placed on a higher plane of nutrition of 4 Kg CDC/cow/d 28 days before calving.

3.3.3 Feeds

Napier grass

Establishment of Napier grass (NG) was done at 14 days intervals for a period of 56 days. This was done in 4 plots of approximately 0.5 ha each to achieve same stage of maturity of NG throughout the trial. Before the onset of the long rains (March 2016), land was ploughed and harrowed. NG planting was done as per recommended spacing of 0.5 m between canes and 1.0 m between rows and fertilizer (di-ammonium phosphate fertilizer, DAP) applied at a rate of 40 Kg/ha of. Harvesting was done daily (after 42 d) followed by manual weeding and top-dressing with 60 Kg/ha of calcium ammonium nitrate (NH_4NO_3 + CaMg $(CO_3)_2$) fertilizer. The NG was then chaffed in a two-roller engine driven chaff cutter (Model J-56 Jawala Singh &sons, Coraya, Punjab), and spread to wilt before feeding.

Sweet Potato silage

Three dual-purpose varieties of sweet potato (*Ipomea batatas*; cv.: Kenspot 1, SPK 013, SPK 117) were each established on 0.65 ha plot. The plot was prepared before the long rains of March 2016. It was ploughed and sprayed with a pre-emergence herbicide (Lumax 537.5 SE, Syngenta, Nairobi Kenya) a week before planting at a rate of 4 L/ha. Planting seeds were obtained from disease-free breeding plots at KALRO and planted at a spacing of 1.0 m between rows and 0.2 m between plants. Weeding was done at 42 days after planting.

Vines silage making was done using a technique developed by the international potato center (CIP) (Lukuyu *et al.* 2012a). The process and equipment used in the silage making has been thoroughly described elsewhere (Goopy and Odongo 2017) but briefly: vines from the three varieties were harvested at 150 days. They were spread under a shade and left to wilt for one day, then chopped separately to 20-30 mm length using an engine driven chaff cutter (model J-56 Jawala Singh & Sons, Coraya, Punjab). The vines from the three varieties were then weighed separately and mixed in equal portions (w/w) by hand on a tarpaulin with 10% w/w fresh chopped NG and 5% w/w wheat bran (WB). The silo was made from1000-gauge silage tube (Asami Ltd., Nairobi) (L: 2.5 m Diam:1.0 m) tied at one end, then folded inside out and held in place by a custom-made, hinged drum (L: 1.2 m Diam:0.86 m). The base of the silage tube held a perforated flexible rubber tube (L:2.3 m Diam:25.0 mm), formed into a circle using a flexible pipe with an attached T-piece. The mixture was manually compacted in layers of about 8 Kg and molasses diluted with water (1:1 v/v) was sprayed onto each layer until the silo was deemed full at approximately 2 m height and the remaining tubing tied tightly to seal the silo and exclude air. The top of the silo was weighted using large stones to promote compaction during fermentation, the compacting drum was removed, and the filled silo anchored. Twenty-three silos were produced for each tranche and the silage was deemed to be ready to feed after 30 d.

3.3.4 Experimental diets, feeding and data collection

A basal diet of chaffed NG was offered at 10% of live weight (LW) (fresh weight basis) in two equal portions, at 08:30 h and at 15:30 h. Water was provided *ad lib*. The treatments were either a commercial dairy concentrate (CDC) offered at 7 Kg/d, or a mixture of SPVS and WB at a ratio of 2:1 w/w (fresh weight basis) fed at 18k g/d. The treatments were offered in equal portions at each feeding. Feed and refusals were weighed and recorded each morning, and the basal diet adjusted weekly to allow for 10% refusals.

Milking was done at 06:00 h and 15:00 h by hands and milk production recorded daily. Feed and refusals were recorded daily, and subsamples taken for the last 28 d of the (56 d) measurement periods, liveweight was recorded weekly using a digital platform weighing scale (model PS 1500 MS. HD, Highland scales limited, Nairobi, Kenya).

Feed and refusals were dried at 55°C for 72 h, ground through a 1mm screen using a hammer mill (model; MF 10 basic Microfine grinder IKA. Germany) and stored in airtight bottles at -4°C. All samples were analyzed according to standard analytical procedures as follows:

True dry matter was determined following drying at 105°C for 24h, ash was determined by combustion in a muffle furnace at 550°C for 8h (AOAC, 1990 Method no. 924.05), Acid Detergent Fibre (ADF) and Neutral Detergent Fibre (NDF) were determined by ANKOM^{200} fiber analyzer (ANKOM Technology Corp., Fairport, NY) (AOAC, 1990 Method no. 930.10), and total N content by micro Kjeldahl (AOAC, 1990 Method no. 988.05) with selenium tablets used as catalyst.

Energy requirement and intake calculations

Energy expenditure and intake for each treatment were calculated by estimating energy requirements for each animal based on mean liveweight, mean liveweight change and milk production in each period. Metabolizable energy (ME) content of the experimental diets (NG, SPVS, WB and CDC) were calculated using equations appropriate to the feed type from the Australian Feed Industry Association - laboratory methods manual (Piltz and Law 2007) as follows.

NG: ME (MJ/Kg DM) = 0.164DMD (%) + EE% -

1.61 SPVS: ME (MJ/Kg DM) = 0.16DOMD (%)

CDC & WB: ME (MJ/Kg DM) = 0.858 + 0.138 DOMD (%) + 0.272 EE (%)

Where: ME is metabolizable energy (MJ/Kg DM), EE is the ether extract (g/k g DM) determined by method number 1.14R (AFIA 2014).

%DMD (dry matter digestibility) = 83.58 – 0.824ADF + 2.626N

%DOMD (dry organic matter digestibility) = 2.11 + 0.961DMD.

Metabolic Energy expenditure was calculated using equations from the Nutrient Requirements of Domestic Ruminants, (CSIRO 2007): as follows

MER_{TOTAL} (MJ/day) = MER_M + $MER_{G/L}$ + MER_L

Where: MER_M is the energy (MJ/day) requirement for maintenance, $MERG_{/L}$ is the energy requirement for live weight change and MER_L is the energy requirement for lactation.

Milk sample collection

The animals were milked in the morning at 06:00 h and in the afternoon at 14:00 h and milk yield/animal/day recorded. Milk sample per animal in each lactation stage was collected into 60 ml sampling bottles and frozen at -20^0 C to be analyzed later.

3.4 Assessment of the economic benefit of feeding sweet potato vines silage as an alternative protein supplement to lactating dairy cows.

3.4.1 Gross margin

The gross margin analysis of feeding the 3 alternative diets was calculated as follows:

GM = [(ML x MP) – (ML x FC)] / ML

Where, GM is gross margin in Kenyan shillings (KES.), ML is milk produced: l/cow/d, MP is market milk price (KES.) and FC is cost of feed per liter of milk produced (KES.)

The cost of feed (FC) for the individual feeds was calculated as follows.

Commercial dairy concentrate (CDC)

The cost of the raw materials used to make the commercial concentrate was calculated (Table 1). After feed formulation, the concentrate was then packed in to 50 Kg bags and then transported to the research station. Packaging and transport costs were then added to the cost of purchasing and milling and the total cost was then divided by the amount of feed produced to get the cost of 1 Kg of CDC.

Wheat bran (WB)

Purchasing cost per kilo of wheat bran was all inclusive of milling, packaging and transport as it was supplied to the research station by a contracted miller.

Napier grass (NG)

The production cost of Napier grass was calculated by summing up the cost of hiring land at the research station, hiring a tractor to plough, cost of di-ammonium phosphate (DAP) fertilizer at 40 Kg/ha for NG planting, labour cost for planting, weeding and harvesting as outlined in Table 1. Chaffing NG was costed by calculating the fuel used by the petrol-driven chaff cutter and the cost of hiring the operator. This was pro-rated over the entire yield of NG. The total cost was then divided by the amount of NG harvested to get the cost of 1 Kg of NG.

Table 1. Unit cost (KES.) of inputs used to calculate cost of production of Napier grass (NG), commercial dairy concentrate (CDC) and sweet potato vine silage plus wheat bran (SPVSWB)

Quantity	Item	Unit	Unit cost (KES)	Total cost (KES)
	Cost of producing sweet potato vines			
1200	Seed stock	seedlings	3	3,600
75	Labor (planting, weeding and harvesting)	Man days	500	37,500
2	Tractor hire	Ha	1,500	3,000
400	Fertilizer	Kg	70	28,000
3	Herbicide	l	1,000	3,000
	Total cost of producing sweet potato vines (A)			75,100
1200	Revenue from harvested tubers (B)	Kg	33	39,600
	Production cost less revenue (A-B)			35,500
	Cost of producing 1 Kg sweet potato vines			**3.0**
	Cost of producing sweet potato vine silage			
450	Sweet potato vine	Kg	3	1,350
2.5	Silage tube	m	200	500
1	Compacting drum		300	300
1	PVC tube	m	120	120
1	Flexible tube	m	80	80
10	Molasses	Kg	30	300
15	Wheat Bran	Kg	17	255
50	Napier	Kg	2	105
3	Chaffing fuel	l	100	300
1	Labor	Man days	500	500
	Total cost of producing sweet potato vine silage			3,810
	Cost of 1 Kg sweet potato vine silage			7.6
	Cost of 1 Kg sweet potato vine silage plus 1Kg wheat bran (SPVSWB)			**24.6**

	Cost of producing Napier grass			
5	Seed stock	t	1,000	5,000
2	Tractor hire	ha	1,500	3,000
80	Planting fertilizer	Kg	70	5,600
100	Chaffing fuel	l	100	10,000
120	Topdressing fertilizer	Kg	40	4,800
110	Labor (planting, weeding, harvesting and chaffing)	Man days	500	55,000
	Total cost of producing Napier grass			83,400
	Cost of 1 Kg Napier grass			**2.1**
	Cost of producing 1-ton dairy concentrate			
320	Maize germ	Kg	22	7,040
300	Wheat bran	Kg	17	5,100
100	Cotton seed cake	Kg	40	4,000
60	Sunflower meal	Kg	30	1,800
200	Wheat pollard	Kg	30	6,000
10	Di-calcium phosphate	Kg	95	950
4	Mineral-vitamin premix	Kg	130	520
6	Limestone	Kg	50	300
980	Milling cost	Kg	10	9,800
1000	Transport cost	Kg	7	7,000
	Total cost of commercial dairy concentrate			42,510
	Cost of 1 Kg commercial dairy concentrate			**43**

Sweet potato vine silage (SPVS)

The cost of vine production was calculated by considering several inputs including cost of hiring land at the research station and hiring a tractor to plough the land as outlined in Table 1. The cost of hiring a tractor was a one-off cost that would cover fueling, servicing the tractor and driver's allowances. The labour cost for planting, weeding and harvesting was calculated by multiplying the number of man-days by the rate of hiring a casual labor in the area (Table 1). Chaffing the vines was costed by calculating the fuel used by the petrol-driven chaff cutter and the cost of hiring the operator. The vines were ensiled using a method and cost outlined in the SPV silage-making manual (Lukuyu *et al.* 2012a). The tubers harvested from the SPV plots were weighed and valued as per the prevailing market price. The cost of producing SPVS was calculated as the cost of producing the vines plus the cost of making silage less the (would be) revenue from the tubers produced. The total cost was then divided by the amount of SPVS produced to get the cost of 1 Kg of SPVS.

3.4.2 Chemical analysis

This was determined as outlined in objective 1.

3.4.3 Analysis of milk

The samples were thawed at room temperature then milk components (milk fat, protein, solid not fat (SNF), lactose, total solids and salts) were analyzed using a lactoscan ultrasound milk analyzer (Lactoscan 11-17-7520, Milkotronic LTD, 8900 Nova Zagora, Bulgaria).

3.4.4 Data analysis

The effect of supplementation with SPVSWB or CDC on milk production, milk components, dry matter intake and weight change variables was analyzed using ANOVA of R 3.0.3 statistical program (Team 2013). Differences among means were compared by least-square means method and the level of significance was determined at 0.05.

4.0 RESULTS

4.1 Vine yield dry matter

The effect of variety and harvesting regime on vines dry matter (DM) yields is shown in Table 2. For both harvesting regimes, variety SPK 013 yielded more foliage (t DM/ha) compared to Kenspot I and SPK 117. At 75d harvest, SPK013 had significantly ($P<0.05$) higher DM yield (3.1 t DM/ha) but not significantly different from Kenspot 1 (2.6 t DM/ha), while SPK117 had the lowest (1.3 t DM/ha). The vines DM yield of INT at 150 days after establishment was significantly different between varieties ($P<0.05$). The varieties SPK013 and SPK117 were significantly higher than Kenspot1. SPK013 had the highest DM yield (4.2 t DM/ha) while Kenspot1 had the lowest (1.0 t DM/ha).

Table 2: Effect of variety and harvesting regime on vines dry matter yield (t DM/ha) of three varieties of sweet potato vines.

	Variety				
Days to Harvest	Kenspot 1	SPK 013	SPK 117	sem	P-value
INT at 75 d	2.6^{ab}	3.1^{a}	1.3^{b}	0.32	0.002
INT at 150 d	1.0^{b}	4.2^{a}	3.7^{a}	0.54	<0.001
INT total (INT at 75d + INT at 150 d)	3.6^{b}	7.3^{a}	5.0^{ab}	0.67	<0.001
FIN at 150 d	2.3^{d}	5.6^{a}	4.2^{c}	0.59	<0.001
sem	0.30	0.76	0.25		
P-value	0.001				

INT at 75: harvested at 75d, INT at 150: harvested at 150d, FIN at 150: harvested only at 150d after planting

^{abc}Means within the same row and column with different superscript are significantly different at $P<0.05$

Results in Table 2 shows that SPK 013 had the highest vine DM yield (7.3 and 5.6t DM/ha), as compared to Kenspot 1 (3.6 and 2.3 t DM/ha) and SPK117 (5.0 and 4.2t DM/ha) for both for INT and FIN respectively. The vines DM yields of INT total were significantly different between varieties Kenspot 1 and SPK013 but not between SPK117 and either Kenspot 1or SPK013. There was significant difference in vine yield for FIN between SPK013 and Kenspot 1, and SPK117. Vine DM yield was significantly higher for INT total (3.6 and 5.0t DM/ha) as compared to FIN (2.3 and 4.2t DM/ha) for Kenspot 1 and SPK117 respectively.

4.2 Tuber yield dry matter

Table 3 shows effect of variety and harvesting regime on roots DM yield. For both INT and FIN, there was significant difference of tuber yield between SPK013 and both Kenspot 1 and SPK117, but there was no significant difference between Kenspot 1 and SPK117. Partial harvesting at 75d significantly reduced the root biomass yield for SPK013. Kenspot 1 and SPK117 also showed reduction in tuber dry matter yield, but the differences were not significant. SPK 013 had the lowest root DM yield (0.8 t DM/ha) for INT but the highest (2.0 t DM/ha) for FIN. INT had reduced tuber DM yield by 11, 60 and 16% for Kenspot 1, SPK 013 and SPK 117 respectively when compared to the respective FIN plots.

Table 3: Effect of variety and harvesting regime on tuber dry matter yield (t DM/ha) of three varieties of sweet potato.

	Variety				
Days to Harvest	Kenspot 1	SPK 013	SPK 117	sem	P-value
INT	1.6^{a}	0.8^{b}	1.6^{a}	0.16	<0.001
FIN	1.8^{ad}	2.0^{c}	1.9^{ad}	0.19	<0.001
sem	0.09	0.26	0.24		
P-value	<0.001				

INT; Vines harvested at 75days and 150 days. FIN: Vines harvested at 150 days.
^{abc}Means within the same row and column with different superscript are significantly different at P<0.05

4.3 Effect harvesting regime on chemical composition

The effect of harvesting regime on the DM, CP, NDF and ADF content of vines is shown in Table 4. There were significant differences between varieties for both INT and FIN in DM, CP, and NDF. For ash content, significant differences were between Kenspot 1 and SPK013 (FIN) and between SPK013 and SPK117 (FIN). However, ADF did not show significant differences between the varieties in both INT and FIN. The harvesting regime had a significant effect on dry matter content where FIN resulted in higher DM as compared to INT for all the three varieties. There was a significant difference in DM content between the varieties where Kenspot 1 recorded the highest DM content (21.7% and 23.9%). The same trend was observed for ADF, NDF and ash where the contents were significantly higher for FIN as compared to INT.

The CP content of the vines ranged from 19.2 to 27.2% and was significantly different between the two harvesting regimes for all the three varieties where FIN had lower CP values (P<0.05) as compared to INT for all varieties. The CP content was also significantly different between the varieties, with SPK 013 having the highest content for both harvesting regimes.

Table 4: Effect of variety and harvest regime on chemical composition of vines from three varieties of sweet potato.

	Kenspot1		SPK013		SPK117			
Component	INT	FIN	INT	FIN	INT	FIN	sem	p-value
DM	21.7^{b}	23.9^{a}	19.0^{c}	20.7^{b}	16.8^{d}	20.9^{b}	0.14	<0.001
CP	25.0^{b}	19.2^{e}	27.2^{a}	22.1^{c}	26.6^{b}	20.1^{d}	0.06	
ADF	24.7^{a}	32.3^{b}	23.6^{a}	33.3^{b}	23.0^{a}	37.2^{b}	0.19	
NDF	35.8^{a}	33.1^{c}	36.7^{a}	35.4^{ab}	33.9^{bc}	35.1^{ab}	0.33	
ASH	9.2^{c}	10.3^{bc}	10.5^{bc}	12.8^{a}	9.2^{c}	11.2^{b}	0.12	

^{abc}Means within the same row with different superscript are significantly different at P<0.05 INT-harvested at 75 and 150 days after planting; FIN- harvested once at 150 days after planting

4.4 Effect of amount of molasses and storage period on silage pH

The effect of storage time and amount of molasses on the pH of the sweet potato vines silage is shown in Table 5.

Mean pH value was significantly higher for silage with 0% molasses (4.56) as compared to silage with 2 and 4% molasses (4.08 and 4.04 respectively). Storage period influenced pH where there was decline in pH from the first sampling period of 7 d (4.27) to 21 d (3.99) where the pH stabilized from 28 d to 56 d. However, there was no interaction between storage period and amount of molasses.

Table 5. Effect of ensiling sweet potato vines with different amounts of molasses and different storage periods on pH.

	Amount of molasses					
Storage period (d)	0%	2%	4%	**mean**	sem	p-value
7	4.6	4.1	4.1	**4.27^{a}**	0.118	<0.001
14	4.2	3.9	4.0	**4.04^{b}**	0.094	
21	4.3	3.8	3.9	**3.99^{b}**	0.098	
28	4.8	4.4	4.1	**4.05^{b}**	0.134	
56	4.9	4.2	4.1	**4.07^{b}**	0.165	
Mean	**4.56^{a}**	**4.08^{b}**	**4.04^{b}**			
sem	0.098	0.069	0.033			
p-value	<0.001					

^{abc}*Means within the same row and column with different superscript are significantly different at P<0.05*

4.5 Effect of amount of molasses and storage period on crude protein

The effect of amount of molasses and storage time on CP content of the SPV silage is shown in Table 6. There was no significant (*P<0.05*) interaction effect between ensilage time and molasses amount on CP content. The CP content at 0% molasses silage treatment was significantly lower (16.25) compared with the 2% molasses having the highest CP content (18.25) with 4% being intermediate (17.03%). The CP content at 7 d storage period was the highest (19.54) and was significantly different from that at 21, 28, and 56 d but not to 14 d storage periods. The CP content at 56 d storage was significantly lower (15.62) than all other storage periods.

Table 6. Effect of ensiling sweet potato vines with different amounts of molasses and different storage periods on crude protein content (%DM).

	Amount of molasses					
Storage period (d)	0%	2%	4%	**mean**	sem	p-value
7	19.94	19.92	18.75	**19.54^{a}**	0.460	<0.001
14	19.18	18.45	17.92	**18.52^{a}**	0.806	
21	18.65	17.79	17.22	**17.89^{b}**	0.797	
28	16.47	17.71	15.68	**16.62^{b}**	0.580	
56	13.92	17.38	15.57	**15.62^{c}**	0.731	
Mean	**16.25^{b}**	**18.25^{a}**	**17.03^{c}**			
sem	0.432	0.311	0.418			
p-value	<0.001					

^{abc}Means within the same row and column with different superscript are significantly different at P<0.05

4.6 Effect of amount of molasses amount and storage period on NDF, ADF and ash

The effect of amount of molasses and storage time on NDF, ADF and ash content of the SPV silage is shown in Table 7. The NDF content was significantly higher (32.83) for 0% molasses treatment as compared to 2 and 4% (30.6 and 27.7 respectively). The same was observed for ADF where it was significantly higher for 0% (31.62) molasses as compared to 2 and 4% (30.04 and 28.53 respectively). However, there was no significant difference in ADF content between 0 and 2% molasses inclusion amount.

There was significant difference in ash content between the three amounts of molasses. 4% molasses had the highest ash content (10.06) compared to 2% (9.46) and 0% (8.98). The ash content increased as the silage storage period progressed and was lowest at day 7 (8%).

For all the three parameters however, there was no interaction between storage time and amount of molasses.

Table 7. Effect of ensiling sweet potato vines with different amounts of molasses and different storage periods on neutral detergent fiber (NDF), acid detergent fiber (ADF) and ash content.

	Storage period (d)	Amount of molasses 0%	2%	4%	mean	sem	p-value
NDF (%DM)	7	36.70	36.39	32.84	**35.31[a]**	1.432	<0.001
	14	33.53	30.42	29.80	**31.25[b]**	1.619	
	21	32.15	29.17	26.47	**29.26[c]**	1.545	
	28	31.28	30.43	25.09	**28.93[c]**	0.844	
	56	30.49	26.53	24.5	**27.17[d]**	1.456	
	mean	**32.83[a]**	**30.6[b]**	**27.7[c]**			
	sem	1.497	1.749	1.379			
	p-value	<0.001					
ADF (%DM)	7	33.01	31.25	30.01	**31.09[a]**	1.470	<0.001
	14	32.25	30.05	29.80	**30.10[b]**	0.893	
	21	32.05	30.42	29.00	**30.09[b]**	0.756	
	28	31.64	29.93	26.47	**29.01[c]**	1.171	
	56	29.15	28.53	27.35	**28.30[d]**	0.894	
	mean	**31.62[a]**	**30.04[a]**	**28.53[b]**			
	sem	1.308	1.349	0.828			
	p-value	<0.001					
ASH (%DM)	7	6.25	8.37	9.40	**8.00[c]**	0.594	<0.001
	14	7.91	9.44	10.38	**9.24[b]**	0.457	
	21	9.61	9.28	9.38	**9.42[b]**	0.116	
	28	10.30	9.88	10.31	**10.16[a]**	0.159	
	56	10.83	10.32	10.85	**10.67[a]**	0.151	
	mean	**8.98[b]**	**9.46[c]**	**10.06[a]**			
	sem	0.564	0.237	0.204			
	p-value	<0.001					

[abc]Means within the same row and column with different superscript are significantly different at P<0.05

4.7 Chemical composition of the basal diet and refusals

The chemical composition of the basal diet for the two treatments are shown in Table 8.

There were no differences in DM (P=0.47), Ash (P=0.48) or NDF (P=0.37) content between the offered Napier basal diet and refusals for either of the 2 treatments. There was a trend towards a lower CP (P=0.09) and higher ADF (P=0.10) in the refusals.

Table 8. Composition (g/Kg DM) of the Napier Grass (NG) basal diet and its refusals from Friesian cows supplemented with either Commercial Dairy Concentrate (CDC) or Sweet Potato Vine plus Wheat Bran (SPVSWB)

	NG as fed	NG refusals CDC	NG refusals SPVSWB	sem	P-Value
DM (g/Kg)	213.9[a]	281.6[a]	283.9[a]	13.44	0.47
CP	79.1[a]	69.6[a]	70.7[a]	3.04	0.09
NDF	615.7[a]	622.3[a]	631.6[a]	7.82	0.37
ADF	414.5 [a]	432.9 [a]	431.7 [a]	6.45	0.10
Ash	105.2[a]	94.3[a]	100.8[a]	6.25	0.48

CDC: commercial dairy concentrate; SPVSWB: sweet potato vines silage plus wheat bran
[abc] Means within the same row with different superscript are significantly different at $P<0.05$

4.8 Chemical composition of the treatment diets

The DM, Ash, CP, NDF and ADF content of the different diets and diet ingredients are shown in Table 9. The SPVSWB was lower by almost half the DM content of CDC, with NDF and ADF almost twice on a DM basis. They were however similar in CP and ME content (Table 9).

Table 9. Composition (g/Kg DM) of Commercial Dairy Concentrate (CDC), Sweet Potato Vine Silage (SPVS), Wheat Bran (WB) and Sweet Potato Vine Silage plus Wheat Bran (SPVSWB).

	CDC	SPVS	WB	SPVSWB
DM (g/Kg)	868.2	240.2	870.0	450.1
Ash (g/Kg)	69.4	112.0	56.1	93.4
CP (g/Kg)	153.6	171.0	124.4	137.3
NDF (g/Kg)	227.9	427.0	352.0	402.0
ADF (g/Kg)	119.0	294.0	226.3	271.4
ME (MJ/Kg DM)	12.5	9.7	11.8	11.1

CDC: commercial dairy concentrate; SPVSWB: sweet potato vines silage plus wheat bran

4.9 Effect of supplementation on milk yield, live weight change and feed intake

The effect of supplementing lactating cows with either commercial concentrate or sweet potato vine silage is shown in Table 10. There were no differences in live weight (LW) ($P = 0.41$) or parity ($P = 0.18$) between animals fed on sweet potato vine silage plus wheat bran (SPVSWB) and commercial dairy concentrate (CDC). However, there were significant differences in daily milk yield (DMY) between treatments (CDC and SPVSWB) and between treatment periods (early and late lactation).

Table 10. Milk yield (DMY) (Kg/d), live weight change (LW) (Kg), dry matter (DMI), crude protein (CPI), neutral detergent fibre intake (NDFI) of dairy cows fed various diets

	Late lactation		Early lactation			
	CDC	SPVSWB	CDC	SPVSWB	sem	P- value
DMY (Kg/d)	7.50^{a}	6.18^{b}	16.04^{c}	14.16^{d}	0.160	<0.001
LW Δ (Kg)	3.14^{a}	3.30^{a}	0.38^{ab}	-1.42^{b}	0.702	<0.001
DMI (Kg)	13.53^{a}	11.34^{a}	12.97^{a}	11.07^{b}	0.390	0.003
CPI (Kg)	1.53^{a}	1.45^{ab}	1.48^{ab}	1.35^{b}	0.032	0.010
NDFI (Kg)	5.97^{ab}	6.40^{a}	5.62^{ab}	5.01^{b}	0.249	0.002

CDC: commercial dairy concentrate; SPVSWB: sweet potato vines silage plus wheat bran
^{abc}Means within the same row with different superscript are significantly different at $P<0.05$

Daily milk yield (DMY) was significantly lower in late lactation (LL) than in early lactation (EL) for the two treatment groups (7.5 vs 16.04 for CDC and 6.18 vs 14.16 for SPVSWB in late and early lactation respectively). Comparison between treatments also showed that DMY was higher for CDC than for SPVSWB for both periods, (Table 8), and there was no interaction effect between treatment and the stage of lactation (P = 0.75). Live weight change for SPVSWB in early lactation was different from other treatment groups in late lactation but similar to CDC in early lactation, but dry matter intake (DMI) was lower for SPVSWB than CDC in both late and early lactation.

4.10 Energy balance

The ME intake estimated ME expenditure and ME balance for the experimental cows is shown in Table 11. Calculated energy intake and expenditure for all treatment groups indicated that both groups of cows were in a significant positive energy balance in late lactation, and that this surplus was similar for both diets which is consistent with the observed weight gains for both groups during the same period. Similarly, both CDC and SPVSWB were in slightly negative energy balance during early lactation, mediated by reduced energy intake and greatly increased DMY (Table 11). The liveweight change results in Table 11 showed marginal weight gain for CDC and weight loss for SPVSWB diet during the early lactation period.

Table 11. Mean metabolizable intake (MJ/d) and metabolizable energy requirement (MJ/d) for maintenance, weight change and lactation of dairy cows.

	Late lactation		Early lactation			p-value
Item	CDC	SPVSWB	CDC	SPVSWB	sem	
ME intake (MJ/d)	**131.3 [a]**	**123.3 [a]**	**127.1[a]**	**109.8 [b]**	**3.05**	**<0.001**
ME expenditure MJ/d)						
Maintenance	43.6	43.2	42.0	40.2		
Lactation	40.4	32.2	86.2	76.3		
LW *Δ*	18.2	17.7	2.9	-1.6		
TOTAL	**102.2** [a]	**94.1** [a]	**131.1** [b]	**115.4** [ab]	**4.48**	**0.002**
ME balance (MJ/d)	*29.1 [a]*	*29.2 [a]*	*-4.0 [b]*	*-5.7 [b]*	*1.43*	*<0.001*

CDC: commercial dairy concentrate, SPVSWB: sweet potato vine silage with wheat bran. [abc]Means within the same row with different superscript are significantly different at P<0.05

4.11 Gross margins of milk

The gross margin analysis of milk production using the 2 types of supplements during early and late lactation is shown in Table 12. The cost of the dietary supplement was significantly (p<0.01) higher for CDC as compared to SPVSWB. However, gross margin of supplement per Kg of milk produced was significantly (P<0.01) higher in SPVSWB (Ksh. 3.8 and 28.2) than CDC (Ksh. -4.8 and 21.9) for late and early lactation respectively.

Table 12. Gross margins (Ksh.) of milk produced by lactating cows in early and late lactation.

	Late lactation		Early lactation			
	CDC	SPVSWB	CDC	SPVSWB	sem	P-value
Milk yield (Kg)	7.5^a	6.2^b	16.0^c	14.0^d	0.16	<0.002
Feed cost/L (Ksh.)	49.8^a	41.2^b	23.1^c	16.8^d	0.51	<0.001
Gross margin/L (Ksh.)	-4.8^a	3.8^b	21.9^c	28.2^d	0.57	<0.001

CDC: commercial dairy concentrate, SPVSWB: sweet potato vine silage with wheat bran
^{abc}*Means within the same row with different superscript are significantly different at P<0.05*

4.12 Milk composition

The fat, SNF, lactose, protein and TS content of milk from the experimental cows is shown in Table 13.

Table 13. Milk composition (%) of cows supplemented with fixed level of either Commercial Dairy Concentrate (CDC) or Sweet Potato Vine plus Wheat Bran (SPVSWB)

	Late lactation		Early lactation			
Milk component (%)	CDC	SPVSWB	CDC	SPVSWB	sem	p-value
Fat	4.1^a	3.8^a	3.4^b	3.2^b	0.24	0.02
SNF	8.3	7.4	8.5	7.7	0.42	0.35
Lactose	4.6	4.1	4.7	4.3	0.28	0.35
Salts	0.7	0.6	0.7	0.6	0.04	0.38
Protein	3.0	2.7	3.1	2.8	0.18	0.34
Total solids	12.1	11.5	11.9	10.9	0.56	0.57

^{abc}*Means within the same row with different superscript are significantly different at P<0.05*

Butter fat content was not significantly different (p>0.05) between the treatments within the same lactation periods. However, for each treatment, the fat increased significantly (p<0.05) from early to late lactation. All other milk components did not show any significant difference between treatment groups within or between the two lactation stages. However, there were trends towards lower levels of milk components in SPVSWB as compared to CDC in both LL and EL. For instance, protein was lower for SPVSWB (2.7%) as compared to CDC (3.0%) in late lactation. The same trend was observed in early lactation where the protein content was 2.8% and 3.1% for SPVSWB and CDC respectively.

5.0 DISCUSSION

5.1 Effect of harvesting regime on dry matter yield and nutrient content of dual-purpose sweet potato varieties.

There were variety differences in vine production for INT (3.6, 7.3 and 5.0 t DM/ha for Kenspot 1, SPK013 and SPK117 respectively) and FIN (2.3, 5.6 and 4.2 t DM/ha for Kenspot 1, SPK013 and SPK117 respectively) (Table 2). These results were within the range of reported vine DM yields in earlier studies; 1.4-8.3 t/ha (Pedrosa *et al.* 2015) at 230 days after planting, 3.7-7.4 t/ha (Viana *et al.* 2011) at 180 days after planting; and 4.2-7.9 t/ha (Dornas 2012) at 150 days after planting. However, the current results were higher than 3.05-4.95 t/ha (Andrade Júnior *et al.* 2012) at 163 days after planting. This difference between the varieties implied that the accumulation of dry matter varied between varieties at different growth stages (Miron *et al.* 2006). Vine DM yield of vines harvested at 230 days was within the range of yield at 150 days suggesting that beyond 150 days, the vine dry mass accumulation slowed down probably due to loss of leaves (Pedrosa *et al.* 2015).

The vine dry matter production for INT at 75 and INT at 150 days after planting were both lower than yield of FIN for all varieties except Kenspot 1. (Table 2). This was consistent with Ahmed *et al.* (2012) who reported that harvesting vines at 105 days yielded 15 and 12% more than harvesting at 45 and 75 days after planting respectively. However, the cumulative harvesting (INT total) yields were higher than single harvest (FIN) for all the varieties by 60, 16 and 11% for SPK013, SPK117 and Kenspot 1 respectively.

The increase in vine dry matter (DM) yield for FIN (Table 2) as compared to individual harvests for INT (75 and 150 d) was probably due to the vines being left to grow continuously over a longer time thus accumulating more DM. This gave the vines sufficient time for leaf growth thus enhancing photo-assimilation leading to stemming (Ahmed *et al.* 2012). For INT, the vines were not allowed enough time to recover between the 75 d harvest and the final harvest at 150 d as suggested by (Olorunnisomo 2007). As the plant progresses with age, moisture content reduces while the cell content increases leading to increase in DM content (Marković *et al.* 2012). It could also be due to reduced vine length and a smaller number of leaves per plant, because, removal of a photo-synthetically active portion of sweet potato as early as 4 weeks after planting had a suppressing effect on the vine length (109.5 cm/ plant) as compared to zero pruning (218.5 cm/ plant) (Aniekwe 2014). However, in other cases, dry matter yield has been reported to decrease with longer harvesting intervals. Miron *et al.* (2006) reported that this was probably due to depletion of water-soluble carbohydrates especially for plants under water stress. But because water was not a limiting factor in the current study, dry matter accumulation continued until 150 days after planting.

The cumulative vine DM yield for INT from the two harvests (75 and 150 d) was higher by 57, 13 and 19% for Kenspot 1, SPK013 and SPK117 respectively compared with the single harvest (150 d) in FIN plots (Table 2). This was comparable to 20-49% increase in fresh vine production reported by Gomes and Carr, (2001) when harvesting frequency increased from one to four times a season. This could be because, as age progresses, biomass production reaches an optimum point beyond which it decreases part (Frankow-Lindberg and Lindberg 2003). Part of this decline is due to photosynthates being redirected to production of tuber at the expense of vines. In an experiment on harvesting intervals, harvesting vines at short intervals of 20 d resulted to 36% higher vine DM yield as compared to a single harvest at 120 d (An 2004). This was because at 120 d, many leaves were senescent and some of them had dried off. However, these results were in contrast to those reported by Kiozya *et al*. (2001), that there was improved vine yield with longer cutting interval. Delayed harvesting of vines resulted to higher vine yields, probably due to partitioning of the accumulated carbohydrates towards regeneration of new leaves (Ahmed *et al.* 2012).

Tuber dry matter yield ranged between 0.8 and 1.6 t DM/ ha for INT and 1.8 to 2.0 t DM/ha for FIN (Table 3). This was 11, 16 and 60% reduction of tuber DM yield for Kenspot 1, SPK117 and SPK 013 respectively, for INT compared to FIN. The yields for Kenspot 1 and SPK117 were comparable to Ahmed *et al.* (2012) who reported that harvesting vines at 45 and 75 d after planting decreased tuber root yields by 10 and 7% respectively, compared to those whose vines were not partially harvested. They were also within the range reported by An *et al*. (2003) that, removal of up to 50% of the vines at 30 days reduced tuber production by about 20% while greater proportion of defoliation reduced tuber yield by up to 50%. In the same study, it was shown that the effect of partial harvesting was higher on tuber than leaf yield. The higher reduction in SPK013 was comparable to a study in Nigeria, where root yield was found to decrease by 31-48% by removing the vine tips, while removing the whole vines led to root yield decrease of 54-62% (Dahniya *et al.* 1985). The same study reported that frequency of vine harvesting influenced roots production by reducing the marketable root yield by 58% (from 18.8 to 7.9t DM/ha). Aniekwe, (2014) also reported a reduced weight (3.73 Kg) of root tuber per plant when the vines were pruned as compared to 5.06 Kg with no pruning.

Variety SPK013 tuber yield was 2.0 t DM/ha compared to 1.8 and 1.9 for Kenspot 1 and SPK 117 (Table 3). This was comparable to 2.9 t DM/ha and 3.0t DM/ha reported by Mwololo *et al.* (2012) for varieties 440015 and K135 respectively. However, it was lower than 5.4 and 4.3 t DM/ha reported by for varieties SPK013 and SPK004 respectively (Mcharo and Ndolo 2013). The higher tuber yield of SPK013 in this study could be attributed to the genetic makeup of the plant (Mwololo *et al.* 2012), which could lead to localization of genes responsible for increase in number and weight of tubers (Esan and Omilani 2018). However, despite having the highest tuber production for FIN (2.0 t DM/ha) as compared to 1.9 and 1.8 t DM/ha for SPK117 and Kenspot 1 respectively, SPK013 production for INT was 50% (0.8 t DM/ha) of that of Kenspot 1 and SPK 117 (1.6 t DM/ha each). This resulted to the highest tuber reduction (60%) after partial harvesting (INT) as compared to 16 and 11% reduction for SPK117 and Kenspot 1 respectively. This was consistent with earlier findings that the highest yielding varieties are the most susceptible to stress caused by water shortage, disease and defoliation (Gibson and Aritua 2002). This could explain why most farmers continue to grow local varieties that are less susceptible to stressful conditions. However, this can be an objective for sweet potato breeding programs, to develop varieties that are both high tuber yielding and tolerant to vine defoliation.

The lower tuber production for INT could be attributed to the partial harvesting at 75 d, which reduced the leaf surface area, thus lowering the photosynthetic activity in the plant. This affected tuber growth as 90% of the tuber weight is reported to be contributed by the photosynthetic outputs (Paradiso *et al.* 2019). Root tuber weight change is as a result accumulation of photosynthesis products, leading to increase in cell number, size and thus weight (Placide *et al.* 2015). The photosynthesis process takes place in the leaves and therefore apical shoot harvest of the vines has been reported to reduce tuberous root yield significantly (Mark and Korpu 2020). Tuber initiation in most varieties is reported to occur between 14 and 56 days after planting and any kind of vine removal 70 days after planting affects tuber development (Olorunnisomo 2007). However, in contrast Ahn (1993) reported that root tuber initiation occurs between 50- 60 days after planting and any pruning done after this time may not have serious effects on the root yield.

In the current study, it is possible that dry matter accumulation was redirected to leaf regeneration when the vines were cut at 75 days, at the expense of the roots. After cutting the vines, the three varieties could have channeled most of their photosynthetic products into the shoots for vine regeneration (Kathabwalika *et al.* 2013). It is for this reason that the decision on whether and when to do partial harvesting, should be influenced more by the need for tuber production. In an ideal situation, sweet potato vines should not be removed until the tubers are harvested for the best tuber yields. However, in most of the smallholder farms, partial harvesting is necessitated by animal fodder shortages (Kabirizi *et al.*) and has to be done for the sake of fodder for animals. Under these circumstances, it is suggested that the vines should be harvested when the plant has completed about 60% of its growth phase in order to increase herbage for animal feed without compromising tubers yield (Ahmed *et al.* 2012). In an earlier study, the partial harvesting was suggested not to be later than 28 days after planting (Nwinyi 1992) but in a more recent study, partial harvesting for dual purpose sweet potato can be done as late as 84 days after planting (Aniekwe 2014). In several studies, it was shown that vine yield was little affected by partial harvesting, and therefore, effect on tuber should be the main factor to consider when harvesting SPV for animal fodder (Dahyniya, 1981; Nguyen and Bautista, 1999). Roy and Ravi (1990) in India reported that during the rainy season, defoliation of 15cm vines at 2 months after planting, had no effect on the root yield. The study argued that increased tuber yield is not always associated with high vine production. The same study further concluded that if vines are not pruned, they grow vigorously producing large quantity of leaves at the expense of tubers. This means therefore that; it is necessary to harvest the top part of the vines for animal fodder.

From the results on vine and tuber yield (Table 2 and 4), variety SPK117 and Kenspot 1 had a better balance between vine production for fodder through partial harvesting and tuber production for human consumption. This is because when partially defoliated, SPK117 and Kenspot 1 lost 16 and 11% of tuber production as compared to 60% lost by SPK013. For INT, SPK 117 produced

38.9% more in total vine production compared to Kenspot 1. It is for this reason that we recommend variety SPK117 if animal fodder shortages necessitate partial harvesting.

Results in Table 4 indicated that defoliation influenced quality properties of vines in all the three varieties studied. Dry matter (DM) of vines varied among the varieties from 16.8-21.7% for INT and 20.7-23.9% for FIN (Table 4). This was within the ranges (17.3% and 17.4-24.4%) reported by Weldegeriel, (2007) and Pedrosa *et al*. (2015) respectively. However, this was below the range of 24.7% recommended for silage making (Atis *et al.* 2012) necessitating the vines to be wilted prior to silage making.

DM was significantly higher for FIN ranging from 20.7-23.9% than INT which ranged from 16.8-19.7% across all the three varieties (Table 4). Dry matter accumulation in vines is one of the most important measure of adaptability to stress conditions, in this case vine defoliation. In the current study variety Kenspot 1 had the highest DM even after partial harvesting (21.7%), as compared to SPK 013 (19.0%) and SPK 117 (16.8%). This could have indicated that Kenspot 1 was more resilient to defoliation than the other varieties. At 150 days after planting (FIN), Kenspot 1 still recorded the highest DM content of 23.9% as compared to 20.7 and 20.9% for SPK013 and SPK017 respectively. This could mean that the variety had wide adaptability or specific adaptability for the region of study, which gave it a better genotype by environment interaction (Abidin *et al.* 2005).

DM is very critical as it affects voluntary feed intake in forages and it varies due to various factors, among them variety, climate and soil types (Manrique and Hermann 2002). When below 20% in forages, it is reported to lead to increased water content in the rumen, limiting feed intake (Zereu *et al.* 2014). This is very critical especially for vines used for ensiling as low DM would require wilting or additives. However, the low DM could be an advantage in some situations, for instance, a study on goats showed that low DM levels in sweet potato vines could reduce water requirements in area with severe water shortages (Zereu *et al.* 2014).

The crude protein (CP) content of the different SPV varieties (Table 4) harvested at different times ranged from 19.2 to 27.2% and were within values reported in several studies. Variety AB95002 harvested at 60 days after planting had CP content of 29.8% (Frankow-Lindberg and Lindberg 2003) while Kenspot 1 and 2 had 23.7 and 19.2% CP respectively, both varieties harvested at 120 days (Kenana 2016). This level of CP implies that the three varieties could be potential high protein forages which could be used to supplement low quality forages fed to livestock. The differences in CP content among the varieties could be attributed to the genetic differences between the varieties, or variations that sweet potato varieties exhibit in the leaf to stem ratio (Frankow-Lindberg and Lindberg 2003), (although this was not part of the results reported) in this study. It could also be due to differences in leaf cell wall contents and stem botanical fractions (Larbi *et al.* 2007b).

The average vine CP content for the different vine harvesting regimes showed significant differences for INT and FIN. As shown in Table 6, CP for FIN was lower by 23.2, 18.8, and 24.4% compared to INT for varieties Kenspot 1, SPK013 and SPK117 respectively. This agreed with Olorunnisomo (2007) that harvesting vines at 150 days after planting yielded lower CP content (20.1%) as compared to 26.7% for those harvested at 28 days after planting. In a similar study, An *et al.* (2003) reported reduced CP content in vines harvested 120 days (25.5%) after planting, compared to 29.8% for those harvested earlier at 60 days. This was reported to be as a result of leaf senescence and other leaves dropping off as the vines progressed in maturity (Larbi *et al.* 2007a). The difference in CP content between the two harvesting regimes could also be due to the fact that, crude protein of sweet potato vines decreases when cutting intervals are long as reported in earlier studies (Olorunnisomo 2007). This could be because frequent vine harvesting results to younger vines which are high in CP. A different study suggested that there could be dry matter redirection towards protein accumulation when vines were cut frequently, but when the vines were left to uncut, fibre accumulated, at the expense of fiber content (Issa 2015). Another possible explanation for the higher CP for INT as compared to FIN could be because dry matter accumulation occurs in the first few weeks of growth (Yeng *et al.* 2012). As the vines age, there is reduced nutrient uptake and, in some cases, further growth resulted in even more nutrient reduction (Kathabwalika *et al.* 2013).

The NDF content ranged between 33.1 to 36.7 across all the three varieties which was lower compared to other studies (Table 4). For instance, Olorunnisomo, (2007) reported NDF content of 44.5, 46, 48 and 49 g/Kg for vines harvested 4, 6, 8 and 10 weeks after harvesting respectively. Pedrosa *et al*. (2015) reported NDF level of 46.6 g/Kg from fifteen cultivars of sweet potato vines that were harvested after 230 days. The difference could have been due to differences in the harvesting time, where more mature vines tend to have higher cell wall content, and varietal differences where some varieties have higher leaf to stem ratio (Larbi *et al.*, 2007b). The NDF content reported in this study was below the maximum recommended level by Van Soest (1994), of 60% beyond which there would be a significant reduction voluntary feed intake by animals.

The NDF content for FIN was higher (36.7, 35.8 and 35.1%) as compared to INT (33.1, 33.9 and 35.4) for Kenspot1, SPK013 and SPK117 respectively. This was in agreement with Olorunnisomo, (2007) who reported an increased NDF content (49%) for the vines left uncut as compared to 44.5% for vines cut at 4 weeks after planting. This could be due to increase in concentration of cell wall component with maturity (Etela *et al.* 2009). The fibre content of tropical forages is reported to be lower when harvested at an earlier age as compared to late harvesting (Phuc and Lindberg 2001). The NDF content in the roughage feeds plays an important role of maintaining rumen health and improving feed conversion in ruminants (Tekce and Gül 2014). It is also an important source of metabolizable energy in ruminants and promotes rumination and saliva production, which lowers pH to the appropriate levels in the rumen (Maktabi *et al.* 2016). However, NDF levels in the diets have to be within the recommended limits as it affects both forage digestibility and animal capacity to consume the forage (Harper and McNeill 2015). Dry matter intake is reported to increase with increase in NDF content in feed (Arelovich *et al.* 2008) but beyond 45.8% DM intake decreases. This is reported to be more important when feeding temperate forages such as sweet potato vines to high yielding animals. The reduced intake is reported to be as a result of rumen fill (Harper, 2015) and the indigestible component of NDF that is unavailable to rumen microbes (Huhtanen *et al.* 2006). This limits the ability of the animal to consume enough feed to meet nutrient requirements, leading to reduced productivity.

The ADF content ranged from 23.0 to 24.7 and 32.3 to 37.2% for INT and FIN respectively across all the three varieties (Table 4). This was slightly higher than the range reported by Olorunnisomo (2007) (25.5 to 30.5%), and 34.7% reported by Pedrosa *et al*. (2015). The ADF content in the current study could be higher than the reported studies because of varietal differences and differences in harvesting time. The ADF content of INT was significantly lower than FIN across all the three varieties (23.0 to 24.7 and 32.3 to 37.2% for INT and FIN respectively), which was slightly higher but comparable to Lam, (2016) who reported ADF content of 20.7% for vines harvested 80 days after harvesting. However, the results of this study showed lower ADF content compared to a study by Ali *et al.* (2015), where ADF content ranged from 34.9 to 40.3% when vines were harvested at 70 days and 46.5 to 52.6% when vines were harvested at 110 days. Vines harvested at 150 days (FIN) had higher ADF content compared to FIN probably due to accumulation of cell wall content as the vines progressed in age (Ali *et al.* 2016). This increase in cell wall content is reported to be detrimental to organic molecules that are actively involved in metabolic processes resulting to reduction in organic compound levels (Monção *et al.* 2016). Cutting interval in vines is reported to influence composition of cell constituents, with influence varying with phenological stage of the plant (Pena *et al.* 2009).

The ash content shown (Table 4) ranged between 9.2 to 12.8% of DM across all the three varieties, which was comparable to 13.5% reported by An, (2004) and 8.7-11.6% reported by Oduro, (2008) but lower than 17.8% reported by Farrell *et al*. (2000). However, in the Farrell *et al*. (2000) study, the high ash content was suspected to be as a result of soil contamination. In a study on legumes, Hoffman (2005) reported that normal ash content should border around 9% and forages containing 10- 18% are highly likely to be contaminated with soil. Soil contamination leads to exogenous minerals such as silica (Hoffman 2005), which negatively affects palatability and forage digestibility (Mayland and Shewmaker 2001). It is for this reason therefore that feed rations should contain as little soil contamination as possible. The soil contamination theory could also explain the relatively higher ash content in FIN as compared to INT across the three varieties in the current study. For INT, ash content ranged from 9.2 to 10.5% of DM as compared to 10.3 to 12.8% of DM for FIN (Table 4). This difference in the two harvesting regimes could be due to the fact that FIN stayed longer in the field before harvesting which could lead to more exposure to soil contamination than INT. It could also be due to higher deposits of mineral elements in the leaves (Owusu *et al.* 2008) for FIN as the vines stayed in the field for longer period compared to INT.

The ash content in forages is important because it is an indication of mineral contents preserved in the plant. These minerals are of nutritional value to animals and reduce the need for supplementation in the diets (Hoffman 2005).

5.2 Effect of amount of molasses and storage period on silage quality of sweet potato vines.

The amount of molasses had a significant effect on the pH of the SPV silage where the mean pH of 0% amount of molasses was the highest (4.56), compared with 4.08 and 4.04 for 2 and 4% molasses (Table 5). In agreement, An and Lindberg, (2004) reported pH of 4.35, 4.21 and 3.98

when sweet potato vines were ensiled with 0, 3 and 6% molasses respectively, while Kaya and Caliskan, (2010) reported pH of 3.68, 3.35 and 3.46 when sweet potato vines were ensiled with 0, 2 and 4% molasses respectively. Silages from different forages have been reported to have different pH. Kung Jr, (2018) in a review reported that pH of legume silages below 35% DM was 4.3-4.5, grass silages of 25-35% DM was 4.3-4.7 and 3.7-4 for corn silage 30-40% DM.

Silage pH is one of the most important factors in maintaining long term stability of silages (Kung Jr *et al.* 2018), and is often used as a parameter to evaluate silage quality (Kaya and Caliskan 2010). During silage making, the fermentation process that occurs determines how fast the pH will drop, which can have an effect on nutrient loss which can later influence the feed intake in animals (Oladosu *et al.* 2016). The success of the fermentation process is indicated by the production of acids to reduce the pH and it affects the quality of the silage.

When low pH is achieved, it decreases plant enzyme activity and slows the proliferation of clostridia and enterobacteria (Muck 2010). The pH of silage is affected by several factors among them DM content. Above DM of 40-45%, pH increases due to decrease in water available for the lactic acid bacteria growth (Whiter and Kung Jr 2001). Other factors include concentration of water-soluble carbohydrates (Downing *et al.* 2008) and buffering capacity of a crop, mostly legumes high in protein and ash content (Kung Jr *et al.* 2018).

The high pH for 0% molasses was probably due to low amount of fermentable substrates present in SPV, low dry matter content and high buffering capacity (Hadgu *et al.* 2015). Generally, tropical forages have low DM and low WSC content leading to poor fermentation during ensiling (Muhlbach 2000). For silage fermentation to be successful, the ensiling material should contain enough WSC level of 60 to 80g/Kg DM (Amer *et al.* 2012). Several studies have reported varying levels of WSC content in SPV ranging from 42 g/Kg (Donas 2012) to 52 g/Kg of DM (Pedrosa *et al.* 2015). This is further reduced by wilting where WSC are reported to be reduced due to consumption of sugars by fungi and yeast during wilting process (Santos *et al.* 2010). Inclusion of molasses, which has been reported to contain WSC of up to 62.3% DM (Palmonari *et al.* 2020), could help in improving the WSC content in SPV silage. WSC are fermented by lactic acid bacteria into lactic acid, reducing the pH of the silage which in turn inactivates the spoilage bacteria (Bautista-Trujillo *et al.* 2009). Without additives, it takes long (up to 45 days) in low WSC forages such as SPV, for population of lactic acid producing bacteria to peak (An and Lindberg 2004)and that could be the reason for the high pH level in 0% molasses silage. This delay is a prerequisite for low quality silage which can lead to spoilage.

The results on the effect of storage on pH (Table 5) show that pH dropped significantly from 4.27 at day 7 to 4.04 at day 14 of storage, and thereafter stabilizing through day 56 (Table 5). This downward trend agrees with Der Bedrosian *et al.* (2012) that pH of corn silage decreased from 5.77 to an average of 3.72 after 45 days of ensiling. The same study reported an increase in lactic acid from 0.98% at day 45 to 1.71% at day 360 which implies that pH reduces further even in longer storage of silages. The results also agree with An and Lindberg, (2004) who reported a reduction of pH from 5.93 to 3.9 between day 0 and 14 of ensiling sweet potato vines mixed with 3% molasses. During the silage storage period, the fermentation phase is reported to last between 7 and 45 days (Kung Jr *et al.* 2018). During this period, lactic acid bacteria ferment soluble sugars to produce lactic acid that lowers pH leading to reduction and eventual stoppage of active metabolic processes (Der Bedrosian *et al.* 2012). However, studies by Kleinschmit, (2006) and Hermann, (2011) reported reduction in lactic acid and increase in acetic acid concentration for prolonged storage periods as compared with silages stored for a few days (Kleinschmit and Kung Jr 2006; Herrmann *et al.* 2011). This could be because some strains of lactic acid bacteria are known to utilize lactic acid anaerobically when sugars in the silage become limiting.

There was 6.7% decline of mean CP content between 0% and 4% amount of molasses (Table 6), a trend that agreed with Kim and Adesogan, (2006) who reported 19% reduction in CP quantity in corn silage when moisture level was increased by 4 mm of water. In another study, same trend was observed where CP in orchard grass silage reduced by 11.2%, when DM was reduced from 44.29 to 20.35% (Yahaya *et al.* 2002). This could be because of higher moisture content in the 4% amount of molasses as compared to 2%, which agrees with previous studies that high moisture content affects nutrients in silages. High moisture content encourages clostridia proliferation that causes proteolysis which leads to excessive protein degradation, and utilization of other nutrients such as water-soluble carbohydrates (Kim and Adesogan 2006). This situation is made worse when the high moisture silages are ensiled for longer time.

The low CP (16.25%) in the 0% molasses inclusion could be as a result of protein break down as a result of increase in silage temperature, due to low fermentable sugars content (Adesogan and Newman 2010). When WSC are not adequate, fermentation does not start early enough leading to proliferation of the spoilage bacteria (Adesogan and Newman 2010). The action of these bacteria plus continued respiration process of the plant cells produces heat that increases silage temperature leading to deterioration of proteins (Adesogan and Newman 2010).

Storage period significantly affected the quality of silage. Beyond 21 days, pH, CP, NDF, ADF and ash which are the main quality indicators in silage, showed decline in quality. CP decreased from 19.54 to 15.62% from 7 to 56 days of storage period, which could be as a result of bacterial deamination of amino acids. The deamination is reported to be indicated by increase in ammonia-N over time, which would be lost through silage effluent. A steady increase of ammonia-N from 5.7 to 8.2% of N in sweet sorghum ensiled between 30 and 120 days has been reported (Naeini *et al*., 2014). An and Lindberg, (2004) also reported an increase of ammonia-N from 1.13 to 3.8% of N, when sweet potato leaves were ensiled for 56 days. The decreased protein content could also be due to degradation of proteins in the silage due to solubilization by lactic and acetic acid (Hoffman *et al.* 2011). McEniry *et al*. (2011) reported that prolonged silage storage of 18 compared to 7 months had a negative impact on quality, especially in low DM forages such as SPV. This resulted to reduced lactic acid leading to loss of DM and development of visible molds. The study indicated that, for prolonged storage, the silage should be well compacted covered to prevent air ingress during the storage period. However, other studies have reported increase in CP digestibility. In a study by Newbold *et al*. (2006), there was increased soluble N content of corn silage with longer storage period. This was due to proteolytic activity in high moisture forages over extended periods of ensiling (Hoffman *et al.* 2011).

The storage period is therefore a crucial parameter in quality silage production (Mohd-Setapar *et al.* 2012). In most farms, the storage period of silage depends on the purpose of silage making. In some cases, it can be few months if the silage is made from high quality fodder that is only available at a particular time of the year or, long term, if the silage is to supply fodder during periods of shortage that may occur annually or over a number of years (Mannetje 2000). Panyasak, (2014) recommended that for favorable silage quality, the minimum period for storage is 30 days before feeding to the animals.

The NDF content decreased by 23.1% as ensiling period progressed from 7 to 56 days (Table 7). This decrease was consistent with Naeini *et al*. (2014) who reported decrease in NDF (544 to 495 g/Kg DM) of sweet sorghum silage stored between 30 and 120 days, and Yahaya *et al*. (2001) who reported a decrease from 50.3 to 43.9% in orchard grass silage stored for 91 days. The same study reported a considerable loss of hemicellulose and pectin fractions in alfalfa and orchard grass silage. This could be as a result of degradation of the cell wall by cellulase and hemicellulase enzymes and/or production of organic acids during fermentation (Yahaya *et al.*, 2001). The organic acids may have led to acid hydrolysis which caused degradation of hemicellulose, resulting to reduced fibrous fraction of the silage (Der Bedrosian *et al.* 2012). This degradation is also reported to substantially increase NDF digestibility with increased storage time especially in corn silages (Hallada *et al.*2008).

The ADF content reduced from 31.09 to 28.3% from day 7 to 56 of silage storage across all amounts of molasses (Table 7). These results compare well to Yahaya *et al*. (2002) who reported a decrease of ADF content from 31-29% and 27-26% in low and high moisture grass silage respectively stored for 90 days. Ayako *et al*. (2000) reported 10% ADF loss during the first 21 days and 2% during 21 to 91 days of ensiling high moisture lucerne. The reduction in ADF was probably due to increased microbial activity during the storage period that increases loss of cellulose, a content of ADF (Yahaya *et al.* 2002).

The ash content showed a steady increase from 8 to 10.67%, an increase of 33.4% for a storage period of 56 days. The trend was consistent with other studies which reported increase in ash content as the storage period increased. For instance, Weinberg and Chen, (2013) reported 49-56% increase in ash content for silage stored for 90 days. However, this trend was inconclusive as 19% decline was reported in corn silage stored for 90 days (Saricicek *et al.* 2016). Ash content increased with increase in amount of molasses where the results indicated 8.98, 9.46 and 10.06% for 0, 2 and 4% molasses inclusion. This could have been due to mineral content in molasses. A study on 16 samples of cane molasses reported average ash content of 13.1% (Palmonari *et al.* 2020).

From this study, it is evident that initial stages of ensiling showed good fermentation characteristics for both 2 and 4% molasses, indicated by low pH and high protein content. This may be attributed to availability of sufficient fermentable substrates for lactic acid bacteria as compared to the silage with no molasses added. However, as the storage period progressed, there was a trend of reduction in quality. The reason for this could have been decrease in WSC at later stages of ensiling. Naeini *et al*. (2014) reported a rapid decrease in WSC content from 166 to 96.7 g/ Kg DM within the first 30 days of ensiling sweet sorghum. This was attributed to the rapid microbial utilization of sugars in the early stages of ensiling. It is well documented that fermentable substrate in form of WSC affects the rate of pH decline during the initial stages of silage fermentation thus leading to stable silage (Yuan *et al.* 2015). In previous studies, there has been a wide variation in the sufficient WSC content adequate for silage making but a recent study showed that 41.2 to 78.86 g/Kg DM could be sufficient to produce silage of good quality (Pereira *et al.* 2021). In the present study, molasses inclusion could have provided adequate WSC to produce good quality silage as compared to 0% amount of molasses.

5.3 Effect of supplementing lactating dairy cows on Napier basal diet with sweet potato vine silage on dry matter intake, milk production and milk composition.

The CP content of NG in this study of 7.9% (Table 8) was within the range of 7.6% in the NG fed to dairy cows by smallholder farmers in the tropics (Wouters, 1987), 7.5% in Ethiopia (Zewdu 2005), but lower than 9.92% (Maleko *et al.* 2019) and 11.8% (Kariuki *et al.* 1998) reported in Tanzania and Kenya respectively. The CP content was less than the minimum 17.5% set by National Research Council for optimum level of milk production (Mutsvangwa *et al.* 2016). SPVS used in this study had a CP content of 17.1% and in view of its protein content was thought to be a suitable protein source for feeding dairy cows. A study by Gunderson *et al*. (1998) reported that lactating cows required diets with CP content of between 16.1 to 18.9% to produce optimally. Considering this, the diet combination of both treatments in this study could only support sub-optimal milk production. Furthermore, the low ME content of SPVS (9.7 MJ/Kg DM) required it to be combined with another feed to improve the ME content to the targeted 11.0 MJ/Kg DM. The resulting supplement (SPVSWB) was lower in both energy and protein as compared to CDC (Table 9), which contributed to animals fed SPVSWB having lower DMY than those fed the reference diet.

The DM intake for SPVSWB was lower by 16.2% and by 14.7% for LL and EL, while at the same time the NDF content for SPVSWB was higher by 76.3% (Table 9). From these two parameters, it is possible that CDC was easily digestible providing more nitrogenous compounds, a favorable environment for the rumen microbes to digest fiber faster (Sampaio *et al.* 2010a). This could have led to faster turnover in the rumen, leading to higher feed intake, and subsequently higher milk yield.

Apart from energy intake, milk production may also have been affected by the quantity and quality of protein provided by the experimental diets. Protein supplementation is reported to improve voluntary dry matter intake in ruminants on poor quality topical forages (Wickersham *et al.* 2008). In a study on lactating dairy cows, DM intake improved 45.6% when poor quality hay was supplemented with a protein source (Souza *et al.* 2010). The nitrogenous compounds in CP help in growth of fibrolytic bacteria in the rumen which increases the rate of passage in the rumen thus improving intake (Franco *et al.* 2021). This improves digestion of fibre leading to increased fibrous carbohydrates in forages which eventually increase energy supply (Souza *et al.* 2010). Rumen protein degradability is an important factor that is used to determine the quality of tropical feeds. Sweet potato vines are one of the tropical forages reported to have rumen protein degradation of 722.1 g/Kg CP (Kabi *et al.* 2005).

The degradability of the proteins determines the N availability to rumen microbes but only to some extent because once the protein degraded is in excess of microbial needs, the rest is excreted as urea (Colmenero and Broderick 2006). When untreated silages are fed, there is increased protein degradation in the rumen and lowered rumen undegraded protein (Alstrup *et al.* 2014). In the current study, it is suspected that the possible rumen undegradable protein in SPVSWB may have reduced milk yield. However, the positive effects of rumen undegradable protein on milk production have not been well demonstrated in literature (Santos *et al.* 1998).

The effect of CP in stimulating dietary intake, and therefore digestible nutrients, is known to occur at two levels. Firstly, at the rumen metabolism level where the CP, especially the degradable protein nitrogen, boosts the NH_3-N level in the rumen to thresholds required by rumen microbes (Wanapat *et al.* 2013), especially the cellulolytic bacteria to operate optimally. Enhanced activities of rumen microbes is beneficial from two perspectives; higher fribrolytic activity which results in more energy from volatile fatty acids (VFA) being released from the ingested feed, and also a boost in higher microbial crude protein flowing to the small intestines resulting in high productivity (Castillo-González *et al.* 2014). In addition, a higher CP, especially the undegradable dietary protein (UDP) also boosts the total amino acids absorbed from the small intestines into the body tissues. An elevated level of amino acids, and especially the limiting amino acids, is a major boost at the tissue metabolism level where there is increased efficiency in energy metabolism, especially the VFA and more so acetate resulting in higher productivity in the dairy cow (Kolver 2003). It is well known that high genetic merit dairy cow's productivity, especially in early lactation, is in most cases limited by unavailability of limiting amino acids rather than energy. This is because a dairy cow can effectively mobilize endogenous energy reserves from the adipose tissues resulting in weight loss, to compensate for energy deficit arising from depressed DMI during that period (Kaufman *et al.* 2018). However, the same cannot be said for protein in the muscles, as the capacity for protein mobilization is very limited. Such cows inevitably end up producing less milk, until such a time when adequate protein (and therefore amino acid) is made available through supplementation with dietary UDP. The supplementation results in improved lactation performance in the dairy cow.

During late lactation (LL) DMY was 17% lower for cows fed sweet potato vine plus wheat bran (SPVSWB) compared to those fed CDC while in early lactation (EL), DMY was 13% lower (Table 10). The current study shows large differences in milk production response between LL and EL, an observation that concurs with a number of trials reviewed by Davison and Elliott (1993), who showed that early, mid and late lactation responded differently to supplementation. The reduced milk production response in the late lactation could be due to lower feed conversion efficiency (Wachirapakorn *et al.* 2016). It could be also due to the animals diverting energy from milk production to supporting foetus (CSIRO 2007), considering that all the animals in late lactation in the current study were pregnant.

Energy and protein intake are two crucial nutrients in production of milk. A study by Sutter and Beever (2000) reported loss of weight for cows in early lactation as a result of body reserves being mobilized for milk protein and fat synthesis, a situation more prominent where feeding is inadequate. Such body weight losses are as a result of the nutritive value of feed not meeting the animal daily requirements to support milk production (Etela *et al.* 2008). In the current study, animals were fed *ad libitum* during both periods, but SPVSWB animals consumed lesser amounts of feed on a DM basis compared to CDC during both periods. During LL as shown in Table 11, the difference in ME intake (131.3 vs 123.3 MJ/d for CDC vs SPVSWB respectively) was equivalent to the difference in metabolizable energy (ME) for DMY (40.2 vs 32.2 MJ/d for CDC vs SPVSWB respectively) suggesting that differences in energy intake between groups lead to the 17.3% decrease in DMY for SPVSWB.

Dry matter intake (DMI) and nutrient composition of diet is an important factor in the nutrition of the lactating cow as it determines the nutrient availability to support milk production. Animals fed SPVSWB consumed lower DM both in late (12.97vs11.07) and early lactation (13.53vs11.34). This reduced DMI during both early and late lactation for SPVSWB could be due to high fibre content (40.2 and 27.1% for NDF and ADF respectively), low ME (11 MJ/Kg DM), or low DM content (45%).

The main chemical predictor for DMI in cattle is reported to be Neutral Detergent Fibre (NDF) (Waldo 1986). The NDF and voluntary intake of forages are highly interlinked where high NDF content negatively affects voluntary feed intake in cattle (Gwayumba *et al.* 2002). The basal feed in this study (Napier grass) was high in NDF, and this was held constant across treatment groups. NDF content for SPVSWB was higher by 75% than the CDC. The fiber content of a diet is the main factor that influences rumen fill and subsequently DMI (Fustini *et al.* 2017). This is caused by the bulkiness of the feed, leading to activation of pressure and stretch receptors in the reticulorumen wall as reported by Van Soest, (1994).

Ideally, low and medium energy diets should have highest intakes, as compared to high energy feeds, for the animal to meet its energy requirements (Brand *et al.* 2017). However, intake can also be affected by gut fill limitation and subsequently rate of rumen clearance, especially for diets low in energy but high in fiber (Kubkomawa *et al.* 2013). Due to low DM content in silages, voluntary feed intake has been reported to reduce to as low as 8.4 Kg/d DM (Gwayumba *et al.* 2002). Moisture content of 45-55% was found to be ideal for silages (Zheng *et al.* 2011). Grant et al. (1974), reported a 15% increase in Napier grass intake after wilting. However, other studies by Thomas *et al.* (1961) and Clancy *et al.* (1977) have disputed the reported influence of moisture content on dry matter intake. Considering the contradicting findings on the effect of moisture content on DM intake, it is not clear if the reduced intake for SPVSWB in this study was as a result of high moisture content. Rate of rumen turnover might also have contributed to the differences in feed intake in the current study where there could be faster rate of fermentation of grain (Colucci *et al.* 1982) as compared to silage leading to higher intake observed in CDC.

Despite SPVSWB having lower DMY during both late and early lactation periods, the Gross Margins of feeding SPVSWB were higher (KES 3.8) than those fed CDC (KES -4.8) for LL and KES 28.2 vs KES 21.9 for EL (Table 12), due to the lower cost of producing the SPVSWB supplement. This had a substantial impact on the gross margins of the supplements in both LL and EL, although it was clear that it was not economically attractive to feed either supplement during

LL on the basis of DMY response alone.

Milk components presented in Table 13 show that fat content ranged between 3.2 and 4.1% and protein content between 2.7 to 3.0%. The range was within reported range for Friesian breed in the tropics of 2.8-5.5% and 2.8-3.9% for fat and protein respectively (Lam *et al.* 2010). The higher protein content of milk from cows on CDC (3.0 and 3.1%) than SPVSWB (2.7 and 2.8%) in LL and EL respectively, could have been probably due to higher energy intake in CDC (131.3 and 127.1 MJ/d) compared to SPVSWB (123.3 and 109.8 MJ/d) for LL and EL respectively. When energy intake is increased, the glucogenic amino acids are spared from the process of gluconeogenesis leading to increased amino acids, which are the precursors of milk protein synthesis (Mackle *et al.* 1999). This in turn results to elevated protein content in the milk. On the other hand, supplementing cows with feed high in fiber content would lead to increased milk fat content due to increased production of volatile fatty acids (Sterk *et al.* 2011). In the current study it was expected that the high fiber content for SPVSWB would have resulted to significantly higher milk fat content than CDC. High fibre content in the diet is known to promote acetate type of fermentation and acetate being a lipogenic VFA naturally tend to favour higher butterfat content due to increased lipogenesis. However, this was not the case and this can be explained by the low DM intake in SPVSWB than CDC.

The significantly higher milk fat content for late lactation as compared to early lactation was probably due to concentrating effect of declining milk volume in the late lactation (Mahmoud *et al.* 2014). It is reported that when milk production decreases, like in the case of late lactation, fat content increases due to concentration of solid components (Chilliard *et al.* 2003). It could have been also due to the fact that most of milk components (mainly total solids, ash and fats) increase with increasing stage of lactation (Aganga *et al.* 2002).

5.4 Conclusions

1. Partial harvesting of vines reduced tuber dry matter yield by 11, 16 and 60% for Kenspot 1, SPK117 and SPK 013 respectively. However, partial harvesting improved vine yield by 57, 19 and 30% for Kenspot 1, SPK117 and SPK 013 respectively.
2. Inclusion of molasses in sweet potato silage lowered pH thus improving quality of the silage. 2% molasses amount inclusion resulted in the best quality silage in terms of CP content and pH level.
3. Supplementing lactating cows with sweet potato vine silage reduced milk yield by 17 and 13% in late lactation and early lactation respectively, as compared to supplementing with a commercial dairy concentrate. Dry matter intake was also lower by 16.2 and 14.7% for the groups supplemented with sweet potato vine silage, for LL and EL respectively. The same trend was observed for milk quality where supplementing with sweet potato silage resulted to lower CP content (2.7 and 2.8% DM) as compared to commercial concentrate (3.0 and 3.1% DM) for LL and EL respectively.
4. Gross Margins (KES/L) of supplementing with sweet potato silage were higher (KES 3.8) than those fed commercial dairy concentrate (KES -4.8) for late lactation and KES 28.2 for sweet potato silage vs KES 21.9 commercial dairy concentrate for EL which was attributed to lower cost of producing the sweet potato silage supplement.

5.5 Recommendations

Varieties SPK117 and Kenspot 1 are recommended for fodder and root production, as they had better balance between vine production for fodder through partial harvesting and tuber production for human consumption. Partial harvesting at 75 days before the final harvest is recommended to optimize the biomass yield and quality of the vines.

For quality sweet potato vine silage, it can be recommended that amount of molasses should be at 2%, which will provide water soluble carbohydrates and lower the pH for quality silage. Beyond 2% molasses, there will be dilution effect of the nutrients and excessive moisture level to an already low DM sweet potato vine.

It can be recommended from the study that sweet potato vine silage can be fed in combination with other by-products, for moderate milk production which will result to a lower cost of supplementation than conventional grain-based supplementation. In smallholder farmers' situations where grain supplements are unavailable and expensive, SPVS can be used as a cheap and readily available source of energy and protein for ruminant feeding. Therefore, this calls for sweet potato to be incorporated into smallholder farming systems.

Further research work should be undertaken to improve the energy content of SPVS, and this could be by including the rejected or unsalable tubers in the silage making process. This could have the advantage of reducing the quantity of wheat bran needed to improve the ME. Although not demonstrated here, small changes, such as outlined, may produce rates of DMY that are equivalent to grain-based supplementation. Furthermore, there should be a breeding program to develop new varieties of sweet potatoes that are both high yielding in tuber production and highly tolerant to partial harvesting.

5.6 References

Abdullah, A.S. (**2014**) Minimum tillage and residue management increase soil water content, soil organic matter and canola seed yield and seed oil content in the semiarid areas of Northern Iraq. Soil and Tillage Research **144:**150-155.

Abidin, P., Eeuwijk, F., Stam, P., Struik, P., Malosetti, M., Mwanga, R., Odongo, B., Hermann, M. and Carey, E. (**2005**) Adaptation and stability analysis of sweet potato varieties for low-input systems in Uganda. Plant Breeding **124:**20-25.

Adesogan, A. and Newman, Y. (**2010**) Silage harvesting, storing, and feeding. University of Florida Extension **3:**311-327.

Adesogan, A.T. and Dahl, G.E. (**2020**) Milk Symposium Introduction: Dairy production in developing countries. Journal of Dairy Science **103:**9677-9680.

AFIA (2014) -Laboratory Methods Manual; a reference manual of standard methods for analysis of fodder. (8th version) (Australian Fodder Industry Association: Melbourne, Australia). ISBN 0642585997

Aganga, A., Amarteifio, J. and Nkile, N. (**2002**) Effect of stage of lactation on nutrient composition of Tswana sheep and goat's milk. Journal of food Composition and Analysis **15:**533-543.

Agarussi, M.C.N., Pereira, O.G., da Silva, V.P., Leandro, E.S., Ribeiro, K.G. and Santos, S.A. (**2019**) Fermentative profile and lactic acid bacterial dynamics in non-wilted and wilted alfalfa silage in tropical conditions. Molecular biology reports **46:**451-460.

Agbede, T. and Adekiya, A. (**2009**) Tillage effects on soil properties and performance of sweet potato on an Alfisol in Southwestern Nigeria. American-Eurasian Journal of Sustainable Agriculture **3:**561-568.

Agenäs, S., Heath, M., Nixon, R., Wilkinson, J. and Phillips, C. (**2006**) Indicators of under nutrition in cattle. Animal welfare **15:**149-160.

Ahmed, M., Nigussie-Dechassa, R. and Abebie, B. (**2012**) Effect of planting methods and vine harvesting on shoot and tuberous root yields of sweet potato [*Ipomoea batatas (L.) Lam*.] in the Afar region of Ethiopia. African Journal of Agricultural Research **7:**1129-1141.

Ahn, P.M. (1993) Tropical Soils and Fertilizer Use. Longman scientific and technical publishers. ISBN: 0582775078, United Kingdom. pp 247-252

Alexandratos, N. and Bruinsma, J. (**2012**) World agriculture towards 2030/2050: the 2012 revision. FAO ESA working paper **12:**1-2.

Ali, R., Mlambo, V., Mangwe, M. and Dlamini, B. (**2016**) Chemical composition, nitrogen degradability and in vitro ruminal biological activity of tannins in vines harvested from four tropical sweet potato (*ipomoea batatas L.*) varieties. Journal of Animal Physiology and Animal Nutrition **100:**61-68.

Alstrup, Weisbjerg, M.R., Hymøller, L., Larsen, M.K., Lund, P. and Nielsen, M.O. (**2014**) Milk production response to varying protein supply is independent of forage digestibility in dairy cows. Journal of Dairy Science **97:**4412-4422.

Amanlou, H., Farahani, T.A. and Farsuni, N.E. (**2017**) Effects of rumen undegradable protein supplementation on productive performance and indicators of protein and energy metabolism in Holstein fresh cows. Journal of Dairy Science **100:**3628-3640.

Amer, S., Hassanat, F., Berthiaume, R., Seguin, P. and Mustafa, A. (**2012**) Effects of water soluble carbohydrate content on ensiling characteristics, chemical composition and in vitro gas production of forage millet and forage sorghum silages. Animal Feed Science and Technology **177:**23-29.

Aminah, A., Bakar, A. and Izham, A., 1999. Silages from Tropical Forages: Nutritional Quality and Milk Production. FAO Electronic Conference on Tropical Silage 1999. Rome.

An, L.V. (2004) Sweet potato leaves for growing pigs: Biomass yield, digestion and nutritive value. Asian-Australasian Journal of Animal Sciences **17:**497-503

An, L.V. and Lindberg, J.E. (**2004**) Ensiling of sweet potato leaves (Ipomoea batatas (L.) Lam) and the nutritive value of sweet potato leaf silage for growing pigs. Asian-Australasian Journal of Animal Sciences **17:**497-503.

Andrade Júnior, V.C.d., Pereira, R.C., Neiva, I.P., Ribeiro, K.G., Figueiredo, J.A. and Viana, D.J.S. (**2012**) Sweet potato silage. Horticulture Brasil **85:**51-60.

Andrade, M.I., Naico, A., Ricardo, J., Eyzaguirre, R., Makunde, G.S., Ortiz, R. and Grüneberg, W.J. (**2016**) Genotype× environment interaction and selection for drought adaptation in sweet potato (*Ipomoea batatas [L.] Lam*.) in Mozambique. Euphytica **209:**261-280.

Aniekwe, N. (**2014**) Influence of pinching back on the growth and yield parameters of sweet potato varieties in Southeastern Nigeria. Journal of Animal and Plant Sciences **20:**3194-3201.

Ann, K., Mike A, I. and John M, K. (**2015**) Value addition and performance of informal dairy enterprises in Kenya: A product diversification perspective. IOSR Journal of Business and Management **17:**

AOAC (**1990**) Official Method of Analysis. (15th edition). Association of Official Analytical Chemists Inc: Washington, DC.

Apata, D. and Babalola, T. (**2012**) The use of cassava, sweet potato and cocoyam, and their by-products by non–ruminants. International Journal of Food Science and Nutrition

Engineering **2:**54-62.

Arelovich, H., Abney, C., Vizcarra, J. and Galyean, M. (**2008**) Effects of dietary neutral detergent fiber on intakes of dry matter and net energy by dairy and beef cattle: analysis of published data. The Professional Animal Scientist **24:**375-383.

Ashbell, Kipnis, T., Titterton, M., Hen, Y., Azrieli, A. and Weinberg, Z.G. (**2001**) Examination of a technology for silage making in plastic bags. Animal Feed Science and Technology **91:**213-222.

Ashbell, Weinberg, Z., Hen, Y. and Filya, I. (**2002**) The effects of temperature on the aerobic stability of wheat and corn silages. Journal of Industrial Microbiology and Biotechnology **28:**261-263.

Atis, I., Konuskan, O., Duru, M., Gozubenli, H. and Yilmaz, S. (**2012**) Effect of harvesting time on yield, composition and forage quality of some forage sorghum cultivars. International Journal of Agriculture and Biology **14:**

Ayantunde, A.A., Fernández Rivera, S. and McCrabb, G. (2005) Coping with feed scarcity in smallholder livestock systems in developing countries. (International Livestock Research Institute:

Baile, C.A. and Forbes, J.M. (**1974**) Control of feed intake and regulation of energy balance in ruminants. Physiological reviews **54:**160-214.

Bajpai, V. and Swain, B. The State of Food Security Report 2012 and the Enigma of Achieving Millennium Development Goals. World **1000:**18.6.

Bargo, F., Muller, L., Kolver, E. and Delahoy, J. (**2003**) Production and digestion of supplemented dairy cows on pasture. Invited review. Journal of Dairy Science. **86:**1.

Bautista-Trujillo, G.U., Cobos, M.A., Ventura-Canseco, L.M.C., Ayora-Talavera, T., Abud-Archila, M., Oliva-Llaven, M.A., Dendooven, L. and Gutierrez-Miceli, F.A. (**2009**) Effect of sugarcane molasses and whey on silage quality of maize. Asian Journal of Crop Science **1:**34-39.

Bayble, T., Melaku, S. and Prasad, N. (**2007**) Effects of cutting dates on nutritive value of Napier (Pennisetum purpureum) grass planted sole and in association with Desmodium (*Desmodium intortum*) or Lablab (*Lablab purpureus*). Livestock Research for Rural Development **19:**120-136.

Bell, M., Eckard, R., Moate, P.J. and Yan, T. (**2016**) Modelling the Effect of Diet Composition on Enteric Methane Emissions across Sheep, Beef Cattle and Dairy Cows. Animals **6:**54.

Berem, R.M., Obare, G. and Bett, H. (**2015**) Analysis of factors influencing choice of milk marketing channels among dairy value chain actors in Peri-urban Areas of Nakuru County, Kenya. European Journal of Business Management **7:**174-179.

Bingi, S. and Tondel, F. (**2015**) Recent developments in the dairy sector in Eastern Africa. Briefing note of the European Centre for Development Policy Management **78:**19.

Bioethics, N.C. (**2004**) The use of GM crops in developing countries. Case study **5:**

Blajman, J.E., Paez, R.B., Vinderola, C.G., Lingua, M.S. and Signorini, M. (**2018**) A meta-analysis on the effectiveness of homofermentative and heterofermentative lactic acid bacteria for corn silage. Journal of applied microbiology **125:**1655-1669.

Boadi, D., Wittenberg, K. and McCaughey, W. (**2002**) Effects of grain supplementation on methane production of grazing steers using the sulphur (SF6) tracer gas technique. Canadian Journal of Animal Science **82:**151-157.

Boland, F., O'Grady, L. and More, S. (**2013**) Investigating a dilution effect between somatic cell count and milk yield and estimating milk production losses in Irish dairy cattle. Journal of Dairy Science **96:**1477-1484.

Borreani, G., Tabacco, E., Schmidt, R., Holmes, B. and Muck, R. (**2018a**) Silage review: Factors affecting dry matter and quality losses in silages. Journal of Dairy Science **101:**3952-3979.

Borreani, G., Tabacco, E., Schmidt, R.J., Holmes, B.J. and Muck, R.E. (**2018b**) Silage review: Factors affecting dry matter and quality losses in silages. Journal of Dairy Science **101:**3952-3979.

Bossen, D., Weisbjerg, M.R., Munksgaard, L. and Højsgaard, S. (**2009**) Allocation of feed based on individual dairy cow live weight changes: I: Feed intake and live weight changes during lactation. Livestock Science **126:**252-272.

Brand, T., Van Der Merwe, D., Swart, E. and Hoffman, L. (**2017**) Comparing the effect of age and dietary energy content on feedlot performance of Boer goats. Small Ruminant Research **157:**40-46.

Brito, A., Tremblay, G., Bertrand, A., Castonguay, Y., Bélanger, G., Michaud, R., Lapierre, H., Benchaar, C., Petit, H. and Ouellet, D. (**2008**) Alfalfa cut at sundown and harvested as baleage improves milk yield of late-lactation dairy cows. Journal of Dairy Science **91:**3968-3982.

Brown (**1978**) A difference in N use efficiency in C3 and C4 plants and its implications in adaptation and evolution. Crop Science **18:**93-98.

Brüning, D., Gerlach, K., WEIß, K. and Südekum, K.H. (**2018**) Effect of compaction, delayed sealing and aerobic exposure on maize silage quality and on formation of volatile organic compounds. Grass and Forage Science **73:**53-66.

Bryant, A. and Trigg, T. (**1982**) The nutrition of the grazing dairy cow in early lactation. Occasional Publication, New Zealand Society of Animal Production (New Zealand)

Burke, F., O'Donovan, M., Murphy, J., O'Mara, F. and Mulligan, F. (**2008**) Effect of pasture allowance and supplementation with maize silage and concentrates differing in crude protein concentration on milk production and nitrogen excretion by dairy cows. Livestock Science **114:**325-335.

Busha, A. (2006) Effect of N and P Application and Seedbed Types on Growth, Yield and Nutrient Content of Sweet Potato [*Ipomoea batatas L. (Lam)*], Grown in West Wollega, M. Sc. Thesis, Haramaya University, Ethiopia.

Calabrò, S., López, S., Piccolo, V., Dijkstra, J., Dhanoa, M.S. and France, J. (**2005**) Comparative analysis of gas production profiles obtained with buffalo and sheep ruminal fluid as the source of inoculum. Animal Feed Science and Technology **123–124, Part 1:**51-65.

Cappellozza, B.I., Bohnert, D.W., Reis, M.M., Swanson, K.C., Falck, S.J. and Cooke, R.F. (**2021**) Influence of amount and frequency of protein supplementation to steers consuming low-quality, cool-season forage: Intake, nutrient digestibility, and ruminal fermentation. Journal of animal science **4:**1-12.

Caro, D., Kebreab, E. and Mitloehner, F.M. (**2016**) Mitigation of enteric methane emissions from global livestock systems through nutrition strategies. Climatic Change **137:**467-480.

Chalfant, R., Jansson, R., Seal, D. and Schalk, J. (**1990**) Ecology and management of sweet potato insects. Annual Review of Entomology **35:**157-180.

Charmley, E. and Thomas, C. (**1987**) Wilting of herbage prior to ensiling: effects on conservation losses, silage fermentation and growth of beef cattle. Animal Science **45:**191-203.

Chedly, K., Lee, S. and Brooklyn Valley, R. (**1999**) Paper 6.0: Silage from by-products for smallholders-Kayouli Chedly and Stephen Lee.

Cheli, F., Campagnoli, A. and Dell'Orto, V. (**2013**) Fungal populations and mycotoxins in silages: From occurrence to analysis. Animal Feed Science and Technology **183:**1-16.

Cherney, J. and Cherney, D. (**2003**) Assessing silage quality. Silage science and technology **42:**141-198.

Chilliard, Y., Ferlay, A., Rouel, J. and Lamberet, G. (**2003**) A review of nutritional and physiological factors affecting goat milk lipid synthesis and lipolysis. Journal of Dairy Science **86:**1751-1770.

Choudhury, S. and Headey, D.D. (**2018**) Household dairy production and child growth: Evidence from Bangladesh. Economics & Human Biology **30:**150-161.

Chowdhury, S., Rexroth, H., Kijora, C. and Peters, K. (**2002**) Lactation performance of German Fawn goat in relation to feeding level and dietary protein protection. Asian-Australasian Journal of Animal Sciences **15:**222-237.

Clancy, M., Wangsness, P. and Baumgardt, B. (**1977**) Effect of silage extract on voluntary intake, rumen fluid constituents, and rumen motility. Journal of Dairy Science **60:**580-590.

Clark, C. and Wright, V. (**1983**) Effect and reproduction of *Rotylenchulus reniformis* on sweet potato selections. Journal of nematology **15:**197.

Coblentz, W., Coffey, K. and Chow, E. (**2016**) Storage characteristics, nutritive value, and fermentation characteristics of alfalfa packaged in large-round bales and wrapped in stretch film after extended time delays. Journal of Dairy Science **99:**3497-3511.

Colmenero, J.O. and Broderick, G. (**2006**) Effect of dietary crude protein concentration on milk production and nitrogen utilization in lactating dairy cows. Journal of Dairy Science **89:**1704-1712.

Cooper, R. and Hutley, B. (**2010**) Guide to the assessment and analysis of silage for the general practitioner. In Practice **32:**8-15.

Crowder, L.V. and Chheda, H.R. (1982) Tropical Grassland Husbandry, Longman publishers Ltd., London.

Dahniya, M., Hahn, S. and Oputa, C. (**1985**) Effect of shoot removal on shoot and root yields of sweet potato. Experimental Agriculture **21:**183-186.

Davison, T. and Elliott, R. (**1993**) Response of lactating cows to grain-based concentrates in northern Australia. Tropical Grasslands **27:**229-237.

Der Bedrosian, M., Nestor Jr, K. and Kung Jr, L. (**2012**) The effects of hybrid, maturity, and length of storage on the composition and nutritive value of corn silage. Journal of Dairy Science **95:**5115-5126.

Devendra, C. and Leng, R. (**2011**) Feed resources for animals in Asia: issues, strategies for use, intensification and integration for increased productivity. Asian-Australasian Journal of

Animal Sciences **24:**303-321.

Dijkstra, J., Ellis, J.L., Kebreab, E., Strathe, A.B., López, S., France, J. and Bannink, A. (**2012**) Ruminal pH regulation and nutritional consequences of low pH. Animal Feed Science and Technology **172:**22-33.

Dillon, P., Crosse, S. and O'Brien, B. (**1997**) Effect of concentrate supplementation of grazing dairy cows in early lactation on milk production and milk processing quality. Irish journal of agricultural and food research145-159.

Dom, M., Ayalew, W. and Tarabu, J. (**2011**) Effect of blending sweet potato silage with commercial pellet feed or farm made concentrate (fish meal and copra meal) on the performance of local crossbred pigs in Papua New Guinea (PNG). Journal of South Pacific Agriculture **15:**62-70.

Dominguez, P. (**1992**) Feeding of sweet potato to monogastrics. Roots, tubers, plantains and bananas in animal feeding (Editors: D Machin and S Nyvald) FAO: Rome217-233.

Downing, T., Buyserie, A., Gamroth, M. and French, P. (**2008**) Effect of water soluble carbohydrates on fermentation characteristics of ensiled perennial ryegrass. The Professional Animal Scientist **24:**35-39.

Drejer Storm, I., Sorensen, J., Rasmussen, R., Fog Nielsen, K. and Thrane, U. (**2008**) Mycotoxins in silage. Stewart Postharvest Rev **6:**1-12.

Duguma, B. and Janssens, G.P.J. (**2016**) Assessment of feed resources, feeding practices and coping strategies to feed scarcity by smallholder urban dairy producers in Jimma town, Ethiopia. SpringerPlus **5:**717.

Dulphy, J., Remond, B. and Theriez, M. (1980) Ingestive behavior and related activities in ruminants. In Digestive Physiology and Metabolism in Ruminants. MTP press limited, pp. 103-122.

Edmond, J.B. and Ammerman, G.R. (**1971**) Sweet potatoes: Production, processing, marketing. Van Nostrand Reinhold/AVI publishers, New York.

Edmunds, B., Spiekers, H., Südekum, K.H., Nussbaum, H., Schwarz, F. and Bennett, R. (**2014**) Effect of extent and rate of wilting on nitrogen components of grass silage. Grass and Forage Science **69:**140-152.

Elferink, S., Driehuis, F., Gottschal, J.C. and Spoelstra, S.F. (**2000**) Silage fermentation processes and their manipulation. FAO Plant Production and Protection, pp17-30.

Ertl, P., Klocker, H., Hörtenhuber, S., Knaus, W. and Zollitsch, W. (**2015**) The net contribution of dairy production to human food supply: The case of Austrian dairy farms. Agricultural Systems **137:**119-125.

Esan, V. and Omilani, O. (**2018**) Assessment of four sweet potato (*Ipomoea batatas L.)* varieties for adaptability and productivity in Iwo, Osun State. Asian Journal of Agricultural and Horticultural Research1-8.

Etela, I., Bamikole, M., Ikhatua, U. and Kalio, G. (**2008**) Sweet potato and green panic as sole fodder for stall-fed lactating White Fulani cows and growing calves. Tropical Animal Health and Production **40:**117-124.

Etela, I., Larbi, A., Ikhatua, U. and Bamikole, M. (**2009**) Supplementing Guinea grass with fresh sweet potato foliage for milk production by Bunaji and N'Dama cows in early lactation. Livestock Science **120:**87-95.

FAO (2011) Dairy Development in Kenya. Rome, Italy.

Filya, I., Ashbell, G., Hen, Y. and Weinberg, Z. (**2000**) The effect of bacterial inoculants on the fermentation and aerobic stability of whole crop wheat silage. Animal Feed Science and Technology **88:**39-46.

Forbes, J. (**2000**) Physiological and metabolic aspects of feed intake control. Farm animal metabolism and nutrition. Wallingford: CAB International319-334.

Franco, M.O., Detmann, E., Batista, E.D., Rufino, L., Paulino, M.F. and VALADARES, S.C. (**2021**) Nutritional performance and metabolic characteristics of cattle fed tropical forages with protein and starch supplementation. Anais da Academia Brasileira de Ciências **93:**

Frankow-Lindberg, B.E. and Lindberg, J.E. (**2003**) Effect of harvesting interval and defoliation on yield and chemical composition of leaves, stems and tubers of sweet potato (*Ipomoea batatas L. (Lam.))* plant parts. Field Crops Research **82:**49-58.

Fustini, M., Palmonari, A., Canestrari, G., Bonfante, E., Mammi, L., Pacchioli, M., Sniffen, G., Grant, R., Cotanch, K. and Formigoni, A. (**2017**) Effect of undigested neutral detergent fiber content of alfalfa hay on lactating dairy cows: Feeding behavior, fiber digestibility, and lactation performance. Journal of Dairy Science **100:**4475-4483.

Gao, Z., Li, C., Bai, J. and Fu, J. (**2020**) Chinese consumer quality perception and preference of sustainable milk. China Economic Review **59:**100939.

Gebru, H. (**2001**) Role of livestock in food security and food self sufficiency in the Highland production system. Livestock in Food Security–Roles and Contributions **3:**

Gerlach, K., Roß, F., Weiß, K., Büscher, W. and Südekum, K.-H. (**2013**) Changes in maize silage fermentation products during aerobic deterioration and effects on dry matter intake by goats. Agricultural and Food Science **22:**168-181.

Giang, H., Ly, L. and Ogle, B. (**2004**) Evaluation of ensiling methods to preserve sweet potato roots and vines as pig feed. Livestock Research for Rural Development **16:**1-7.

Gibson, R. and Aritua, V. (**2002**) The perspective of sweet potato chlorotic stunt virus in sweetpotato production in Africa: A review. African Crop Science Journal **10:**281-310.

Giridhar, K. and Samireddypalle, A. (2015) Impact of climate change on forage availability for livestock. In 'Climate Change Impact on Livestock: Adaptation and Mitigation.' ISBN: 978-81-322-2264-4, pp. 97-112.

Gomes, A., Jacovaci, F., Bolson, D., Nussio, L., Jobim, C. and Daniel, J. (**2019**) Effects of light wilting and heterolactic inoculant on the formation of volatile organic compounds, fermentative losses and aerobic stability of oat silage. Animal Feed Science and Technology **247:**194-198.

Goopy, J. and Odongo, D. (2017) 'sweet potato silage for better dairy feeding and feed management.' Available at https://www.youtube.com/watch?v=17VMd_jZ09g [Accessed 21/03/2018].

Graham-Rowe, D. (**2011**) Agriculture: Beyond food versus fuel. Nature **474:** S6-S8.

Grainger, C., Wilhelms, G. and McGowan, A. (**1982**) Effect of body condition at calving and level of feeding in early lactation on milk production of dairy cows. Australian Journal of Experimental Agriculture **22:**9-17.

Griggs, T. and Villareal, R.L. (1982) Sweet potato: Proceedings of the First International Symposium. Taipei, TW: Asian Vegetable Research and Development Center.

Guenni, O., Marín, D. and Baruch, Z. (**2002**) Responses to drought of five Brachiaria species. I. Biomass production, leaf growth, root distribution, water use and forage quality. Plant and Soil **243:**229-241.

Gwayumba, W., Christensen, D.A., McKinnon, J.J. and Yu, P. (**2002**) Dry matter intake, digestibility and milk yield by Friesian cows fed two Napier grass varieties. Asian-Australasian Journal of Animal Sciences **15:**516-521.

Hadgu, G.Z., Negesse, T. and Nurfeta, A. (**2015**) Nutritive value of fresh, dried (hay) and ensiled vines of four sweet potato (Ipomoea batatas) varieties grown in southern Ethiopia. Tropical and Subtropical Agroecosystems **18:**195-205.

Haigh, P. and Parker, J. (**1985**) Effect of silage additives and wilting on silage fermentation, digestibility and intake, and on liveweight change of young cattle. Grass and Forage Science **40:**429-436.

Hallada, C., Sapienza, D. and Taysom, D. (**2008**) Effect of length of time ensiled on dry matter, starch and fiber digestibility in whole plant corn silage. J. Dairy Sci **91:**30.

Handford, C.E., Campbell, K. and Elliott, C.T. (**2016**) Impacts of milk fraud on food safety and nutrition with special emphasis on developing countries. Comprehensive Reviews in Food Science and Food Safety **15:**130-142.

Harper, K.J. and McNeill, D.M. (**2015**) The role iNDF in the regulation of feed intake and the importance of its assessment in subtropical ruminant systems (the role of iNDF in the regulation of forage intake). Agriculture **5:**778-790.

Harper, L., Denmead, O., Freney, J. and Byers, F. (**1999**) Direct measurements of methane emissions from grazing and feedlot cattle. Journal of animal science **77:**1392-1401.

Hartinger, T., Gresner, N. and Südekum, K.-H. (**2019**) Effect of Wilting Intensity, Dry Matter Content and Sugar Addition on Nitrogen Fractions in Lucerne Silages. Agriculture **9:**11.

Henderson, N. (**1993**) Silage additives. Animal Feed Science and Technology **45:**35-56.

Herrero, M. and Thornton, P.K. (2013) Livestock and global change: emerging issues for sustainable food systems. Proceedings of the National Academy of Sciences, 110(52): 20878-20881.

Herrero, M., Thornton, P.K., Notenbaert, A.M., Wood, S., Msangi, S., Freeman, H., Bossio, D., Dixon, J., Peters, M. and van de Steeg, J. (**2010**) Smart investments in sustainable food production: revisiting mixed crop-livestock systems. Science **327:**822-825.

Herrmann, C., Heiermann, M. and Idler, C. (**2011**) Effects of ensiling, silage additives and storage period on methane formation of biogas crops. Bioresource Technology **102:**5153-

5161.

Hoffman, P., Esser, N., Shaver, R., Coblentz, W., Scott, M.P., Bodnar, A., Schmidt, R. and Charley, R. (**2011**) Influence of ensiling time and inoculation on alteration of the starch-protein matrix in high-moisture corn. Journal of Dairy Science **94:**2465-2474.

Hoffman, P.C. (**2005**) Ash content of forages. Focus on forage **7:**1-2.

Hong, N., Wanapat, M., Wachirapakorn, C., Pakdee, P. and Rowlinson, P. (**2003**) Effects of timing of initial cutting and subsequent cutting on yields and chemical compositions of cassava hay and its supplementation on lactating dairy cows. Asian Australas. J. Anim. Sci **16:**1763-1769.

Hue, K.T., Do Thi Thanh Van, I.L., Wredle, E. and Spörndly, E. (**2012**) Effect of harvesting frequency, variety and leaf maturity on nutrient composition, hydrogen cyanide content and cassava foliage yield. Asian-Australasian Journal of Animal Sciences **25:**1691.

Huhtanen, P., Nousiainen, J. and Rinne, M. (**2006**) Recent developments in forage evaluation with special reference to practical applications.

Ingvartsen, K.L., Aaes, O. and Andersen, J.B. (**2001**) Effects of pattern of concentrate allocation in the dry period and early lactation on feed intake and lactational performance in dairy cows. Livestock Production Science **71:**207-221.

Issa, E. (2015) Effect of leaf harvest and frequency on growth, yield and quality of sweet potato (*Ipomoea batatas L*.), MSc Thesis, Sokoine University of Agriculture, Tanzania.

Jorgensen, S., Pookpakdi, A., Tudsri, S., Stölen, O., Ortiz, R. and Christiansen, J. (**2010**) Cultivar-by-cutting height interactions in Napier grass (Pennisetum purpureum Schumach) grown in a tropical rain-fed environment. Acta Agriculturae Scandinavica Section B–Soil and Plant Science **60:**199-210.

Kabi, F., Bareeba, F., Havrevoll, Ø. and Mpofu, I. (**2005**) Evaluation of protein degradation characteristics and metabolizable protein of elephant grass (Pennisetum purpureum) and locally available protein supplements. Livestock Production Science **95:**143-153.

Kabirizi, J., Nampijja, Z. and Lutwama, V. A review of sweet potato (Ipomoea batatas) residues as feed resource for ruminants.

Kaiser, Piltz, J.W., Hamilton, J.F. and Havilah, E.J. (**2000**) Effect of time of day on the WSC content of kikuyu grass. FAO: plant production and protection, pp143-146.

Kaiser and Weiss, K. (**1997**) Fermentation process during the ensiling of green forage low in nitrate. 2. Fermentation process after supplementation of nitrate, nitrite, lactic acid bacteria and formic acid. Archiv fur Tierernahrung **50:**187-200.

Kaitibie, S., Omore, A., Rich, K. and Kristjanson, P. (**2010**) Kenyan Dairy Policy Change: Influence Pathways and Economic Impacts. World Development **38:**1494-1505.

Kapinga, R., Ewell, P., Jeremiah, S. and Kileo, R. (**1995**) Sweet potato in Tanzanian fanning and food systems: Implications for research. Development, Tanzania

Kariuki, J., Tamminga, S., Gitau, G., Gachuiri, C. and Muia, J. (**1999**) Performance of Sahiwal and Friesian heifers fed on Napier grass supplemented with graded levels of lucerne. South African Journal of Animal Science **29:**

Kariuki, J.N., Gachuiri, C.K., Gitau, G.K., Tamminga, S., Van Bruchem, J., Muia, J.M.K. and Irungu, K.R.G. (**1998**) Effect of feeding Napier grass, lucerne and sweet potato vines as sole diets to dairy heifers on nutrient intake, weight gain and rumen degradation. Livestock Production Science **55:**13-20.

Karuri, H.W., Olago, D., Neilson, R., Mararo, E. and Villinger, J. (**2017**) A survey of root knot nematodes and resistance to Meloidogyne incognita in sweet potato varieties from Kenyan fields. Crop Protection **92:**114-121.

Kathabwalika, D., Chilembwe, E., Mwale, V., Kambewa, D. and Njoloma, J. (**2013**) Plant growth and yield stability of orange fleshed sweet potato (*Ipomoea batatas*) genotypes in three agro-ecological zones of Malawi. International Research Journal Agricultural Science and Soil Science **3:**383-392.

Kaufman, J., Pohler, K., Mulliniks, J. and Ríus, A. (**2018**) Lowering rumen-degradable and rumen-undegradable protein improved amino acid metabolism and energy utilization in lactating dairy cows exposed to heat stress. Journal of Dairy Science **101:**386-395.

Kaya, S. and Caliskan, M.E. (**2010**) Effects of molasses and ground wheat additions on the quality of groundnut, sweet potato, and Jerusalem artichoke tops silages. African Journal of Agricultural Research **5:**829-833.

KDB (2015) Kenya Dairy Board Annual Report. Available at http://kdb.co.ke/press/publications/reports/21-kdb-2014-annual-report/file.

Kebreab, E., Smith, T., Tanner, J. and Osuji, P. (**2005**) Review of undernutrition in smallholder ruminant production systems in the tropics. Coping with Feed Scarcity in Smallholder Livestock Systems in Developing Countries. Animal Sciences Group, Wageningen UR, Wageningen, The Netherlands3-95.

Kenana, R. (**2016**) Evaluation of yields and nutritive composition of dual purpose sweet potato vine cultivars for forage use.

Kennedy, J., Dillon, P., Faverdin, P., Delaby, L., Buckley, F. and Rath, M. (**2002**) The influence of cow genetic merit for milk production on response to level of concentrate supplementation in a grass-based system. Animal Science **75:**433-445.

Khan, M., Iqbal, Z., Sarwar, M., Nisa, M., Khan, M., Lee, W., Lee, H., Kim, H. and Ki, K. (**2006**) Urea treated corncobs ensiled with or without additives for buffaloes: Ruminal characteristics, digestibility and nitrogen metabolism. Asian australasian journal of animal sciences **19:**705.

Khan, Z., Midega, C., Nyang'au, I., Murage, A., Pittchar, J., Agutu, L., Amudavi, D. and Pickett, J. (**2014**) Farmers' knowledge and perceptions of the stunting disease of Napier grass in Western Kenya. Plant Pathology **63:**1426-1435.

Kidoido, M. and Korir, L. (**2015**) Do low-income households in Tanzania derive income and nutrition benefits from dairy innovation and dairy production? Food Security **7:**681-692.

Kim, J.-M., Park, S.-J., Lee, C.-S., Ren, C., Kim, S.-S. and Shin, M. (**2011**) Functional properties of different Korean sweet potato varieties. Food Science and Biotechnology **20:**1501-1507.

Kim, S. and Adesogan, A. (**2006**) Influence of ensiling temperature, simulated rainfall, and delayed sealing on fermentation characteristics and aerobic stability of corn silage. Journal of Dairy Science **89:**3122-3132.

Kiozya, H., Mtunda, K., Kapinga, R., Chirimi, B. and Rwiza, E. (**2001**) Effect of leaf harvesting frequency on growth and yield of sweet potato in the Lake Zone of Tanzania. African Crop Science Journal **9:**97-101.

Klapwijk, C., Bucagu, C., van Wijk, M.T., Udo, H., Vanlauwe, B., Munyanziza, E. and Giller, K.E. (**2014**) The ‘One cow per poor family’programme: Current and potential fodder availability within smallholder farming systems in southwest Rwanda. Agricultural Systems **131:**11-22.

Kleiber, M. (**1961**) The fire of life. An introduction to animal energetics. The fire of life. An introduction to animal energetics.

Kleinschmit, D. and Kung Jr, L. (**2006**) The effects of Lactobacillus buchneri 40788 and Pediococcus pentosaceus R1094 on the fermentation of corn silage. Journal of Dairy Science **89:**3999-4004.

Kenya National Bureau of Statistics (2010) The 2009 Kenya population and housing census (vol. 1). Kenya National Bureau of Statistics

Köhler, B., Diepolder, M., Ostertag, J., Thurner, S. and Spiekers, H. (**2013**) Dry matter losses of grass, lucerne and maize silages in bunker silos. Agricultural and Food Science **22:**145-150.

Krpálková, L., Cabrera, V.E., Vacek, M., Štípková, M., Stádník, L. and Crump, P. (**2014**) Effect of prepubertal and post pubertal growth and age at first calving on production and reproduction traits during the first 3 lactations in Holstein dairy cattle. Journal of Dairy Science **97:**3017-3027.

Kubkomawa, H., Nafarnda, D., Adamu, S., Tizhe, M., Daniel, T., Shua, N., Ugwu, C., Opara, M., Neils, J. and Okoli, I. (**2013**) Current Approaches to the Determination of Feed Intake and Digestibility in Ruminant Animals-A Review. International Journal of Biosciences, Agriculture and Technology **5:**15-25.

Kung Jr, L., Shaver, R., Grant, R. and Schmidt, R. (**2018**) Silage review: Interpretation of chemical, microbial, and organoleptic components of silages. Journal of Dairy Science **101:**4020-4033.

Kung, L. and Shaver, R. (**2001**) Interpretation and use of silage fermentation analysis reports. Focus on forage **3:**1-5.

Lam, V. (2016) Agricultural potential of sweet potato (*Ipomoea batatas, L. (Lam)*) for forage production. Livestock Research for Rural Development **28 (6)**, Available at http://www.lrrd.org/lrrd28/6/lam28101.html [Accessed 20/11/2017].

Lam, V., Wredle, E., Van Man, N. and Svennersten-Sjaunja, K. (**2010**) Smallholder dairy production in Southern Vietnam: Production, management and milk quality problems. African Journal of Agricultural Research **5:**2668-2675.

Lanyasunya, T., Rong, W., Abdulrazak, S. and Mukisira, E. (**2006a**) Effect of Supplementation on Performance of Calves on Smallholder Dairy Farms in Bahati Division of Nakuru District, Kenya. Pakistan Journal of Nutrition **5:**141-146.

Lanyasunya, T., Wang, H., Mukisira, E., Abdulrazak, S. and Ayako, W. (**2006b**) Effect of seasonality on feed availability, quality and herd performance on smallholder farms in Ol-Joro-Orok Location/Nyandarua District, Kenya. Tropical and Subtropical Agroecosystems **6:**87-93.

Larbi, A., Etela, I., Nwokocha, H., Oji, U., Anyanwu, N., Gbaraneh, L., Anioke, S., Balogun, R. and Muhammad, I. (**2007a**) Fodder and tuber yields, and fodder quality of sweet potato cultivars at different maturity stages in the West African humid forest and savanna zones. Animal Feed Science and Technology **135:**126-138.

Larbi, A., Etela, I., Nwokocha, H., Oji, U., Anyanwu, N., Gbaraneh, L., Anioke, S., Balogun, R. and Muhammad, I. (**2007b**) Fodder and tuber yields, and fodder quality of sweet potato cultivars at different maturity stages in the West African humid forest and savanna zones. Animal Feed Science and Technology **135:**126-138.

Larsen, M.K., Kidmose, U., Kristensen, T., Beaumont, P. and Mortensen, G. (**2013**) Chemical composition and sensory quality of bovine milk as affected by type of forage and proportion of concentrate in the feed ration. Journal of the Science of Food and Agriculture **93:**93-99.

Lättemäe, P. and Lingvall, P. (**1996**) Effect of hexamine and sodium nitrite in combination with sodium benzoate and sodium propionate on fermentation and storage stability of wilted and long cut grass silage. Swedish Journal of Agricultural Research **26:**135-146.

Laudadio, V. and Tufarelli, V. (**2010**) Effects of pelleted total mixed rations with different rumen degradable protein on milk yield and composition of Jonica dairy goat. Small

Ruminant Research **90:**47-52.

Lawrence, D.C., O'Donovan, M., Boland, T.M., Lewis, E. and Kennedy, E. (**2015**) The effect of concentrate feeding amount and feeding strategy on milk production, dry matter intake, and energy partitioning of autumn-calving Holstein-Friesian cows. Journal of Dairy Science **98:**338-348.

Lazzarini, I., Detmann, E., Sampaio, C.B., Paulino, M.F., Valadares Filho, S.d.C., Souza, M.A.d. and Oliveira, F.A. (**2009**) Intake and digestibility in cattle fed low-quality tropical forage and supplemented with nitrogenous compounds. Revista Brasileira de Zootecnia **38:**2021-2030.

Lebot, V. (**2009**) Tropical root and tuber crops: cassava, sweet potato, yams and aroids CAB International publishers. 413p.

León-Velarde, C. (**2000**) Using competing traits to select dual-purpose sweetpotato in native germplasm. International Potato Center (CIP), Lima, Peru289-294.

Linn, J. and Kuehn, C. (1997) 'The effects of forage quality on performance and cost of feeding lactating dairy cows, western Canadian dairy seminar.'

Liu, Q., Wu, J., Dong, Z., Wang, S. and Shao, T. (**2020**) Effects of overnight wilting and additives on the fatty acid profile, α-tocopherol and β-carotene of whole plant oat silages. Animal Feed Science and Technology **260:**114370.

Lounglawan, P., Lounglawan, W. and Suksombat, W. (**2014**) Effect of Cutting Interval and Cutting Height on Yield and Chemical Composition of King Napier Grass (Pennisetum Purpureum x Pennisetum Americanum). APCBEE Procedia **8:**27-31.

Low, Ball, A., Magezi, S., Njoku, J., Mwanga, R., Andrade, M., Tomlins, K., Dove, R. and van Mourik, T. (**2017a**) Sweet potato development and delivery in sub-Saharan Africa. African Journal of Food, Agriculture, Nutrition and Development **17:**11955-11972.

Low, J.W., Mwanga, R.O., Andrade, M., Carey, E. and Ball, A.-M. (**2017b**) Tackling vitamin A deficiency with biofortified sweet potato in sub-Saharan Africa. Global food security **14:**23-30.

Low, J.W., Ortiz, R., Vandamme, E., Andrade, M., Biazin, B. and Grüneberg, W.J. (**2020**) Nutrient-dense orange-fleshed sweet potato: advances in drought-tolerance breeding and understanding of management practices for sustainable next-generation cropping systems in sub-Saharan Africa.

Lugojja, F., Ogenga-Latigo, M. and Smit, N. (**2001**) Impact of defoliation on the agronomic performance of sweetpotato in Uganda. African Crop Science Journal **9:**103-108.

Lukuyu, Franzel, S., Ongadi, P. and Duncan, A.J. (2011a) Livestock feed resources: Current production and management practices in central and northern rift valley provinces of Kenya. Livestock Research for Rural Development **23 (5)**, Available at http://www.lrrd.org/lrrd23/5/luku23112.htm [Accessed 03/06/2018].

Lukuyu, Gachuiri, C., Agili, S., Leon-Velarde, C. and Kirui, J. (Ed. J Low (2012a) 'Making high quality sweet potato silage: An improved tube silage making method.' (International Potato Center: Nairobi, Kenya)

Lukuyu, Kitalyi, A., Franzel, S., Duncan, A.J. and Baltenweck, I. (**2009**) Constraints and options to enhancing production of high quality feeds in dairy production in Kenya, Uganda and Rwanda.

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

Lukuyu, B., Gachuiri, C., Lukuyu, M., Lusweti, C. and Mwendia, S. (2012b) 'Feeding dairy cattle in East Africa.' (East Africa Dairy Development Project: Nairobi, Kenya)

Luyen, L.T. and Preston, T. (**2012**) Growth performance of New Zealand White rabbits fed sweet potato (*Ipomoea batatas*) vines supplemented with paddy rice or Guinea grass supplemented with commercial concentrate. Livestock Research for Rural Development **24:**127.

Ly, N.T., Ngoan, L.D., Verstegen, M.W. and Hendriks, W.H. (**2010**) Ensiled and dry cassava leaves, and sweet potato vines as a protein source in diets for growing Vietnamese Large White× Mong Cai pigs. Asian-Australasian Journal of Animal Sciences **23:**1205-1212.

Mackle, T., Bryant, A., Petch, S., Hill, J. and Auldist, M. (**1999**) Nutritional influences on the composition of milk from cows of different protein phenotypes in New Zealand. Journal of Dairy Science **82:**172-180.

Magcale-Macandog, D., Predo, C., Menz, K. and Predo, A. (**1998**) Napier grass strips and livestock: a bioeconomic analysis. Agroforestry Systems **40:**41-58.

Mahmoud, N., El Zubeir, I. and Fadlelmoula, A. (**2014**) Effect of stage of lactation on milk yield and composition of first kidder Damascus does in the Sudan. Journal of Animal Production. Adv **4:**355-362.

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

Maktabi, H., Ghasemi, E. and Khorvash, M. (**2016**) Effects of substituting grain with forage or nonforage fiber source on growth performance, rumen fermentation, and chewing activity of dairy calves. Animal Feed Science and Technology **221:**70-78.

Maleko, D., Mwilawa, A., Msalya, G., Pasape, L. and Mtei, K. (**2019**) Forage growth, yield and nutritional characteristics of four varieties of Napier grass (*Pennisetum purpureum*

Schumach) in the west Usambara highlands, Tanzania. Scientific African **6:** e00214.

Mannetje (2000) 'Silage making in the tropics with particular emphasis on smallholders. Proceedings of the FAO Electronic Conference on Tropical Silage, 1 September-15 December 1999, Silage making in the tropics with particular emphasis on smallholders. Proceedings of the FAO Electronic Conference on Tropical Silage, 1 September-15 December 1999.'.

Manrique, K. and Hermann, M. (**2002**) Effect of GxE Interaction on Root Yield and Beta-carotene Content of Selected Sweet potato (*Ipomoea batatas (L) Lam*.) Varieties and Breeding Clones.

Mark, Y. and Korpu, M. (**2020**) Effects of severity of apical shoot harvest on growth and tuber yield of two sweet potatoes varieties. African Journal of Plant Science **14:**83-101.

Marković, J.P., Štrbanović, R.T., Terzić, D.V., Djokić, D.J., Simić, A.S., Vrvić, M.M. and Živković, S.P. (**2012**) Changes in lignin structure with maturation of alfalfa leaf and stem in relation to ruminants nutrition. African Journal of Agricultural Research **7:**257-264.

Mattson, W.J. and Addy, N.D. (**1975**) Phytophagous insects as regulators of forest primary production. Science515-522.

Mayberry, D., Ash, A., Prestwidge, D., Godde, C.M., Henderson, B., Duncan, A., Blummel, M., Ramana Reddy, Y. and Herrero, M. (**2017**) Yield gap analyses to estimate attainable bovine milk yields and evaluate options to increase production in Ethiopia and India. Agricultural Systems **155:**43-51.

Mayland, H.F. and Shewmaker, G.E. (**2001**) Animal health problems caused by silicon and other mineral imbalances. Range Management **54:**441-446.

Mburu, L., Wakhungu, J. and Gitu, K. (**2007**) Determinants of smallholder dairy farmers' adoption of various milk marketing channels in Kenya highlands. Livestock Research for Rural Development **19:**9.

McAllister, T. and Hristov, A. (**2000**) The fundamentals of making good quality silage. Advanced Dairy Technology **12:**318-399.

McDermott, J., Staal, S., Freeman, H., Herrero, M. and Van de Steeg, J. (**2010**) Sustaining intensification of smallholder livestock systems in the tropics. Livestock Science **130:**95-109.

McDonald, P. (**1991**) Microorganisms. The biochemistry of silage81-151.

McDonald, P., Henderson, A. and Heron, S. (**1991**) The biochemistry of silage. Chalcombe Publ., Bucks, UK. The biochemistry of silage. 2nd ed. Chalcombe Publ., Bucks, UK.-.

McEniry, J., Forristal, P. and O'Kiely, P. (**2011**) Factors influencing the conservation characteristics of baled and precision-chop grass silages. Irish journal of agricultural and food research175-188.

McEvoy, M., Kennedy, E., Murphy, J.P., Boland, T.M., Delaby, L. and O'Donovan, M. (**2008**) The Effect of Herbage Allowance and Concentrate Supplementation on Milk Production Performance and Dry Matter Intake of Spring-Calving Dairy Cows in Early Lactation. Journal of Dairy Science **91:**1258-1269.

McGarry Wolf, M., Butler, L.J., Martin, A.J. and Foltz, J.D. (**2009**) Factors influencing the purchase decision for milk labelled rBST-free and organic. Journal of Food Distribution Research **40:**187-191.

Mcharo, M. and Ndolo, P. (**2013**) Root-yield performance of pre-release sweet potato genotypes in Kenya. Journal of Applied Biosciences **65:**

McKay, Z.C., Lynch, M.B., Mulligan, F.J., Rajauria, G., Miller, C. and Pierce, K.M. (**2019**) The effect of concentrate supplementation type on milk production, dry matter intake, rumen fermentation, and nitrogen excretion in late-lactation, spring-calving grazing dairy cows. Journal of Dairy Science **102:**5042-5053.

Meeske, R., Basson, H. and Cruywagen, C. (**1999**) The effect of a lactic acid bacterial inoculant with enzymes on the fermentation dynamics, intake and digestibility of *Digitaria eriantha* silage. Animal Feed Science and Technology **81:**237-248.

Meijs, J. (1981) Herbage intake by grazing dairy cows. Wageningen University and Research.

Mertens, D.R. (**1994**) Regulation of forage intake. Forage quality, evaluation, and utilization, pp 450- 493.

Meyreles, L. and Preston, T. (**1977**) Sweet potato forage as cattle feed: effect on voluntary intake of different amounts added to a basal diet of chopped sugar cane stalk. Tropical Animal Production **3:**224-228.

Miron, J., Solomon, R., Adin, G., Nir, U., Nikbachat, M., Yosef, E., Carmi, A., Weinberg, Z.G., Kipnis, T. and Zuckerman, E. (**2006**) Effects of harvest stage and re-growth on yield, composition, ensilage and in vitro digestibility of new forage sorghum varieties. Journal of the Science of Food and Agriculture **86:**140-147.

Mohd-Setapar, S., Abd-Talib, N. and Aziz, R. (**2012**) Review on crucial parameters of silage quality. APCBEE Procedia **3:**99-103.

MoLD (2010) Kenya National Dairy Masterplan Program: A report on situational analysis of the dairy sub-sector. No. 28, Nairobi, Kenya.

Monção, F.P., Oliveira, E., Gabriel, A.d.A., Nascimento, F.d.A., Pedroso, F.W. and Freitas, L.L. (**2016**) Nutritional parameters of leaf blade from different tropical forages. Scientia Agraria Paranaensis **15:**185-193.

Moon, N.J. (**1983**) Inhibition of the growth of acid tolerant yeasts by acetate, lactate and propionate and their synergistic mixtures. Journal of applied Bacteriology **55:**453-460.

Mose, L., Wanyama, J., Lusweti, C., Wanjekeche, E., Rono, C., Wachiye, B. and Mutoko, C. (**2006**) Assessing the impact of sweet potato production and utilisation technologies on food security in North Rift Region.

Muck, R.E. (**2010**) Silage microbiology and its control through additives. Revista Brasileira de Zootecnia **39:**183-191.

Muhlbach, P. (**2000**) Additives to improve the silage making process with tropical forages. FAO plant production and protection papers151-164.

Muia (2000) 'Use of Napier grass to improve smallholder milk production in Kenya.' (sn]:

Muia, J., Kariuki, J., Mbugua, P., Gachuiri, C., Lukibisi, L., Ayako, W. and Ngunjiri, W. (**2011a**) Smallholder dairy production in high altitude Nyandarua milk-shed in Kenya: Status, challenges and opportunities. Livestock Research for Rural Development **23:**2011.

Muia, J., Kariuki, J., PN, M., Gachuiri, C., Lukibisi, L., Ayako, W. and Ngunjiri, W. (**2011b**) Smallholder dairy production in high altitude Nyandarua milk-shed in Kenya: status, challenges and opportunities. Livestock Research for Rural Development **23:**9-14.

Mulungu, L.S., Mwailana, D.J., Reuben, S.S., Tarimo, J.A., Massawe, A.W. and Makundi, R.H. (**2006**) Evaluation on the effect of topping frequency on yield of two contrasting sweet potato (Ipomoea batatas L.) genotypes. Journal of Applied Sciences **6:**1132-1137.

Muriuki, H. (**2011**) Dairy development in Kenya. Food and Agricultural Organization, Rome

Mushtaque, M., Ishaque, M. and Ahamd, M. (**2010**) Growth and herbage yield of Setaria sphacelata grass in response to varying clipping stages. JAPS, Journal of Animal and Plant Sciences **20:**261-265.

Mutavi, S.K., Kanui, T.I., Njarui, D., Musimba, N. and Amwata, D.A. (**2016**) Innovativeness and adaptations: the way forward for small scale peri-urban dairy farmers in semi-arid regions of south eastern Kenya.

Mutsvangwa, T., Davies, K., McKinnon, J. and Christensen, D. (**2016**) Effects of dietary crude protein and rumen-degradable protein concentrations on urea recycling, nitrogen balance, omasal nutrient flow, and milk production in dairy cows. Journal of Dairy Science **99:**6298-6310.

Mwendia, S., Wanyoike, M., Wahome, R. and Mwangi, D. (**2006**) Farmers' perceptions on importance and constraints facing Napier grass production in Central Kenya.

Mwololo, J., Mburu, M. and Muturi, P. (**2012**) Performance of sweet potato varieties across environments in Kenya. International Journal of Agronomy and Agricultural Research **2:**1-11.

Negawo, A.T., Teshome, A., Kumar, A., Hanson, J. and Jones, C.S. (**2017**) Opportunities for Napier Grass (Pennisetum purpureum) Improvement Using Molecular Genetics. Agronomy **7:**28.

Ng'ang'a, S., Kungu, J., Ridder, N.d. and Herrero, M. (**2010**) Profit efficiency among Kenyan smallholder milk producers: A case study of Meru-South district, Kenya.

Ngailo, S., Mtunda, K., Shimelis, H.A. and Sibiya, J. (**2016**) Assessment of sweet potato farming systems, production constraints and breeding priorities in eastern Tanzania. South African Journal of Plant and Soil **33:**105-112.

Nguyen, T., Ngoan, L., Bosch, G., Verstegen, M. and Hendriks, W. (**2012**) Ileal and total tract apparent crude protein and amino acid digestibility of ensiled and dried cassava leaves and sweet potato vines in growing pigs. Animal Feed Science and Technology **172:**171-179.

Ni, K., Wang, F., Zhu, B., Yang, J., Zhou, G., Pan, Y., Tao, Y. and Zhong, J. (**2017**) Effects of lactic acid bacteria and molasses additives on the microbial community and fermentation quality of soybean silage. Bioresource Technology **238:**706-715.

Nishino, N., Li, Y., Wang, C. and Parvin, S. (**2012**) Effects of wilting and molasses addition on fermentation and bacterial community in guinea grass silage. Letters in applied microbiology **54:**175-181.

Njarui, D., Gatheru, M., Wambua, J., Nguluu, S., Mwangi, D. and Keya, G. (**2011a**) Feeding management for dairy cattle in smallholder farming systems of semi-arid tropical Kenya. Livestock Research for Rural Development **23:**

Njarui, D., Gichangi, E., Gatheru, M., Nyamabti, E., Ondiko, C., Njunie, M., Ndungu-Magiroi, K., Kiiya, C., Kute, C. and Ayako, W. (**2016a**) A comparative analysis of livestock farming in smallholder mixed crop-livestock systems in Kenya: 1. Livestock inventory and management. Livestock Research for Rural Development **28:**16-20.

Njarui, D., Gichangi, E., Gatheru, M., Nyambati, E., Ondiko, C., Njunie, M., Ndungu-Magiroi, K., Kiiya, W., Kute, C. and Ayako, W. (**2016b**) A comparative analysis of livestock farming in smallholder mixed crop-livestock systems in Kenya: 1. Livestock inventory and management. Livestock Research for Rural Development **28:**

Njarui, D.M.G., Gatheru, M., Wambua, J.M., Nguluu, S.N., Mwangi, D.M. and Keya, G.A. (**2011b**) Consumption Patterns and Preference of Milk and Milk Products among Rural and Urban Consumers in Semi-Arid Kenya. Ecology of Food and Nutrition **50:**240-262.

Norton, B. and Poppi, D. (**1995**) Composition and nutritional attributes of pasture legumes.

Nwinyi, S. (**1992**) Effect of age at shoot removal on tuber and shoot yields at harvest of five sweet potato (*Ipomoea batatas (L.) Lam*) cultivars. Field Crops Research **29:**47-54.

Nyaata, O.Z., Dorward, P.T., Keatinge, J.D.H. and O'Neill, M.K. (**2000**) Availability and use of dry season feed resources on smallholder dairy farms in central Kenya. Agroforestry Systems **50:**315-331.

Nyambati, E.M., Muyekho, F.N., Onginjo, E. and Lusweti, C.M. (**2010**) Production, characterization and nutritional quality of Napier grass [*Pennisetum purpureum (Schum*.)] cultivars in Western Kenya. African Journal of Plant Science **4:**496-502.

O'brien, P.J. (**1972**) The sweet potato: its origin and dispersal. American anthropologist **74:**342-365.

Odero-Waitituh, J. (**2017**) Smallholder dairy production in Kenya; a review. Livestock Research for Rural Development **29:**139-142.

Oladosu, Y., Rafii, M.Y., Abdullah, N., Magaji, U., Hussin, G., Ramli, A. and Miah, G. (**2016**) Fermentation quality and additives: a case of rice straw silage. BioMed research international **2016:**

Olorunnisomo, O. (**2007**) Yield and quality of sweet potato forage pruned at different intervals for West African dwarf sheep. Livestock Research for Rural Development **19:**32-41.

Oltenacu, P.A. and Broom, D.M. (**2010**) The impact of genetic selection for increased milk yield on the welfare of dairy cows. Animal welfare **19:**39-49.

Ongadi, P., Wahome, R., Wakhungu, J. and Okitoi, L. (**2010**) Modeling the influence of existing feeding strategies on performance of grade dairy cattle in Vihiga, Kenya. Livestock Research for Rural Development **22:**56.

Onyalo, P.O. (**2019**) Women and agriculture in rural Kenya: role in agricultural production. International Journal of Humanities and Social Science **4:**1-10.

Owusu, D., Ellis, W.O. and Oduro, I. (**2008**) Nutritional potential of two leafy vegetables: Moringa oleifera and Ipomoea batatas leaves. Scientific Research and Essay **3:**057-060.

Pahlow, G., E. Muck, R., Driehuis, F., Oude Elferink, S. and Spoelstra, S.F. (2003) 'Microbiology of Ensiling.'

Palmonari, A., Cavallini, D., Sniffen, C., Fernandes, L., Holder, P., Fagioli, L., Fusaro, I., Biagi, G., Formigoni, A. and Mammi, L. (**2020**) Characterization of molasses chemical composition. Journal of Dairy Science **103:**6244-6249.

Paradiso, R., Arena, C., Rouphael, Y., d'Aquino, L., Makris, K., Vitaglione, P. and De Pascale, S. (**2019**) Growth, photosynthetic activity and tuber quality of two potato cultivars in controlled environment as affected by light source. Plant Biosystems-An International Journal Dealing with all Aspects of Plant Biology **153:**725-735.

Pedrosa, C.E., Andrade Júnior, V.C., Pereira, R.C., Dornas, M.F., Azevedo, A.M. and Ferreira, M.A. (**2015**) Yield and quality of wilted sweet potato vines and its silages. Horticultura Brasileira **33:**283-289.

Pena, K.d.S., Nascimento Júnior, D.d., Silva, S.C.d., Euclides, V.P.B. and Zanine, A.d.M. (**2009**) Características morfogênicas, estruturais e acúmulo de forragem do capim-tanzânia submetido a duas alturas e três intervalos de corte. Revista Brasileira de Zootecnia **38:**2127-2136.

Pereira, R.C., Dornas, M.F.S., Ribeiro, K.G., de Souza, I.A., Agarussi, M.C.N., da Silva, V.P., de Andrade Junior, V.C. and Pereira, O.G. (**2021**) Nutritive value, fermentation profile and effluent loss in sweet potato vine silage, with or without microbial inoculant. Grassland Science **67:**41-47.

Pérez, R. and Fujita, T. (1997) 'Feeding pigs in the tropics.' (FAO), Italy, Rome

Peters, D. (**2008**) Assessment of the potential of sweet potato as livestock feed in East Africa: Rwanda, Uganda, and Kenya. A report presented to The International Potato Center (CIP) in Nairobi 64.

Peters, D., Tinh, N.T. and Thach, P.N. (**2002**) Sweet potato root silage for efficient and labor-saving pig raising in Vietnam. AGRIPA. Rome, Italy: Food and Agriculture Organization. Retrieved from *www. fao. org/docrep/article/agrippa/554_en. htm* on November **23:**2002.

Phesatcha, K. and Wanapat, M. (**2016**) Improvement of nutritive value and in vitro ruminal fermentation of Leucaena silage by molasses and urea supplementation. Asian-Australasian Journal of Animal Sciences **29:**1136.

Phuc, B.H.N. and Lindberg, J. (**2001**) Ileal apparent digestibility of amino acids in growing pigs given a cassava root meal diet with inclusion of cassava leaves, leucaena leaves and groundnut foliage. Animal Science **72:**511-517.

Piltz, J. and Law, D. (**2007**) AFIA-laboratory methods manual. Australian Fodder Industry Association Inc, Balwyn Google Scholar

Pinares-Patiño, C., Holmes, C., Lassey, K. and Ulyatt, M. (**2008**) Measurement of methane emission from sheep by the sulphur hexafluoride tracer technique and by the calorimetric chamber: failure and success. Animal **2:**141-148.

Pitt, R. and Muck, R. (**1993**) A diffusion model of aerobic deterioration at the exposed face of bunker silos. Journal of Agricultural Engineering Research **55:**11-26.

Placide, R., Shimelis, H., Laing, M. and Gahakwa, D. (**2015**) Farmers' perceptions, production and productivity constraints, preferences, and breeding priorities of sweet potato in Rwanda. HortScience **50:**36-43.

Preston, T., Carcano, C., Alvarez, P. and Gutierrez, D. (**1976**) Rice polishings as a supplement in a sugar cane diet: effect of level of rice polishings and of processing the sugar cane by deriding or chopping. Tropical Animal Production **1:**150-163.

Ray, R.C. and Ravi, V. (**2005**) Post Harvest Spoilage of Sweet potato in Tropics and Control Measures. Critical Reviews in Food Science and Nutrition **45:**623-644.

Rees, D.V.H. (**1982**) The aerobic deterioration of grass silage and its effect on the water-soluble carbohydrate and the associated heat production. Journal of the Science of Food and Agriculture **33:**499-508.

Riaz, M., Südekum, K.-H., Clauss, M. and Jayanegara, A. (**2014**) Voluntary feed intake and digestibility of four domestic ruminant species as influenced by dietary constituents: A meta-analysis. Livestock Science **162:**76-85.

Richards, S., VanLeeuwen, J., Shepelo, G., Gitau, G.K., Kamunde, C., Uehlinger, F. and Wichtel, J. (**2015**) Associations of farm management practices with annual milk sales on smallholder dairy farms in Kenya. Vet World **8:**88-96.

Richards, S., VanLeeuwen, J.A., Shepelo, G., Gitau, G.K., Wichtel, J., Kamunde, C. and Uehlinger, F. (**2016**) Randomized controlled trial on impacts of dairy meal feeding interventions on early lactation milk production in smallholder dairy farms of Central Kenya. Preventive Veterinary Medicine **125:**46-53.

Roche, J.R. (**2007**) Milk production responses to pre-and post-calving dry matter intake in grazing dairy cows. Livestock Science **110:**12-24.

Roche, J.R., Heiser, A., Mitchell, M.D., Crookenden, M.A., Walker, C.G., Kay, J.K., Riboni, M.V., Loor, J.J. and Meier, S. (**2017**) Strategies to gain body condition score in pasture-based dairy cows during late lactation and the far-off nonlactating period and their interaction with close-up dry matter intake. Journal of Dairy Science **100:**1720-1738.

Root, C. (**2010**) Sweet Potato Technical Manual. Caribbean Agricultural Research and Development **4:**976-978.

Rose, I.M. and Vasanthakaalam, H. (**2011**) Comparison of the nutrient composition of four sweet potato varieties cultivated in Rwanda. American journal of food and nutrition **1:**34-38.

Rotz, C.A. (2003) 'How to maintain forage quality during harvest and storage, Western Canadian Dairy Seminar.'

Safayi, S. and Nielsen, M.O. (**2013**) Intravenous supplementation of acetate, glucose or essential amino acids to an energy and protein deficient diet in lactating dairy goats: Effects on milk production and mammary nutrient extraction. Small Ruminant Research **112:**162-173.

Salehi, S., Lashkari, S., ABBASI, R.E. and KAMANGAR, H. (**2014**) Nutrient digestibility and chemical composition of potato (*Solanum tuberosum L.*) vine as alternative forage in ruminant diets. Agricultural Communications **2:**63-66.

Samková, E., Špička, J., Pešek, M., Pelikánová, T. and Hanuš, O. (**2012**) Animal factors affecting fatty acid composition of cow milk fat: A review. South African Journal of Animal Science **42:**83-100.

Sampaio, C.B., Detmann, E., Paulino, M.F., Valadares Filho, S.C., de Souza, M.A., Lazzarini, I., Paulino, P.V.R. and de Queiroz, A.C. (**2010a**) Intake and digestibility in cattle fed low-quality tropical forage and supplemented with nitrogenous compounds. Tropical Animal Health and Production **42:**1471-1479.

Sampaio, C.B., Detmann, E., Paulino, M.F., Valadares Filho, S.C., de Souza, M.A., Lazzarini, I., Rodrigues Paulino, P.V. and de Queiroz, A.C. (**2010b**) Intake and digestibility in cattle fed low-quality tropical forage and supplemented with nitrogenous compounds. Tropical Animal Health and Production **42:**1471-1479.

Santos, Santos, J., Theurer, C. and Huber, J. (**1998**) Effects of rumen-undegradable protein on dairy cow performance: A 12-year literature review1. Journal of Dairy Science **81:**3182-3213.

Santos, A., Ávila, C. and Schwan, R.F. (**2013**) Selection of tropical lactic acid bacteria for enhancing the quality of maize silage. Journal of Dairy Science **96:**7777-7789.

Santos, J.E.P. and De Vries, A. (**2019**) The Value of Milk Fat. EDIS **2019:**

Santos, M., Castro, A.G., Perea, J., García, A., Guim, A. and Hernández, M.P. (**2010**)

Fatores que afetam o valor nutritivo da silagens de forrageiras tropicais. Archivos de Zootecnia **59:**25-43.

Saricicek, B.Z., Yildirim, B., Kocabas, Z. and Demil, E.Ö. (**2016**) The effects of storage time on nutrient composition and silage quality parameters of corn silage made in plastic mini silo in laboratory conditions. Journal of the Institute of Science and Technology **6:**177-183.

Scott, G. (**1992**) Sweet potatoes as animal feed in developing countries: present patterns and future prospects. Roots, tubers, plantains and bananas in animal feeding. FAO, Rome, Italy **3:**13-98.

Sheahan, A.J., Gibbs, S.J. and Roche, J.R. (**2013**) Timing of supplementation alters grazing behavior and milk production response in dairy cows. Journal of Dairy Science **96:**477-483.

Sheehy, M.R., Fahey, A.G., Aungier, S.P.M., Carter, F., Crowe, M.A. and Mulligan, F.J. (**2017**) A comparison of serum metabolic and production profiles of dairy cows that maintained or lost body condition 15 days before calving. Journal of Dairy Science **100:**536-547.

Smith (2002) Some tools to combat dry season nutritional stress in ruminants under African conditions.

Smith, J., Sones, K., Grace, D., MacMillan, S., Tarawali, S. and Herrero, M. (**2013**) Beyond milk, meat, and eggs: Role of livestock in food and nutrition security. Animal Frontiers **3:**6-13.

Souza, M.A., Detmann, E., Paulino, M.F., Sampaio, C.B., Lazzarini, Í. and Valadares Filho, S.C. (**2010**) Intake, digestibility and rumen dynamics of neutral detergent fibre in cattle fed low-quality tropical forage and supplemented with nitrogen and/or starch. Tropical

Animal Health and Production **42:**1299-1310.

Spoelstra, S., Courtin, M. and Van Beers, J. (**1988**) Acetic acid bacteria can initiate aerobic deterioration of whole crop maize silage. The Journal of Agricultural Science **111:**127-132.

Stark, B.A. and Wilkinson, J.M. (1988) 'Proceedings of a conference on silage effluent-problems and solutions, Conference on Silage Effluents-Problems and Solutions. Staffordshire (UK). 2 Feb 1988.'.

Stathers, T., Bechoff, A., Sindi, K., Low, J. and Ndyetabula, D., (2013). Everything you ever wanted to know about sweetpotato: Reaching agents of change ToT manual. 5: Harvesting and postharvest management, processing and utilisation, marketing and entrepreneurship.

Stathers, T., Namanda, S., Mwanga, R., Khisa, G. and Kapinga, R. (**2005**) Manual for sweet potato integrated production and pest management farmer field schools in sub- Saharan Africa.

Steinfeld, H., Gerber, P., Wassenaar, T., Castel, V., Rosales, M., Rosales, M. and de Haan, C. (2006) 'Livestock's long shadow: environmental issues and options.' FAO

Sterk, A., Johansson, B., Taweel, H., Murphy, M., Van Vuuren, A., Hendriks, W. and Dijkstra, J. (**2011**) Effects of forage type, forage to concentrate ratio, and crushed linseed supplementation on milk fatty acid profile in lactating dairy cows. Journal of Dairy Science **94:**6078-6091.

Stobbs, T. (**1973**) The effect of plant structure on the intake of tropical pastures. I. Variation in the bite size of grazing cattle. Australian Journal of Agricultural Research **24:**809-819.

Stockdale, C. (**2000**) Levels of pasture substitution when concentrates are fed to grazing dairy cows in northern Victoria. Australian Journal of Experimental Agriculture **40:**913-921.

Sun, H., Mu, T., Xi, L., Zhang, M. and Chen, J. (**2014**) Sweet potato (*Ipomoea batatas L.*) leaves as nutritional and functional foods. Food Chemistry **156:**380-389.

Sutton, Bines, J., Morant, S., Napper, D. and Givens, D. (**1987**) A comparison of starchy and fibrous concentrates for milk production, energy utilization and hay intake by Friesian cows. The Journal of Agricultural Science **109:**375-386.

Sylvester, T.R. (2010) An evaluation of the effects of two different inoculants on the quality of potato hash silage for grower pigs. Central University of Technology, Free State.

Syomiti, M., Wanyoike, M., Wahome, R. and Kuria, J. (**2011**) The status of maize stover utilization as feed for livestock in Kiambu and Thika districts of Kenya: Constraints and opportunities. Animal Science Journal **8:**9-13.

Taboada, A., Novo-Uzal, E., Flores, G., Loureda, M., Ros Barcelo, A., Masa, A. and Pomar, F. (**2010**) Digestibility of silages in relation to their hydroxycinnamic acid content and lignin composition. Journal of the Science of Food and Agriculture **90:**1155-1162.

Tafaj, M., Junck, B., Maulbetsch, A., Steingass, H., Piepho, H.P. and Drochner, W. (**2004**) Digesta characteristics of dorsal, middle and ventral rumen of cows fed with different hay qualities and concentrate levels. Archives of Animal Nutrition **58:**325-342.

Tan, S., Aziz, A.A., Zaharah, A., Salma, O. and Khatijah, I. (**2007**) Selection of sweetpotato clones with high ß-carotene for processing of nutritious food products. Journal of Tropical Agriculture and Food Science **35:**213-220.

Team, R.C. (**2013**) R: A language and environment for statistical computing.

Tekce, E. and Gül, M. (**2014**) Ruminant beslemede NDF ve ADF'nin önemi. Atatürk Üniversitesi Veteriner Bilimleri Dergisi **9:**63-73.

Terry, E.R., Akoroda, M. and Arene, O. (1986) Tropical root crops: root crops and the African food crisis, proceedings, 3rd Triennial Symposium of the International Society for Tropical Root Crops. 17-23 August Owerri, Nigeria.

Tessema, Z., Mihret, J. and Solomon, M. (**2010a**) Effect of defoliation frequency and cutting height on growth, dry-matter yield and nutritive value of Napier grass (*Pennisetum purpureum (L.) Schumach*). Grass and Forage Science **65:**421-430.

Tessema, Z.K., Mihret, J. and Solomon, M. (**2010b**) Effect of defoliation frequency and cutting height on growth, dry-matter yield and nutritive value of Napier grass (*Pennisetum purpureum (L.) Schumach*). Grass and Forage Science **65:**421-430.

Thorpe, W., Muriuki, H., Omore, A., Owango, M. and Staal, S. (2000) Dairy development in Kenya: the past, the present and the future. In 'Annual symposium of the animal production society of Kenya, March 22-23, 2000. KARI headquarters, Nairobi'.

Throat, S., Gupta, R., Shankhpal, S. and Parnerkar, S. (**2016**) Effect of Supplementing Formaldehyde Treated Rape Seed Meal on Milk Production, Gross Milk Composition, Digestibility of Nutrients and Feed Conversion Efficiency in High Producing Crossbred Cows. Livestock Research International **4:**68-74.

Titterton, M., Maasdorp, B., Mhere, O., Mugweni, B. and Nyomi, L. (**2004**) The production of high quality silage from adapted forage and legume crops for the maintenance of dairy cow productivity on smallholder farms through the dry season in the semi-arid region in Zimbabwe. Final Technical Report. 130 pp.

Tolera, A., Merkel, R.C., Goetsch, A.L., Tilahun, S. and Negesse, T. (2000) 'Nutritional constraints and future prospects for goat production in East Africa, The Opportunities and Challenges of Enhancing Goat Production in East Africa. A conference held at Awassa College of Agriculture, Debub University.'

Tomlinson, A., Powers, W., Van Horn, H., Nordstedt, R. and Wilcox, C. (**1996**) Dietary protein effects on nitrogen excretion and manure characteristics of lactating cows.

Transactions of the ASAE **39:**1441-1448.

Treacher, R., Reid, I. and Roberts, C. (**1986**) Effect of body condition at calving on the health and performance of dairy cows. Animal Science **43:**1-6.

Tsou, S.C. and Hong, T.-L. (1989) 'Digestibility of sweet potato starch, Improvement of Sweet Potato (*Ipomoea Batatas*) in Asia: Report of the" Workshop on Sweet Potato Improvement in Asia," Held at ICAR, Trivandrum, India... October 24-28, 1988.' (International Potato Center:

Turano, B., Tiwari, U.P. and Jha, R. (**2016**) Growth and nutritional evaluation of Napier grass hybrids as forage for ruminants. Tropical Grasslands-Forrajes Tropicales **4:**168-178.

Tyasi, T.L., Gxasheka, M. and Tlabela, C. (**2015**) Assessing the effect of nutrition on milk composition of dairy cows: A review. International Journal of Current Science **17:**56-63.

Van Soest, P. (**1965**) Symposium on factors influencing the voluntary intake of herbage by ruminants: voluntary intake in relation to chemical composition and digestibility. Journal of animal science **24:**834-843.

VanLeeuwen, J.A., Mellish, T., Walton, C., Kaniaru, A., Gitau, R., Mellish, K., Maina, B. and Wichtel, J. (**2012**) Management, productivity and livelihood effects on Kenyan smallholder dairy farms from interventions addressing animal health and nutrition and milk quality. Tropical Animal Health and Production **44:**231-238.

Viana, D.J.S., Andrade Júnior, V.C.d., Ribeiro, K.G., Pinto, N.A.V.D., Neiva, I.P., Figueiredo, J.A., Lemos, V.T., Pedrosa, C.E. and Azevedo, A.M. (**2011**) Potential of silages of sweet potato foliages for animal feeding. Ciência Rural **41:**1466-1471.

Wachirapakorn, C., Pilachai, K., Wanapat, M., Pakdee, P. and Cherdthong, A. (**2016**)

Effect of ground corn cobs as a fiber source in total mixed ration on feed intake, milk yield and milk composition in tropical lactating crossbred Holstein cows. Animal Nutrition **2:**334-338.

Waldo, D. (**1986**) Effect of forage quality on intake and forage-concentrate interactions. Journal of Dairy Science **69:**617-631.

Wambugu, S., Kirimi, L. and Opiyo, J. (**2011a**) Productivity trends and performance of dairy farming Kenya. Tegemeo Institute of Agricultural Policy and Development **43:**11-15.

Wambugu, S., Kirimi, L. and Opiyo, J. (2011b) A report on Productivity trends and performance of dairy farming in Kenya. Tegemeo Institute of Agricultural Policy and Development, Nairobi, Kenya.

Wanapat (**2009**) Potential uses of local feed resources for ruminants. Tropical Animal Health and Production **41:**1035-1049.

Wanapat and Kang, S. (**2015**) Cassava chip (*Manihot esculenta Crantz*) as an energy source for ruminant feeding. Animal Nutrition **1:**266-270.

Weber, C., Hametner, C., Tuchscherer, A., Losand, B., Kanitz, E., Otten, W., Singh, S.P., Bruckmaier, R.M., Becker, F., Kanitz, W. and Hammon, H.M. (**2013**) Variation in fat mobilization during early lactation differently affects feed intake, body condition, and lipid and glucose metabolism in high-yielding dairy cows. Journal of Dairy Science **96:**165-180.

Weigel, K. (**2004**) Exploring the role of sexed semen in dairy production systems. Journal of Dairy Science **87:** E120-E130.

Weinberg and Ashbell, G. (**2003**) Engineering aspects of ensiling. Biochemical Engineering Journal **13:**181-188.

Weinberg and Muck, R. (**1996**) New trends and opportunities in the development and use of inoculants for silage. FEMS Microbiology Reviews **19:**53-68.

Weinberg, Z., Khanal, P., Yildiz, C., Chen, Y. and Arieli, A. (**2010**) Effects of stage of maturity at harvest, wilting and LAB inoculant on aerobic stability of wheat silages. Animal Feed Science and Technology **158:**29-35.

Welter, S.C. (**1993**) Responses of plants to insects: eco-physiological insights. International crop science I773-778.

Whiter, A. and Kung Jr, L. (**2001**) The effect of a dry or liquid application of Lactobacillus plantarum MTD1 on the fermentation of alfalfa silage. Journal of Dairy Science **84:**2195-2202.

Wickersham, T., Titgemeyer, E., Cochran, R., Wickersham, E. and Gnad, D. (**2008**) Effect of rumen-degradable intake protein supplementation on urea kinetics and microbial use of recycled urea in steers consuming low-quality forage. Journal of animal science **86:**3079-3088.

Widodo, Y., Wahyuningsih, S. and Ueda, A. (**2015**) Sweet Potato Production for Bio-ethanol and Food Related Industry in Indonesia: Challenges for Sustainability. Procedia Chemistry **14:**493-500.

Wijitphan, S., Lorwilai, P. and Arkaseang, C. (**2009**) Effect of cutting heights on productivity and quality of King Napier grass (*Pennisetum purpureum* CV King Grass) under irrigation. Pakistan Journal of Nutrition **8:**1244-1250.

Wilkins, R. (2005) 'Silage: a global perspective.' (Science Publisher Inc.: Enfield, NH, USA:

Wilson, J. and Wong, C. (**1982**) Effects of shade on some factors influencing nutritive quality of green panic and siratro pastures. Australian Journal of Agricultural Research **33:**937-949.

Wolf, C.A. (**2012**) Dairy farmer use of price risk management tools. Journal of Dairy Science **95:**4176-4183.

Woodward, S., Chaves, A., Waghorn, G. and Laboyrie, P. (2002) 'Supplementing pasture-fed dairy cows with pasture silage, maize silage, Lotus silage or sulla silage in summer. Proceedings of the New Zealand Grassland Association.'

Woolfe, J.A. (1992) 'Sweet potato: an untapped food resource.' (Cambridge University Press:

Yahaya, M., Kawai, M., Takahashi, J. and Matsuoka, S. (**2002**) The effects of different moisture content and ensiling time on silo degradation of structural carbohydrate of orchardgrass. Asian-Australasian Journal of Animal Sciences **15:**213-217.

Yamamoto, Y., Gaudu, P. and Gruss, A. (**2011**) Oxidative stress and oxygen metabolism in lactic acid bacteria. Lactic Acid Bacteria and Bifidobacteria: Current Progress in Advanced Research 91-102.

Yearsley, J., Tolkamp, B.J. and Illius, A.W. (**2001**) Theoretical developments in the study and prediction of food intake. Proceedings of the Nutrition Society **60:**145-156.

Yeng, S., Agyarko, K., Dapaah, H., Adomako, W. and Asare, E. (**2012**) Growth and yield of sweet potato (*Ipomoea batatas L.*) as influenced by integrated application of chicken manure and inorganic fertilizer. African Journal of Agricultural Research **7:**5387-5395.

Yitbarek, M.B. and Tamir, B. (**2014**) Silage additives. Open Journal of Applied Sciences **2014:**

Yooyongwech, S., Samphumphuang, T., Tisarum, R., Theerawitaya, C. and Cha-Um, S. (**2017**) Water-Deficit Tolerance in Sweet Potato [*Ipomoea batatas (L.) Lam*.] by Foliar

Application of Paclobutrazol: Role of Soluble Sugar and Free Proline. Frontiers in plant science **8:**1400.

Yuan, X., Guo, G., Wen, A., Desta, S.T., Wang, J., Wang, Y. and Shao, T. (**2015**) The effect of different additives on the fermentation quality, in vitro digestibility and aerobic stability of a total mixed ration silage. Animal Feed Science and Technology **207:**41-50.

Zailan, M., Yaakub, H. and Jusoh, S. (**2018**) Yield and nutritive quality of Napier (Pennisetum purpureum) cultivars as fresh and ensiled fodder. The Journal of Animal and Plant Sciences **28:**63-72.

Zereu, G., Negesse, T. and Nurfeta, A. (**2014**) Chemical composition and in vitro dry matter digestibility of vines and roots of four sweet potato (*Ipomoea batatas*) varieties grown in southern Ethiopia. Tropical and Subtropical Agroecosystems **17:**547-555.

Zewdu, T. (**2005**) Variation in growth, yield, chemical composition and in vitro dry matter digestibility of Napier grass accessions (Pennisetum purpureum). Tropical Science **45:**67-73.

Zewdu, T. and Baars, R.M.T. (**2003**) Effect of cutting height of Napier grass on rumen degradation and in vitro dry matter digestibility. Tropical Science **43:**125-131.

Zheng, Y., Yates, M., Aung, H., Cheng, Y.-S., Yu, C., Guo, H., Zhang, R., VanderGheynst, J. and Jenkins, B.M. (**2011**) Influence of moisture content on microbial activity and silage quality during ensilage of food processing residues. Bioprocess and biosystems engineering **34:**987-995.

Zhu, W., Wei, Z., Xu, N., Yang, F., Yoon, I., Chung, Y., Liu, J. and Wang, J. (**2017**) Effects of Saccharomyces cerevisiae fermentation products on performance and rumen fermentation and microbiota in dairy cows fed a diet containing low quality forage. Journal of Animal Science and Biotechnology **8:**36.