EVALUATION OF FORAGE SWEET POTATO CULTIVARS AS FEED FOR RUMINANTS

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DECLARATION AND RECOMMENDATION

I declare that this thesis is my original work and has not been presented for the award of a degree in any other university.

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DEDICATION

To God be the glory! Great things He hath done!
So loved He the world that He gave us His Son,
Who yielded His life an atonement for sin,
And opened the life-gate that all may go in.

> ***Praise the Lord! Praise the Lord!***
> ***Let the earth hear His voice!***
> ***Praise the Lord! Praise the Lord!***
> ***Let the people rejoice!***
> ***Oh, come to the Father, through Jesus the Son:***
> ***And give Him the glory! Great things He has done!***

Oh perfect redemption, the purchase of blood!
To every believer the promise of God;
The vilest offender who truly believes,
That moment from Jesus a pardon receives.

Great things He hath taught us, great things He hath done,
And great the rejoicing through Jesus the Son:
But purer and higher and greater will be
Our wonder, our transport, when Jesus we see!

Scripture Union (2004). Golden Bells, Hymn: 36

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"Be ye strong therefore, and let not your hands be weak: for your work shall be rewarded" II Chronicles 15:7. King James Version.

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF PLATES

ABBREVIATIONS AND ACRONYMS

ADF	Acid detergent fibre
ADG	Average daily gain
ADL	Acid detergent lignin
ANOVA	Analysis of variance
AOAC	Association of Official Analytical Chemists
ARC	Australian Research Council
BA	Butyric acid
BF	Butter fat
CH_4	Methane
CIP	International Potato Reseach Centre
CP	Crude protein
CRD	Completely randomised design
DM	Dry matter
FAOSTAT	Food and Agriculture Organisation Statistics
FCE	Feed conversion efficiency
GLM	General linear model
GE	Gross energy
IVOMD	*in vitro* organic matter digestibility
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
LSD	Least significant difference
ME	Metabolisable energy
mg	Milligramme
MP	Microbial protein
NDF	Neutral detergent fibre
NH_3-N	Ammonia nitrogen
OM	Organic matter
OMD	Organic matter digestibility

PF	Partition factor
PRF	Protein-rich forage
RCBD	Randomised complete block design
SCFA	Short-chain fatty acids
SAS	Statistical Analysis System
SNF	Solids not-fat
SPCSV	Sweet potato chlorotic stunt virus
SPFMV	Sweet potato feathery mottle virus
SPVD	Sweet potato virus disease
SSA	Sub-Sahara Africa
TA	Total acidity
TS	Total solids
VFA	Volatile fatty acids
WSC	Water soluble carbohydrates

ABSTRACT

There is potential in Kenya to utilize forage sweet potato (*Ipomoea batatas* (L) Lam) cultivars as livestock feed. There are many cultivars of forage sweet potato in Kenya whose feeding values have not been evaluated. The objectives of the current study were: 1) evaluate forage sweet potato cultivars for crude protein (CP) yield and digestibility at different harvesting ages, 2) evaluate their conservation potential as silage or hay and 3) determine sheep growth performance and goat milk yield when fed on these cultivars. Cultivars K158, Marooko and Wagabolige recorded high CP yield (1597-1679 kg/ha) and digestibility (711-851 g/kg DM) at the four harvesting ages and their optimum content of dry matter (DM) (166-168), organic matter (OM) (880-882) and CP (170-171 g/kg DM) was at 120 days. Using weighted scoring method K158, Marooko and Wagabolige (scoring 21-24) were ranked the three most superior forage cultivars and were recommended for further evaluation. Calcium (Ca) (4.40-8.41), magnesium (Mg) (3.20-5.15), phosphorus (P) (31.01-37.38), potassium (K) (11.80-25.01), sodium (Na) (4.31-8.75 g/kg DM); cobalt (Co) (247.2-252.6), copper (Cu) (22.7-56.6), iron (Fe) (278.0-326.3), manganese (Mn) (116.2-217.4) and zinc (Zn) (136.4-180.8 mg/kg DM) in all the cultivars decreased with age. For the conservation using silage, the 5% molasses rate provided adequate water soluble carbohydrates for optimal silage fermentation (pH 4.0). Marooko (NH_3-H, 5.5) fermented the best quality silage followed by K158 (6.4) then Wagabolige (6.6 % of total N). Shredding increased DM (298.8-306.2) in all the cultivars and Wagabolige dried more rapidly (330.2) than K158 (310.0) and Marooko (263 g/kg DM) when dried whole or shredded. These cultivars differed in CP (156.8-170.4), neutral detergen fibre (NDF) (373.0-397.1), acid detergen fibre (ADF) (280.3-283.4), acid detergen lignin (ADL) (85.0-117.1 g/kg DM) and there were minimal losses due to spoilage and crop respiration during hay making. These cultivars had similar DM (93.8-98.1), OM (82.0-85.6) and NDF (37.6-38.8 g/kg $W^{0.75}$) intake, DM (740.3-744.1) and OM (747.0-751.7 g/kg DM) digestibility and rumen fermentation characteristics (pH 6.80-6.86). The cultivars differed in CP (10.7-16.9 g/kg $W^{0.75}$) and metabolizable energy (ME) (0.94-0.99 MJ/kg $W^{0.75}$) intake, CP digestibility (737.4-821.1 g/kg DM) and nitrogen balance in sheep (2.7-4.5 g/day). Cultivars K158, Marooko and Wagabolige provided high ME (9.7-10.2 MJ/kg DM), recorded superior intake of digestible OM (74.5-75.8), CP (13.8-16.1) and NDF (27.4-30.8 g/kg $W^{0.75}$). Sheep fed

on these cultivars attained average daily gain (ADG) and feed efficiency (FCE) beyond 143.0 g and 13.0 kg which were considered high. Cultivar K158 had the highest ME (10.2 MJ/kg DM) and ME (1.17 MJ/kg $W^{0.75}$) intake in goats. These cultivars affected the milk yield and composition, digestibility of CP (750.0-826.1) and NDF (627.4-680.9 g/kg DM), their gross (17.6-19.5) and digestible intake (13.8-16.1 g/kg $W^{0.75}$) by goats but did not affect the rumen fermentation characteristics. The goat daily milk yield was 680, 585 and 492 g when fed on K158, Marooko and Wagabolige, respectively. The goats fed on K158 produced milk containing high butter fat (BF) (35.7), protein (44.7), lactose (53.9), solid non-fat (SNF) (108.9 g/kg) and freezing point depression (-0.63^{o}C) and goats fed on the test cultivars differed in milk total solids (TS) (107.4-141.2 g/kg). According to milk yield, the cultivars ranking in descending order was K158, Marooko and Wagabolige but according to milk composition qualities the rank was K158, Wagabolige and Marooko respectively. Cultivars K158, Marooko and Wagabolige yielded high CP and recorded high digestibility and should be harvested at 120 days to maintain high nutritive quality. Silage making using 5% molasses was the suitable conservation method as hay making was unsuccessful. The ADG and feed efficiency were similar for the sheep on cultivars K158, Marooko and Wagabolige indicating that any one of them was recommended to feed growing sheep. Among the three forage sweet potato cultivar evaluated in the current study, K158 was the most suitable to feed dairy goats. These cultivars have a potential as feed resource for ruminants in Kenya.

CHAPTER 1

GENERAL INTRODUCTION

1.1. Background information

Sweet potatoes (*Ipomoea batatas* (L) Lam) are grown for human consumption in many parts of the world. The world's production is estimated at 107 million metric tonnes of which 94% and 5% of the total production is in Asia and Africa, respectively (FAOSTAT, 2011). The remaining production mainly comes from Latin America. China alone produces more than 75% of the world's sweet potatoes. In Asia, over 50% of sweet potato produced is fed to livestock (Scott, 1992; Woolfe, 1992), while those produced in Africa are mainly for human consumption (Scott, 1992; Gichuki *et al.*, 2005; Olorunnisomo, 2007a). In Kenya, 760,000 tonnes of sweet potatoes are produced annually mainly for household consumption (Wheatley and Loechl, 2008). Approximately 75% of the sweet potatoes produced in Kenya are grown in the Lake Victoria basin in Western Kenya, 20 and 5% in the Central Highlands and Rift Valley areas of Kenya, respectively (Kihurani, 2004).

In terms of composition, sweet potatoes contain carbohydrates, crude protein, minerals and vitamins (Grüneberg *et al.*, 2005; Andrade *et al.*, 2009). Currently, the orange-fleshed varieties are being promoted in Sub-Sahara Africa (SSA) as a means of combating wide spread vitamin A deficiency that causes blindness in young children (Jaarsveld *et al.*, 2005; Low *et al.*, 2007). The young and tender green leaves of sweet potato are consumed by humans as a vegetable in many places (Ishinda *et al.*, 2000; Ishiguro *et al.*, 2004; Wheatley and Loechl, 2008).

Sweet potatoes are adapted to small scale production and grow well under different farming conditions in the world (Wheatley and Loechl, 2008; Andrade *et al.*, 2009; Claessens *et al.*, 2009). They efficiently utilize solar radiation better than wheat, rice and cassava which are common staple food in the tropics (Ramirez, 1992). Yields can be increased by over 40% without additional fertilizer and pesticide use but through better cultural practices (Andrade *et al.*, 2009).

There are over 500 accessions cultivated in Kenya with characteristic genetic variability from which superior cultivars can be selected (Karachi, 1982a; Gichuki *et al.,* 2005; Oggema *et al.,* 2007). These cultivars can broadly be classified into those that predominantly produce roots, dual purpose and forage types (Karachi, 1982a; Semenye *et al.,* 1989; Larbi *et al.,* 2007). The dual purpose varieties have the potential to be integrated into an efficient crop-livestock production system in Kenya (Karachi, 1982a, b; Semenye *et al.,* 1989; Snijders *et al.,* 1992).

Furthermore, to provide livestock with feeds from forage cultivars of sweet potato all year, conservation of these cultivars into hay and silage is essential and needs to be explored. Hay and silage are means of preserving important nutrients thus enabling livestock farmers to avail highly nutritious diets to their livestock throughout the year leading to improved animal production performance. Available literature shows that there are few studies on forage cultivars of sweet potato in Eastern Africa (Ondabu *et al.,* 2007; Peters, 2008; Wheatley and Loechl, 2008).

Most often, available roughages in Kenya are of low quality as they contain high fibre and/or low protein, especially, in the dry season and hence cannot sustain high livestock performance (Gitau *et al.,* 1994; Kariuki, 1998). The problem is compounded by seasonal variation in quality and quantity of fodder due to the unpredictable weather conditions, poor soil fertility and poor cultural practices. As a result, inadequate nutrition is a major limitation to livestock productivity in Kenya (Ouda *et al.,* 2001; Kiragu *et al.,* 2003; Ilatsia *et al.,* 2007).

1.2. Statement of the problem

A major challenge facing livestock production in Kenya, particularly in low rainfall areas, is the seasonal variation in terms of quality and quantity of available forages, particulary the natural pasture, as it is influenced by seasonality of rainfall. The growth and abundance of forage increases at the onset of the rains and trails off to little or no growth at the height of the dry season. The quality of the forages decreases with age and rainfall. This seasonality of forage production causes surplus production during wet season leading to wastage and huge deficit during dry season. To even out this seasonal forage availability and quality, there is need to undertake forage conservation into silage and hay (Kaiser *et al.,* 2000; Pitz *et al.,* 2000; Suttie, 2000).

The deterioration in the quality of roughages in terms of protein and energy content and digestibility during the dry season means that it cannot sustain high livestock production performance. Protein in particular, is expensive in Kenya and is known to be a major limiting nutrient in all livestock production systems. Sweet potato forage is rich in protein just like leguminous forage and is well adapted to small scale production and grows well under many farming conditions. Therefore, there is potential in Kenya to utilize sweet potato forage as cheap protein source to improve livestock production performance either as sole feed or as a protein supplement to poor quality roughages such as cereal crop residues. However, there is little documentation on the management and even nutritive value of many forage cultivars of sweet potato available in Kenya. Besides, most of the available information is old and is on a few unimproved cultivars, harvested at late age and evaluated in regions which have different climatic conditions to those prevailing in Kenya (Olorunnisomo, 2007a, b; Kebede *et al.*, 2008). Consequently, it is not easy to make reliable feeding recommendations on forage sweet potato to livestock farmers in Kenya. It is, therefore, important to generate new information on selected cultivars of forage sweet potato at an earlier stage of maturity. In recent years, Kenya Agricultural and Livestock Research Organization (KALRO) in collaboration with International Potato Research Centre (CIP) has introduced new cultivars of sweet potatoes. Though various agronomic studies have been conducted, not much has been studied in terms of their feeding value including conservation potential as silage or hay.

About 1.2 million tonnes of fresh vines are produced annually in Kenya during a short root harvest period (Kihurani, 2004; Rono *et al.,* 2006). Forage (leaf, petiole and stem) contribute about 64 % of total biomass in root cultivars of sweet potatoes (Khalid *et al.,* 2013). To ensure availability of good quality feeds throughout the year, conservation of forage sweet potato into silage or hay is essential. Unfortunately, the biological processes that occur in these forages during conservation as silage or hay are not adequately documented. For example, the effect of the relatively low DM content in forage cultivars on the fermentation quality of the silage is unclear. The most suitable DM content in silage material is known to range between 20 to 30% DM. In addition, low DM in these cultivars can cause loss of valuable soluble nutrients through silage effluent that affects the amount of water soluble carbohydrates (WSC) that is available to enable sufficient fermentation and lower the buffering capacity of the crop. Silages

from tropical forages generally tend to have low WSC and high buffering capacity that cause increased silage pH leading to poor silage fermentation. Despite the existence of these knowledge gaps some of these cultivars are already being used by livestock farmers in the field. For example, a survey conducted in Trans Nzoia County (Kenya) by Rono *et al.* (2006) found that over 78 percent of sampled farmers fed sweet potato forage to their livestock. There is, therefore, need to provide scientific data on yield and nutritive values of the recently identified sweet potato forage cultivars with a view to enhancing their exploitation as livestock feed.

1.3. Objectives of the study

1.3.1. Broad objective

To evaluate the feeding value and conservation potential of forage sweet potato cultivars for ruminants.

1.3.2. Specific objectives

These were:

(i) To evaluate new forage cultivars of sweet potato for DM and CP yield and *in vitro* digestibility in order to select three most superior cultivars.

(ii) To determine the effect of harvesting age on chemical composition of selected new forage cultivars of sweet potato.

(iii) To evaluate the conservation potential as silage or hay of selected new forage cultivars of sweet potato.

(iv) To determine the *in vivo* digestibility, rumen fermentation characteristics, nutrient intake and growth rate of sheep fed on selected new forage cultivars of sweet potato.

(v) To determine the nutrient intake, milk yield and milk composition of dairy goats fed on selected new forage cultivars of sweet potato.

1.4 Hypotheses: The following null hypotheses (**H_0**) were postulated:-

(i) The new forage cultivars of sweet potato have similar DM and CP yield and *in vitro* digestibility.

(ii) The harvesting age has no effect on the chemical composition of selected forage cultivars of sweet potato.

(iii) The conservation potential as silage or hay of the selected new forage cultivars of sweet potato is similar.

(iv) There is no difference in nutrient intake, *in vivo* digestibility, rumen fermentation characteristics and growth rate of sheep fed on selected new superior forage cultivars of sweet potato.

(v) There is no difference in nutrient intake, milk yield and milk composition of dairy goats fed on selected new cultivars of sweet potato.

1.5 Justification

Although superior new forage cultivars have been identified and evaluated through agronomic studies, their conservation potential, nutritive value as ruminant feed and potential in stimulating livestock production performance, including nutrient intake, growth and milk yield have not been adequately evaluated and documented in Kenya. The current study is intended to evaluate the nutritive value of new selected forage cultivars of sweet potato as ruminant feed and thus contribute to this knowledge gap. Furthermore, the biological processes that occur in these cultivars during conservation as silage or hay have not been well studied and documented. The recommendations derived from this study will greatly assist the farmers since sweet potatoes are well adapted to small scale production and grow well under different farming conditions. This will increase utilization of forage sweet potato and the diversity of forages available to them, reduce seasonality of forage quality and quantity availability thereby leading to improved livestock performance, regular supply of animal products and increased household income.

1.6 Outputs

(i) Superior forage cultivars of sweet potato identified.

(ii) The nutritive value of superior forage cultivars of sweet potato determined and documented.

(iii) The potential for conservation, as silage or hay, of selected superior forage cultivars of sweet potato evaluated and documented.

(iv) The performance of sheep and goats fed on selected new superior forage cultivars of sweet potato determined and reported.

(v) Results of the study presented in workshops, conferences and symposia and also published in peer reviewed journals.

(vi) PhD Thesis.

CHAPTER 2

GENERAL LITERATURE REVIEW

2.1. Classification of sweet potato cultivars

Sweet potato cultivars can broadly be classified into root, dual purpose and forage producing types (Karachi, 1982a; Semenye *et al.,* 1989; Larbi *et al.,* 2007). The dual purpose varieties have the potential to be integrated into an efficient mixed crop-livestock production system in Kenya (Karachi, 1982a; Semenye *et al.,* 1989; Claessens *et al.,* 2009). The various forage sweet potato varieties are suitable for livestock feeding (Karachi, 1982a, b; Semenye *et al.,* 1989; Snijders *et al.,* 1992). Indeed, sweet potato forage has been identified as protein-rich forage (PRF) thus putting it in the same category as leguminous forages such as desmodium and lucerne.

2.2. Variation in DM yield of forage sweet potato

2.2.1. Cultivars

There are three categories of sweet potato cultivars: those that produce high tonnage of roots that are used mainly for human consumption, dual purpose cultivars that produce both roots and heavy foliage and forage types which produce heavy foliage (Karachi, 1982a, b; Irungu *et al.,* 2000; Larbi *et al.,* 2007). The forage cultivars yielded high DM and are therefore suitable as livestock feed. There is, however, scarcity in published data on forage cultivars of sweet potato as research has concentrated on improvement of sweet potato root yield and quality for human consumption (Kihurani, 2004; Grüneberg *et al.,* 2005; Andrade *et al.,* 2009).

Some forage cultivars of sweet potato establish slowly in their early stages of growth but thereafter spread rapidly and accumulate a lot of DM (Kinyua, 2013). Other cultivars have rapid initial growth rate and maintain high DM accumulation rate throughout their uninterrupted growth period (Larbi *et al.,* 2007; Olorunnisomo, 2007a, b). Additionally, some cultivars grow slowly and have a poor persistence which results in poor forage DM yield throughout their growth cycle. Kinyua (2013) studied establishment and dry matter yield of six sweet potato varieties. At a site called Lelechwet in Nandi County, cultivars Kemb 23 and Kemb 36 spread

rapidly after harvesting and yielded 3.5 and 3.7 t DM at 150 days. Gweri had an intial slow start and afterwards yielded the highest DM (5.0 t) (Kinyua, 2013). Cultivar 103001 recorded slow growth throughout the study leading to the lowest DM yield (0.8 t). This variation in DM yield among forage cultivars has been reported elsewhere (KARI, 1990; Grüneberg *et al.*, 2005; Larbi *et al.*, 2007).

High DM yield recorded in sweet potato under water stress conditions may be an indication of efficient water use hence better drought tolerance (Chowdhury and Naskar, 1993; Kelm *et al.,* 2000; Grüneberg *et al.,* 2005). Snijders *et al.* (1992) also reported an increase in DM yield with age caused by an accompanying rise in DM content due to accumulation in the proportion of dead leaves. Again, DM content tended to increase during the dry season due to dehydration and deliberate wilting after harvest by the farmer, likewise causing an increase in vine DM. Some forage cultivars of sweet potato can withstand frequent harvest with resultant increase in cumulative yield (Larbi *et al.,* 2007; Olorunnisomo, 2007a, b). Additional studies are needed if the goal in sweet potato cultivation is both high forage yield and important nutritional traits are to be achieved (Grüneberg *et al.,* 2005; Andrade *et al.,* 2009). Kinyua (2013) and Niyireeba *et al.* (2013a) contributed to this goal by selecting dual purpose sweet potato varieties under varying harvesting regimes and different altitudes in Kenya and Rwanda, respectively.

2.2.2. Agronomic conditions

Sweet potatoes are grown in the highlands of Sub-Saharan Africa (SSA) that are up to 2,200 m above sea level and with night temperatures close to 5°C (Andrade *et al.,* 2009). Usually sweet potato responds to cold tropical highlands by partitioning nutrients towards increased forage DM production and reduced storage root production. However, there are many genotypes that have been observed to yield storage roots in the cold tropical highland environment at 2,700 m above sea level (Andrade *et al.,* 2009).

Climatic factors, especially rainfall and temperature, cause differences in growth rate of sweet potatoes and the subsequent DM yield (Grüneberg *et al.,* 2005; Larbi *et al.*, 2007; Andrade *et al.,* 2009). For example, Irungu et al. (2000) grew cultivar Kemb 10 at different sites in Kenya including Embu, Kakamega and Muguga and obtained significantly different forage yields of 8.4, 5.4 and 4.9 tonnes DM/ha respectively, perhaps due to rainfall, temperature and elevation

differences (Oggema *et al.,* 2007). Larbi et al. (2007) working in two zones in West Africa also reported variations in yield and optimal harvesting age among 18 sweet potato cultivars. During the dry season, DM content tends to increase due to dehydration while favourable moisture regime causes rapid growth with the resultant foliage having low DM content (Snijders *et al.,* 1992; Kiragu and Tamminga 1997; Larbi *et al.,* 2007).

The genetic basis of adaptation of sweet potato to drought stress is largely not well elucidated. In SSA there is low practice of sweet potato as an irrigated crop (Andrade *et al.,* 2009). Differences in response of various genotypes in irrigated and non-irrigated experiments appeared to be correlated with the ability for deep rooting and extensive development of the root system in the early stage. Relative water content (Chowdhury and Naskar, 1993) and water use efficiency (Kelm *et al.,* 2000) appeared to be other important traits that enable sweet potato to adapt to drought. There is a need to develop eco-zone specific recommendations for suitable genotype, depending on expected use and management regimes (Kinyua, 2013; Nyiriba *et al.,* 2013a, b).

2.2.3. Harvesting interval, fertilization, tillage and weeding

Management regimes such as harvesting interval, fertilization and weeding affect DM yield. Snijders *et al.* (1992) showed a significant leaf loss with prolonged harvesting interval and an increase in the proportion of stem to leaf from a cutting interval of 120 to 180 days. These factors will contribute to reduced DM yield especially, with early maturing sweet potato cultivars. For example, tuber producing cultivars are harvested within 150 days after establishment having lost a substantial proportion of photosynthetic leaves (Irungu *et al.,* 2000). This variation in DM yield among cultivars with extended harvesting interval has also been reported by other researchers (KARI, 1990; Larbi *et al.,* 2007; Olorunnisomo, 2007a, b). The increased DM yield is due to the fact that increased cutting interval gave plants sufficient time to recover. Too frequent defoliation, however, disrupts the photosynthetic process and therefore affects recovery and overall DM yield. These factors enable the forage cultivars of sweet potato to continue accumulating DM while early maturing tuber producing cultivars have reduced DM yield (Snijders *et al.,* 1992). The forage cultivars of sweet potato hence partition DM accumulation to favour leaf production (Snijders *et al.,* 1992; Olorunnisomo, 2007a, b). Also, an

increased number of harvests per year generally increases DM yield annually (An *et al.,* 2003; Larbi *et al.*, 2007; Olorunnisomo, 2007a, b), provided the harvesting interval allows the cultivars adequate recovery period.

Sweet potato adapts well to marginal soil fertility conditions, allowing farmers flexibility on how they incorporate the crop into their farming system. Most farmers do not apply manure or inorganic fertilizer in sweet potato cultivation (Gichuki *et al.,* 2005; Andrade *et al.,* 2009). The crop can take advantage of residual moisture and fertility following the harvest of the main crop in the rotation. Hence, it has been reported that soil type, previous crop and nitrogen fertilization to previous crop influenced yield (Andrade *et al.,* 2009). Sweet potato clones exhibited higher storage root and biomass yields at high nitrogen application compared with no fertilization (Kelm *et al.,* 2000; Grüneberg *et al.,* 2005). Nitrogen fertilization resulted in increased above ground biomass with subsequent decreased harvest indices. Olorunnisomo (2007a, b) reported 39% increase in DM yield of sweet potato forage due to fertilizer application. When the effects of good tillage were combined with those of fertilizer application, the yield increased by 76% thus indicating the importance of both practices in sweet potato forage cultivation.

Generally, sweet potato is considered a low input crop and apart from an initial weeding and earthing-up, little major field work is invested in the crop (Andrade *et al.,* 2009; Claessens et al., 2009; Kebede *et al.,* 2011). The short maturity period and quick ground cover may obviate much weeding. However, Olorunnisomo (2007a) reported that the yield of sweet potato forage increased when tillage or fertilizer was applied and there was a 20% and 39% increase in yield of the forage when the experimental plots were only tilled or only fertilized, respectively. Combined tillage and fertilizer application increased sweet potato forage DM yield by 76% which suggested that fertilizer application had a greater influence than tillage on DM yield in sweet potato. Additionally, untilled plots were invaded by weeds more frequently than tilled plots necessitating weeding thrice compared to twice for tilled plots.

2.2.4. Diseases and pests

The humid, low and mid-elevation regions with very short dry seasons tend to have high incidences of sweet potato virus disease (SPVD) pressure. The SPVD complex caused by mixed

infection of sweet potato feathery mottle virus (SPFMV) and sweet potato chlorotic stunt virus (SPCSV) is by far the most destructive viral disease of sweet potatoes causing yield losses of up to 50% (Carey *et al.,* 1999). The development of new sweet potato varieties with resistance to SPVD will result in significantly higher yields. Farmers normally use cuttings from their previous crop as planting material making the control of the disease difficult (Karyeija *et al.,* 1998). Furthermore, it is difficult for farmers to identify infected plants as reported by Njeru *et al.* (2006) who observed that 83% of symptomatic plants and 31% of asymptomatic plants were virus infected and with mixed infections common in symptomatic plants but not so in asymptomatic plants.

Sweet potato weevils are another cause of yield losses. Three main economically important sweet potato weevils: *Cylas formicarius* which occurs globally, while *C. puncticollis* and *C. brunneus* are the main species common in Africa (Odongo *et al.,* 2003). The most damaging stage of weevils is the larval stage. The larvae mainly attack stems and underground parts, although they may also feed on leaves. Adult weevils oviposit in the bases of vines and in exposed roots, while the larvae tunnel through storage roots causing major economic losses (Odongo *et al.,* 2003). The damage caused by larvae and adults also stimulates the production of toxins which make the storage roots unhealthy for human consumption (Odongo *et al.,* 2003). Weevil population and damage is most prevalent during dry seasons as drought increases soil cracking, thus exposing roots to weevils. However, the severity of weevil damage will vary with the variety, planting method, time of planting, crop age and crop management (Maling'a *et al.,* 2002).

2.3. Chemical composition of forage cultivars of sweet potato

Intensification of livestock production requires high yielding and nutritious forages. For example, high DM and OM intake is essential to provide adequate metabolizable energy to ruminants (Preston and Leng, 1987). Preston and Leng (1987) also showed that the DM content in a feed is positively correlated with its OM content. Nutritionally high quality forages should contain more than 80 g CP/kg DM and over 7.5 MJ ME/kg DM below which forages are classified as low quality (Leng, 1990). Above this threshold, rumen microbial activities are stimulated due to the availability of rumen degradable nitrogen (Van Soest, 1994) thus making

such forage nutritious to ruminants. Crude protein is therefore an important indicator of quality of livestock feeds. Besides, the forage NDF content should be at least 150 g/kg DM for growing ruminants (Strasia and Gill 1990), and generally below 600 g/kg DM beyond which a feed is classified as poor quality (Meissner *et al.,* 1991). Hence, it is essential to review the causes of variation in chemical composition in forage cultivars of sweet potato and rank them on their suitability as ruminant diets.

2.3.1. Causes of variation in chemical composition

2.3.1.1. Site, plant part and age

Sweet potato growth site, season of growth and harvesting age affect its chemical composition. The effect of cultivation site is mainly due to climatic factors, especially elevation, rainfall, temperature and soil type (Grüneberg *et al.,* 2005; Larbi *et al.,* 2007; Andrade *et al.,* 2009). During the dry season, DM content tends to increase due to dehydration while favourable moisture regime causes rapid growth with the resultant foliage having low DM content (Snijders *et al.,* 1992; Kiragu and Tamminga 1997; Larbi *et al.,* 2007).

The sweet potato part (leaf, petiole or stem) will also influence the composition (An et al., 2003; Aregheore, 2003; Ngyen and Ogle, 2005). Orodho *et al.* (1993) and Akinrinde (2006) separated sweet potato forage into leaf, petiole, stem and the whole plant. The petiole contained the highest concentration of calcium and potassium followed by the leaf blade. The stem and the whole plant had similar concentration of calcium and potassium. Snijders *et al.* (1992) showed a decrease in photosynthetic leaves and increase in dead leaves as forage sweet potato aged. Young leaves are rich in nutrients while old leaves have low protein and contain high fibre (Snijders *et al.,* 1992; Olorunnisomo, 2007b; Akinrinde, 2006). The forage sweet potato cultivars have an optimum harvesting age and beyond this age, leaf senescence occurred and their quality deteriorated (Snijders *et al.,* 1992).

An increase in DM content may be due to maturation whereas low DM content may indicate that the sweet potato was at vegetative growth (Snijders *et al.,* 1992; Kiragu and Tamminga, 1997; Larbi *et al.,* 2007). According to Snijders *et al.* (1992) and Kiragu and Tamminga (1997), as the ash content in sweet potato forage decreased with age, the OM content increased. Therefore, low OM content may indicate that the sweet potato forage cultivars were at

a vegetative stage and at the early stage of growth. The CP content of sweet potato forage is high at young vegetative stage through nutrient apportioning in favour of protein accumulation (An *et al.,* 2003; Ondabu *et al.,* 2005; Larbi *et al.,* 2007) and declines with extended cutting intervals. This is due to increased age (Snijders *et al.,* 1992; Kiragu and Tamminga 1997; Olorunnisomo, 2007b). However, variation in CP may indicate that the forage cultivars responded differently to extended cutting interval (An *et al.,* 2003; Larbi *et al.,* 2007). Hence, short cutting intervals are preferable for some cultivars particularly those with a high and quick regeneration potential but longer cutting interval is recommended for others (Snijders *et al.,* 1992; Larbi *et al.,* 2007; Olorunnisomo, 2007b).

2.3.1.2. Fertilization

Among the majority of the communities in SSA, sweet potato root is a major staple crop hence its use as livestock feed is limited and sweet potato forage although valuable as forage for livestock is usually left on the field as a residue after root harvest (Olorunnisomo, 2007a, b; Mutandwa, 2008; Kebede *et al.,* 2011). Most available reports recorded yield as fresh weight as the interest was to calculate total biomass yield and in cases where planting material increase was the research area, vine length was reported (Gichuki *et al.,* 2005). Such limitation in information may be due to low investments in sweet potato breeding to select cultivars that respond to fertilization (Gibson *et al.,* 2008; Andrade *et al.,* 2009). As sweet potato breeding uses multi-trait selection procedures which cause reduction in progress on individual trait improvement (Grüneberg *et al.,* 2005; Andrade *et al.,* 2009), priority work has concentrated on root yield, its DM and nutrient content (Gichuki *et al.,* 2005; Mutandwa, 2008; Andrade *et al.,* 2009). However, Grüneberg *et al.* (2005) did not record any fertilizer rate effect on DM content of sweet potato clones whereas Snijders *et al.* (1992) reported an insignificant increase in CP with increased fertilizer rate. It seems, therefore, that nitrogen fertilization increases total DM yield without significantly affecting CP content.

2.3.1.3. Cultivars

Dry matter, Organic matter and Crude protein

The cultivar composition may be attributed to their genetic differences (Sinjders *et al.*, 1992; Ngyen and Ogle, 2005; Olorunnisomo, 2007b). The composition can be within close range as reported by researchers in Kenya (Kariuki, *et al.*, 1998; Ondabu *et al.*, 2005; Kiragu *et al.*, 2007) and in Nigeria (Olorunnisomo, 2007b).

The DM content of sweet potato forage ranges from 114 to 209 g/kg DM (Chhay *et al.*, 2007; Olorunnisomo, 2007b; Kebede *et al.*, 2008). The variation in DM content depended on the cultivar and the stage of maturity (Snijders *et al.*, 1992; Kiragu and Tamminga, 1997; Larbi *et al.*, 2007). Kiragu and Tamminga (1997) showed that DM content increased from 12 to 24 weeks. Snijders *et al.* (1992) reported a significant leaf loss, decreased photosynthetic leaf and an increase in the proportion of stem to leaf with prolonged cutting interval causing increased fibre. The content of DM in forages is positively correlated with its OM content (Preston and Leng, 1987). The OM in sweet potato forage ranges from 861.0 to 890 g/kg DM (Farrell *et al.*, 2000; Iyeghe-Erakpotobor *et al.*, 2006; Chhay *et al.*, 2007). High OM is essential to provide adequate metabolizable energy for ruminants (Preston and Leng, 1987).

The CP content of sweet potato forage ranges from 107 to 267 g CP/kg DM (Giang *et al.*, 2004; Lam and Ledin, 2004; Kiragu *et al.*, 2007). The sweet potato forage is nutritionally good quality forage as it contains more than 80 g CP/kg DM below which forages are classified as low quality (Leng, 1990; Ondabu *et al.*, 2005). Above this threshold CP content, rumen microbial activities are stimulated (Van Soest, 1994), thus making such forages of better feeding value. In fact, sweet potato forage has been used widely in Kenya as feed for livestock either as sole feed (Semenye *et al.*, 1989; Orodho *et al.*, 1993; Kariuki *et al.*, 1998) or in othert parts of the world as protein supplements to poor quality roughages such as cereal crop residues **(**Wilman *et al.*, 1999; Kebede *et al.*, 2008).

Neutral Detergent Fibre, Acid Detergent Fibre and Acid Detergent Lignin

The sweet potato forage has adequate fibre measured as neutral detergent fibre (NDF). Dietary fibre is essential for rumination, saliva flow, rumen buffering and health of rumen wall

(Fox *et al.,* 1992). Suitable forages for growing ruminants should contain NDF at more than 150 g/kg DM and below 600 g/kg DM as beyond this value, feed is classified as poor quality (Strasia and Gill, 1990; Meissner *et al.,* 1991). The NDF content of sweet potato forage ranges from 346 to 490 g/kg DM (Dominquez and Ly, 1997; Farrell *et al.,* 2000; Ontiti *et al.,* 2000). Likewise, Giang et al. (2004), Ouda *et al.* (2004) and Lam and Ledin (2004) and more recently Olorunnisomo (2007a, b) and Kebede et al. (2008) have recorded similar values. However, their values were lower than those reported by Snijders *et al.* (1992) (392-412 g/kg DM), Kariuki *et al.* (1998) (506 g/kg DM) and Kiragu *et al.* (2007) (502 g/kg DM) under irrigated conditions. The differences observed may be due to age at harvest, cultivar used and a site effect. Olorunnisomo, (2007a, b) reported that sweet potato forage maintained a relatively constant NDF with increased harvesting interval. The low NDF content was consistent with the general observation of lower NDF content in non-grass fodders (Minson, 1990). Nonetheless, all sweet potato cultivars had NDF content within the recommended range of 150 to 600 g/kg for growing ruminants (Strasia and Gill, 1990; Meissner *et al.,* 1991).

The ADF in sweet potato forage ranges from 199 to 372 g/kg DM (Kariuki, *et al.,* 1998; Ontiti *et al.,* 2000; An *et al.,* 2005). The reported sweet potato ADL content ranged from 70 to 156 g/kg DM (Dominguez and Ly, 1997; Ouda *et al.,* 2004; Kebede *et al.,* 2008). The lignin content also increased with age and with prolonged dry period. The lignin levels were relatively high being a characteristic associated with forbs (Van Soest, 1994; Karachi and Dzowela, 1990). Increased forage content of ADF and ADL tends to lower digestibility, hence, generally the lower their content in the feed the higher the quality (Meissner *et al.,* 1991; Van Soest, 1994).

2.4. Causes of variation in mineral content

Available literature does not provide comprehensive mineral analysis and the causes of their variation in forage cultivars of sweet potato (Agbede and Adekiya, 2011; Chuang *et al.,* 2011; Heuze *et al.,* 2011). However, sweet potato cultivar, growth site, season of growth and harvesting age have been reported to affect mineral content (Pace *et al.,* 2006; Mortley *et al.,* 2009; Chuang *et al.,* 2011). The effects of growth site are through soil mineral content and climatic characteristics (Akinrinde, 2006; Mortley *et al.,* 2009; Chuang *et al.,* 2011). The sweet

potato part (leaf, petiole or stem) will also influence the composition (Wilman *et al.,* 1999; Aregheore, 2003; Ngyen and Ogle, 2005). For example, Orodho *et al.* (1993) and Akinrinde (2006) separated sweet potato forage into leaf, petiole, stem and the whole plant. The petiole contained the highest concentration of calcium (9 g/kg DM) and potassium (86 g/kg DM) followed by the leaf blade (Ca, 8; K, 48 g/kg DM). The stem and the whole plant had similar concentration of calcium (50-70 g/kg DM) and potassium (55-56 g/kg DM). Phosphorus concentration was similar among the four sweet potato forage parts studied (30-40 g/kg DM). Mineral variation may, also, be due to maturation and senescence as the total ash in sweet potato forage decreased with age (Snijders *et al.,* 1992; Monamodi *et al.,* 2003; Larbi *et al.,* 2007).

Fertilizer and manure application rates caused mineral variation in sweet potato as Akinrinde (2006) reported increased phosphorus (9-12 g/kg DM) with increased application rate of phosphatic fertilizer. The author also reported that phosphorus concentration in sweet potato leaves depended on the cultivar and age. Aregheore and Tofinga (2004), Magagula *et al.* (2010) and Agbede and Adekiya (2011) showed variation with increased manure rate (22-27 g/kg DM). The concentration was shown to decrease (10-3 g/kg DM) with increased age of forage sweet potato (Monamodi *et al.,* 2003; Akinrinde, 2006; Olorunnisomo, 2007a, b). The handling of samples may cause variation in mineral concentration through contamination especially in areas with industrial pollution. For example, Magagula (2010), Chuang *et al.* (2011) and Mwaniri *et al.* (2011) rinsed the sample thoroughly with water to remove extraneous contamination and Oduro *et al.* (2008) and Mwaniri *et al.* (2011) steam blanched the samples before oven drying.

2.5. Conservation of forage sweet potato

Seasonal production of forages is a major challenge facing livestock production in Kenya, particularly in low rainfall areas. The quality and quantity of available forages depend on the rainfall pattern. The growth and abundance of forage increases at the onset of the rains and trails off to little or no growth at the height of the dry season. The problem is further compounded by unpredictable rainfall and frequent prolonged dry periods and drought causing severe shortage of forage for livestock. This seasonality of forage production causes surplus production during wet seasons and big deficits during dry season. For example, about 1.2 million tonnes of fresh vines are produced annually in Kenya mainly during sweet potato root harvest

(Karachi, 1982a; Kihurani, 2004; Rono *et al.,* 2006). To even out this seasonal variability in quantity and quality, farmers should undertake forage conservation into hay and silage.These can be availed throughout the year and help improve animal performance. Forage cultivars of sweet potato can be conserved to mitigate forage inadequencies. Furthermore, wide use of these cultivars will contribute to diversification of livestock feed resources.

2.5.1. Preparation and quality of forage sweet potato silage

Ensiling of forage crops contributes towards the optimization of tropical and sub-tropical animal production systems, but is currently not yet widely applied in Kenya. This is perhaps due to the low prices for animal products, the low levels of mechanization, high costs of silo sealing materials and lack of ensiling experience (Wilkinson *et al.,* 1996). More research is, therefore, needed to address problems associated with ensiling tropical forages. Tropical grasses and legumes have, for example, a relatively high concentration of cell wall components and a low level of fermentable carbohydrates (Jarrige *et al.,* 1982).

The initial silage fermentation can be sub-optimal due to insufficient amounts of water soluble carbohydrates (WSC). The amount of WSC necessary to obtain sufficient fermentation also depends on the DM content and the buffering capacity of the crop (Titterton and Bareeba, 2000). Tropical fodders and legume give silage that generally tend to have high buffering capacity (Suttie, 2000) causing increased silage pH (Titterton and Bareeba, 2000) leading to poor silage fermentation (Muhlbach, 2000; Pitz *et al.,* 2000). If the silage has a very low DM content, most of the carbohydrate source may be lost in the effluent during the first few days of ensilage (Titterton and Bareeba, 2000).

The most suitable DM content of the silage material is within the range of 20 to 30% DM. Ensiling material with less than 20% DM may create an unsuitable environment for proper silage fermentation (McDonald *et al.,* 1995). Such unfavourable conditions are unsuited to lactic acid bacteria but encourage multiplication of clostridial bacteria that cause poor silage (Jarrige *et al.,* 1982). In addition, it may result in the loss of valuable nutrients because water and soluble nutrients seep out and accumulate at the bottom of the silo as silage effluent (Titterton and Bareeba, 2000). However, forages with DM above 50% reduce water availability and are considered difficult to ensile (Wilkinson *et al.,* 1996). High DM also makes compaction difficult,

leading to over-heating from aerobic respiration hence loss of carbohydrates. Forages with insufficient fermentable substrate or too low DM ferment poorly (Jarrige *et al.*, 1982). In such forages, sufficient fermentation can only be achieved if the fermentable substrate is increased, by adding sugars such as molasses, cereal germ and bran directly during ensiling process. Molasses is the most widely used carbohydrate source and is of particular benefit when applied to crops low in water soluble carbohydrates, such as tropical legumes and grasses (Titterton and Bareeba, 2000).

Tropical grasses and legumes for ensilage need to be cut before heading as in such vegetative stage, protein and digestibility are high. However, militating against this is the relatively high moisture content and low DM at this stage, which can adversely affect fermentation quality of the silage (McDonald *et al.*, 1995). Hence, wilting is essential to increase DM in the grasses and legumes. Unfortunately research into time of wilting has produced extremely variable results apparently due to weather conditions such as humidity, wind speed and prevailing ambient temperature (McDonald *et al.*, 1995). Warm humid conditions, like in the high-rainfall tropics, are not conducive to rapid field drying. Biochemical losses from respiration could be higher than losses from un-wilted silage and digestibility of the silage is reduced (Thomas and Thomas, 1985). Hence, wilting only appears to be necessary if crops in the field are still very wet at harvesting, conditions are conducive to rapid drying and large silos are used to store the silage.

The silage pH of tropical forages should normally be below 4.8 (Irungu *et al.*, 1999; Snijders and Wouters, 2000). Within the silo, the pH may tend to increase in wilted silage due to difficulty in silage compaction which delays establishment of anaerobic conditions (Kaiser *et al.*, 2000; Pitz *et al.*, 2000; Suttie, 2000). Consequently, a high loss of soluble carbohydrates occurs, a reduction in protein content and an increased de-naturing of amino acids arising from the elevated temperature in the silo. Furthermore, the protein also undergoes extensive hydrolysis leading to a high level of ammonia nitrogen (NH_3-N) in place of true protein in the ensiled material. These processes elevate silage buffering capacity (Suttie, 2000) causing increased silage pH (Titterton and Bareeba, 2000), particularly in tropical fodders and legumes leading to poor silage fermentation (Muhlbach, 2000; Pitz *et al.*, 2000).

2.5.2. Preparation and quality of forage sweet potato hay

The trend in moisture loss may be a cultivar characteristic. For example, sweet potato forage cultivars may lose moisture at different rates suggesting that their morphology and physiological activities are different. According to Suttie (2000) the initial moisture loss is rapid through the open stomata but following wilting the stomata close and moisture loss through the waxy epidermis of the plant leaves and stems decreases. With coarse forage, some mechanical chopping or crimping are essential for the forage to dry rapidly and evenly. The duration of sun drying affects the DM content of sweet potato forage as a reflection of fast leaf drying compared to slow rate in the waxy and fleshy stems (Suttie, 2000).

The DM content in these cultivars depended on the stage of maturity (Snijders *et al.*, 1992; Kiragu and Tamminga, 1997; Larbi *et al.*, 2007). Kiragu and Tamminga (1997) showed that DM content increased with age from 12 to 24 weeks in sweet potato. Hence, mature forage cultivars are expected to attain safe hay moisture storage level of 15 % more rapidly than those at early and vegetative growth stages (Snijders *et al.*, 1992; Kiragu and Tamminga 1997; Larbi *et al.*, 2007). However, harvesting of sweet potato forage at late maturity is not recommended as the nutritive value is high at young vegetative stage (Larbi *et al.*, 2007; Olorunnisomo, 2007b) and declines with maturity (Snijders *et al.*, 1992; Kiragu and Tamminga 1997; Olorunnisomo, 2007b).

2.5.3. Method of drying

In hay making rapid moisture reduction is essential to reduce losses due to spoilage and rapid crop respiration (Suttie, 2000). It is essential that a lower than 15 % moisture content in the forage be achieved rapidly. However, excessive drying should be avoided as it can lead to shattering of leaves and loss of nutrients (Titterton and Bareeba, 2000). Rapid moisture reduction decreases tissue respiration in the plant material to bare minimum to safeguard nutrient loss. Hence, sun drying is a more suitable drying method than shade drying because it results in faster moisture loss. Unfortunately, prolonged sun drying causes nutrient losses through oxidation and destruction of pigments and carotene.

Leaves are predominantly involved in the initial rapid dehydration while longer duration of sun-drying may be essential for moisture loss from plant stems (Suttie 2000). Moisture loss in

sweet potato forage can be hastened through mechanical treatments such as chopping, crushing, rolling, chuffing or crimping which break the cellular structure of the plant to expose a larger surface for moisture to evaporate rapidly. For these treatments to succeed, efficient equipment which are well designed and calibrated for these purposes are needed to reduce losses of plant sap and soluble carbohydrates during such processes. However, under the farming conditions in Kenya these treatments are uneconomical. A common practice is to spread and turn the hay in the field for more ventilation and increased air circulation to hasten the rate of hay drying.

2.6. Performance of animals fed sweet potato forage

2.6.1 Nutrient intake and digestibility of forage sweet potato

In Kenya, Kariuki *et al.* (1998) showed that sweet potato forage can replace lucerne in diets for weaned calves. Additionally, Semenye *et al.* (1989) and Orodho *et al.* (1993) successfully used sweet potato forage as milk replacer in kids and calves, respectively. This suggests that sweet potato forage can be used as protein-rich forage just like leguminous forages.

Feed intake by sheep was highest when sweet potato forage and roots were mixed in equal proportions of 50:50 (Olorunnisomo, 2007b). Average daily feed intake was 626, 635, 627 and 596 g when sweet potato forage comprised 25, 50, 75 and 100% of the diet, the remainder being sweet potato roots. Beyond the 50:50 ratio of sweet potato forage and roots mixture, any additional sweet potato forage in the diet did not improve intake by sheep. This ratio may have been the optimum protein-energy intake by the sheep, consequently promoting optimum microbial activity in the rumen. In an experiment where sweet potato forage replaced sesbania (*Sesbania grandiflora*), Lam and Ledin (2004) reported a decline in nutrient intake in goats as the proportion of sweet potato forage increased. This was attributed to the higher concentration of DM, CP and more bypass protein in sesbania compared to sweet potato forage.

Kiragu and Tamminga (1987) recorded increased DM intake in pre-weaning calves supplemented with sweet potato forage compared to calves fed on milk alone and this reduced rearing cost by 50%. Supplementing Napier grass with sweet potato forage also increased DM intake in calves (Kiragu *et al.*, 2007) and Kariuki *et al. (*1998) likewise, reported that sweet potato forage met the DM and CP requirement of weaned calves. Wilman *et al.* (1999) recorded higher DM intake in sheep fed sweet potato forage compared to those fed on millet leaves and

stovers of millet, sorghum and maize. Ashiono *et al.* (2006) reported increased DM intake on supplementing dairy cows with sweet potato vine on sorghum silage basal diet. Semenye *et al.* (1989) fed sweet potato forage as milk replacer in kids and Orodho *et al.* (1993) succeeded to replace milk with sweet potato forage in calf diets.

In growing ruminants, high growth rates showed that the efficiency of nutrient incorporation for cell growth was not hindered (Hagerman *et al.,* 1992; Kaitho, 1997). According to Aregheore (2003), Etela et al. (2008) and Kebede *et al.* (2008) sweet potato forage is high quality and can be fed as sole diets to ruminants (Semenye *et al.,* 1989; Orodho *et al.,* 1993; Kariuki *et al.,* 1998). Sweet potato forage can, also, be used as supplements to monogastric livestock such as pigs (An *et al.,* 2005; Chhay *et al.,* 2007; Regnier *et al.,* 2013) and is in most cases considered to be among the protein-rich forages.

Dry matter digestibility improved when sweet potato forage was harvested at 4 and 6 weeks compared to 8 weeks (Larbi *et al.,* 2007; Olorunnisomo, 2007b) and the DM digestibility ranged from 640 to 757 g/kg DM. The digestibility of ADF and gross energy increased with reduction in harvesting interval. Improved digestibility was associated with higher protein content and reduced fibre levels in the forage as the frequency of harvesting increased (An *et al.,* 2003; Larbi *et al.,* 2007; Olorunnisomo, 2007a, b). Larbi *et al.* (2007) showed that the average CP, degradable fraction, rate of degradation and effective degradation were relatively higher when sweet potato forage was harvested at 12 instead of 20 weeks after planting. Dry matter degradability was also shown to be higher in sweet potato forage compared to green panic (*Panicum maximum*) in lactating cattle (Etela *et al.,* 2008). Aregheore (2003) also recorded higher nutrient digestibility among goats fed a sole diet and mixed diets of sweet potato forage with batiki grass (*Ischaemum aristatum*) compared to a sole diet of batiki grass. Likewise, Wilman *et al.* (1999) showed higher digestibility in sheep fed on sweet potato forage compared to those fed on crop residues.

Sweet potato forage has high DM and OM digestibility of above 750 g/kg DM (Etela *et al.,* 2008; Larbi *et al.,* 2007; Olorunnisomo, 2007a) hence are unlikely to limit nutrient intake. Minson (1990) showed that nutrient digestibility was positively correlated to OM digestibility which in turn was related to the energy available in the forage. This study, also, showed that nutrient digestibility rose with increased metabolizable energy density and a reduction in NDF.

Sweet potato forage is known to contain less than 490 g NDF/kg DM (Ouda *et al.,* 2004; Ashiono *et al.,* 2006; Kebede *et al.,* 2008) hence will not limit nutrient digestibility and metabolizable energy intake. However, the cellular structure and the inherent attributes of NDF and CP will affect their digestibility (Hagerman *et al.,* 1992; Kaitho, 1997). Adequate protein digestability and available energy are essential for sufficient NH_3-N incorporation into microbial protein synthesis (Preston and Leng, 1987). Furthermore, the supply of soluble N and fermentable OM in the rumen must be synchronized.

To rank forages according to their nutritive value, Norton and Poppi (1995) considered potential digestibility and voluntary intake. Fodders having high nutrient digestibility and nutrient intake were ranked as highly nutritious. The high DM and OM digestibility of above 750 g/kg DM (Larbi *et al.,* 2007; Olorunnisomo, 2007a; Etela *et al.,* 2008) and the high nutrient intake at above 100g DM/kg metabolic body size ($W^{0.75}$) (Kariuki *et al.,* 1998; Aregheore, 2003; Etela *et al.,* 2008) in sweet potato forage place it in the class of nutritious forages. According to Agricultural Research Council (ARC, 1984), a diet containing metabolizable energy beyond 9.7 MJ/kg DM and DM intake beyond 90.5 g/$W^{0.75}$ is classified as a highly nutritious diet and those below these values were less nutritious diets. Sweet potato forage also qualifies as a highly nutritious diet under this classification (Kariuki *et al.,* 1998; Etela *et al.,* 2008) and therefore is unlikely to limit feed intake in ruminants.

2.6.2. Effects of feeding forage sweet potato on animal performance

Feeding sweet potato forage to livestock has been reported by various researchers. Average daily gain (ADG) of sheep was 71.0, 86.4, 78.1 and 56.9 g when sweet potato forage comprised 25, 50, 75 and 100% of the diet, the remainder being sweet potato roots (Olorunnisomo, 2007b). Weight gain was highest when goats were fed on sweet potato forage and roots mixed in equal proportions. This proportion also had the best feed conversion ratio, suggesting that the feed was more efficiently utilized at this level of mixture in the diet. Lam and Ledin (2004) in an experiment where sweet potato forage replaced sesbania (*Sesbania grandiflora*), showed a decline in ADG in goats as the proportion of sweet potato forage increased. This was attributed to the higher concentration of DM, CP and more bypass protein in Sesbania compared to sweet potato forage. Kebede *et al.* (2008), however, showed that sweet

potato forage could replace up to 50% of the concentrate in fattening goats. The goats attained ADG of 60.1, 59.5, 56.3, 33.0 and 20.8g on substituting 25, 50, 75 and 100% concentrate, respectively. Aregheore (2003) documented that the daily live weight gains of goats were affected by forage type and the ratio offered. The goats on sole sweet potato forage diet and those on mixed diets of sweet potato forage with batiki grass recorded higher ADG and feed conversion efficiency compared to a sole diet of batiki grass (Aregheore, 2003).

Semenye and Hutchcroft (1992) demonstrated that sweet potato forage met the nutrient requirement of goat kids when fed at 30 g DM/kg body weight per day. Also, Boran weaned calves fed sweet potato hay at 500 g per day on top of free-choice Rhodes grass hay attained similar ADG to those fed 200 g per day cotton seed cake (Karachi and Dzowela, 1990). Likewise, young bulls fed on sugar cane tops supplemented with sweet potato forage increased their feed intake and weight gain (Dominquez, 1992). Kiragu and Tamminga (1987) recorded increased pre-weaning ADG in calves supplemented with sweet potato forage compared to those fed on milk alone and this reduced rearing cost by 50%. Calves fed on Napier grass and supplemented with sweet potato forage also increased their pre-weaning performance (Kiragu *et al.,* 2007). Kariuki *et al.* (1998) also showed that sweet potato forage can sustain live weight gains similar to those obtained by weaned calves fed on lucerne. Likewise, Etela *et al.* (2008) reported that lactating cattle sustained higher milk yields on sweet potato forage compared to a basal diet of Green panic (*Panicum maximum*) alone. Sweet potato forage increased feed intake (Wilman *et al.,* 1999; Larbi *et al.,* 2007; Olorunnisomo, 2007a), through optimizing the protein-energy intake and promoted optimum microbial activity in the rumen. This increased feed digestibility (An *et al.,* 2005; Aregheore, 2003; Olorunnisomo, 2007a,b), enabled higher DM degradability, raised the degradable fraction, increases the rate of degradation and effective degradation in diets containing sweet potato forage (Larbi *et al.,* 2007; Etela *et al.,* 2008). These diets improved livestock performance through increased daily live weight gain and improved feed conversion efficiency (Kiragu and Tamminga, 1987; Aregheore, 2003; Olorunnisomo, 2007b); higher milk yields (Etela *et al.,* 2008); reduced cost of rearing young stock (Kiragu and Tamminga, 1987; Orodho *et al.,* 1993; Kariuki *et al.,* 1998) and fattening livestock (Semenye *et al.,* 1989; Dominquez, 1992; Kebede *et al.,* 2008).

2.7. Potential use of sweet potato forage cultivars as feed for livestock in Kenya

Protein is a major limiting nutrient to livestock production in Kenya as most of the available forage types are low in protein (Kaitho, 1997; Kariuki, 1998). Sweet potato forage contains more than the 80 g CP/kg DM (Karachi, 1982a, b; Semenye *et al.*, 1989; Kariuki *et al.*, 1998) required by growing ruminants and can be fed to livestock either as sole feed (Semenye *et al.*, 1989; Orodho *et al.*, 1993; Kiragu and Tamminga, 1997) or supplement. This can improve the quality of basal feeds with low CP content such as Napier grass and other poor quality roughages such as cereal crop residues (Wilman *et al.*, 1999) and also as a concentrate feed (An *et al.*, 2005; Kebede *et al.*, 2008; Regnier *et al.*, 2013).

Potential, therefore, exists in Kenya to utilize sweet potato forage to increase the productivity, efficiency and profitability of the livestock industry through providing adequate nutrition by way of sweet potato forages that will reduce young stock mortality and increase growth rate, optimize fertility in adult livestock and increase milk and meat production (Claessens *et al.*, 2009). These potential benefits of sweet potato forage as livestock feed need to be taken advantage of by farmers. If implemented, this will expand sweet potato cultivation, diversify its utilization and spread the benefits among smallholder livestock farmers who are the majority of those growing sweet potato in Eastern Africa (Peters, 2008; Wheatley and Loechl, 2008; Andrade *et al.*, 2009).

CHAPTER 3

EVALUATION OF FORAGE SWEET POTATO CULTIVARS FOR OPTIMAL HARVESTING AGE AND NUTRIENT CONTENT

3.0. Abstract

There is potential in Kenya to utilize sweet potato forage as cheap protein source to improve livestock performance either as sole feed or as a protein supplement to poor quality roughages such as cereal crop residues. However, there is little documentation on the management and even nutritive value of many forage cultivars of sweet potato available in Kenya. The objective of the current study was to evaluate forage sweet potato cultivars for dry matter (DM) and crude protein (CP) yield and *in vitro* digestibility to select the three most promising cultivars. Harvesting age affected the total DM, CP yield and *in vitro* digestibility of the cultivars. The highest DM (9.4-9.8 t/ha) and CP yield (1597-1679 kg/ha) and *in vitro* digestibility (846-851 g/kg DM) were recorded at 120 days for K158, Marooko and Wagabolige. The content of DM, OM, NDF, ADF and ADL increased with age but the CP decreased with increased age. These nutrient content were at their optimum at 120 days for K158, Marooko and Wagabolige with ranges being DM (166-168), OM (880-882), NDF (384-400), ADF (275-282) and ADL (86-114 g/kg DM). Crude protein content decreased from 171 to 151 g/kg DM at 90 to 150 days for K158, Marooko and Wagabolige. Hence cultivars K158, Marooko and Wagabolige should be harvested at 120 days to achieve high DM and CP yield and good nutritive value for ruminants. Cultivars K158, Marooko and Wagabolige were, therefore, selected for further experimental evaluation.

3.1. Introduction

The composition of farage sweet potato is influenced by age and plant part (leaf, petiole or stem) (An *et al.,* 2003; Aregheore, 2003; Ngyen and Ogle, 2005). Low DM content was observed in young forage sweet potato which increases with maturation (Snijders *et al.,* 1992; Kiragu and Tamminga 1997; Larbi *et al.,* 2007). Studies on forage sweet potato in Kenya reported decreased ash content with age (Snijders *et al.,* 1992; Kiragu and Tamminga, 1997). There was high CP content in forage sweet potato during young growth stage through nutrient

apportioning in favour of protein accumulation (An *et al.,* 2003; Larbi *et al.,* 2007; Olorunnisomo, 2007b) which declined with extended cutting intervals (Snijders *et al.,* 1992; Kiragu and Tamminga 1997; Olorunnisomo, 2007b).

Management regimes such as harvesting interval influence DM yield. However, Snijders *et al.* (1992) showed a significant leaf loss with prolonged harvesting interval and an increase in the proportion of stem to leaf from a cutting interval of 120 to 180 days. These factors contributed to reduced DM yield especially, in early maturing sweet potato cultivars (KARI, 1990; Larbi *et al.,* 2007; Olorunnisomo, 2007a, b). The increased DM yield was due to increased cutting interval that gave plants sufficient time to recover. Forage sweet potato cultivars partition DM accumulation to favour leaf production (Snijders *et al.,* 1992; Olorunnisomo, 2007a, b; Oggema *et al.,* 2007). More harvests per year generally increase DM yield (An *et al.,* 2003; Larbi *et al.,* 2007; Olorunnisomo, 2007a, b), provided the harvesting interval allows the cultivars adequate recovery period.

There is limited documented information on the digestibility of forage sweet potato cultivars in Kenya, in particular the effects of harvesting age on digestibility (Ondabu *et al.,* 2005; Ondabu *et al.,* 2007). Measurement of *in vitro* gas production can provide valuable quantitative information that simulates the kinetics of rumen digestion (Menke *et al.,* 1979; Menke and Steingass, 1988). Increased supply of fermentable carbohydrates and nitrogen increases fermentation, microbial growth and microbial protein synthesis (Sommat *et al.,* 2000; Akinfemi, 2010; Mirzaei-Aghsaghali *et al.,* 2011).

The objective of the current study was to evaluate selected forage sweet potato cultivars for DM and crude protein (CP) yield and *in vitro* digestibility to allow determination of the effect of harvesting age on chemical composition of three most promising cultivars.

3. 2. Materials and methods

3. 2.1. Study site

The study was conducted at the Kenya Agricultural and Livestock Research Organization (KALRO) in Lanet located in the outskirts of Nakuru town, Nakuru County, Kenya. The site is 0º 18’S, 36º 09’E and 1920 m above sea level. The area receives on average 800 mm rainfall

annually with a relative humidity of 83%. It also has a bimodal rainfall distribution; with the long rains occurring late March to May and the short rains received in October and November (Jaetzold *et al.,* 2006). The mean maximum and minimum temperatures are 26^{o}C and 10^{o}C, respectively. The study site falls within agro-ecological zone (AEZ) IV (Jaetzold *et al.,* 2006) with soils classified as humic nitosols under FAO soil classification.

3. 2. 2. Experimental design

A fine seed bed was prepared by leveling uniformly using a tractor attached with tine harrow followed by a roller. Three parallel experimental plots were laid out along less than 0.5 % field gradient. Each plot was divided into six plots measuring 3 metres in width and 5 metres in length (Figure. 3.1). Five forage cultivars of sweet potato (99/1, K049, K158, Marooko and Wagabolige) and a control cultivar (Mugande) were replicated at random in each of the three plots. Mugande was chosen as the control cultivar because it is commonly cultivated by most farmers within the study area. This procedure was replicated four times producing four experimental blocks in a randomized complete block design (RCBD). The five improved forage sweet potato cultivars and control cultivar were harvested at 90, 120, 150 and 180 days allocated at random.

The cultivars were planted on the respective field plots using 50 cm long cuttings, in holes dug on the flat ground in rows 60 cm apart and the plants were spaced 30 cm apart within rows. A base fertilizer dressing with Di-ammonium phosphate (DAP) was done at planting and top dressing with calcium ammomium nitrate (CAN) at 45 days after planting. The fertilizer was applied according to Wielemaker and Boxem (1982) during planting at the rate of 54 and 20 kg/ha of nitrogen (N) and phosphorus (P), respectively; and after establishment (45 days after planting), the plots were cut back and top dressed with 52 kg N/ha. Potassium was not applied as soils at Lanet area are known to contain adequate potash to meet the requirements for normal growth of forage sweet potato cultivars (Wielemaker and Boxem, 1982). The subsequent re-growth was harvested at the experimentally assigned harvest age of 90, 120, 150 and 180 days respectively. The blocks and field plots were separated by 1 metre wide paths and the experimental plots were kept clean by regular hand weeding.

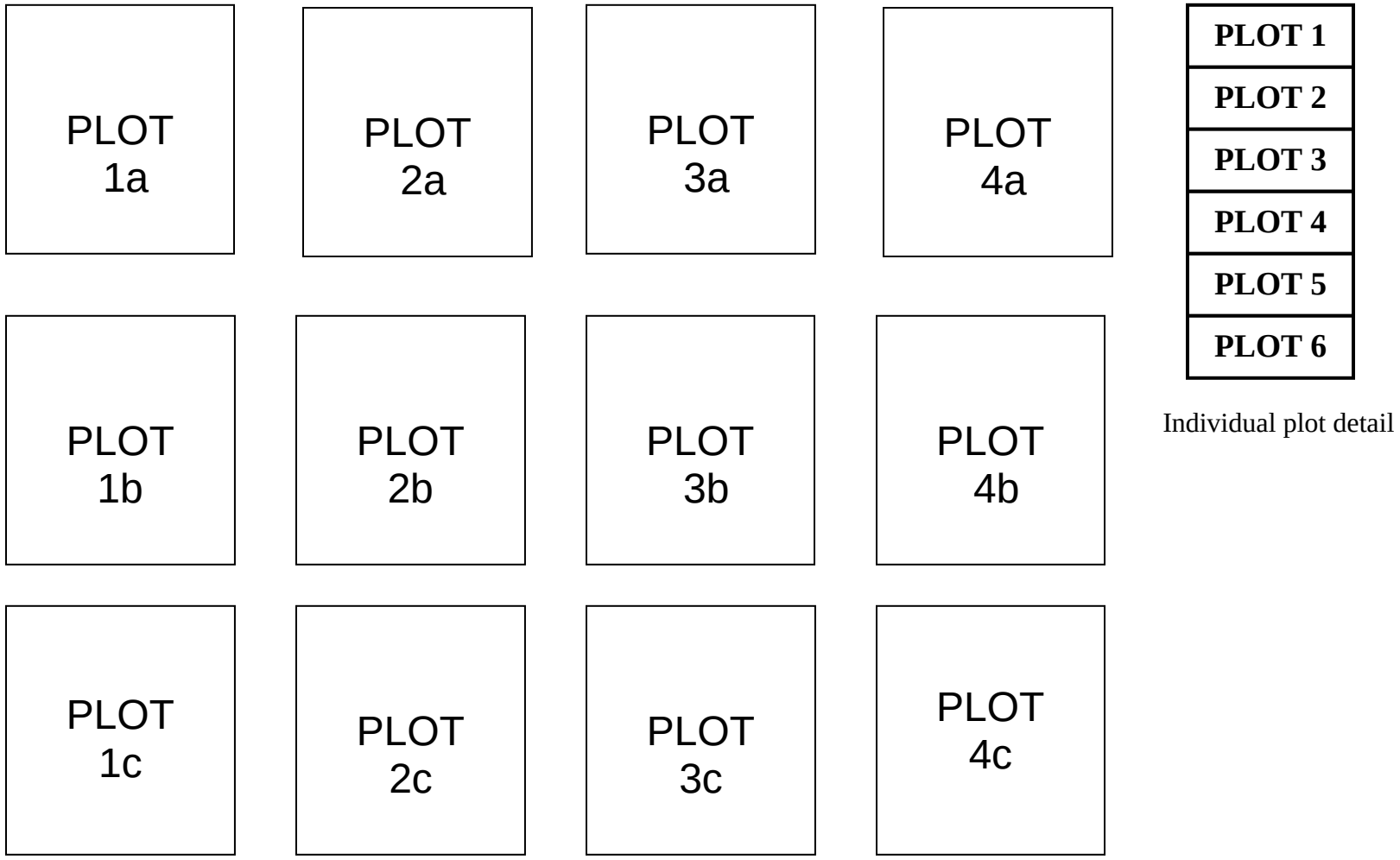

Figure: 3.1. Experimental field layout

3. 2.3. Determination of chemical composition and CP yield

The forage sweet potato cultivars in the experimental plots were left to re-grow after initial cut back at 45 days and top dressing. Using hand clippers, the forage re-growth of each of the cultivars within a field plot was harvested at the ages of 90, 120, 150 and 180 days, respectively. The harvested forage from each plot was individually weighed, chopped, thoroughly mixed and sub-sampled for proximate analysis. The proximate analysis, including DM, Ash, OM and CP, were done according to AOAC (1998) procedures. Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) were analysed according to Van Soest *et al.* (1991). The CP yield of each forage cultivar was calculated as kg CP/ha as follows:-

CP yield per ha (kg/ha) = CP% X DM yield (kg /ha)

3. 2.4. Determination of *in vitro* organic matter digestibility and ME

The forage from each plot was individually weighed, thoroughly mixed and sub-samples taken for *in vitro* digestibility according to Menke *et al.* (1979) and Menke and Steingass (1988).

3.2.4.1. Preparation of media

Buffer and mineral solutions were prepared and placed in a water bath at 39^{o}C under continuous flushing with carbon dioxide (CO_2). Rumen fluid was collected before the morning feeding from three rumen cannulated sheep fed on hay. The rumen fluid was collected from sheep into pre-warmed insulated bottles, filtered through three layers of cheese-cloth and flushed with CO_2. The well mixed and CO_2 flushed rumen fluid was added to the buffered rumen solution (1:2 v/v), which was maintained in a water bath at 39^{o}C, and mixed.

Samples (200 mg) of ground air dried forage sweet potato cultivars were accurately weighed into syringes fitted with plungers. These samples were corrected to DM basis. Buffered rumen fluid (30 ml) was pipetted into each syringe, containing the feed sample and immediately placed into water bath at 39^{o}C. Three syringes with only buffered rumen fluid were incubated and considered as blanks. The syringes were gently shaken every 2 hr and the incubation terminated after recording the 96 hr gas volume. The gas production was recorded after 3, 6, 9, 12, 24, 48, 72 and 96 hr of incubation. Total gas production values were corrected for the blank

incubation and reported gas values expressed in ml/200 mg DM. The following equations were used to calculate organic matter digestibility (OMD) and metabolizable energy (ME), respectively, according to Makkar (2004):

OMD (%) = 14.88 + 0.889GP+ 0.45CP +0.0651XA (Equation 1)

ME (MJ/kg DM) = 2.2 +0.136GP +0.057CP (Equation 2)

Where:

ME is metabolizable energy

OMD is organic matter digestibility

GP is 24 hr gas production (ml/200 mg DM)

CP is crude protein (% of DM)

XA is ash (% of DM)

Partition factor (PF) was defined as the ratio of substrate truly degraded *in vitro* to volume of gas produced (Makkar, 2004). Short chain fatty acids content in milligrammes (mg) per litre was calculated as SCFA= 0.0239GP – 0.0601 according to Akinfemi *et al.* (2009). Microbial protein production in g/kg DM was calculated as 19.3 g microbial nitrogen/kg OMD multiplied by the factor 6.25 according to Czerkawski (2006).

3. 2.5. Statistical analyses

The general linear model (GLM) of SAS (2003) was used to compute analysis of variance for RCBD for DM, CP yield, nutrient composition and *in vitro* OM digestibility, cumulative gas production, partition factor (PF), ME, SCFA and MP of the forage sweet potato cultivars at their respective harvesting ages. The separation of means was done using least significant difference (LSD) procedures.

The following statistical model was used:-

$Y_{ijk} = \mu + \alpha_j + \beta_k + \acute{\epsilon}_{ijk}$

Where Y_{ijk} = Estimated cultivar CP yield or mean nutrient and fibre content, *in vitro* OM digestibility, cumulative gas production, PF, ME, SCFA and MP

μ = Overall cultivar mean

α_j = Effect of harvesting age

β_k = Block effect

$\acute{\epsilon}_{ijk}$ = Residual error of treatment effects

On the basis of DM and CP yield, nutrient composition, ME and *in vitro* OM digestibility, the best three forage sweet potato cultivars were selected for further evaluation as reported in subsequent chapters.

3. 3. Results

3. 3.1. Evaluation of new forage sweet potato cultivars for DM and CP yield

3. 3.1.1. DM and CP yield

The harvesting age affected (P<0.05) the total DM and CP yield of the cultivars (Table 3.1). Generally, the highest DM and CP yield was recorded at 120 days for K158, Marooko and Wagabolige and at 180 days for 99/1 and K049. Mugande recorded its highest DM yield at 150 days and the six cultivars yielded the lowest DM at 90 days.

Cultivars 99/1, K049, K158 and Wagabolige yielded their lowest (P<0.05) CP at 90 days. Mugande recorded its highest (P<0.05) CP yield at 90 days and its lowest CP yield at 180 days. In order of increasing CP yield, the three superior cultivars can be ranked as K158, Wagabolige and Marooko at an optimal age of maturity of 120 days. This ranking was similar to that observed for DM yield.

3.3.2. Effect of harvesting age of new forage sweet potato cultivars on chemical composition

3.3.2.1. Dry matter and crude protein

The harvesting age influenced (P<0.05) the DM and CP content in all forage sweet potato cultivars (Table 3.2). Generally, the DM increased (P<0.05) from 90 to 120 days then decreased to 180 days in all cultivars. The lowest (P<0.05) DM was in Wagabolige and the highest in Marooko at 90 and 120 days, respectively. The control cultivar (Mugande) also recorded its lowest and highest DM at 90 and 120 days.

Generally, the CP tended to decrease with age until 150 days for 99/1, Marooko, Mugande and Wagabolige. Most cultivars had their highest CP at 120 days and their lowest CP at 150 days. The optimum harvesting age to attain optimal CP was 90 days for cultivars 99/1 and Mugande and 120 days for K049, K158, Marooko and Wagabolige. The control cultivar Mugande was observed to contain the lowest CP at all the stages of growth.

Table 3.1: Effects of harvesting age on dry matter and crude protein yield of different forage sweet potato cultivars

	Harvesting age (days)			
Cultivar	90	120	150	180
Dry matter yield, (t/ha)				
99/1	5.0_2^a	5.5_2^b	6.3_2^c	6.0_2^d
K049	3.3_1^a	4.1_1^b	4.3_1^c	5.2_1^d
K158	8.0_5^a	9.8_5^d	9.2_5^c	9.0_5^b
Marooko	9.2_6^{ab}	9.4_4^c	9.1_5^a	9.3_6^{bc}
Wagabolige	7.0_4^a	9.5_4^d	8.7_4^c	8.2_4^b
Mugande	6.1_3^a	6.7_3^b	7.7_3^d	7.2_3^c
Crude protein yield (kg/ha)				
99/1	858.0_2^a	887.3_3^b	978.2_3^c	1014.4_3^d
K049	524.3_1^a	707.8_1^b	728.4_1^b	884.1_2^c
K158	1309.5_4^a	1678.5_5^d	1478.4_6^b	1528.7_5^c
Marooko	1567.8_5^b	1597.2_4^c	1422.8_5^a	1593.4_6^{bc}
Wagabolige	1190.6_3^a	1607.6_4^d	1315.9_4^b	1405.1_4^c
Mugande	862.5_2^c	808.6_2^{ab}	833.7_2^b	782.6_1^a

LSD ($P<0.05$) for comparing effect of harvest age (row) on total DM yield means = 0.14, SEM=0.05
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on total DM yield means = 0.17, SEM=0.06
LSD ($P<0.05$) for comparing effect of harvest age (row) on total CP yield means = 26.5, SEM=9.30
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on total CP yield means = 32.5, SEM=11.4
^{abcd} Means within a row bearing different superscripts are different ($P<0.05$)
$_{123456}$ Means within a column bearing different subscripts are different ($P<0.05$)
SEM: Standard Error of Means

Table 3.2: Effects of harvesting age on dry matter, crude protein and organic matter composition (g/kg DM) of different forage sweet potato cultivars

	Harvesting age (days)			
Cultivar	90	120	150	180
Dry matter content				
99/1	142.1_4^a	161.0_1^c	158.6_1^b	163.7_{23}^d
K049	144.2_5^a	165.5_2^c	158.8_1^b	158.8_1^b
K158	132.5_3^a	165.6_2^c	158.4_1^b	158.8_1^b
Marooko	127.2_2^a	168.2_3^c	163.4_2^b	165.0_3^b
Wagabolige	123.4_1^a	167.5_3^c	167.4_3^c	163.0_2^b
Mugande	143.2_{45}^a	169.2_3^c	167.4_3^b	168.0_4^{bc}
Crude protein content				
99/1	171.7_4^d	162.3_2^b	157.8_3^a	168.1_2^c
K049	160.6_2^a	171.2_3^c	169.4_5^b	170.0_{23}^{bc}
K158	163.0_3^a	170.7_3^b	161.3_4^a	169.3_{23}^b
Marooko	170.4_4^b	169.9_3^b	156.4_3^a	171.3_3^b
Wagabolige	170.9_4^b	169.8_3^b	150.7_2^a	170.7_3^b
Mugande	142.1_1^c	120.1_1^b	108.2_1^a	108.2_1^a
Organic matter content				
99/1	838.5_4^a	881.9_1^c	872.3_1^b	871.6_4^b
K049	823.5_1^a	880.0_1^d	872.6_1^c	864.4_{12}^b
K158	836.7_{34}^a	881.5_1^d	878.6_2^c	863.8_1^b
Marooko	828.1_2^a	880.9_1^d	874.3_1^c	868.9_3^b
Wagabolige	835.2_3^a	880.3_1^d	874.3_1^c	866.9_{23}^b
Mugande	876.2_5^a	880.7_1^b	882.7_3^b	874.5_5^a

LSD (P<0.05) for comparing effect of harvest age (row) on DM means = 1.6, SEM=0.56

LSD (P<0.05) for comparing effect of fodder cultivar (column) on DM means = 1.9, SEM=0.68

LSD (P<0.05) for comparing effect of harvest age (row) on CP means = 1.7, SEM=0.58

LSD (P<0.05) for comparing effect of fodder cultivar (column) on CP means = 2.0, SEM=0.71

LSD (P<0.05) for comparing effect of harvest age (row) on OM means = 2.2, SEM=0.78

LSD (P<0.05) for comparing effect of fodder cultivar (column) on OM means = 2.7, SEM=0.96

^{abcd} Means within a row bearing different superscripts are different (P<0.05)

$_{12345}$ Means within a column bearing different subscripts are different (P<0.05)

SEM: Standard Error of Means

3. 3.2.2. Organic matter

The harvesting age affected (P<0.05) the OM in all the six cultivars (Table 3.2). Generally, OM increased (P<0.05) until 120 days and thereafter declined in all the cultivars except in Mugande. Therefore, the highest OM was recorded at 120 days in all cultivars except Mugande where the OM was similar (P>0.05) at 120 and 150 days. The lowest OM was at 90 days in all the cultivars. The optimum age to attain optimal OM in the five cultivars was 120 days. In the control cultivar Mugande there was increased OM (P<0.05) until 150 days, which declined at 180 days.

3. 3.2.3. Neutral detergent fibre

Harvesting age affected (P<0.05) the NDF in all forage sweet potato cultivars (Table 3.3). Generally, NDF increased (P<0.05) with age in all cultivars except in Wagabolige where there was a decline at 120 days. The highest (P<0.05) NDF was recorded at 180 days and the lowest at 90 days for all cultivars. However, Mugande recorded similar (P>0.05) NDF at 90 and 120 days and beyond this age NDF increased.

3. 3.2.4. Acid detergent fibre

The harvesting age influenced (P<0.05) ADF in all cultivars (Table 3.3). Generally, ADF increased (P<0.05) with age, except for 99/1 and K049 that recorded similar (P>0.05) ADF between 90 to 150 days and 90 to 120 days respectively. The highest (P<0.05) ADF in the cultivars was recorded at 150 days except in Mugande and Marooko where it was highest at 120 and 180 days, respectively. The optimum age to attain suitable ADF for ruminants in all the cultivars was not later than 120 days as beyond this age the ADF tended to increase (P<0.05).

3. 3.2.5. Acid detergent lignin

Harvesting age affected (P<0.05) the ADL of the six forage sweet potato cultivars (Table 3.3). Generally, all cultivars had increased (P<0.05) ADL with increased age except Mugande which had similar (P>0.05) ADL at 150 and 180 days which was lower than at 120 days. The optimum harvesting age to attain optimal ADL in the five test cultivars was between 90 and 120

Table 3.3: Effects of harvesting age on neutral detergent fibre, acid detergent fibre and acid detergent lignin (g/kg DM) of different forage sweet potato cultivars

	Harvesting age (days)			
Cultivar	90	120	150	180
Neutral detergent fibre				
99/1	359.8_{1}^{a}	396.1_{2}^{b}	419.9_{34}^{c}	420.5_{12}^{c}
K049	376.7_{3}^{a}	406.0_{3}^{b}	425.0_{4}^{c}	435.7_{3}^{d}
K158	403.4_{4}^{a}	399.9_{2}^{a}	413.8_{23}^{b}	419.9_{12}^{c}
Marooko	366.8_{2}^{a}	384.3_{1}^{b}	398.2_{1}^{c}	423.7_{2}^{d}
Wagabolige	404.9_{4}^{b}	398.0_{2}^{a}	407.9_{2}^{b}	415.6_{1}^{c}
Mugande	404.0_{4}^{a}	408.7_{3}^{ab}	412.5_{2}^{b}	437.2_{3}^{c}
Acid detergent fibre				
99/1	282.3_{4}^{a}	284.7_{3}^{ab}	284.3_{2}^{ab}	287.9_{2}^{b}
K049	277.3_{34}^{a}	277.3_{12}^{a}	291.4_{3}^{b}	277.6_{1}^{a}
K158	257.1_{1}^{a}	274.9_{1}^{b}	293.5_{3}^{d}	282.9_{2}^{c}
Marooko	264.4_{2}^{a}	280.0_{23}^{b}	281.9_{2}^{b}	294.0_{3}^{c}
Wagabolige	274.4_{3}^{a}	282.1_{23}^{b}	283.5_{2}^{bc}	286.7_{2}^{c}
Mugande	279.5_{4}^{b}	292.1_{4}^{c}	276.4_{1}^{ab}	273.4_{1}^{a}
Acid detergent lignin				
99/1	103.1_{3}^{a}	129.9_{4}^{b}	135.9_{4}^{c}	155.1_{4}^{d}
K049	70.2_{1}^{a}	82.6_{1}^{b}	90.9_{2}^{c}	110.4_{2}^{d}
K158	72.6_{1}^{a}	85.8_{1}^{b}	92.5_{2}^{c}	111.1_{2}^{d}
Marooko	96.1_{2}^{a}	99.9_{2}^{b}	118.9_{3}^{c}	134.6_{3}^{d}
Wagabolige	104.9_{3}^{a}	114.1_{3}^{b}	135.6_{4}^{c}	152.6_{4}^{d}
Mugande	71.9_{1}^{a}	84.0_{1}^{c}	77.0_{1}^{b}	74.5_{1}^{b}

LSD (P<0.05) for comparing effect of harvest age (row) on NDF means = 4.9, SEM=1.74

LSD (P<0.05) for comparing effect of fodder cultivar (column) on NDF means = 6.1, SEM=2.13

LSD (P<0.05) for comparing effect of harvest age (row) on ADF means = 4.1, SEM=0.88

LSD (P<0.05) for comparing effect of fodder cultivar (column) on ADF means = 5.0, SEM=1.08

LSD (P<0.05) for comparing effect of harvest age (row) on ADL means = 3.3, SEM=1.14

LSD (P<0.05) for comparing effect of fodder cultivar (column) on ADL means = 4.0, SEM=1.41

$^{abcd:}$ Means within a row bearing different superscripts are different (P<0.05)

$_{1234:}$ Means within a column bearing different subscripts are different (P<0.05)

SEM: Standard Error of Means

days. The highest ADL for the cultivars was at 180 days except in Mugande which was at 120 days. The lowest ADL was at 90 days for all the six cultivars.

3.3.3. Effect of harvesting age on *in vitro* organic matter digestibility, metabolizable energy and microbial protein yield

3.3.3.1. *In vitro* organic matter digestibility

Harvesting age significantly affected ($P<0.05$) *in vitro* organic matter digestibility (IVOMD) (Table 3.4). Most of the cultivars recorded their highest ($P<0.05$) OMD at 120 days except 99/1 and Mugande that recorded their highest value at 180 days. Cultivars 99/1, K049 and Mugande recorded their lowest ($P<0.05$) OMD at 90 days while Marooko and Wagabolige; K158 recorded their lowest value at 150 and 180 days, respectively. Unlike the other cultivars, Mugande recorded similar ($P>0.05$) OMD between 90 and 150 days. The highest ($P<0.05$) OMD was recorded in Wagabolige at 90, 120 and 150 days and in Marooko at 180 days. The lowest ($P<0.05$) OMD was in K158 at all the four harvesting ages.

3. 3.3.2. Cumulative gas production

Harvesting age affected ($P<0.05$) the cumulative gas production (ml/g OM) at 96 hr in the cultivars (Table 3.4). Generally most of the cultivars recorded their highest gas volume ($P>0.05$) at the harvesting age of 120 days although the volume did not significantly differ from ($P>0.05$) that produced at 90 and 180 days except for 99/1. Cultivars Mugande and Wagabolige each recorded similar ($P>0.05$) gas volume at all four ages. The highest ($P<0.05$) gas volume was recorded in K049 and 99/1 at 90, 120 days, respectively and in Wagabolige at 150 and 180 days. The lowest ($P<0.05$) gas volume was in 99/1 at 180 days and in Mugande at 90, 120 and 150 days. The trends in cumulative gas production from 3 to 96 hrs of incubation for cultivars harvested at 90, 120, 150 and 180 days are shown on Figures 3.2, 3.3, 3.4 and 3.5, respectively.

Table 3.4: Effects of harvesting age of forage sweet potato cultivars on *in vitro* organic matter digestibility (g/kg DM) and cumulative gas production (ml/g OM).

	Harvesting age (days)			
Cultivar	90	120	150	180
In vitro organic matter digestibility				
99/1	695.6_1^{a}	760.5_2^{c}	723.7_2^{b}	769.2_2^{d}
K049	730.3_3^{a}	830.4_4^{d}	739.9_3^{b}	807.2_3^{c}
K158	700.1_1^{b}	711.3_1^{c}	707.7_1^{bc}	683.8_1^{a}
Marooko	717.9_2^{b}	850.7_5^{c}	699.4_1^{a}	851.0_4^{c}
Wagabolige	842.4_5^{b}	845.8_5^{b}	829.0_5^{a}	844.2_4^{b}
Mugande	775.3_4^{a}	781.4_3^{a}	775.1_4^{a}	812.6_3^{b}
Cumulative gas production				
99/1	229.5_2^{b}	270.3_3^{c}	230.3_1^{b}	199.0_1^{a}
K049	261.8_4^{b}	258.9_{23}^{b}	243.9_{23}^{a}	263.0_3^{b}
K158	243.1_{23}^{ab}	254.3_{23}^{b}	240.3_{23}^{a}	250.6_3^{ab}
Marooko	241.9_{23}^{ab}	247.5_2^{b}	229.4_{12}^{a}	250.8_3^{b}
Wagabolige	250.2_{34}	255.4_{23}	256.2_3	256.5_3
Mugande	210.7_1	219.6_1	220.1_1	216.1_2

LSD ($P<0.05$) for comparing effect of age at harvest (row) on *OMD* means = 8.2, SEM=2.9
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on *OMD* means = 10.1, SEM=3.5
LSD ($P<0.05$) for comparing effect of age at harvest (row) on cumulative gas production = 13.5, SEM=4.7
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on cumulative gas production = 16.5, SEM=5.8
^{abcd} Means within a row bearing different superscripts are different ($P<0.05$)
$_{12345}$ Means within a column bearing different subscripts are different ($P<0.05$)
SEM: Standard Error of Means

3.3.3.3. Partition factor

The harvesting age influenced (P<0.05) the partition factor (PF) in the six cultivars (Table 3.5). Generally, the PF was lowest (P<0.05) at 150 days in 99/1, K158, Wagabolige and Mugande but this value was lowest (P<0.05) at 90 and 180 days in Marooko and K049, respectively. The PF in general did not differ (P>0.05) within most of the cultivar across the remaining harvesting ages. The highest and lowest (P<0.05) PF was recorded in Mugande and Morooko at all four harvesting ages, respectively.

3.3.3.4. Metabolizable energy

The harvesting age influenced (P<0.05) the metabolizable energy (ME) in the six cultivars (Table 3.5). Most of the cultivars recorded their lowest ME at 90 days and their highest at 120 days. However, Marooko recorded the highest ME at 180 days and Wagabolige maintained similar ME across the harvesting ages. The highest (P<0.05) ME was recorded in Wagabolige at all four harvesting ages. The lowest (P<0.05) ME was in Mugande at 90 days and in 99/1 at 120, 150 and 180 days.

3.3.3.5. Short chain fatty acids

Harvesting age affected (P<0.05) total short chain fatty acid (SCFA) fermentation in the six cultivars (Table 3.6). Cultivars 99/1, Wagabolige and Mugande each produced similar (P>0.05) quantity of SCFA at all four ages, while K049, K158 and Marooko each recorded similar (P>0.05) SCFA at 90 and 150 days; 120 and 180 days respectively. The age at 120 days appears to be optimum harvesting age for SCFA production. The highest (P<0.05) SCFA was recorded in Wagabolige at all four harvesting ages. The lowest (P<0.05) SCFA was in K049 at 90 days and in 99/1 at 120, 150 and 180 days.

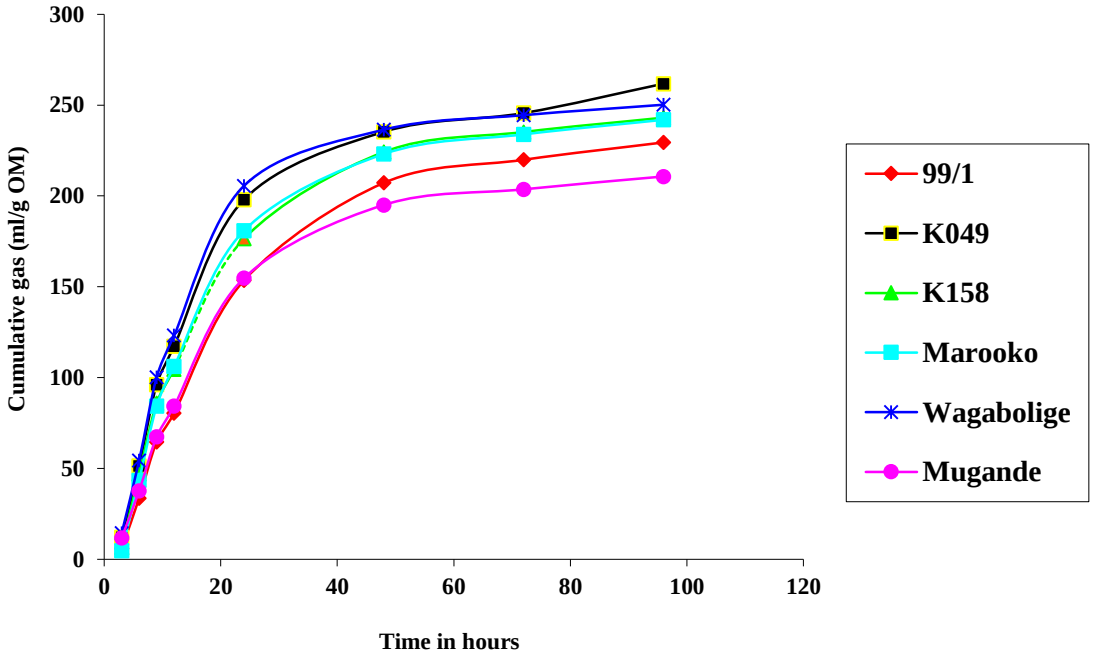

Figure: 3. 2. Cumulative gas production in forage sweet potato cultivars at 90 days

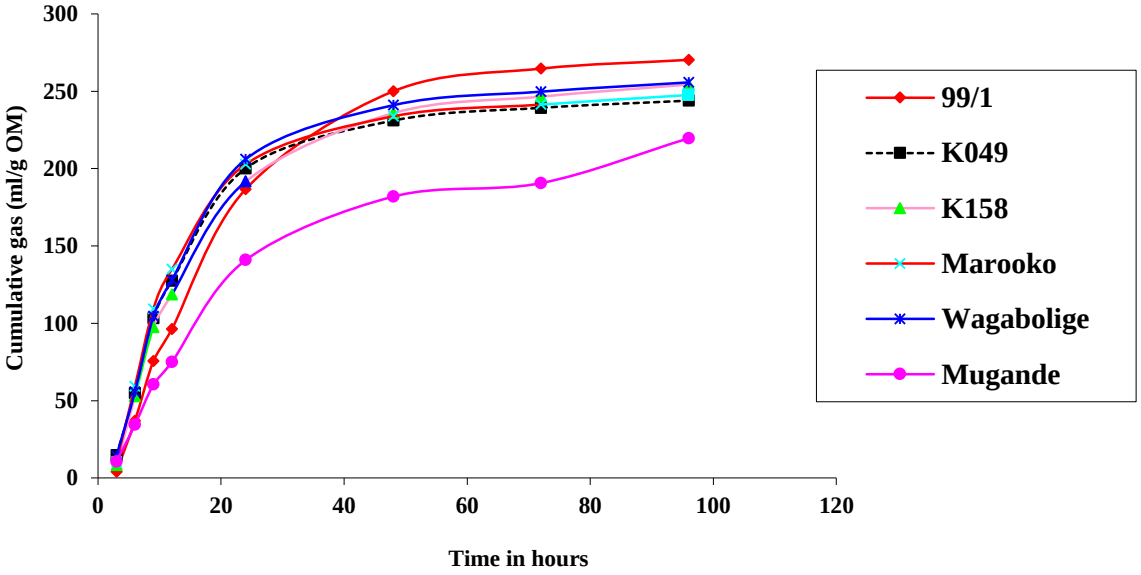

Figure: 3.3. Cumulative gas production in forage sweet potato cultivars at 120 days

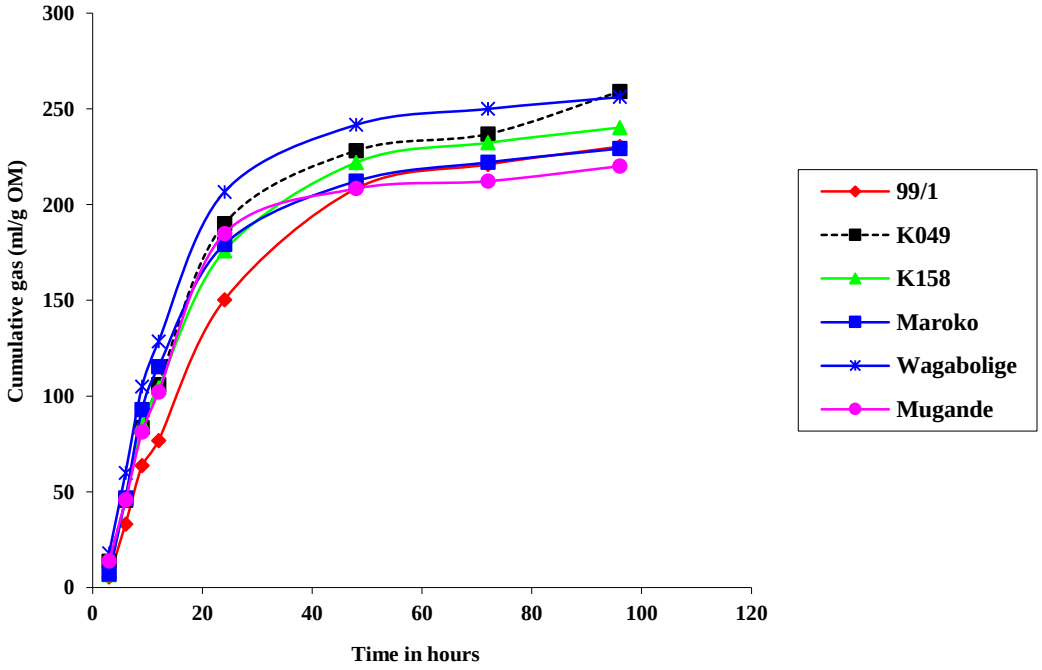

Figure: 3. 4. Cumulative gas production in forage sweet potato cultivars at 150 days

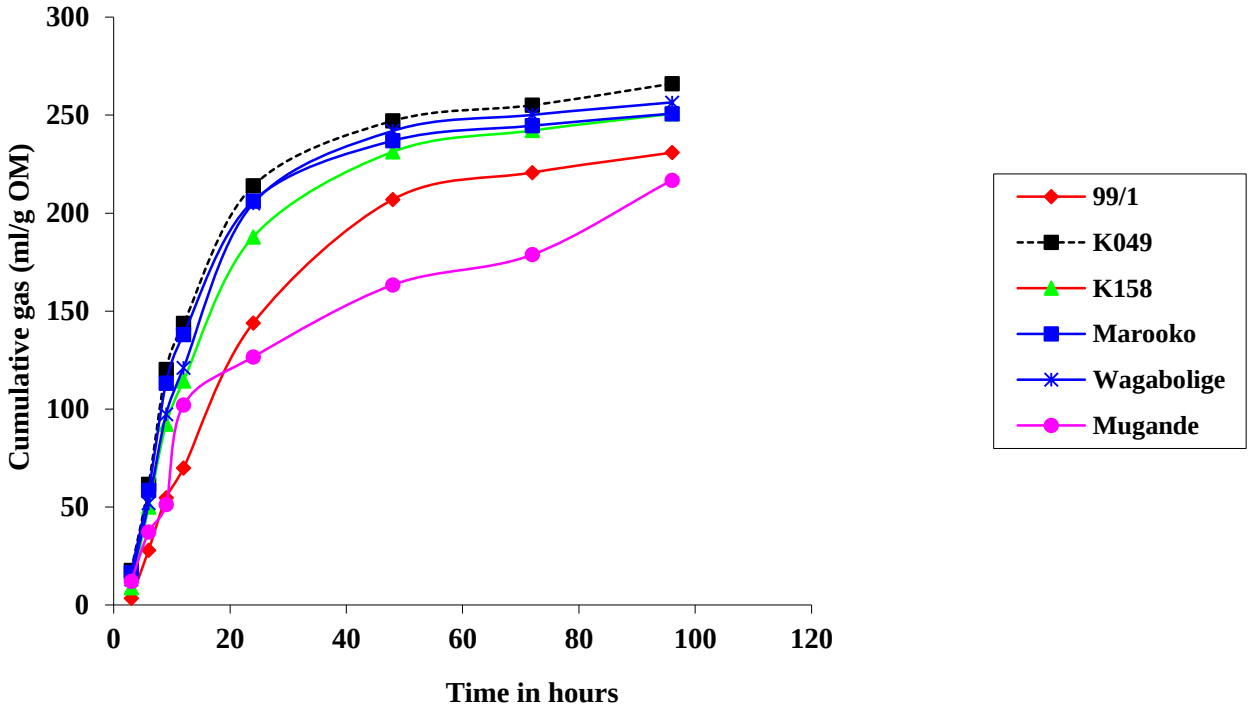

Figure: 3.5. Cumulative gas production in forage sweet potato cultivars at 180 days

Table 3.5: Effects of harvesting age of forage sweet potato cultivars on partition factor and metabolizable energy (MJ/ kg DM).

	Harvesting age (days)			
Cultivar	90	120	150	180
Partition factor				
99/1	3.07_{12}^{b}	3.10_{23}^{b}	2.87_{1}^{a}	3.00_{2}^{b}
K049	3.13_{2}^{b}	3.20_{34}^{b}	3.17_{2}^{b}	3.00_{2}^{a}
K158	2.93_{1}^{b}	2.93_{1}^{b}	2.77_{1}^{a}	2.70_{1}^{a}
Marooko	2.93_{1}^{a}	3.03_{12}^{a}	3.37_{34}^{b}	3.40_{3}^{b}
Wagabolige	3.50_{3}^{b}	3.27_{4}^{a}	3.30_{23}^{a}	3.43_{3}^{b}
Mugande	3.77_{4}^{c}	3.73_{5}^{bc}	3.50_{4}^{a}	3.63_{4}^{b}
Metabolizable energy				
99/1	7.52_{23}^{b}	7.43_{1}^{b}	7.37_{1}^{ab}	7.25_{1}^{a}
K049	7.26_{1}^{a}	7.63_{23}^{c}	7.46_{1}^{b}	7.67_{23}^{c}
K158	7.43_{1}^{a}	7.82_{3}^{b}	7.45_{1}^{a}	7.77_{3}^{b}
Marooko	7.58_{3}^{a}	8.10_{4}^{b}	7.54_{1}^{a}	8.28_{4}^{c}
Wagabolige	8.18_{4}	8.13_{4}	8.28_{2}	8.24_{4}
Mugande	7.38_{12}^{a}	7.59_{12}^{b}	7.44_{1}^{ab}	7.56_{2}^{b}

LSD ($P<0.05$) for comparing mean effect of age at harvest (row) on partition factor = 0.12, SEM=0.04
LSD ($P<0.05$) for comparing mean effect of fodder cultivar (column) on partition factor = 0.15, SEM=0.05
LSD ($P<0.05$) for comparing mean effect of age at harvest (row) on metabolizable energy = 0.15, SEM=0.05
LSD ($P<0.05$) for comparing mean effect of fodder cultivar (column) on metabolizable energy = 0.19, SEM=0.07
^{abc} Means within a row bearing different superscripts are different ($P<0.05$)
$_{12345}$ Means within a column bearing different subscripts are different ($P<0.05$)
SEM: Standard Error of Means

Table 3.6: Effects of harvesting age of forage sweet potato cultivars on total rumen short chain fatty acids production (mg/L) and microbial protein synthesis (g/kg DM).

	Harvesting age (days)			
Cultivar	90	120	150	180
Total rumen short chain fatty acids production				
99/1	0.71_{2}	0.71_{1}	0.68_{1}	0.71_{1}
K049	0.67_{1}^{a}	0.73_{1}^{b}	0.70_{12}^{a}	0.75_{2}^{b}
K158	0.69_{12}^{a}	0.77_{2}^{b}	0.69_{12}^{a}	0.75_{2}^{b}
Marooko	0.72_{2}^{a}	0.82_{3}^{b}	0.71_{12}^{a}	0.84_{3}^{b}
Wagabolige	0.82_{3}	0.84_{3}	0.84_{3}	0.83_{3}
Mugande	0.72_{2}	0.72_{1}	0.72_{2}	0.74_{12}
Rumen microbial protein synthesis				
99/1	83.9_{1}^{a}	91.8_{2}^{b}	91.9_{3}^{b}	92.8_{2}^{b}
K049	88.1_{3}^{a}	100.2_{4}^{c}	89.2_{2}^{a}	97.4_{3}^{b}
K158	84.4_{1}^{b}	85.4_{1}^{b}	85.8_{1}^{b}	82.5_{1}^{a}
Marooko	86.6_{2}^{b}	102.6_{5}^{c}	84.4_{1}^{a}	102.6_{4}^{c}
Wagabolige	101.6_{5}^{b}	102.0_{5}^{b}	100.0_{5}^{a}	101.8_{4}^{b}
Mugande	93.5_{4}^{a}	93.5_{3}^{a}	94.3_{4}^{a}	97.9_{3}^{b}

LSD ($P<0.05$) for comparing mean effect of age at harvest (row) on short chain fatty acids = 0.03, SEM=0.01
LSD ($P<0.05$) for comparing mean effect of fodder cultivar (column) on chain fatty acids = 0.03, SEM=0.01
LSD ($P<0.05$) for comparing mean effect of age at harvest (row) on microbial protein synthesis = 1.15, SEM=0.40
LSD ($P<0.05$) for comparing mean effect of fodder cultivar (column) on microbial protein synthesis = 1.40, SEM=0.49
^{abc} Means within a row bearing different superscripts are different ($P<0.05$)
$_{12345}$ Means within a column bearing different subscripts are different ($P<0.05$)
SEM: Standard Error of Means

3.3.3.6. Microbial protein synthesis

The harvesting age influenced the microbial protein (MP) synthesis in the six cultivars (Table 3.6). Cultivars 99/1 and K049 recorded their lowest ($P<0.05$) MP at 90 days; Wagabolige and Marooko at 150 days; K158 at 180 days respectively. Cultivars K158 and Mugande maintained similar ($P>0.05$) MP synthesis at 90, 120 and 150 days while Wagabolige recorded similar ($P>0.05$) MP synthesis at 90, 120 and 180 days. Cultivar K049 recorded similar ($P>0.05$) MP synthesis at 90 and 150 days while Marooko, also, recorded similar ($P>0.05$) MP synthesis at 120 and 180 days respectively. The optimum harvesting age appears to be 120 days for MP synthesis. The highest and the lowest ($P<0.05$) MP was recorded in Wagabolige and K158 at all four harvesting ages, respectively.

3.3.4. Selection of the most superior forage sweet potato cultivars and their optimal harvesting age

Cultivars K158, Marooko and Wagabolige were superior in dry matter and crude protein yields as they recorded significantly higher DM and CP yields at all four harvesting ages compared to the other cultivars (Table 3.1). These three cultivars recorded their highest DM and CP yield at 120 days making this age the most appropriate harvesting age. The cultivars also contained their optimum DM, OM and CP at 120 days (Tables 3.2) and there was little change in NDF, ADF and ADL with increased harvesting ages (Table 3.3). Cultivars K158, Marooko and Wagabolige, also, recorded their optimum metabolizable energy at 120 days (Table 3.5).

Available roughages in Kenya contain low protein, especially during the dry season, hence cannot sustain high livestock performance (Gitau, 1994; Kariuki, 1998). Protein is expensive to buy hence a weight of 0.40 was assigned to the protein content in forage sweet potato (DiStefano *et al.*, 2009; Table 3.7). The yield of protein and DM per hectare was important because the higher the yield the higher the number of livestock that can be sustained, therefore, the weight factor was assigned at 0.25 and 0.20 respectively. Tropical roughages contain high fibre that limits the energy available to livestock although alternative energy sources are available and are cheaper than the cost of protein. Energy was assigned a weight of 0.15. The six sweet potato cultivars were scored in decreasing values of 30, 25, 20, 10, 8 and 7%, the highest and lowest scores per criteria being 30 and 7% respectively (Table 3.7).

Table 3.7: Ranking of forage sweet potato cultivars harvested at 120 days using Weighted Scoring Method

Criteria	Weight	99/1		K049		K158		Marooko		Wagabolige		Mugande	
		Score	Wted	Score	Wted	Score	Wted	Score	Wted	Score	Wted	Score	Wted
DMY	0.20	8.0	1.6	7.0	1.4	30.0	6.0	20.0	4.0	25.0	5.0	10.0	2.0
CPY	0.25	10.0	2.5	7.0	1.8	20.0	5.0	25.0	6.3	30.0	7.5	8.0	2.0
CP	0.40	8.0	3.2	30.0	12.0	25.0	10.0	20.0	8.0	10.0	4.0	7.0	2.8
ME	0.15	7.0	1.1	10.0	1.5	20.0	3.0	25.0	3.8	30.0	4.5	8.0	1.2
Total	1.0		8.4		16.7		24.0		22.1		21.0		8.0
Rank			5		4		1		2		3		6

DMY= Dry matter yield, CPY= Crude protein yield, CP= Crude protein, ME= Metabolizable energy, Wted= Weighted Score

Weights were from 0 to 1.0 and Scores were 30, 25, 20, 10, 8 and 7 % from the highest score to the lowest

Ranking the six forage sweet potato cultivars using DM and CP yield, CP and ME at 120 days, cultivars K158, Marooko and Wagabolige were, therefore, selected as the three most superior cultivars for further evaluation.

3. 4. Discussion

3. 4.1. Dry matter yield

Cultivar K049 recorded lowest DM yield for all the four harvesting ages and among all the cultivars in the study probably due to slow growth and poor persistence (Somda *et al.,* 1991; Caliskan, 2007; Hue *et al.,* 2011). The increase in DM yield in all cultivars with delayed harvesting age is in agreement with Olorunnisomo (2007b) and Ahmed *et al.* (2012) but at variance with Snijders *et al.* (1992) who showed similar DM yield with extended age. This difference could have arisen in that Snijders *et al.* (1992) may have studied earlier maturing cultivars than those studied by Olorunnisomo (2007a, b) and in the current study. Somda *et al.* (1991) and MacLaurin and Kays (1993) using different varieties showed that sweet potato cultivars lost up to 2.8 tonnes DM per ha during 140 days of growth. The percentage leaf loss increased linearly during the growing season (Somda and Kays, 1990a; MacLaurin and Kays, 1993). There was positive correlation between leaf shedding and dry weight yield hence the higher the DM yield the higher the DM loss through leaf shedding (Somda *et al.,* 1991; MacLaurin and Kays, 1993). Also Karachi (1982a, b), Irungu *et al.* (2000), Mbwaga *et al.* (2007) and Satapathy *et al.* (2007) showed wide variation in yield among cultivars and between experimental sites.

The lowest DM yield in the present study was in the range of 3.1 to 5.1 tonnes DM/ha reported by Karachi (1982b) for sweet potato cultivars at Alupe, Kenya but it was much lower than 6.9 to 9.7 tonnes DM /ha recorded at Kakamega, Kenya (Karachi 1982a, b). The other cultivars in the current study had higher yields than all cultivars studied at Alupe and most of those at Kakamega (Karachi, 1982a, b). Those cultivars whose DM yield values were within those of the current study received high rate of fertilizer (Karachi, 1982b). Rate of fertilizer application and the variation in the experimental site have been shown to cause variation in DM yield (Ankumah *et al.,* 2003; Xu *et al.,* 2007; Mukhtar 2010). The age at harvest by Karachi (1982a, b) and Semenye *et al.* (1989) was prolonged compared to 90 to 180 days in the current study and longer growth duration has been shown to increase DM yield (Nath *et al.,* 2007; Olorunnisomo, 2007b; Satapathy *et al.,* 2007). Shorter harvesting

age will enable livestock farmers to increase the number of harvests with the resultant higher annual DM yield (Snijders *et al.,* 1992; Gomes and Carr, 2001; Satapathy *et al.,* 2007).

The climatic factors at the current study site may be optimal for the cultivars as reported by Hill *et al.* (1996), Gomes and Carr (2001) and Shuang *et al.* (2008) while the stage of harvesting allowed adequate time for plants to recover as reported by Wang and Li (2001), Larbi *et al.* (2007) and Olorunnisomo (2007b). Too frequent defoliation may disrupt the photosynthetic process and therefore affect recovery and overall DM yield from the cultivars (Caliskan, 2007; Hue *et al.,* 2011). Such high harvest frequency negatively affects regrowth and may even result in death of plants due to exhausting of plant carbohydrates reserves. The cultivars studied may have rapidly partitioned DM accumulation to favour leaf production within the harvesting ages tested (Somda and Kays, 1990a; Somda *et al.,* 1991; Olorunnisomo, 2007b). Somda and Kays (1990b); Somda *et al.* (1991); Snijders *et al.* (1992) reported decreased photosynthetic leaves and increased dead leaves with extended harvesting ages, an indication of decreased photosynthetic efficiency.

3. 4.2. Crude protein yield

The optimal CP yield was recorded at 120 days in the majority of test cultivars suggesting that the cultivars responded to harvesting regimes in a similar way. Information on CP yield of forage sweet potato cultivars is scarce in the literature (Peters, 2008; Wheatley and Loechl, 2008; Andrade *et al.,* 2009). However, data on DM yield and CP recorded by Ruiz (1982), Snijders *et al.* (1992), Olorunnisomo (2007b) and Naskar and Nedunchezhiyan (2009) were used to calculate the CP yield they attained. These calculations showed that CP yield ranged between 744.8 and 729.4 kg/ha during 131 and 165 days (Ruiz 1982); 1,069.1 and 1,389.6 kg/ha during 90 and 180 days (Snijders *et al.,* 1992); 995.8 and 1,620.1 kg/ha during 42 and 126 days (Olorunnisomo, 2007b); 2,376.4 to 5,774.7 kg/ha during 120 days (Naskar and Nedunchezhiyan, 2009). The CP yield recorded from K049 and Mugande at 120, 150 and 180 days were similar to yields recorded by Ruiz (1982) and higher than yield by K049 at 90 days. Those CP yields recorded in 99/1 at 150 and 180 days were similar to the yields recorded by Snijders *et al.,* (1992) at 90 days growth and also those recorded by Olorunnisomo (2007b) at 42 days but they were higher than the yields of 99/1 at 90 and 120 days and by Mugande at 90 days.

The CP yield recorded by K158, Marooko and Wagabolige at all the four ages were within the range reported by Snijders *et al.* (1992) and Olorunnisomo, (2007b) but were

lower than those reported by Naskar and Nedunchezhiyan (2009). The CP yield recorded by K158, Marooko and Wagabolige at 120 and 150 days was higher than the yield reported by Snijders *et al.* (1992) at 180 days and Ruiz (1982) at 165 days, indicating a higher CP yield potential among the test cultivars even at a younger regrowth. The differences in CP yield between the current cultivars and those reported by Ruiz (1982) and Olorunnisomo (2007b) may be because they studied dual purpose cultivars. Naskar and Nedunchezhiyan (2009) reported yield from their 10 most suprior genotypes from their forage yield selection programme. Additionally the fertilizer regimes were different which is known to affect yield (Ankumah *et al.*, 2003; Satapathy *et al.*, 2007; Xu *et al.*, 2007).

3.4.3. Dry matter content

The similarity in DM at 150 and 180 days for most cultivars may indicate that the cultivars had achieved their optimum DM accumulation and that senescence may have began (Snijders *et al.*, 1992; Caliskan *et al.*, 2007; Hue *et al.*, 2011). Furthermore, the trend in cultivar performance may be attributed to their genetic differences hence the trend in treatment effects (Sinjders *et al.*, 1992; Ngyen and Ogle, 2005; Olorunnisomo, 2007b). The DM values obtained in this study were within the range of 114.0 to 209.0 g/kg DM reported by other workers in Kenya (Kariuki, *et al.*, 1998; Ondabu *et al.*, 2005; Kiragu *et al.*, 2007) and in Nigeria (Olorunnisomo, 2007b).

The DM in 99/1, K158, Marooko and Wagabolige were within the range reported by Karachi, (1982a), Snijders *et al.* (1992) and Irungu *et al.* (2000) for different cultivars although the current cultivars were harvested at an earlier age. This is advantageous as ruminants offered these forage cultivars will ingest higher DM and less amount of water compared to other cultivars. Forage sweet potato cultivars that contained low DM were observed to cause a lot of urination and loose dung which may indicate an upset in rumen function (Robinson *et al.*, 1990). Furthermore, the ruminant may be unable to ingest adequate DM in a day to meet its energy requirement.

3. 4.4. Crude protein

The decline in CP after 120 days (Table 3.2) may be due to increased cultivar age (Kiragu and Tamminga, 1997; Ngyen and Ogle, 2005; Olorunnisomo, 2007b). However, the cultivars responded differently to delay in harvesting age. The study showed that harvesting age was more important than the cultivar in affecting the CP in forage sweet potato cultivars.

The decline in CP content with increased age was due to an increase in fibre and decreased leaf to stem ratio (Somda *et al.,* 1991; Snijders *et al.,* 1992; Olorunnisomo, 2007b). The CP values obtained in this study are within the range reported in the literature (Larbi *et al.,* 2007; Olorunnisomo, 2007b; Kebede *et al.,* 2008). All the six cultivars were suitable as CP supplements to poor quality roughages such as cereal crop residues (Semenye *et al.,* 1989; Orodho *et al.,* 1993; Kariuki *et al.,* 1998) to improve performance in livestock production. The cultivars K158, Marooko and Wagabolige had high CP yield per ha and could be used by livestock farmers in areas suitable for their growth. However, the suitability of these cultivars need to be tested in other environments and management regimes as they cause variation in DM and CP yield as well as protein content (Karachi, 1982a, b; Snijders *et al.,* 1992; Irungu *et al.,* 2000).

3. 4.5. Organic matter

Generally, the OM was lowest at 90 days and highest at 120 days among the cultivars and thereafter, OM decreased with increasing age. This trend is in agreement with previous observations by Kiragu and Tamminga (1997) and Snijders *et al.* (1992) who showed that as ash content in forage sweet potato cultivars decreased with age (225-135; 149-127 g/kg DM), OM increased (775-865; 851-873 g/kg DM). The lower OM at 90 and 180 days may indicate that the cultivars at the two ages were at a more vegetative stage than at 120 days (Kiragu and Tamminga, 1997; Snijders *et al.,* 1992). The trend in OM (824-884 g/kg DM) was similar to that of DM (123-169 g/kg DM) and in agreement with reports by Preston and Leng (1987) who showed that the DM content in a feed is positively correlated with its OM. Generally, the OM of the test cultivars is in the range reported in the literature (822, 990, 884 g/kg DM) (Farrell *et al.,* 2000; Iyeghe-Erakpotobor *et al.,* 2006; Chhay *et al.,* 2007).

3. 4.6. Neutral detergent fibre

The increased NDF and ADF with increased harvesting age in most cultivars may be an indication of early maturity. Snijders *et al.* (1992) showed a decrease in photosynthetic leaves and increase in dead leaves as forage sweet potato aged. With maturity, plants partition nutrients in favour of structural fibre and reduced photosynthetic leaves (Somda *et al.,* 1991; Snijders *et al.,* 1992; Olorunnisomo, 2007b). The plants increase the proportion of dead leaves which are known to contain high structural fibre. Olorunnisomo (2007b), however, reported a relatively stable NDF (445-480 g/kg DM) with increased harvesting interval in

sweet potato forage. The elevated NDF and ADF recorded among the cultivars at 120 days and beyond indicated that this age was the optimum and leaf senescence occurred beyond this age (Snijders *et al.*, 1992).

The relatively low NDF in the cultivars was consistent with the general observation that non-grass fodders contain lower NDF (Minson, 1990). Nonetheless, these cultivars had NDF higher than 150g/kg DM, the level recommended by Strasia and Gill (1990) as being suitable for growing ruminants. These cultivars, however, contained NDF below 600g/kg DM beyond which a feed is classified as poor quality (Meissner *et al.*, 1991). The NDF in the cultivars was within the range of reported values in literature ranging from 345.8 to 490.4 g/kg DM (Dominquez and Ly, 1997; Farrell *et al.*, 2000; Ontiti *et al.*, 2000). Likewise, Giang *et al.* (2004); Ouda *et al.* (2004); Lam and Ledin, (2004), and more recently Olorunnisomo (2007b) and Kebede et al. (2008) also observed values within this range. However, their values were lower than those reported by Snijders *et al.* (1992), Kariuki, *et al.* (1998) and Kiragu *et al.* (2007) at 398.0 to 506.0 g/kg DM under irrigation. These higher values may be due to harvesting age, variety used, availability of water and a site effect (Karachi 1982a, b; Irungu *et al.*, 2000).

3. 4.7. Acid detergent fibre and Acid detergent lignin

The general increase in the ADF observed with increased age from 90 days to 180 days is in agreement with Snijders *et al.*, (1992) (312-327 g/kg DM) who reported a significant leaf loss, decreased photosynthetic leaf and an increase in the proportion of stem to leaf with prolonged cutting interval. Plant stems are known to contain more fibre than young leaves (Lam and Ledin, 2004; Kebede *et al.*, 2008). This contradicts with Olorunnisomo (2007a, b) who reported a relatively stable fibre value (255-290 g/kg DM) with increased harvesting interval in sweet potato forage. The ADF and ADL values observed in the present study were similar to those reported by Dominguez and Ly (1997), Lam and Ledin (2004) and Kebede *et al.* (2008) (270-320; 80-140 g/kg DM). Generally, low ADL (below 100 g/kg DM) is beneficial to enable diet digestibility in ruminants. The lignin level in the cultivars was relatively high, ranging between 84.0 to 129.9 g/kg DM, being a characteristic associated with forbs (121-162 g/kg DM) (Van Soest, 1994; Karachi and Dzowela, 1990).

3.4.8. *In vitro* organic matter digestibility

The effect of harvesting age on the *in vitro* organic matter digestibility (IVOMD) of the six cultivars is in agreement with observations by Kiragu and Tamminga (1997) and Snijders *et al.* (1992) who reported that as ash content in sweet potato forage decreased with age OM increased. Organic matter content of forages has been shown to be positively correlated to OMD (Kamalak *et al.*, 2004; Karabulut *et al.*, 2007; Akinfemi, 2010). The lower OMD in K158 at 90 and 180 days may indicate that the cultivar was at a more vegetative stage than at 120 days (Kiragu and Tamminga, 1997; Snijders *et al.*, 1992). In addition, the lower OMD in the cultivars beyond 120 days may be attributed to an increase in mature leaves (Snijders *et al.*, 1992) which are known to contain high NDF. High NDF has been shown to be negatively correlated to OMD (Kamalak *et al.*, 2004; Karabulut *et al.*, 2007; Akinfemi, 2010). The lower OMD recorded among the cultivars beyond 120 days showed that this age was the optimum and an accumulation in the proportion of dead leaves occurred beyond this age (Snijders *et al.*, 1992). At the optimal age, plant leaves have been shown to record high OMD (more than 600 g/kg DM) which decreases thereafter (Sallam, 2005).

3.4.9. Cumulative gas production

The little effect of age to cumulative gas production is in agreement with Olorunnisomo, (2007b) who showed that the OM being the main source of fermentable carbohydrates did not differ among cutting ages between 30 and 150 days. The differences in harvesting ages may have been too small to cause sufficient chemical composition difference in the sweet potato cultivars to influence cumulative gas production as shown in Figures 3.2 to 3.5 (Abas *et al.*, 2005; Kilic and Garipoglu, 2009; Edwards *et al.*, 2012a, b). For example, on supplementing tanna grass (*Brachiaria arrecta*) with gliricidia leaves (*Gliricidia sepium*) it was not until gliricidia leaves attained 22.5% rate when the cumulative gas volume significantly increased from 219 ml/gm OM at 7.5 or 15% supplementation to 292 ml/gm OM (Edwards *et al.*, 2012b). Hence, cumulative gas production in Mugande and Wagabolige was not influenced by havesting age (Abas *et al.*, 2005; Sallam, 2005; Saricicek and Kilic, 2009). The optimum harvesting age appears to be 120 days for cumulative gas production in 99/1, K049, K158 and Marooko.

3.4.10. Partition factor

Partition factor (PF) was defined as the ratio of substrate truly degraded *in vitro* (mg) to volume of gas produced by it (ml) (Makkar, 2004). The PF is, therefore, a measure of efficiency of microbial mass production or efficiency of microbial protein production. Feeds with high PF mean that proportionately more degradable matter was incorporated into microbial mass. This was the case in the current study as the change in PF was in tandem with MP trends in all cultivars. The theoretical range for PF is 2.74 to 4.41 (Blummel and Becker, 1997; Makkar, 2004). Hence the PF values in the current study were within the documented values. According to Blummel and Becker (1997), Arhab *et al.* (2009) and Arhab *et al.* (2010) plants with high PF are generally highly digestible and the values correlate well with DM intake in ruminants. The trend in PF in the current study was in phase with OMD which was in agreement with Blummel and Becker (1997). The age at harvest had little effect on PF as the OMD did not greatly vary with age.

3.4.11. Metabolizable energy

The fact that ME did not vary widely with extended harvesting age of cultivars is in agreement with Olorunnisomo (2007b) who showed that the energy did not vary between 30 and 150 days harvesting intervals. This was particularily demonstrated in Wagabolige whose ME value was similar across harvesting ages. This occurred as the OM being the main source of energy did not differ among the harvesting ages (Olorunnisomo, 2007b). Oduro *et al.* (2008) showed that there was little difference in energy among various sweet potato cultivars. However, the wide variation in ME recorded in Marooko may be attributed to difference in OM at different havesting ages.

The metabolizable energy values were within the range reported by other workers (Kariuki *et al.*, 1998; Aregheore and Tofinga, 2004; Antia *et al.*, 2006; Oduro *et al.*, 2008) but these values were slightly lower than those reported by Olorunnisomo (2007b). This difference may arise due to cultivar and site differences as observed by Karachi (1982a, b), Irungu *et al.* (2000) and Mirzaei-Aghsaghali *et al.* (2011). The climatic factors at the study site may be optimal for these cultivars and the harvesting age allowed adequate time for plants to accumulate optimal energy as shown by Larbi *et al.* (2007) and Olorunnisomo (2007b). These cultivars may have rapidly partitioned energy accumulation to favour leaf production (Snijders *et al.*, 1992; Olorunnisomo 2007b) within the various ages. Sweet potato leaves have been shown to contain higher metabolizable energy than stems essentially due to

their lower fibre content and high OMD (Aregheore and Tofinga, 2004). Snijders *et al.* (1992) recorded decrease in photosynthetic leaves and increase in dead leaves with extended harvesting age, an indication of decreased photosynthetic efficiency.

3.4.12. Short chain fatty acids

The harvesting age influenced the total short chain fatty acid (SCFA) fermentation in the six cultivars of sweet potato. This was in agreement with Irungu et al. (2000), Ngyen and Ogle (2005) and Olorunnisomo (2007b) who showed that different sweet potato cultivars responded differently to extended harvesting age. The similarity in amount of fermented SCFA in 99/1, Wagabolige and Mugande each at the four ages could be attributed to similarity in chemical composition (Kamalak *et al.,* 2004; Karabulut *et al.,* 2007; Akinfemi, 2010). Organic matter has been shown to be positively correlated to *in vitro* digestibility as high digestibility enables increased production of SCFA, while NDF was negatively correlated to *in vitro* digestibility (Mirzaei-Aghsaghali *et al.,* 2011; Mohammadadadi and Chaji, 2012; Taher-Maddah *et al.,* 2012). The similarity in SCFA in some test cultivars at different ages at harvest was in agreement with Oduro *et al.* (2008) who showed that there was little difference in energy among various sweet potato cultivars.

3.4.13. Microbial protein synthesis

In the current study harvesting age affected the microbial protein (MP) synthesis in the six cultivars. This was in agreement with Irungu *et al.* (2000), Ngyen and Ogle (2005) and Olorunnisomo (2007b) who showed that different sweet potato cultivars responded differently to extending harvesting age. Cultivars 99/1 and K049 recorded their lowest MP at 90 days; Wagabolige and Marooko at 150 days; K158 and Mugande at 180 days, respectively. These ages in general coincided with their lowest CP as shown in Section 3.4.4, OMD and SCFA production which reduced MP synthesis in the current study (Kilic and Garipoglu, 2009; Arhab *et al.,* 2010; Edwards et al, 2012b). The similarity in MP synthesis in K158 and Mugande at 120, 150 and 180 days, Wagabolige at 90, 120 and 180 days and Marooko at 120 and 180 days, respectively, may also be due to their similarity in CP, OMD and SCFA production at their respective harvesting ages (Mirzaei-Aghsaghali *et al.,* 2011; Mohammadadadi and Chaji, 2012). The similarity in CP, OMD and SCFA production at respective ages in K049 at 90 and 150 days may have applied although the OMD was lower at 90 days than at 150 days (Naskar *et al.,* 2009; Mirzaei- Aghsaghali *et al.,* 2011). This may

have been caused by lower protein availability at 90 days compared to 150 days as shown in Section 3.4.3.

3.4.14. Most superior forage sweet potato cultivars and their optimal harvesting age

Cultivars K158, Marooko and Wagabolige illustrated the potential of forage sweet potato productivity. The selected cultivars produced high quantities of DM and CP and can be harvested at an earlier age without much reduction in yield. The short harvesting age can enable livestock farmers to increase the number of harvests with the resultant higher annual DM and CP yield. As protein is a major limiting nutrient in Kenyan livestock production systems, cultivars K158, Marooko and Wagabolige appear suitable supplements to poor quality roughages such as cereal crop residues and also as sole feed. Hence, from the current study, cultivars K158, Marooko and Wagabolige were selected for further evaluation, including mineral composition, conservation characteristics and livestock performance as reported in subsequent chapters.

The optimal harvesting age of the majority of sweet potato cultivars as indicated by DM, OM, CP, OMD and ME appeared to be 120 days. Wagabolige recorded the highest OMD, ME, SCFA and microbial protein synthesis at this age. Marooko was equal to Wagabolige in OMD, ME, SCFA and microbial protein synthesis and K158 had the next highest ME and SCFA. Hence K158, Marooko and Wagabolige were the three superior forage sweet potato cultivars which should be widely popularized among livestock farmers.

3. 5. Conclusions and recommendations

The three forage sweet potato cultivars differed in DM and CP yields and *in vitro* digestibility. The harvesting age had effect on chemical composition of selected forage cultivars of sweet potato. These three cultivars recorded their highest DM and CP yield at 120 days, making this age the appropriate harvesting age. These cultivars had their optimum DM, OM and CP; OMD, ME, SCFA and microbial protein synthesis at 120 days and there was little change in NDF, ADF and ADL with increased harvesting ages. Cultivars K158, Marooko and Wagabolige should be widely popularized among livestock farmers to enhance animal performance by bridging the energy and protein gap.

CHAPTER 4

EFFECTS OF HARVESTING AGE ON MACRO AND MICRO MINERAL CONTENT OF FORAGE SWEET POTATO CULTIVARS

4.0. Abstract

Forages are the main sources of nutrients for livestock in Kenya. Variations in mineral concentrations in fodder have been reported depending on season, state of the pastures and soil mineral composition and surveys have confirmed mineral deficiencies in forages. The objective of the current study was to evaluate six sweet potato cultivars on their macro and micromineral content at different harvesting ages. The harvesting age influenced the concentration of macro and microminerals. The harvesting age influenced the concentration of calcium (4.36-8.85), magnesium (2.21-5.36), phosphorus (27.48-38.40), potassium (9.18-29.15) and sodium (4.31-8.75 g/kg DM) in the six cultivars. There was no clear trend in all the minerals as all cultivars differed in calcium and sodium concentration at the four harvesting ages. Calcium, magnesium and phosphorus concentration decreased with increased harvesting age while there was an increase in sodium concentration with age. The trend in potassium concentration was not consistent among the cultivars. The trend in the influence of harvesting age on micro-minerals was inconsistent. Harvesting age influenced cobalt (106.2-290.9), copper (17.8-93.6), iron (230.0-401.0), manganese (116.2-288.6) and zinc (130.7-234.2 g/kg DM) concentration in the forage sweet potato cultivars. All cultivars differed in cobalt concentration at the four harvesting ages and micromineral concentration decreased with increased harvesting age beyond 120 days. It was recommended that further research should be done to analyze the mineral concentration in various parts of sweet potatoes cultivars to increase available literature. Mineral bioavailability studies are required to acertain the mineral adequancy in selected forage sweet potato cultivars.

4.1. Introduction

In Kenya, natural pastures are the main sources of nutrients for livestock. The seasonality in quantity and quality of available herbage has a marked influence on livestock productivity. Variations in mineral concentrations in pastures have been reported depending on season, state of the pastures and soil mineral composition (Jumba *et al.*, 1995a, b; Kuria *et al.*, 2004; Mtui *et al.*, 2006). Detailed surveys carried out in East Africa have confirmed mineral deficiencies in pastures (Mwakatundu 1977; Mtui *et al.*, 2006; Kakengi *et al.*, 2007).

These deficiencies affect the biological systems of livestock, including slow development and impaired reproduction (Kakengi *et al.,* 2007; Mtui *et al.*, 2007).

The National Research Council, (NRC, 1989) and its earlier editions provided the elemental requirements for growth in dairy heifers and milk production in lactating cows. Consequently, Kakengi *et al.* (2007), Mtui et al. (2006) and Mtui et al. (2007) in their studies covering both dry and wet seasons recorded widespread deficiencies in copper, magnesium, manganese and phosphorus in Eastern Africa. The authors reported that the severity of copper deficiency was seasonal with the severity reduced during the wet season. Mtui *et al.* (2006) and Mtui *et al.* (2007) reported adequacy of calcium, phosphorus and iron while Mwakatundu (1977) reported adequacy of magnesium and manganese in Eastern Africa. Kuria *et al.* (2004) reported that the forages preferred by camels in Northen Kenya were deficient in copper and zinc and that between 22 to 50% of the forages were inadequate in phosphorus and potassium. These widespread mineral deficiencies require mineral supplementation to bridge the shortfall in mineral supply (Kuria *et al.,* 2004; Mtui *et al.,* 2006; Kakengi *et al.,* 2007).

Mineral supplementation strategies to livestock have included use of commercial mineral supplements as they increased milk yield, conception rates, produced heavier calves and maintained better animal condition than controls, particularly in the dry season (Kakengi *et al.,* 2007). For commercial mineral supplementation to succeed, it is important that general level of nutrition with regard to energy and protein is maintained in the dry season (Mwakatundu 1977; Kakengi *et al.,* 2007; Mtui *et al.,* 2007). This requires pasture improvement strategies including incorporation of legumes in the pasture. The grass-legume mixture ensures adequate intake of cobalt by grazing animals because legumes have been reported as efficient in accumulating zinc and cobalt (Hodgson *et al.,* 1962; Kakengi, *et al.,* 2007). Also mineral deficiency in pasture herbage is often a result of a deficiency of the mineral in the soil (Mwakatundu, 1977; Jumba *et al.,* 1995 a, b; Mtui *et al.,* 2008).

The potential role of fertilizers in meeting animal requirements for minerals has been reported and recommendations documented on fertilizer packages that are location specific. For example, copper deficiency in animals may be treated by top dressing pastures with copper sulphate (Hodgson *et al.,* 1962). Individual minerals may be administered as a drench, injection or slow release pellets. The use of "copper bullet" has been recommended for range livestock but this would require professional supervision. It should be noted, however, that

inadequate or erratic rainfall may be dominant over soil effects in determining the mineral concentrations of the herbage (Mwakatundu 1977; Mtui *et al.*, 2006).

Majority of forage sweet potato cultivars in Eastern Africa have not been adequately evaluated in terms of their mineral contents (Ondabu *et al.*, 2007; Wheatley and Loechl, 2008; Andrade *et al.*, 2009). The objective of the current study was to evaluate six sweet potato cultivars on their macro- and micro-mineral content at different harvesting ages.

4. 2. Materials and methods

4.2.1. Study site

The study site was as described in Chapter 3 in section 3. 2.1.

4.2.2. Experimental design

The Experimental design was as described in Chapter 3 in section 3. 2. 2.

4.2.3. Determination of macro and microminerals

The determination of macro and microminerals was done according to AOAC (1998) procedures. The sweet potato cultivars in the experimental plots were left to re-grow after being cut back and top dressed. Using hand clippers, all the foliage produced by each of the five cultivars and the control cultivar (Mugande), within a field plot were harvested, at the experimentally assigned harvest ages of 90, 120, 150 and 180 days respectively. The plots were carefully harvested, avoiding harvesting too close-to-the ground to ensure minimum sample contamination with soil. The plots were also harvested after the dew and any rain splash had dried to mimnimize mineral dilution through leaching. The foliage from each plot was individually weighed, thoroughly mixed and sub-samples taken for the determination of macrominerals including calcium (Ca), magnesium (Mg), phosphorous (P), potassium (K) and sodium (Na) and microminerals being cobalt (Co), copper (Cu), iron (Fe), manganese (Mn) and zinc (Zn).

The amounts of various macro and microminerals in the cultivars were determined using atomic absorption spectroscopy. The dry, ground samples were weighed and dissolved in nitric acid (HNO_3) 80% (w/v). Digested samples were diluted 1 to 50-fold as required using 0.5% (v/v) hydrochloric acid (HCL). With the aid of an auto-sampler, 20 micro-litre aliquots of the diluted samples and 5 micro-litres of 1.5% (v/v) HNO_3 were injected into the

graphite furnace. Three replicates of each sample were analyzed using SHIMASZU AAB MODEL AA-6300 (Tokyo, Japan) Atomic Absorption and Flame Emission Spectrophotometer according to AOAC (1998) procedures.

4.2.4. Statistical analyses

The general linear model (GLM) of SAS (2003) was used to compute analyses of variance for RCBD for the composition of macro- and micro-minerals in the control cultivar and the five test cultivars at the respective harvesting ages. The separation of the means was done using least significant difference (LSD) procedures.

The following statistical model was used:-

$Y_{ijk} = \mu + \alpha_j + + \beta_k + \acute{\varepsilon}_{ijk}$

Where Y_{ijk} = Estimated cultivar mineral content

μ = Overall mean cultivar mineral content (Ca, Mg, P, K and Na; Co, Cu, Fe, Mn and Zn)

α_j = Effect of harvesting age on cultivar mineral content

β_k = Block effect on mineral content

$\acute{\varepsilon}_{ijk}$ = Residual error effects of treatments on mineral content

4.3. Results

4.3.1. Macrominerals

The harvesting age influenced ($P<0.05$) the concentration of calcium, magnesium, phosphorus, potassium and sodium in the six cultivars (Tables 4.1 to 4.3). There was no clear trend in all the minerals. However, all cultivars differed ($P<0.05$) in calcium and sodium concentration at the four harvesting ages (Tables 4.1 and 4.3). Generally calcium, magnesium and phosphorus concentration decreased ($P<0.05$) with increased harvesting age while there was increase in sodium concentration with age (Tables 4.1, 4.2 and 4.3). The trend in potassium concentration was not consistent as Mugande and Wagabolige recorded their optimal concentration at 90 days; 99/1, K049 and K158 at 120 days and Marooko at 150 days (Table 4.2).

4.3.2. Microminerals

The harvesting age influenced (P<0.05) the cobalt, copper, iron, manganese and zinc concentration in the forage sweet potato cultivars (Tables 4.3 to 4.5). All cultivars differed (P<0.05) in cobalt concentration at the four harvesting ages (Table 4.3). Generally the micro-elements concentration decreased (P<0.05) with increased harvesting age beyond 120 days.

Table 4.1: Effects of harvesting age and cultivar of forage sweet potato on calcium and magnesium content (g/kg DM)

	Harvesting age (days)			
Cultivar	90	120	150	180
Calcium				
99/1	8.01_5^d	6.10_4^a	6.25_3^b	6.57_3^c
K049	7.53_4^d	4.80_2^a	6.42_4^b	6.64_4^c
K158	4.42_2^a	7.68_5^c	6.91_5^b	8.85_6^d
Marooko	4.36_1^a	8.41_6^d	7.19_6^b	7.93_5^c
Wagabolige	4.67_3^b	4.40_1^a	5.81_2^c	6.43_2^d
Mugande	4.36_1^a	5.49_3^c	4.89_1^b	5.65_1^d
Magnesium				
99/1	4.70_5^c	4.78_4^c	3.35_3^a	4.19_3^b
K049	4.78_5^c	2.90_1^b	2.50_1^a	2.84_2^b
K158	4.53_4^b	5.15_5^d	4.18_5^c	2.24_1^a
Marooko	4.08_2^c	3.20_2^b	2.75_2^a	2.76_2^a
Wagabolige	3.85_1^a	3.92_3^b	3.92_4^b	4.19_3^c
Mugande	4.30_3^c	5.36_5^d	3.85_4^b	2.21_1^a

LSD (P<0.05) for comparing effect of age at harvest (row) on calcium means = 0.09, SEM =0.03
LSD (P<0.05) for comparing effect of fodder cultivar (column) on calcium means = 0.11, SEM = 0.04
LSD (P<0.05) for comparing effect of harvest age (row) on magnesium means = 0.17, SEM = 0.0.06
LSD (P<0.05) for comparing effect of fodder cultivar (column) on magnesium means = 0.21, SEM =0.07
abcd: Means within a row bearing different superscripts are different (P<0.05)
123456: Means within a column bearing different subscripts are different (P<0.05)
SEM: Standard Error of Means

Table 4.2: Effects of harvesting age and cultivar of forage sweet potato on phosphorus and potassium content (g/kg DM)

	Harvesting age (days)			
Cultivar	90	120	150	180
Phosphorus				
99/1	27.48_1^a	29.17_1^b	29.25_2^b	29.23_1^b
K049	32.68_3^a	37.81_5^c	34.66_4^b	34.07_3^b
K158	34.86_4^b	34.56_3^{ab}	34.01_4^a	35.63_4^c
Marooko	28.03_1^a	31.01_2^b	37.96_5^c	38.40^d
Wagabolige	30.40_2^a	37.38_5^d	31.21_3^b	33.59_4^c
Mugande	38.15_5^d	36.13_4^c	28.38_1^a	31.25_2^b
Potassium				
99/1	9.27_1^a	18.75_4^d	12.21_2^c	11.89_2^b
K049	15.05_5^a	29.15_6^d	24.94_4^b	25.75_6^c
K158	10.37_2^c	11.80_1^d	9.18_1^a	9.71_1^b
Marooko	13.08_3^a	25.01_5^b	25.86_5^c	25.09_5^b
Wagabolige	18.77_6^d	17.03_3^c	16.52_3^b	13.94_3^a
Mugande	14.19_4^c	13.65_2^b	12.12_2^a	16.49_4^d

LSD (P<0.05) for comparing effect of harvest age (row) on phosphorus means = 0.61, SEM=0.21
LSD (P<0.05) for comparing effect of fodder cultivar (column) on phosphorus means = 0.74, SEM=0.26
LSD (P<0.05) for comparing effect of harvest age (row) on potassium means = 0.15, SEM=0.05
LSD (P<0.05) for comparing effect of fodder cultivar (column) on potassium means = 0.18, SEM=0.06
abcd: Means within a row bearing different superscripts are different (P<0.05)
123456: Means within a column bearing different subcripts are different (P<0.05)
SEM: Standard Error of Means

Table 4.3: Effects of harvesting age and cultivar of forage sweet potato on sodium and cobalt content

	Harvesting age (days)			
Cultivar	90	120	150	180
Sodium (g/kg DM)				
99/1	6.97_3^d	6.21_4^a	6.40_3^b	6.52_3^c
K049	7.45_4^d	5.09_2^a	6.36_3^b	6.49_3^c
K158	4.34_1^a	6.21_4^b	6.85_4^c	8.75_5^d
Marooko	4.31_1^a	8.25_5^d	7.04_5^b	7.85_4^c
Wagabolige	4.66_2^b	4.33_1^a	5.71_2^c	6.36_2^d
Mugande	4.33_1^a	5.44_3^c	4.85_1^b	5.63_1^d
Cobalt (mg/kg DM)				
99/1	203.0_4^c	276.2_4^d	130.6_1^a	142.7_1^b
K049	299.3_6^d	247.0_2^b	284.8_6^c	230.6_3^a
K158	160.8_3^b	252.6_3^c	237.4_5^a	290.9_4^d
Marooko	277.4_5^d	247.2_2^d	215.6_4^b	200.3_1^a
Wagabolige	138.4_2^a	247.2_2^d	142.4_2^b	147.8_2^c
Mugande	106.2_1^a	141.6_1^b	148.4_3^d	142.8_1^c

LSD ($P<0.05$) for comparing effect of harvest age (row) on sodium means = 0.08, SEM=0.03
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on sodium means = 0.10, SEM=0.04
LSD ($P<0.05$) for comparing effect of harvest age (row) on cobalt means = 0.75, SEM=0.26
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on cobalt means = 0.92, SEM=0.32
abcd: Means within a row bearing different superscripts are different ($P<0.05$)
123456: Means within a column bearing different subscripts are different ($P<0.05$)
SEM: Standard Error of Means

Table 4.4: Effects of harvesting age and cultivar of forage sweet potato on copper and iron content (mg/kg DM)

Cultivar	Harvesting age (days)			
	90	120	150	180
Copper				
99/1	53.2_3^a	58.4_5^b	70.8_5^c	59.3_2^b
K049	78.8_5^a	97.8_6^d	93.6_6^c	83.7_4^b
K158	31.4_2^b	22.7_2^a	22.6_1^a	76.9_3^c
Marooko	86.2_6^d	56.6_4^b	54.5_4^a	77.6_3^c
Wagabolige	68.5_4^d	32.8_3^b	25.6_2^a	41.5_1^c
Mugande	21.2_1^b	17.8_1^a	30.8_3^c	88.6_5^d
Iron				
99/1	354.3_4^b	388.0_6^c	320.3_3^a	354.3_2^b
K049	311.0_3^b	230.0_1^a	325.0_4^c	358.3_3^d
K158	367.0_5^d	326.3_5^c	252.7_1^a	294.7_1^b
Marooko	312.7_3^b	286.7_3^a	354.3_5^c	401.0_5^d
Wagabolige	258.0_1^a	278.0_2^b	292.0_2^c	294.3_1^c
Mugande	303.0_2^a	317.7_4^b	370.3_6^c	387.3_4^d

LSD ($P<0.05$) for comparing effect of harvest age (row) on copper means = 1.10, SEM=0.38
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on copper means = 1.35, SEM=0.47
LSD ($P<0.05$) for comparing effect of harvest age (row) on iron means = 2.54, SEM=0.89
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on iron means = 3.11, SEM=1.09
abcd: Means within a row bearing different superscripts are different ($P<0.05$)
123456: Means within a column bearing different subscripts are different ($P<0.05$)
SEM: Standard Error of Means

Table 4.5: Effects of harvesting age and cultivar of forage sweet potato on manganese and zinc content (mg/kg DM)

	Harvesting age (days)			
Cultivar	90	120	150	180
Manganese				
99/1	290.1_5^{d}	258.1_5^{b}	251.8_4^{a}	288.6_6^{c}
K049	267.9_4^{d}	128.0_2^{a}	143.4_1^{c}	132.4_1^{b}
K158	241.5_3^{d}	116.2_1^{a}	171.3_2^{b}	225.6_4^{c}
Marooko	150.7_1^{c}	135.0_3^{a}	142.8_1^{b}	134.8_2^{a}
Wagabolige	291.5_6^{c}	217.4_4^{a}	227.6_3^{b}	217.6_3^{a}
Mugande	238.1_2^{a}	257.6_5^{b}	263.8_5^{c}	270.1_5^{d}
Zinc				
99/1	152.4_1^{b}	178.7_{23}^{c}	153.8_3^{b}	133.3_1^{a}
K049	153.3_1^{b}	184.0_4^{d}	130.7_1^{a}	170.6_3^{c}
K158	169.5_3^{a}	180.8_3^{b}	227.0_5^{d}	184.9_4^{c}
Marooko	216.2_1^{d}	179.6_{23}^{b}	191.4_4^{c}	163.1_2^{a}
Wagabolige	163.6_2^{b}	136.4_1^{a}	140.8_2^{a}	216.2_6^{c}
Mugande	190.4_4^{b}	177.9_2^{a}	234.2_6^{c}	191.6_5^{b}

LSD ($P<0.05$) for comparing effect of harvest age (row) on manganese means = 0.92, SEM=0.32
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on manganese means = 1.13. SEM=0.39
LSD ($P<0.05$) for comparing effect of harvest age (row) on Zn means = 1.72, SEM=0.60
LSD ($P<0.05$) for comparing effect of fodder cultivar (column) on Zn means = 2.11, SEM=0.73
abcd: Means within a row bearing different superscripts are different ($P<0.05$)
123456: Means within a column bearing different subscripts are different ($P<0.05$)
SEM: Standard Error of Means

4.4. Discussion

4.4.1. Macrominerals

4.4.1.1. Calcium

The relatively high calcium concentration in 99/1 and K049 at 90 days compared to other ages showed that their optimal calcium accumulation occurred earlier than in K158, Marooko, Wagabolige and Mugande whose optimum was at 120 days in Marooko and at 180 days in K158, Wagabolige and Mugande (Table 4.1). Cultivars 99/1 and K049 hence matured early and fodder senescence may have been initiated after 90 days as the calcium concentration declined as demonstrated by Snijders *et al.* (1992); Caliskan *et al.* (2007) and Hue *et al.* (2011). Senescence caused the rate of leaf initiation to be lower than leaf death resulting in reduced calcium as young leaves are known to have high nutrient concentration (Snijders *et al.,* 1992; Olorunnisomo, 2007b; Akinrinde, 2006). It has also been reported that the mineral concentration of herbage decreases with age (Minson, 1990; Akinrinde, 2006; Suttle, 2010). Such fodder senescence may have occurred in Marooko after 120 days regrowth as the calcium concentration declined beyond this age. In K158 and Mugande calcium accumulation tended to increase from 90 to 120 days then declined at 150 days. Wagabolige in general tended to increase calcium with increasing age.

The calcium concentration obtained in this study is within the range reported by Magagula *et al.* (2010), Chuang *et al.* (2011) and Heuze *et al.* (2011) (5.6-8.8 g/kg DM) but it was lower than that reported by other researchers (Oduro *et al.,* 2008; Agbede and Adekiya, 2011; Mwaniri *et al.,* 2011) (10-12 g/kg DM). However, these calcium levels are higher than those reported by Areghheore and Tofinga (2004), Antia *et al.* (2006) and OECD (2010) (2.8-3.5 g/kg DM). The higher calcium levels in the current study compared to those reported by Areghheore and Tofinga (2004), Antia *et al.* (2006) and OECD (2010) may occur due to the difference in sweet potato cultivar, growth site, fertilizer or manure regime, season of growth and harvesting interval (Magagula *et al.,* 2010; Agbede and Adekiya, 2011; Mwaniri *et al.,* 2011). The sweet potato part also influenced the composition (Aregheore, 2003; Monamodi *et al.,* 2003; Akinrinde, 2006).

4.4.1.2. Magnesium

The magnesium concentration in cultivars generally declined with increasing age from 120 days (Table 4.1). This agrees with reports by Minson (1990), Akinrinde (2006) and Suttle (2010) who showed that the mineral concentration of herbage decreases with age.

Cultivars 99/1, K158 and Mugande attained their optimal magnesium concentration at 120 days while K049 and Marooko attained it at 90 days. However, K158 and Mugande differed in magnesium concentration at all the four ages which showed that the ages at harvest affected them differently. The similarity in magnesium concentration in 99/1 at 90 and 120 days; K049 at 120 and 180 days; Marooko at 150 and 180 days and Wagabolige at 120 and 150 days respectively showed that the cultivars reacted to age in the same way at their respective ages (Snijders *et al.,* 1992; Ngyen and Ogle, 2005; Olorunnisomo, 2007a, b).

Cultivars 99/1, K049 and Marooko recorded their lowest magnesium concentration at 150 days while K158 and Mugande recorded their lowest magnesium at 180 days. This indicates that K158 and Mugande matured later than 99/1, K049 and Marooko as forage senescence seemed to set in earlier in 99/1, K049 and Marooko than in K158 and Mugande (Monamodi *et al.,* 2003; Akinrinde, 2006). With onset of senescence the rate of leaf initiation was lower than leaf death resulting in reduced magnesium as young leaves are known to have high magnesium concentration (Snijders *et al.,* 1992; Monamodi *et al.,* 2003; Olorunnisomo, 2007b). It has also been recorded that the mineral concentration of herbage decreases with age (Minson, 1990; Akinrinde, 2006; Suttle, 2010).

The magnesium concentration obtained in this study is within the range reported by other workers (Magagula *et al.,* 2010; Agbede and Adekiya, 2011; Chuang *et al.,* 2011; Heuze *et al.,* 2011) (2.9-6.1 g/kg DM). However, some were lower than those reported by Kumagai et al. (1990), Antia et al. (2006) and Agbede and Adekiya (2011) (4.9-8.8 g/kg DM) while others were higher than those reported by Tayie and Asibey-Berko (2001), Aregheore and Tofinga (2004) and OECD, (2010) (2.8-3.4 g/kg DM). Such variation may occur due to differences in the sweet potato cultivar, growth site, fertilizer or manure regime, season of growth and harvesting interval (Monamodi *et al.,* 2003; Magagula *et al.,* 2010; Agbede and Adekiya, 2011). The sweet potato part (leaf, petiole or stem) will also influence the composition (Wilman *et al.,* 1999; Aregheore, 2003; Ngyen and Ogle, 2005). However, there is little documention on magnesium composition in forage sweet potato (Magagula *et al.,* 2010; Agbede and Adekiya, 2011; Chuang *et al.,* 2011).

4.4.1.3. Phosphorus

The general decrease in phosphorus concentration with increased age at 150 days (Table 4.2) agreed with the findings reported in the literature (Monamodi *et al.,* 2003; Akinrinde, 2006; Suttle, 2010). The difference in phosphorus concentration in most of the

cultivars indicated that their phosphorus concentration was affected differently by increased age (Monamodi *et al.,* 2003; Akinrinde, 2006; Olorunnisomo, 2007a, b). In contrast some of the cultivars maintained their phosphorus concentration beyond 120 days probably indicating equilibrium between the rate of leaf initiation and leaf death (Snijders *et al.,* 1992; Monamodi *et al.,* 2003; Olorunnisomo, 2007a, b).

The phosphorus concentration obtained in this study is within the range reported by other workers (Tsega and Tamir, 2009) (27.2-37.3 g/kg DM) and they were higher than those reported by Monamodi *et al.* (2003), Akinrinde, (2006) and Magagula *et al.* (2010) (18.5-25.2 g/kg DM). Such variation may occur in both macro and micro minerals due to the study sweet potato cultivar, growth site, fertilizer or manure regime, season of growth and harvesting interval (Akinrinde, 2006; Magagula *et al.,* 2010; Agbede and Adekiya, 2011). The sweet potato part (leaf, petiole or stem) will also influence the composition (Wilman *et al.,* 1999; Aregheore, 2003; Akinrinde, 2006). However, there is little documention on phosphorus composition in forage sweet potato (Akinrinde, 2006; Magagula *et al.,* 2010; Agbede and Adekiya, 2011).

4.4.1.4. Potassium

Morooko was different from the other five cultivars as it recorded similar potassium concentration at 120 and 180 days as all the other five cultivars differed in potassium concentration at each of the four ages (Table 4.2). The potassium concentrations obtained in this study were within the range reported by Agbede and Adekiya (2011); Chuang *et al.* (2011) and Heuze *et al.* (2011) (12.5-25.8 g/kg DM). However, these values were higher than those reported by Monamodi *et al.* (2003), Aregheore and Tofinga (2004) and Antia *et al.* (2006) (9.0-18.5 g/kg DM). It is also well known that most soils in East Africa are adequate in potassium due to the geological nature of the rocks from which such soils evolved hence it is not a major deficient element in forages grown in these regions (Wielemaker and Boxem, 1982).

4.4.1.5. Sodium

The fact that all cultivars differed in sodium concentration at the four ages indicated the cultivars were affected in a different way by age (Table 4.3). Generally sodium concentration increased with increased age after 120 days. This trend was contrary to the fact that the mineral concentration of herbage decreases with age (Monamodi *et al.,* 2003;

Akinrinde, 2006; Suttle, 2010) but it is in agreement with Pace *et al.* (2006) and Akwaowo *et al.* (2000) who reported increased concentration with increased age. This trend may suggest that sweet potato unlike other forages accumulate sodium with advanced age. Literature on sodium concentration in forage sweet potato cultivars is scanty. However, the values reported in the current study were higher than those reported by Anita *et al.* (2006) and Magagula et al. (2010) (0.1-3.6 g/kg DM) but were within the range reported by OECD (2010) and Heuze *et al.* (2011) (3.6-11.5g/kg DM).

4.4.2. Microminerals

4.4.2.1. Cobalt

The decreased cobalt concentration in most of the cultivars after 120 days of age (Table 4.3) was in agreement with findings reported in the literature (Minson, 1990; Suttle, 2010; Antonious *et al.,* 2011). However, there is scarcity of literature on cobalt concentration as this element is not routinely determined in forage sweet potato. The cultivars were all affected differently by all the four ages studied as their individual cobalt concentration varied at each age.

4.4.2.2. Copper

Cultivars K049, Marooko, Mugande and Wagabolige were typically different as their copper concentration was wide-ranging at all the four ages studied unlike 99/1 and K158 which recorded similar copper concentration at 120 and 180 days; 120 and 150 days, respectively (Table 4.4). The copper concentration obtained in this study was within the range reported by other workers (Monamodi *et al.,* 2003; Magagula *et al.,* 2010; Heuze *et al.,* 2011) (22-84 mg/kg DM) and was higher than that reported by Anita *et al.* (2006), OECD, (2010) and Chuang *et al.* (2011) (0.3-11.3 mg/kg DM). However, there is little documented on copper composition in forage sweet potato (Monamodi *et al.,* 2003; Magagula *et al.,* 2010; Chuang *et al.,* 2011).

4.4.2.3. Iron

Cultivars K049, K158, Marooko and Mugande were distinctively different from 99/1 and Wagabolige as they differed in iron concentration at all the four ages while 99/1 and Wagabolige recorded similar iron concentration at 90 and 180 days and 150 and 180 days, respectively (Table 4.4). The iron concentration obtained in this study was within the range

reported by other workers (Tayie and Asibey-Berko, 2001; Oduro *et al.*, 2008; Chuang *et al.*, 2011) (240-626 mg/kg DM) but were lower than that reported by Heuze *et al.* (2011) and higher than those reported by Antia *et al.* (2006), Mwaniri *et al.* (2011) and Aregheore (2012) (120-160 mg/kg DM). Variation may also be caused by contamination of foliage with soil since most humic nitosols (Red loam soils) are high in iron. The sweet potato part (leaf, petiole or stem) will also influence the composition (Wilman *et al.*, 1999; Monamodi *et al.*, 2003; Antonious *et al.*, 2011). However, there is little documented in the literature on iron composition in forage sweet potato (Anita *et al.*, 2006; Oduro *et al.*, 2008; Magagula *et al.*, 2010).

4.4.2.4. Manganese

Marooko and Wagabolige each contained similar manganese concentration at 120 and 180 days, respectively, indicating that age separately affected their manganese concentration to the same extent (Table 4.5). Cultivars 99/1, K049, K158 and Mugande were distinctively different from Marooko and Wagabolige as they were affected by each age differently hence recorded variable manganese concentration (Sinjders *et al.*, 1992; Ngyen and Ogle, 2005; Olorunnisomo, 2007b). The manganese concentrations obtained in this study were within the range reported by Monamodi *et al.* (2003), Heuze *et al.* (2011) and Chuang *et al.* (2011) (127-300 mg/kg DM). However, these manganese values were higher than those reported by Antia *et al.* (2006) and OECD (2010) (20-131 mg/kg DM). Again, there is little documented literature on manganese composition in at forage sweet potato (Monamodi *et al.*, 2003; Heuze *et al.*, 2011; Chuang *et al.*, 2011).

4.4.2.5. Zinc

The fact that K049, K158 and Marooko each contained different zinc concentration at all the four ages (Table 4.5) showed how differently they were affected by age (Monamodi *et al.*, 2003; Akinrinde, 2006). However, 99/1, Mugande and Wagabolige were affected by age to the same extent as they individually contained similar zinc concentration at 90 and 150 days; 90 and 180; 120 and 150 days respectively. The zinc concentrations obtained in the current study were higher than those reported in the literature (Tayie and Asibey-Berko, 2001; Chuang *et al.*, 2011; Heuze *et al.*, 2011) (20-53 mg/kg DM). However, there is little documented on zinc composition in sweet potato (Chuang *et al.*, 2011; Heuze *et al.*, 2011).

4.5. Meeting mineral requirements for growth in dairy heifers and milk production in lactating cows

The National Research Council (NRC) (1989) provided the elemental requirements for growth in dairy heifers and milk production in cows. These requirements in growing heifers were 2.9, 1.6, 2.9, 6.5 and 1.0 g/kg DM of feed for Ca, Mg, P, K and Na and 0.1, 10, 50, 40 and 40 mg/kg DM of feed for Co, Cu, Fe, Mn and Zn, respectively. These requirements were 4.3, 2.0, 2.8, 9.0 and 1.8 g/kg DM of feed and 0.1, 10, 50, 40 and 40 mg/kg DM of feed in cows producing 10 kg milk daily, respectively. The Ca, Mg, P, K, Na, Co, Cu, Fe, Mn and Zn concentration in all the forage sweet potato cultivars at the different harvesting ages can, therefore, meet the requirement for growing heifers and cows producing 10 kg milk daily (NRC, 1989). However, mineral bioavailability studies are required to assure the mineral adequacy in these forage sweet potato cultivars.

4.6. Conclusions and recommendations

The harvesting age influenced the concentration of macro and microminerals. Generally calcium, magnesium and phosphorus concentration decreased with increased age while there was an increase in sodium concentration with age. The trend in the influence of harvesting age on micro-minerals was inconsistent. All the cultivars at their various harvesting ages met the requirements for Ca, Mg, P, K, Na, Co, Cu, Fe, Mn and Zn in growing heifers and cows producing 10 kg milk daily. Cultivars K158, Marooko and Wagabolige should be widely popularized among livestock farmers to enhance animal performance by bridging the macro and micromineral deficiency.

CHAPTER 5
CONSERVATION POTENTIAL AS SILAGE OR HAY OF SELECTED FORAGE SWEET POTATO CULTIVARS

5.0. Abstract

Many forage sweet potato (*Ipomoea batatas*) cultivars have not been adequately evaluated for their silage and hay-making potential in Eastern Africa. The objective of the study was to determine silage fermentation characteristics and the nutritive value of the resultant silage on adding different rates of molasses to selected forage sweet potato cultivars. The second study evaluated the effects of forage mechanical preparation on drying rate and nutrient composition of these three forage sweet potato cultivars (K158, Marooko and Wagabolige). Laboratory silos were maintained at room temperature for 60 days then sampled to assess pH, nutritive value, total titratable acidity (TA), ammonia nitrogen (NH_3-N) and butyric acid (BA). Silage fermented at 5 and 10% molasses rates contained similar pH (3.94-4.03), organic matter (OM) (863.2-866.7) and neutral detergent fibre (NDF) (370.2-373.1 g/kg DM) but differed in dry matter (DM) (176.4-185.6) and crude protein (CP) (148.2-153.8 g/kg DM). The three rates fermented silage of similar acid detergent fibre (ADF) (280.3-281.8) and acid detergent lignin (ADL) (94.1-96.4 g/kg DM) but differed in NH_3-N and TA. The lowest and highest NH_3-N was recorded at 5% (5.5-6.6) and 0% (5.7-10.1% total N) molasses respectively. Lowest and highest TA was recorded at 0 (40.1-51.9) and 10% (68.8-147.0 g/kg DM) molasses respectively. Molasses improved silage quality through increased DM and titritable acidity, reduced ammonia and butyric acid. In the hay experiment, at 0 hr chopped and shredded cultivars (197.6-211.9); whole and chopped cultivars (211.9-228.3 g/kg DM) respectively recorded similar DM although shredded cultivars (197.6) had lower DM compared to the whole cultivar treatment (228.3 g/kg DM). However, the three mechanical treatments maintained similar DM in cultivars at 24, 48 and 72 hr of drying (228.0-241.4, 298.0-313.1, 342.2-355.1 g/kg DM). Mechanical treatments did not influence nutrient composition but cultivars differed in nutrient composition. The cultivars contained similar gross energy and mechanical treatments and drying durations did not affect their gross energy. Molasses application at 5% was recommended in making high quality silage from forage sweet potato cultivars. Silage making can avail nutritious diets to livestock throughout the year. However, hay making was a poor conservation method for forage sweet potato as it did not attain 800 g/kg DM even after 96 hr of drying.

5.1. Introduction

The seasonal variation of forage production and the need to provide livestock with feeds throughout the year necessitates conservation of forage. Forage can be conserved either as silage or hay. The conservation of forage in form of silage and hay enable livestock farmers to avail highly nutritious diets to their livestock throughout the year hence improving animal production performance. However, many forage cultivars have not been adequately evaluated for silage or hay making potential in Eastern Africa (Ondabu *et al.,* 2007; Peters, 2008; Wheatley and Loechl, 2008).

Ensiling is a preservation method based on the fermentation of forage carbohydrates by micro-organisms under anaerobic conditions to produce organic acids mainly, lactic acid, which reduces the pH of ensiled material, therefore, drastically reducing the activities of clostridia and enterobacteria hence reducing silage deterioration (Tyrolova and Vyborna, 2008; Nkosi *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011). Normally, a minimum of 6 to 12 % water-soluble carbohydrates is required for proper silage fermentation (McDonald *et al.,* 1995). The threshold pH value in typical tropical forages is 4.8 (McDonald *et al.,* 1995; Irungu *et al.,* 1999; Snijders and Wouters, 2000).

Tropical forages are bulky causing difficulty in silage compaction resulting in loss of soluble carbohydrates, protein nitrogen reduction and an increased loss of amines in amino acids causing an increased buffering capacity. These processes result in an increase in silage pH (Titterton and Bareeba, 2000; Murugeswari, *et al.,* 2006, Hiep *et al.,* 2008) particularly with wilted tropical forages and legumes (Muhlbach, 2000; Pitz *et al.,* 2000; Jatkauskas and Vrotniakiene, 2011) which is an indication of poor silage fermentation (Tyrolova and Vyborna, 2008; Nkosi *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011). Hence sub-optimal fermentation conditions cause proteolysis with resultant decrease in CP (Pys *et al.,* 2010; Khan *et al.,* 2011; Nkosi, *et al.,* 2011).

Ammonia concentration in silage reflects the degree of protein degradation and extensive proteolysis adversely affects the nitrogen utilization in ruminants (Tyrolova and Vyborna, 2008; Nkosi, *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011). High amount of titratable acidity characterizes good quality silage as acidification reduces multiplication of clostridia and enterobacteria. This process reduces proteolysis of plant proteins and ammonia concentration (Tyrolova and Vyborna, 2008; Nkosi, *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011). High butyric acid concentration in silage is an indicator of undesirable fermentation that adversely affects silage quality and ultimately DM intake and utilization in

ruminants (McDonald, 1995; Hassen *et al.,* 2009; Muglali *et al.,* 2012). In fact high butyric acid indicates putrefaction rather than ensiling.

While the biological processes that occur in silage and hay making are well documented, this has not been done for forage sweet potato cultivars utilized in Kenya. For example, the DM of any forage material destined for silage making needs to be 20 to 30%. However, forage sweet potatoes are known to have low DM of less than 17% and this is likely to have a major impact on ensiling and hay making. For example, the low DM in these cultivars can cause loss of valuable soluble nutrients through silage effluent that affects the amount of water soluble carbohydrates (WSC) that is available to enable sufficient fermentation and stabilization of buffering capacity of the crop. It may also bring about butyrate rather than lactate type fermentation during ensiling where protein is susceptible to proteolyses. Silages from tropical forages generally tend to have high buffering capacity that causes increased silage pH leading to poor silage fermentation (Titterton and Bareeba, 2000; Murugeswari, *et al.,* 2006, Hiep *et al.,* 2008). Such silages are also susceptible to aerobic deterioration once the silage is exposed at feeding time. The effect of the relatively low DM in forage sweet potato cultivars on hay drying rate, and the duration to attain safe moisture content (i.e. most suitable DM) in hay material has not been documented. Safe hay storage DM is known to range above 80% DM (Seo *et al.,* 2000; Savoie, 2001; Gupter *et al.,* 2002). In addition, low DM in forages such as sweet potato cultivars can experience signicant loss of valuable nutrients through various avenues such as hay respiration, effluent and leaching (Savoie, 1986; Pattey *et al.,* 1988; Savoie and Mailhot, 1988) that affect the nutritive value of the resultant hay to livestock.

Despite the above knowledge gaps, some of these forage sweet potato cultivars are already being used by some livestock farmers in Kenya with some farmers trying all types of forage conservation including silage making. In a survey conducted in Trans Nzoia County, Kenya, Rono *et al.* (2006) found that over 78 percent of sampled farmers fed sweet potato forage to their livestock. There is, therefore, need to provide objective data on silage fermentation and hay characteristics and nutritive values of these cultivars that enable efficient utilization of forage sweet potato cultivars as conserved livestock feed.

The objective of the current study was to evaluate the three most promising forage sweet potato cultivars for silage making and to determine the effects of forage preparation on their drying rate and nutrient composition.

5. 2. Materials and methods

5. 2.1. Study site

The study site was as described in Chapter 3, section 3.2.1.

5. 2.2. Experimental design

The silage experimental design was completely randomized in a factorial arrangement. The selected three forage sweet potato cultivars K158, Marooko and Wagabolige (Chapter 3) formed the main treatments and the three molasses rates (0, 5 and 10 %) were the factor levels. The three cultivars were grown as detailed in Chapter 3 and harvested at 120 days, the optimum harvesting age determined in Chapter 3. Approximately 20 kg of material was fermented into silage by chopping forage sweet potato to 2.5 cm length then compacting, layer by layer, in polythene laboratory tube silos, 150 cm wide and 100 cm tall each. The molasses was applied at a rate of 0, 5 and 10% (w/w) of the 20 kg of the three forage sweet potato cultivars individually. The respective molasses amount was diluting, weight for weight, with water at a ratio of 3:2 forming a homogeneous solution and applying it while mixing the forage thoroughly layer by layer. This procedure was repeated for all the nine treatments consisting of three cultivars and three molasses application rates. The material was ensiled for 60 days in a room after which triplicate samples were taken for each cultivar and each molasses application rate for assessment of pH, chemical composition, total titratable acidity (TA), ammonia nitrogen (NH_3-N) and butyric acid analysis (AOAC 1998).

In the hay experiment, the three sweet potato cultivars (K158, Marooko and Wagabolige) were grown as detailed in section 3.2.2., and harvested at 120 days. The experiment was a split-plot design. The three sweet potato cultivars and the three mechanical treatments (un-chopped, chopped and shredded forage) were the main plots and the five sampling times during drying (0, 24, 48, 72 and 96 hr) formed the sub-plots.

The three cultivars were chopped or shredded using a motorized chopper or shredder, respectively. Twenty kilogrammes (20 kg) each of these cultivars, un-chopped, chopped and shredded respectively were thinly spread (0.5 cm thick) on separate pieces of black polythene sheets (2 metres width and 4 metres length) and exposed to direct sunshine for nine hours between 0700 hr and 1700 hr daily. Triplicate samples (forming replicates) were taken at intervals of 0, 24, 48, 72 and 96 hr from each cultivar and three mechanical treatments. The

DM increase during drying was used to indicate the drying rate as high DM reflected faster moisture loss.

5. 2.3. Chemical analyses

The chemical composition of forage sweet potato silage and hay was determined using AOAC (1998) procedures. To determine the pH, the silage extract was prepared by adding 270 ml of distilled water to 30 g of silage, homogenizing for 5 minutes in a laboratory blender then filtering. The pH of the filtrate was determined using a pH meter HI 2211 (HANNA Instruments, USA).The silage was also analysed for total titratable acidity (TA), NH_3-N and butyric acid (BA) for each treatment (AOAC, 1998). The fibre in form of NDF, ADF and ADL was analysed according to Van Soest *et al.* (1991). The gross energy of the hay triplicate samples was determined using an adiabatic bomb calorimeter. The hay mean DM, proximate composition and gross energy were calculated for each cultivar and mechanical treatment.

5.2.4. Statistical analyses

The general linear model (GLM) was used to compute analysis of variance (SAS, 2003) for a completely randomized design in a factorial arrangement for silage proximate composition, pH, total titratable acidity (TA), NH_3-N and butyric acid content for each rate of molasses inclusion. To separate the means LSD procedure was applied.

The following statistical model was used:

$Y_{ijk} = \mu + \alpha_j + \acute{\varepsilon}_{ijk}$

Where Y_{ijk} = Estimated value of proximate composition, pH, TA, NH_3-N and butyric acid

μ = Overall mean value of composition

α_j = Effects of molasses rate on composition

$\acute{\varepsilon}_{ijk}$ = Residual error effects of molasses rates

Likewise, in the hay experiment, the general linear model (GLM) was used to compute analysis of variance (SAS, 2003) for hay DM, nutrient composition and gross energy for a split-plot design. The three cultivars and the three mechanical treatments (un-chopped, chopped and shredded forage) were analyzed as main plots and the five sampling times (0, 24, 48, 72 and 96 hr) as sub-plots. To separate the mean hay DM, nutrient

composition and gross energy for the three cultivars, the three mechanical treatments and the five sampling times, LSD procedures were applied.

The following statistical model was used:

$Y_{ijk} = \mu + V_i + M_j + \beta(VM_{ij}) + T_K + V_iT_K + M_jT_K + V_iM_jT_K + \acute{\epsilon}_{ijk}$

Where: Y_{ijk} = Estimated nutrient composition (DM, nutrient composition or gross energy)

μ = Overall mean nutrient composition

V_i = Effects of cultivar on nutrient composition

M_j = Effects of mechanical treatment on nutrient composition

T_K = Effects of sampling time on nutrient composition

$\beta(VM_{ij})$ = Residual effects of treatments on nutrient composition (Error A)

$\acute{\epsilon}_{ijk}$ = Residual effects of treatments on nutrient composition (Error B)

5. 3. Results

The results of silage pH, nutrient composition, NH_3-N, titratable acidity (TA) and butyric acid (BA) are presented in Tables 5.1, 5.2 and 5.3.

5.3.1. Effects of molasses rates and cultivars on nutrient composition of silage

The three molasses rates (0, 5 and 10%) and the culivars affected ($P<0.05$) the silage pH and nutrient composition (Tables 5.1). Molasses rates at 5 and 10% fermented silage containing similar ($P>0.05$) pH, OM and NDF but differed in DM and CP. The DM and CP at 0 and 10%; 0 and 5% molasses were similar ($P>0.05$) respectively and all three molasses rates fermented silage of similar ($P>0.05$) ADF and ADL (Tables 5.1). Silage fermented from K158 and Marooko recorded similar ($P>0.05$) pH, DM, ADF and ADL (Tables 5.1). Wagabolige recorded lower ($P<0.05$) pH and DM than K158 and Marooko but higher ADF and ADL than them. Marooko recorded lower NDF and K158 higher value than Wagabolige. Cultivar K158 and Wagabolige recorded similar ($P>0.05$) CP that was lower than in Marooko.

5.3.2. Effects of molasses rates and cultivars on pH and dry matter of silage

The cultivars K158, Marooko and Wagabolige and molasses levels at 0, 5 and 10% affected ($P<0.05$) the silage pH (Table 5.2). All the three cultivars benefited from molasses

application by fermenting silage with lower pH than silage without molasses. The 5% molasses rate seemed to provide adequate soluble fermentable sugar as beyond this rate the silage maintained stable state ($P>0.05$). Silage made from cultivar Wagabolige at the three molasses rates tended to record insignificantly lower pH values than silage fermented from K158 and Marooko.

The three cultivars and the three molasses rates affected ($P<0.05$) the silage DM (Table 5.2). Molasses at 5% produced silage of higher DM ($P<0.05$) than silage fermented using 0 and 10 % molasses in all the three cultivars. The molasses at 10% tended to lower ($P<0.05$) the silage DM in K158 to equal the silage DM ($P>0.05$) that resulted after no molasses was added to the cultivar. These cultivars at 0% molasses fermented silage containing different DM ($P<0.05$). However, the cultivars fermented silage containing similar ($P>0.05$) DM at 5% molasses. Cultivars K158 and Wagabolige recorded similar ($P>0.05$) DM at 10% molasses that was higher than that recorded in Marooko ($P<0.05$).

5.3.3. Effects of molasses rates and cultivars on ammonia nitrogen, titratable acidity and butyric acid of silage made from selected forage sweet potato cultivars

The three molasses rates and cultivars affected ($P<0.05$) the silage ammonia nitrogen (NH_3-N), titratable acidity (TA) and butyric acid (BA) (Table 5.3). Silages fermented from the three molasses rates differed ($P<0.05$) in NH_3-N and TA. The silage from 5 and 10% molasses rate in K158 recorded similar ($P>0.05$) BA but silage from Marooko and Wagabolige at all the three molasses rates differed in BA. The molasses at 5% recorded the lowest ($P<0.05$) NH_3-N in silage prepared from these cultivars. However, the highest ($P<0.05$) NH_3-N was recorded at 0% molasses in K158 and Wagabolige and at 10% molasses in Marooko. These cultivars differed ($P<0.05$) in NH_3-N concentration at 0 and 5% molasses but at 10% molasses K158 and Wagabolige recorded similar ($P>0.05$) NH_3-N. Marooko recorded the lowest NH_3-N ($P<0.05$) at all the three molasses rates.

The molasses at 0% recorded the lowest ($P<0.05$) TA in silage prepared from the three cultivars. However, the highest ($P<0.05$) TA was recorded at 10% molasses in K158 and Marooko and at 5% molasses in Wagabolige. These cultivars differed ($P<0.05$) in TA at 5 and 10% molasses but at 0% molasses, Marooko and Wagabolige recorded similar ($P>0.05$) TA which was lower than ($P<0.05$) in K158. The silage from Marooko and Wagabolige differed ($P<0.05$) in BA concentrations at the three molasses rate. However, silage from K158 recorded similar ($P>0.05$) BA concentration at 5 and 10% molasses which was lower

Table 5.1: Effect of molasses levels and cultivars types on nutrient composition of silage from selected forage sweet potato cultivars

Nutrients	pH	DM	OM	CP	NDF	ADF	ADL
Molasses levels (%)							
0	4.72_2	174.7_1	852.1_1	153.1_2	387.2_2	280.3_1	94.1_1
5	3.94_1	185.6_2	866.7_2	153.8_2	373.1_1	281.8_1	96.3_1
10	4.03_1	176.4_1	863.2_2	148.2_1	370.2_1	281.3_1	96.4_1
LSD	0.17	2.1	3.7	2.9	6.5	5.1	3.3
Cultivar types							
K158	4.31_2	179.5_2	854.1_1	144.0_1	393.5_3	277.3_1	91.5_1
Marooko	4.37_2	180.2_2	875.0_2	169.4_3	350.8_1	279.8_1	87.0_1
Wagabolige	4.01_1	176.9_1	852.9_1	141.6_1	386.1_2	286.3_2	108.2_2
LSD	0.17	2.1	3.7	2.9	6.5	5.1	3.3

Selected forage sweet potato cultivas are K158, Marooko and Wagabolige found in Kenya's Central Highlands

^{123} Means within a column bearing different subscripts are different ($P<0.05$)

DM, OM, CP, NDF, ADF and ADL expressed in g/kg DM

Table 5.2: Effect of cultivar types and molasses levels on pH and dry matter in silage made from selected forage sweet potato cultivars

	Molasses levels (%)			
Cultivar types	0	5	10	LSD
pH				
K158	$4.82_1{}^b$	$3.99_1{}^a$	$4.12_1{}^a$	0.53
Marooko	$4.92_1{}^b$	$4.01_1{}^a$	$4.14_1{}^a$	
Wagabolige	$4.40_1{}^b$	$3.81_1{}^a$	$3.83_1{}^a$	
DM (g/kg DM)				
K158	$175.8_2{}^a$	$185.0_1{}^b$	$177.8_2{}^a$	3.4
Marooko	$179.6_3{}^b$	$187.4_1{}^c$	$173.7_1{}^a$	
Wagabolige	$168.7_1{}^a$	$184.4_1{}^c$	$177.6_2{}^b$	

Selected forage sweet potato cultivas are K158, Marooko and Wagabolige found in Kenya's Central Highlands

^{abc} Means within a row bearing different superscripts are different ($P<0.05$)

^{123} Means within a column bearing different subscripts are different ($P<0.05$)

Table 5.3: Effect of molasses levels and cultivars types on ammonia nitrogen, titratable acidity and butyric acid of silage made from selected forage sweet potato cultivars

	Molasses levels (%)			
Cultivar types	0	5	10	LSD
Ammonia nitrogen (% Total N)				
K158	9.7_2^c	6.4_2^a	7.1_2^b	0.14
Marooko	5.7_1^b	5.5_1^a	6.0_1^c	
Wagabolige	10.1_3^c	6.6_3^a	7.1_2^b	
Titratable acidity (g/kg DM)				
K158	51.9_2^a	80.4_2^b	147.0_3^c	3.2
Marooko	40.1_1^a	76.9_1^b	82.8_2^c	
Wagabolige	42.8_1^a	93.6_3^c	68.8_1^b	
Butyric acid (mg/kg DM)				
K158	222.0_1^b	210.9_2^a	213.0_2^a	2.3
Marooko	224.9_2^c	215.5_3^b	208.5_1^a	
Wagabolige	221.2_1^c	202.5_1^a	213.1_2^b	

Selected forage sweet potato cultivas are K158, Marooko and Wagabolige found in Kenya's Central Highlands

abc: Means within a row bearing different superscripts are different ($P<0.05$)

123: Means within a column bearing different subscripts are different ($P<0.05$)

than ($P<0.05$) at 0% molasses. The highest ($P<0.05$) BA concentration was recorded at 0% molasses in these cultivars. Cultivars K158 and Wagabolige recorded similar ($P>0.05$) BA concentration at 0 and 10% molasses that was lower than that recorded ($P<0.05$) in Marooko at 0% molasses but higher at 10%. Cultivars K158 and Wagabolige recorded their lowest BA concentration at 5% molasses while Marooko recorded its lowest at 10% molasses.

5.3.4. Moisture loss and dry matter in hay

The results of the effects of mechanical treatments, cultivars and sampling time on the nutrient composition of selected forage sweet potato cultivars are presented in Tables 5.4, 5.5, 5.6 and 5.7.

The three mechanical treatments did not influence ($P>0.05$) the nutrient composition in the three cultivars (Table 5.4). Cultivars K158 and Wagabolige recorded similar ($P>0.05$) DM, OM and ADF but differed ($P<0.05$) in CP, NDF and ADL. Drying time only affected

(P<0.05) the DM content without affecting (P>0.05) other nutrients (Table 5.5). The forage sweet potato hay had similar (P>0.05) DM at 0 and 24 hr but the DM significantly increased (P<0.05) at 48, 72 and 96 hr (Table 5.5).

Mechanical treatments and drying time caused shredded cultivars to increase (P<0.05) in DM at all the five drying durations (Table 5.6). Chopped cultivars maintained (P>0.05) their DM between 0 and 24 hr and again between 48 and 72 hr. The cultivars, however, recorded increased (P<0.05) DM at 96 hr that was significantly (P<0.05) higher than at all other times. Cultivars left whole recorded similar (P>0.05) DM at 0 and 24 hr although they had higher (P<0.05) DM at 48, 72 and 96 hr respectively. At 0 hr chopped and shredded cultivars; whole and chopped cultivars, respectively, recorded similar (P>0.05) DM although shredded cultivars had lower DM (P<0.05) compared to the whole cultivar treatment. However, the three mechanical treatments maintained similar (P>0.05) DM in cultivars at 24, 48 and 72 hr of drying. Chopped cultivars and those left whole had similar (P>0.05) DM at 96 hr although the DM was lower than (P<0.05) that of shredded cultivars. Shredded cultivars tended to dry faster (P<0.05) although this difference did not reach significance until the cultivars were dried for 96 hr.

The cultivar and drying time caused Marooko and Wagabolige to maintain similar (P>0.05) DM at 0 and 24 hr of drying (Table 5.6). However, Wagabolige increased (P<0.05) in DM at 48, 72 and 96 hr while Marooko maintained similar (P>0.05) DM at 48 and 72 hr which was lower than (P<0.05) at 96 hr. Cultivar K158 maintained a similar (P>0.05) DM at 48, 72 and 96 hr which was higher than at 0 and 24 hr. Though all cultivars began with similar DM at the start of the experiment, Marooko and Wagabolige; K158 and Marooko ended up with similar DM (P>0.05) at 48 and 96 hr respectively (Table: 5.6). The DM in all the three cultivars was different (P<0.05) at 24 and 72 hr. At 72 and 96 hours, Wagabolige recorded higher (P<0.05) DM than the other two cultivars. Although K158 recorded higher (P<0.05) DM than Marooko at 72 hr, they had similar (P>0.05) DM at 96 hr. At 24 and 48 hr, K158 maintained the highest DM (P<0.05) compared to Marooko and Wagabolige.

The cultivars and mechanical treatment caused K158 and Marooko to maintain similar (P>0.05) DM whether whole, chopped or shredded (Table 6.7). However, shredding tended to increase (P<0.05) DM in Wagabolige compared to drying it whole or chopped. Within each mechanical treatment the cultivars were affected differently (P<0.05). When chopped, K158 and Wagabolige recorded similar (P>0.05) DM which was higher than

(P<0.05) that observed in Marooko. When left whole or shredded, Wagabolige recorded the highest (P<0.05) DM while Marooko recorded the lowest DM (P<0.05).

5.3.5. Gross Energy

The mechanical treatments and drying times did not affect (P>0.05) the cultivars' GE (Tables 5.4 and 5.5). The three cultivars did not influence (P>0.05) their GE (Tables 5.4).

5.4. Discussion

5.4.1. Silage pH

Adding molasses lowered the silage pH and these results are consistent with those of other workers (Yokota *et al.,* 1998; Hiep, 2008; Kaya and Caliskan, 2010). Ensiling preserves forages under anaerobic conditions through production of organic acids (Tyrolova and Vyborna, 2008; Nkosi *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011). Normally a minimum of 6 to 12% water-soluble carbohydrates is required for proper silage fermentation (McDonald *et al.,* 1995). The molasses provided adequate soluble fermentable sugar at 5% addition for all three cultivars beyond which the silage maintained a stable state (Tyrolova and Vyborna, 2008; Nkosi *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011). The fact that K158 and Marooko did not differ in silage pH may indicate that they had similar morphology and that their physiological activities were similar at the molasses rates in the current study (Suttie, 2000; Mahanta and Pachauri 2005; Hassen *et al.,* 2009).

Few studies on ensiling forage sweet potato without molasses have been reported and silage quality was improved on addition of molasses (Hiep *et al.,* 2008). The amount of WSC contained in the three cultivars, K158, Marooko and Wagabolige in the current study was 73.6, 69.7 and 78.6 g/kg DM, respectively (Irungu *et al.,* 2015). Silage made from Marooko without molasses, had a pH value higher than the threshold of 4.8 which has been recorded in typical tropical fodders while K158 just achieved this threshold (Table 5.2) (McDonald *et al.,* 1995; Irungu *et al.,* 1999; Snijders and Wouters, 2000). This is in agreement with Yang *et al.* (2006) who reported that to achieve silage pH value below 4.5 the initial material should contain more than 70 g/kg DM of WSC. However, Wagabolige achieved this threshold without molasses which may indicate that it had higher levels of fermentable carbohydrates and this is in agreement with the findings of Khalid *et al.* (2013). Wagabolige achievement to this threshold without molasses may have been due to hydrolysis of starch in the cultivar to sugars boosting the supply of available sugars for fermentation (Kaiser *et al.,* 2000; Pitz *et*

al., 2000; Murugeswari *et al.,* 2006). Tropical forages are bulky causing difficulty in silage compaction resulting in loss of soluble carbohydrates, protein nitrogen reduction and an increased loss of amines in amino acids causing an increased buffering capacity. These processes result in an increase in silage pH (Titterton and Bareeba, 2000; Murugeswari *et al.,* 2006, Hiep *et al.,* 2008) particularly with wilted tropical forages and legumes (Muhlbach, 2000; Pitz *et al.,* 2000; Jatkauskas and Vrotniakiene, 2011) which is an indication of poor silage fermentation (Tyrolova and Vyborna, 2008; Nkosi *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011).

All the three cultivars benefited from molasses application by fermenting silage with pH lower than the threshold of 4.8 attainable in typical tropical forages (McDonald *et. al.,* 1995; Irungu *et al.,* 1999; Snijders and Wouters, 2000). This indicated that the concentration of water-soluble carbohydrates in molasses was higher than in forage sweet potato cultivars hence readily provided the necessary fermentable carbohydrates (Yokota *et al.,* 1998; Hiep, 2008; Kaya and Caliskan, 2010). However, the physiological activities in silage made from these cultivars without molasses were different from silage with added molasses as their pH were higher (Suttie, 2000; Mahanta and Pachauri, 2005; Hassen *et al.,* 2009). Within the silo, the pH may tend to increase due to difficulty in silage compaction which may have delayed establishment of anaerobic conditions (Kaiser *et al.,* 2000; Pitz *et al.,* 2000; Suttie, 2000). Consequently, loss of soluble carbohydrates may have occurred through aerobic respiration, a reduction in protein content and an increased de-naturing of amino acids due to overheating (Tyrolova and Vyborna, 2008; Nkosi *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011).

5.4.2. Dry matter

Molasses has a higher density than water (Yokota *et al.,* 1998; Hiep *et al.,* 2008). Murugeswari, et al. (2006) and Kaya and Caliskan (2010) recorded high DM in silage upon addition of molasses which was attributed it to high DM in molasses. Hence molasses rate at 5% increased silage DM and the additional water used to dilute the molasses to enable 10% molasses caused lowered DM in silage (Yokota *et al.,* 1998; Hiep *et al.,* 2008). Therefore, the application of molasses at 10% tended to lower the silage DM to equal the silage DM that resulted after no molasses was added to the cultivars. Accordingly molasses addition at 5%

Table 5.4: Effect of mechanical treatments and cultivar types on the nutrient composition (g/kg DM) of hay in selected forage sweet potato cultivars

Nutrients	DM	OM	CP	NDF	ADF	ADL	GE*
Mechanical treatment							
Whole	298.8	869.7	164.5	385.0	282.1	96.4	16.8
Chopped	298.1	870.3	164.7	383.6	281.6	93.8	16.8
Shredded	306.2	870.3	164.6	383.8	281.7	96.9	16.8
LSD	22.6	4.1	1.5	2.8	2.0	5.2	0.2
Cultivar types							
K158	310.0_{2}	870.4	156.8_{1}	382.3_{2}	281.7_{12}	85.0_{1}	16.8
Marooko	263.0_{1}	869.8	170.4_{3}	373.0_{1}	280.3_{1}	85.1_{1}	16.9
Wagabolige	330.2_{2}	870.1	166.5_{2}	397.1_{3}	283.4_{2}	117.1_{2}	16.8
LSD	22.6	4.1	1.5	2.8	2.0	5.2	0.2

Selected forage sweet potato cultivas are K158, Marooko and Wagabolige found in Kenya's Central Highlands

123 Means within a column bearing different subscripts are different ($P<0.05$)

*MJ/kg DM

Table 5.5: Effect of drying time on the nutrient composition (g/kg DM) of hay for selected forage sweet potato cultivars

Nutrients	DM	OM	CP	NDF	ADF	ADL	GE*
Drying time (hrs)							
0	212.6_1	869.9	164.3	385.2	282.1	96.1	16.8
24	233.0_1	870.5	164.8	383.6	282.3	97.6	16.8
48	307.6_2	869.8	164.4	383.9	280.5	92.3	16.8
72	347.2_3	870.4	164.7	385.1	282.3	98.2	16.8
96	404.1_4	869.8	164.7	382.9	281.5	94.2	16.9
LSD	22.4	5.3	3.1	3.6	2.6	6.7	0.2

Selected forage sweet potato cultivas are K158, Marooko and Wagabolige found in Kenya's Central Highlands

[1234] Means within a column bearing different subscripts are different ($P<0.05$)

*MJ/kg DM

Table 5.6: Effect of cultivar, mechanical treatment and drying time on dry matter of hay from selected forage sweet potato cultivars (g/kg DM)

	Time in Hrs					
Nutrients	0	24	48	72	96	LSD
Mechanical Treatment						
Chopped	211.9_{12}^{a}	228.0^{a}	311.1^{b}	344.1^{b}	395.4_{1}^{c}	23.1
Shredded	197.6_{1}^{a}	241.4^{b}	313.1^{c}	355.1^{d}	423.2_{2}^{e}	
Whole	228.3_{2}^{a}	231.8^{a}	298.0^{b}	342.2^{c}	393.8_{1}^{d}	
Cultivar types						
K158	215.6_{1}^{a}	275.2_{3}^{b}	347.6_{2}^{c}	345.8_{2}^{c}	365.7_{1}^{c}	21.7
Marooko	210.3_{1}^{a}	193.5_{1}^{a}	288.9_{1}^{b}	277.8_{1}^{b}	344.2_{1}^{c}	
Wagabolige	211.9_{1}^{a}	232.5_{2}^{a}	286.2_{1}^{b}	418.0_{3}^{c}	502.4_{2}^{d}	

Selected forage sweet potato cultivas are K158, Marooko and Wagabolige found in Kenya's Central Highlands

^{abcde} Means within a row bearing different superscripts are different (P<0.05)

$_{123}$ Means within a column bearing different subscripts are different (P<0.05)

Table 5.7: Effect of cultivar types and mechanical treatment on dry matter of hay from selected forage sweet potato cultivars

	Mechanical Treatment			
Cultivar	Chopping	Shredding	Whole	LSD
DM (g/kg DM)				
K158	317.2_{2}	312.4_{2}	300.4_{2}	21.7
Marooko	259.4_{1}	256.3_{1}	273.2_{1}	
Wagabolige	317.8_{2}^{a}	349.9_{3}^{b}	322.9_{3}^{a}	

Selected forage sweet potato cultivas are K158, Marooko and Wagabolige found in Kenya's Central Highlands

^{ab} Means within a row bearing different superscripts are different (P<0.05)

$_{123}$ Means within a column bearing different subscripts are different (P<0.05)

produced silage with the highest DM. These observations could have occurred as the DM of fresh forage sweet potatoes increased with addition of molasses then it decreased due to the activities of fermentative anaerobes, which break up DM that includes the sugars to form lactic acid, which is essential for silage preservation (McDonald *et al.,* 1995; Kaya and Caliskan, 2010; Pys *et al.,* 2010).

The similarity in silage DM for K158 and Wagabolige at 5 and 10% molasses (Table: 5.2) may indicate their similar reaction at these molasses addition rates (Suttie, 2000; Mahanta and Pachauri, 2005; Hassen *et al.,* 2009). The lower DM recorded in silage fermented from Wagabolige at 0% molasses may have shown that Wagabolige had different DM compared to cultivars K158 and Marooko before molasses addition (Suttie, 2000; Mahanta and Pachauri, 2005; Hassen *et al.,* 2009). However, the fact that K158 and Wagabolige produced silage containing similar DM at 5 and 10% molasses and that the DM in the three cultivars differed when no molasses was added showed that DM highly depended on molasses rate (Yokota *et al.,* 1998; Hiep *et al.,* 2008; Kaya and Caliskan, 2010).

5.4.3. Organic matter

The fact that molasses added at 5 and 10% produced silage with similar OM showed that OM highly depended on molasses rate as molasses contains high OM (Yokota *et al.,* 1998, Murugeswari, *et al.,* 2006; Kaya and Caliskan, 2010). The high OM in the molasses inevitably increased silage OM (Yokota *et al.,* 1998; Hiep *et al.,* 2008; Kaya and Caliskan, 2010).

5.4.4. Crude protein

The lower CP in silage at 10% molasses rate may have indicated sub-optimal fermentation conditions that may have caused proteolysis with resultant decrease in CP. Adding molasses at 10% lowered the CP in silage compared to 0 and 5% molasses which may have caused higher rate of proteolysis (Kaya and Caliskan, 2010). This may also have been due to the low CP in the molasses and the increased molasses addition at 10% inevitably reduced silage CP (Yokota *et al.,* 1998; Hiep *et al.,* 2008; Kaya and Caliskan, 2010). Also the fermentation conditions in the silo may have been sub-optimal which caused excessive activities of fermentative anaerobes resulting in loss of amines in amino acids causing an increased buffering capacity (Giang and Ogle, 2004; Pys *et al.,* 2010; Khan *et al.,* 2011).

Such conditions in the silo may have resulted in butyrate type of fermentation instead of the more favourable lactate type of fermentation. These processes may have resulted in decreased silage CP (Muhlbach, 2000; Pitz *et al.,* 2000; Titterton and Bareeba, 2000).

5.4.5. Neutral Detergent Fibre, Acid Detergent Fibre and Acid Detergent Lignin

Molasses addition tended to reduce NDF as silage fermented without molasses contained higher NDF than when molasses was added at 5 and 10%. This is in accordance with Murugeswari *et al.* (2006) and Kaya and Caliskan (2010) as molasses has no NDF but adds OM (Yokota *et al.,* 1998; Hiep *et al.,* 2008) and molasses enhanced cell wall degradation due to increased silage fermentation caused by the sugars in molasses (Baytok *et al.,* 2005; Kaya and Caliskan, 2010). The similarity in ADF and ADL in silage from all cultivars agrees with Murugeswari *et al.* (2006) and Kaya and Caliskan (2010) as molasses had little ADF and ADL (Yokota *et al.,* 1998; Hiep *et al.,* 2008).

5.4.6. Ammonia nitrogen

The cultivars had different inherent characteristics as they produced silage containing different concentration of NH_3-N and reacted differently on addition of molasses between 0 and 10%. These differences made the cultivars to react differently within each molasses rate and across molasses rates as reported by Mahanta and Pachauri (2005) and Hassen *et al.* (2009) who recorded differences in NH_3-N among different varieties of sorghum and grass silage, respectively. The cultivars in the current study recorded their lowest NH_3-N at 5% molasses. Cultivars K158 and Wagabolige recorded their highest NH_3-N at 0% molasses while Marooko had the highest NH_3-N at 10% molasses.

Ammonia in silage reflects the degree of protein degradation. Extensive proteolysis adversely affects the nitrogen utilization in ruminants (Tyrolova and Vyborna, 2008; Nkosi, *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011). Hence the silages from all cultivars recorded their lowest proteolysis at 5% molasses rate and the highest when 10% molasses was applied. This may indicate that at 5% molasses rate, the soluble sugars were fermented to rapidly lower the silage pH below 4.8 at which point the activities of clostridia and enterobacteria, which are responsible for protein degradation stopped (MacDonald, 1995; Tyrolova and Vyborna, 2008; Jatkauskas and Vrotniakiene, 2011). At 0% molasses in the silages, the level of proteolysis was higher (Mahanta and Pachauri, 2005; Hassen *et al.,* 2009; Nkosi, *et al.,* 2011).

The three molasses rates produced silage that contained similar NH_3-N concentration with those reported by Hassen *et al.* (2009), Nkosi, *et al.* (2011) and Muglali *et al.* (2012). The silages produced in the current study, however, contained higher NH_3-N concentrations than those reported by Murugeswari *et al.* (2006) who ensiled cassava leaves with 2% molasses; and Tyrolova and Vyborna (2008) who studied commercial microbial silage additives which were known to induce suitable silage fermentation. The silages in the current study contained lower NH_3-N than those documented by Phiri, *et al.* (2007), Jatkauskas and Vrotniakiene (2011) and Khan *et al.* (2011) as these silages contained substantial proportions of legumes and tree browse. Tropical legumes are bulky causing difficulty in silage compaction resulting in increased rate of loss of amines in amino acids causing an increased buffering capacity. These processes result in an increase in NH_3-N (Titterton and Bareeba, 2000) particularly with wilted tropical legumes (Muhlbach, 2000; Pitz *et al.,* 2000). However, the NH_3-N in the current study was in agreement with that of Hiep *et al.* (2008) although they studied legume silage as they applied 3 to 9% molasses. The silage prepared from the the three molasses rate contained acceptable range in NH_3-N as for well fermented silage should contain less than 12% NH_3-N of total N (MacDonald, 1995; Hassen *et al.,* 2009; Nkosi, *et al.,* 2011).

5.4.7. Titratable acidity

Acidification of silage reduces multiplication of clostridia and enterobacteria causing reduction in proteolysis of plant proteins and ammonia concentration (Tyrolova and Vyborna, 2008; Nkosi, *et al.,* 2011; Jatkauskas and Vrotniakiene, 2011). The 5 and 10% molasses rates resulted in silages with higher titratable acidity as molasses provided soluble sugars that were fermented to increase the silage titratable acidity to the point the activities of clostridia and enterobacteria, which are responsible for protein degradation stopped (MacDonald, 1995; Tyrolova and Vyborna, 2008; Jatkauskas and Vrotniakiene, 2011). These molasses rates produced silage containing different titratable acidity as molasses was known to be rich in readily fermentable sugars (Murugeswari *et al.,* 2006; Hiep *et al.,* 2008; Kaya and Caliskan, 2010). Increased rate of molasses increased readily fermentable sugars (Murugeswari *et al.,* 2006; Hiep *et al.,* 2008; Kaya and Caliskan, 2010) hence the molasses application at 0% recorded the lowest titratable acidity in prepared silage which may indicate that silage deterioration may have occurred.

The cultivars and molasses rates produced silage that differed in titratable acidity as cultivars are known to differ in silage fermentation characteristics (Mahanta and Pachauri 2005; Hassen *et al.,* 2009) and molasses is known to be rich in readily fermentable sugars (Murugeswari, 2006; Hiep *et al.,* 2008; Kaya and Caliskan, 2010). The three cultivars differed in titratable acidity at 5 and 10% molasses rate as they differed in fermentation characteristics (Mahanta and Pachauri 2005; Hassen *et al.,* 2009) but at 0% molasses Marooko and Wagabolige produced silage of similar fermentation characteristic which was different from K158 silage. This trend may be due to a higher concentration of readily fermentable sugars in Marooko and Wagabolige compared to K158 (Murugeswari, 2006; Hiep *et al.,* 2008; Kaya and Caliskan, 2010). Increased rate of molasses increased readily fermentable sugars (Murugeswari, 2006; Hiep *et al.,* 2008; Kaya and Caliskan, 2010) hence the molasses application at 0% recorded the lowest titratable acidity in silage prepared from the three cultivars. However, the highest titratable acidity was recorded at 10% molasses application in K158 and Marooko and at 5% molasses application in Wagabolige. Wagabolige recorded the highest titratable acidity at lower molasses rate confirms its higher content of readily fermentable cabohydrates (Murugeswari, 2006; Hiep *et al.,* 2008; Kaya and Caliskan, 2010).

5.4.8. Butyric acid

High butyric acid concentration in silage is an indicator of undesirable fermentation that adversely affects DM intake and utilization in ruminants (McDonald, 1995; Hassen *et al.,* 2009; Muglali *et al.,* 2012) and it is an indicator of putrefaction. Hence, the silages may have recorded the highest clostridia deterioration at 0% molasses and lowest at 5 and 10% molasses rates (Hassen *et al.,* 2009; Jatkauskas and Vrotniakiene, 2011; Nkosi *et al.,* 2011). Enhanced activities of clostridia and enterobacteria cause extensive proteolysis resulting in production of branched chain acids such as butyric acid. This process is undesirable because livestock do not consume such silage compared to one high in lactic acid. Butyric acid and acetic acid are by-products of microbial metabolism and such activities cause loss of organic matter and silage putrifaction.

Cultivars K158, Marooko and Wagabolige were different as they produced silage containing different concentration of butyric acid and reacted differently on addition of molasses between 0 and 10%. These differences also caused the cultivars to react differently within each molasses addition and across molasses application rates. This is in concurrence

with Mahanta and Pachauri (2005) and Hassen *et al.* (2009) who recorded differences in butyric acid among different varieties of sorghum and grass silage, respectively. The cultivars K158 and Wagabolige recorded their lowest butyric acid at 5% molasses and Marooko at 10% molasses rate. Hence K158 and Wagabolige recorded their lowest clostridia deterioration at 5% molasses and that of Marooko at 10% molasses rate. The deterioration of these cultivars was highest at 0% molasses application as they recorded their highest butyric acid.

Marooko underwent higher clostridia deterioration compared to K158 and Wagabolige at 0 and 5% molasses rate but this order was reversed at 10% molasses rate (Hassen *et al.,* 2009; Jatkauskas and Vrotniakiene, 2011; Nkosi, *et al.,* 2011). This trend may be due to the higher DM in Marooko silage that may have caused suboptimal compaction enhancing activities of clostridia and enterobacteria (MacDonald, 1995; Tyrolova and Vyborna, 2008; Jatkauskas and Vrotniakiene, 2011). At 10 % molasses the activities of clostridia and enterobacteria affected K158 and Wagabolige at the same level but caused lower deterioration in Marooko (Mahanta and Pachauri, 2005; Hassen *et al.,* 2009; Nkosi, *et al.,* 2011). Enhanced activities of clostridia and enterobacteria cause extensive proteolysis resulting in production of branched chain acids such as butyric acid.

The three molasses rates and cultivars produced silage that contained similar butyric acid concentration with those documented by Hassen *et al.* (2009) and Jatkauskas and Vrotniakiene (2011). The silages produced in the current study, however, contained higher butyric acid concentrations than those studied by Murugeswari *et al.* (2006) who ensiled cassava leaves with 2% molasses and Tyrolova and Vyborna (2008) who studied commercial microbial silage additives which were known to induce suitable silage fermentation (Hiep *et al.,* 2008; Kaya and Caliskan, 2010; Pys *et.al.,* 2010; Nkosi *et al.,* 2011). The silages in the current study contained lower butyric acid concentration than those documented by Phiri, et al. (2007), Khan *et al.* (2011) and Jatkauskas and Vrotniakiene (2011) without additive as these silages contained substantial proportions of legumes and tree browse.

The butyric acid concentration in the current study was in agreement with those of Hiep *et al.* (2008) and Jatkauskas and Vrotniakiene (2011), although the authors studied legume silage and they applied 3 to 9% molasses and commercial additives, respectively. Molasses is known to be rich in readily fermentable sugars whereas commercial additives enhance silage fermentation (Hiep *et al.,* 2008; Tyrolova and Vyborna, 2008; Jatkauskas and Vrotniakiene, 2011). The silage prepared from the three molasses rates contained acceptable

range of butyric acid concentration (less than 500 mg/kg DM) for well fermented silage (MacDonald, 1995; Hassen *et al.*, 2009; Nkosi, *et al.*, 2011).

5.4.9. Moisture loss in hay

Rapid moisture loss in hay making is essential to reduce nutrient losses due to respiration and reduce spoilage (Savoie, 2001; Gupta *et al.*, 2002; Enoh *et al.*, 2005). However, care is needed as rapid and extensive drying can cause leaf shattering of leaves and therefore loss of nutrients. Mechanical treatments increase the rate of drying by exposing a larger surface area for moisture to evaporate rapidly (Pattey *et al.*, 1988; Seo *et al.*, 2000; Suttie, 2000) compared to leaving the forage whole. There was no major advantage in chopping or leaving the cultivars whole in the present study, may suggest that the cultivars were either insufficiently thinly spread or the study was not long enough for these benefits to be recorded (Pattey *et al.*, 1988; Savoie and Mailhot 1988; Enoh *et al.*, 2005). An extended duration may be essential as shown by the fact that although shredded material tended to dry faster, the difference was not significant. The three mechanical treatments did not achieve the 800 g/kg DM recommended as the safe storage moisture within the period of the study (Seo *et al.*, 2000; Wanapat et al, 2000; Enoh *et al.*, 2005).

Cultivars with similar morphological and physiological activities have been shown to lose moisture at similar rates (Pattey *et al.*, 1988; Savoie and Mailhot, 1988; Suttie, 2000). Hence K158 and Wagabolige had probably similar rate of moisture loss as they had similar DM and they differed from Marooko which recorded a lower DM. Wagabolige may be coarser than K158 and Marooko as shredding increased its DM more than in K158 and Marooko. Wagabolige tended to increase in DM most rapidly when dried whole or shredded compared to K158 and Marooko. This may indicate that Wagabolige was leafier than K158 and Marooko as it has been shown that leaves dried faster than fleshy stems (Pattey *et al.*, 1988; Suttie, 2000; Enoh *et al.*, 2005). However, Wagabolige had the highest DM when shredded, an indication that this may be the best mechanical treatment to ensure rapid drying during hay making.

Although the cultivars maintained their DM at 0 and 24 hr, it increased significantly at 48, 72 and 96 hr when the cultivars were dried at the same ambient temperature (Table 5.5 and 5.6). The similarity in DM before 24 hr may suggest an initial slow evaporation which predominantly involved leaves and free moisture on the plant surface (Pattey *et al.*, 1988; Savoie and Mailhot 1988; Gupta *et al.*, 2002). More than 48 hr of sun-drying may be

essential for moisture loss from plant stems to influence DM in these cultivars as shown by the increased moisture loss beyond 48 hr. According to Suttie (2000) the initial moisture loss is rapid through the open stomata but following wilting the stomata tend to close and further moisture loss can only be through the waxy epidermis of plant leaves and stems and this is normally a very slow process.

5.4.10. Nutrient composition

The cultivars in the current study were shown to contain similar OM hence it was consistent that neither the mechanical treatments nor the drying time could affect the vine OM (Pattey *et al.,* 1988). The OM in the cultivars reported in this study under different treatments are within those reported in the literature (Farrell *et al.,* 2000; Iyeghe-Erakpotobor *et al.,* 2006; Chhay *et al.,* 2007).

The difference in CP and NDF in K158 indicated their inherent characteristic (Table 5.4). The CP reported in this study under different treatments is within those reported in the literature (Ondabu *et al.,* 2005; Olorunnisomo 2007a, b; Kebede *et al.,* 2008). Also, the NDF, ADF and ADL values were within the reported range (Giang *et al.,* 2004; Lam and Ledin, 2004; Ouda *et al.,* 2004). As expected the three mechanical treatments and the five sampling times did not affect the CP, OM, NDF, ADF and ADL (Pattey *et al.,* 1988). These facts may show that there were minimal nutrient losses due to spoilage and crop respiration during the study drying periods which is in agreement with reports in the literature (Pattey *et al.,* 1988; Suttie, 2000; Savoie, 2001).

5.4.11. Gross Energy

The three cultivars showed similar OM in the current study and OM is the primary source of energy in a feed. Olorunnisomo (2007b) reported that gross energy (GE) did not differ among the cutting ages in sweet potato. Oduro *et al.* (2008) showed that there was little difference in GE among various sweet potato cultivars. The climatic factors at the study area may be optimal for these cultivars and the harvesting age allowed adequate time for the plants to accumulate optimal GE (Larbi *et al.,* 2007; Olorunnisomo, 2007b). Hence the similarity in GE among the test cultivars showed that they expressed their full potential in GE accumulation. The three mechanical treatments and five sampling times did not affect the sweet potato GE, which were within the range reported by Aregheore and Tofinga (2004), Antia *et al.* (2006) and Oduro *et al.* (2008); but slightly lower than those reported by

Olorunnisomo (2007b). This difference may have arisen due to cultivar differences as reported by Karachi (1982a, b) and Irungu *et al.* (2000).

5.5. Conclusions and recommendations

Molasses tended to reduce NDF, ADF and ADL in silage as it enhanced silage fermentation. Molasses improved silage quality through increased DM and titritable acidity, reduced ammonia and butyric acid. The three cultivars can be ensiled without molasses to produce silage with pH below 4.8 saving money in silage production and can extend silage making in farming situations where silage additives are unavailable. Where molasses is available the 5% molasses rate was recommended in making higher quality silage from sweet potato cultivars. Marooko produced the best silage as it contained the highest DM, OM and CP and low NDF, ADF and ADL and relatively low NH_3-NH and butyric acid. Cultivars K158 and Wagabolige contained similar OM and CP but K158 had lower ADF and ADL and higher DM and NDF than Wagabolige. Wagabolige produced relatively poorer quality silage compared to K158 as it recorded higher NH_3-NH and lower TA.

The sweet potato cultivars maintained similar DM whether whole, chopped or shredded. However, shredding was considered the best treatment to encourage rapid drying. Shredding was recommended as the best treatment to rapidly increase the drying rate in these cultivars.

Wagabolige increased in DM most rapidly when dried whole or shredded compared to K158 and Marooko. Drying time only affected the DM content hence rate of moisture loss, without affecting nutrient composition. The forage sweet potato hay had similar DM at 0 and 24 hr but the DM significantly increased at 48, 72 and 96 hr. However hay making was a poor conservation method for forage sweet potato as it did not attain 800 g/kg DM even after 96 h of drying. Silage making using forage sweet potato cultivars should be popularized to livestock farmers to enable them to avail highly nutritious diets to their livestock throughout the year hence improving livestock production performance.

CHAPTER 6

NUTRIENT INTAKE, *IN-VIVO* DIGESTIBILITY, RUMEN FERMENTATION CHARACTERISTICS AND GROWTH PERFORMANCE OF SHEEP FED FORAGE SWEET POTATO CULTIVARS

6.0. Abstract

Selected forage sweet potato cultivars (*Ipomoea batatas* (L) Lam) have superior forage characteristics, have high rate of regeneration after harvest, are able to smother weeds and can tolerate diseases and moisture stress. However, little information is documented on their feeding value. The study objective was to determine nutrient intake, digestibility, rumen fermentation characteristics and performance of sheep fed on four selected forage sweet potato cultivars (K158, Marooko, Mugande and Wagabolige). Cultivars did not influence intake of dry matter (DM) (93.8-98.1), organic matter (OM) (82.0-85.6), neutral detergent fibre (NDF) (37.6-38.8 g/kg $W^{0.75}$) and metabolizable energy (0.94-0.99 MJ/kg $W^{0.75}$); digestibility of DM (740.3-744.1) and OM (747.0-751.7 g/kg DM) and intake of digestible DM (69.8-72.6) and OM (61.3-64.4 g per kg $W^{0.75}$); rumen pH (6.80-6.86), molar percentages of acetate (68.34-69.59), propionate (21.35-22.58), butyrate (7.43-7.57) and acetate to propionate ratio (3.03-3.20). Cultivars influenced intake of crude protein (CP) (10.7-16.9) and acid detergent fibre (ADF) (25.9-28.5 g/kg $W^{0.75}$). Digestibility of CP (655.7-821.1), NDF (594.1-712.8) and ADF (477.0-483.7 g/kg DM); intake of digestible CP (7.0-13.9) and NDF (22.4-27.7 g per kg $W^{0.75}$) were also influenced by cultivar. CP and NDF digestibility differed among all four cultivars with Morooko and K158 having highest CP and NDF digestibility, respectively. Sheep fed on K158 and Wagabolige ingested similar quantities of digestible CP (11.6-11.8 g per kg $W^{0.75}$) which was lower than in Marooko (13.9 g per kg $W^{0.75}$). The forage sweet potato cultivars affected sheep growth and feed conversion efficiency (FCE). Sheep fed on K158, Marooko and Wagabolige recorded similar growth rate while sheep fed on Mugande grew the least. The mean ADG of the sheep were: 143.0, 158.6, 103.9 and 146.8 g and FCE was 13.6, 13.4, 10.4 and 13.0 kg expressed in gain per 100 kg dry matter on cultivars K158, Marooko, Mugande and Wagabolige, respectively. The four cultivars provided superior feeds to sheep which classify them as high quality forages hence have potential to improve livestock production in Kenya.

6.1. Introduction

Forage sweet potato cultivars have been reported to sustain high nutrient intakes in sheep and goats (Lam and Ledin, 2004; Olorunnisomo, 2007b; Kebede *et al.,* 2008) and could provide nutrients necessary to sustain high average daily gain (ADG). Aregheore (2003) documented that the daily live weight gains of goats were affected by forage type and the ratio offered. The goats on sole forage sweet potato diet and those on mixed diets of forage sweet potato with batiki grass (*Ischaemum aristatum*) recorded higher ADG and feed conversion efficiency compared to a sole diet of batiki grass (Aregheore, 2003). These forage sweet potato characteristics may indicate that the efficiency of nutrient incorporation into weight increase was promoted (Hagerman *et al.,* 1992; Kaitho, 1997). The cultivars have high OM which agrees with the reports by Farrell *et al.* (2000); Iyeghe-Erakpotobor *et al.* (2006) and Chhay *et al.* (2007). The forage sweet potato cultivars have been reported to have high digestibility (Etela *et al.,* 2007; Larbi *et al.,* 2007; Olorunnisomo, 2007b) hence promote nutrient intake.

Minson (1990) showed that nutrient digestibility was positively correlated to OM digestibility which in turn was related to the energy available in the forage. The author showed that nutrient digestibility rose with increased ME density and a reduction in NDF. Forage sweet potato cultivars are known to have low NDF (Ouda *et al.,* 2004; Olorunnisomo, 2007a, b; Kebede *et al.,* 2008) and therefore, are unlikely to limit nutrient and ME intake (Preston and Leng, 1987). It has also been shown that forage sweet potato cultivars can replace lucerne in diets for weaned calves (Kariuki *et al.,* 1998). Additionally, Semenye et al. (1989) and Orodho *et al.* (1993) successfully used sweet potato cultivars as milk replacer in kids and calves respectively. These diets improved livestock performance through increased daily live weight gain and improved feed conversion efficiency (Kiragu and Tamminga, 1997; Aregheore, 2003; Olorunnisomo, 2007b); higher milk yields (Etela *et al.,* 2008); reduced cost of rearing young stock (Orodho *et al.,* 1993; Kiragu and Tamminga, 1997; Kariuki *et al.,* 1998) and fattening livestock (Semenye *et al.,* 1989; Dominguez, 1992; Kebede *et al.,* 2008).

Nutritious and high yielding sweet potato cultivars need to be identified and evaluated and the superior cultivars recommended to livestock farmers. Evaluation studies have identified some superior cultivars on the basis of their forage characteristics, fast regeneration after harvest, ability to smother weeds and tolerance to diseases and moisture stress (Ondabu *et al.,* 2007). However, there is scarce documented information on their feeding value for

livestock (Peters, 2008; Wheatley and Loechl, 2008; Andrade *et al.,* 2009). The little information available is for a few cultivars and is more than 15 years old (Karachi, 1982a, b; Snijders *et al.,* 1992; Kariuki *et al.,* 1998). There is, therefore, need to provide reliable data on performance of livestock fed forage sweet potato cultivars in order to enhance livestock productivity.

The objective of the current study was to determine the nutrient intake, *in vivo* digestibility, rumen fermentation characteristics and performance of sheep fed on selected forage sweet potato cultivars.

6.2. Materials and methods

6.2.1. Study site

The study site was detailed in Chapter 3, section 3.2.1.

6.2.2. Cultivation of forage sweet potato

The cultivars, K158, Marooko, Wagabolige and the control cultivar (Mugande), were grown and harvested at the optimum maturity of 120 days as detailed in Chapter 3, section 3.2.2.

6.2.3. Experimental sheep and feeding in digestibility study

Twenty seven-months old and healthy Red Maasai wether sheep weighing 26.0 $\pm$ 2.2 kg `were obtained from a large flock for this study. The sheep were placed in separate metabolic crates for the digestibility and nitrogen balance study (Plate: 6.1). The sheep group treatments A, B, C and D (five wether sheep per treatment) were fed on respective diets consisting of three high yielding forage sweet potato cultivars (K158, Marooko and Wagabolige) and the fourth cultivar, Mugande, in a completely randomized design (CRD). The cultivar Mugande, commonly cultivated by farmers within the study area for harvesting roots, was used as the control. These cultivars were harvested at 120 days, from their respective plots daily, chopped to 2.5 cm length and offered at 0900 hr daily to sheep in individual troughs. An allowance 15% above the previous day's intake was given to cater for any unexpected increased feed intake. Representative feed samples of each day's batch of forage sweet potato cultivar fed to individual sheep was collected, bulked and frozen for each sheep for the whole experimental period for later analyses. The feed refusals from the previous day's feeding was weighed, recorded, sampled and kept in a deep freezer for later chemical analyses. Water and mineral licks were on offer at all times.

6.2.4. Experimental design in digestibility study

The sheep group treatments A, B, C and D, assigned to treatments in CRD, were allowed a 14 day adaptation period followed by a 7-day data collection period when total collection of faeces and urine was done. The sheep were treated against internal and external parasites during the adaptation period. The sheep were weighed at the start and again at the end of the total collection period. Rumen liquor was obtained from the sheep, using suction through a stomach tube inserted into the rumen through the mouth, on the last day of the experimental period. The plastic tube (about 50 cm in length, inner diameter 15 mm) closed at one end with a cork and perforated with approximately 120 holes of 2.5 mm in diameter was inserted through the mouth and positioned such that the perforated end reached the liquor phase in the ventral sac of the rumen. The rumen liquor was drawn using sucking equipment improvised by creating a vacuum in a corked plastic container connected to the plastic tube. Samples of approximately 200 ml were taken from each sheep. A portion of the rumen liquor sample was acidified by adding 1 ml 20% H_2SO_4 per 5 ml rumen fluid and frozen in tightly capped containers until analysed for NH_3-N (AOAC, 1998). A second portion was acidified with 5% metaphosphoric acid (1 ml acid per 5 ml rumen fluid). This was then centrifuged and refrigerated (4^oC) in tightly capped containers until assayed for VFA using gas liquid chromatography. A third portion (50 ml) was taken to the laboratory for pH determination (Kariuki, 1998). The rumen liquor was sampled and analyzed for total and individual (acetate, butyrate and propionate) VFA and ammonia level (AOAC, 1998). Faeces and urine were pooled separately, for each sheep and sub-sampled for chemical analyses (AOAC, 1998).

6.2.5. Experimental sheep, Feeding and management in the performance study

Twenty four-month old and healthy Red Maasai wether sheep weighing 20.2 $\pm$ 0.6 kg were obtained from a large flock for this study. The sheep were allocated to individual pens at random. The sweet potato cultivation, sheep feeding and feed sampling was as detailed in the digestibility study above, sections 6.2.2 and 6.2.3.

Plate: 6.1. Metabolism crates used for digestibility and nitrogen balance trial

6.2.6. Experimental design in the performance study

The sheep were treated for internal and external parasites using dewormer (Gardal, 10%, containing Ricobendazole, 10% w/v) and acaricide Almatix (Amitraz, 12.5% w/v), respectively, before the start of the experiment and allowed 14 days adaptation period. They were randomly assigned, equally to four treatment groups based on the four forages, balanced for mean initial live weight so that the initial group weights were not significantly different. A completely randomized design (CRD) was adopted in which one group was assigned to one of the four cultivars respectively. The sheep were weighed weekly during the study which lasted for 90 days.

6.2.7. Measurements and proximate analyses

Samples of feed offered and the refusals were collected, dried at 70^{o}C for 24 hr, ground to pass through 1 mm sieve and stored in plastic containers for chemical analyses. Proximate analysis and rumen volatile fatty acids determination was done according to AOAC, (1998). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) was determined using the method of Van Soest *et al.* (1991). The metabolizable

energy (ME) content was estimated using the equation of the Australian Agricultural Council (1990) (AAC, 1990) for tropical forages:

ME (MJ/kg DM) = DOM (g/kg DM) x 18.5 x 0.81

Where, ME = Metabolizable energy (MJ/kg DM)

MJ = Mega Joules

DM = Dry matter

DOM = Digestible organic matter (g/kg)

Growth rate and feed conversion efficiency (FCE) were calculated from data on live weight gain and feed intake, respectively.

6.2.8. Statistical analyses

The data obtained on proximate analysis, nutrient intake and nutrient digestibility, rumen volatile fatty acids, ADG and FCE were subjected to analysis of variance using general linear model (GLM) of SAS (2003). The means were separated using least significant difference procedures.

The following statistical model was used:

$Y_{ij} = \mu + \tau_i + \acute{\varepsilon}_{ijk}$

Where Y_{ij} = Estimated dietary nutrient content, nutrient intake or digestibility, ADG and FCE

μ = Overall mean of diet

τi = Treatment effect on diet

$\acute{\varepsilon}_{ijk}$ = Random error effect on diet

ADG (g/day) was calculated using the following equation:

$$ADG = \frac{\text{Total weight gain}}{\text{Total number of days}}$$

Feed conversion efficiency (FCE), defined as weight gain per 100 kg DM, was calculated using the following equation:

$$FCE = \frac{\text{Total weight gain x 100 kg DM}}{\text{Total DM intake}}$$

6.3. Results

6.3.1. Nutrient composition

The composition of the cultivars offered is as shown in Table 6.1. Mugande, the control cultivar contained the highest quantity of dry matter (DM), organic matter (OM) and neutral detergent fibre (NDF), while K158 and Wagabolige contained the highest acid detergent fibre (ADF) and acid detergent lignin (ADL), respectively. Marooko contained the lowest DM and NDF while the lowest OM was in Wagabolige. Marooko contained the highest crude protein (CP), while Mugande had the lowest. Metabolizable energy (ME) was highest in K158 and lowest in Mugande.

6.3.2. Nutrient Intake in digestibility study

The DM, OM, NDF (g/kg $W^{0.75}$) and ME (MJ/kg $W^{0.75}$) intake was not influenced ($P>0.05$) by the cultivar but the intake of CP, ADF and ADL were influenced ($P<0.05$) by the cultivar (Table 6.2). The sheep fed on Mugande ingested lower nutrients ($P<0.05$) while those on Marooko had higher nutrient intake. All cultivars differed ($P<0.05$) on CP intake. The sheep fed on K158, Marooko and Wagabolige ingested similar ($P>0.05$) quantities of ADF and those fed on Mugande ingested the lowest ADF ($P<0.05$). The sheep fed on K158 and Mugande ingested similar quantities ($P>0.05$) of ADL that was lower than ($P<0.05$) that ingested by sheep on Marooko and Wagabolige.

6.3.3. Nutrient digestibility

The cultivars influenced ($P<0.05$) the digestibility of CP, NDF and ADF but did not affect ($P>0.05$) DM and OM digestibility (Table 6.3). The CP and NDF digestibility differed ($P<0.05$) among all the four cultivars with Morooko and K158 having the highest CP and NDF digestibility, respectively. The ADF digestibility in sheep was similar ($P>0.05$) in K158, Marooko and Mugande but higher ($P<0.05$) in Wagabolige.

Table 6.1: Chemical composition of selected forage sweet potato cultivars

	Nutrient composition (g /kg DM)				
Parameter	K158	Marooko	Wagabolige	Mugande	SEM
Dry matter	177.6	166.9	174.5	179.8	1.3
Organic matter	875.8	872.5	868.6	880.7	1.2
Crude protein	154.1	171.9	166.5	113.7	2.8
Neutral detergent Fibre (NDF)	399.9	384.3	398.0	408.7	3.7
Acid detergent Fibre (ADF)	293.5	281.9	283.5	276.4	1.9
Acid detergent Lignin (ADL)	85.8	99.9	114.1	84.0	2.6
Metabolizable energy (MJ/kg DM)	10.2	9.8	9.7	10.1	0.1

6.3.4. Digestible nutrient intake

The digestible DM, OM and ADF intake (g/kg $W^{0.75}$) were not affected (P>0.05) by the cultivars, however, digestible CP and NDF were affected (P<0.05) (Table 6.4). Sheep fed on K158 and Wagabolige ingested similar (P>0.05) quantities of digestible CP which was lower than in Marooko. Cultivars K158 and Mugande; Mugande and Wagabolige recorded similar (P>0.05) digestible NDF intake but sheep fed on K158 recorded a higher value (P<0.05) compared to Wagabolige.

6.3.5. Nitrogen balance

Cultivars affected (P<0.05) daily nitrogen intake, faecal nitrogen, urinary nitrogen output, retained nitrogen and nitrogen digestibility in sheep (Table 6.5). The sheep fed on K158, Marooko and Wagabolige recorded similar (P>0.05) nitrogen intake and retained nitrogen, respectively. Marooko recorded higher (P<0.05) nitrogen intake by sheep than Mugande. Marooko and Wagabolige recorded higher (P<0.05) retained nitrogen than Mugande. Cultivars K158 and Marooko; Mugande and Wagabolige, respectively, recorded similar (P>0.05) faecal nitrogen but the values in Mugande and Wagabolige were higher than (P<0.05) in K158 and Marooko. Urinary

Table 6.2: Nutrient intake of sheep fed selected forage sweet potato

	Nutrient intake (g /kg $W^{0.75}$)					
Parameter	K158	Marooko	Wagabolige	Mugande	LSD	SEM
Dry matter	97.1	98.1	94.4	93.8	5.6	1.6
Organic matter	85.0	85.6	82.0	82.6	4.9	1.4
Crude protein	14.9^{b}	16.9^{d}	15.7^{c}	10.7^{a}	0.8	0.2
Neutral detergent fibre	38.8	37.8	37.6	38.3	2.3	0.6
Acid detergent fibre	28.5^{b}	27.9^{b}	27.4^{ab}	25.9^{a}	1.6	0.5
Acid detergent lignin	8.3^{a}	9.8^{b}	10.7^{c}	7.9^{a}	0.5	0.1
Metabolizable energy MJ/ kg $W^{0.75}$	0.99	0.95	0.94	0.95	0.08	0.02

^{abcd} Means within a row bearing different superscripts are different ($P<0.05$)

Table 6.3: Nutrient digestibility of sheep fed selected forage sweet potato cultivars

	Nutrient digestibility (g/kg DM)					
Parameter	K158	Marooko	Wagabolige	Mugande	LSD	SEM
Dry matter	740.5	740.3	742.9	744.1	5.4	1.6
Organic matter	749.6	751.7	748.3	747.0	6.1	1.8
Crude protein	783.9^{c}	821.1^{d}	737.4^{b}	655.7^{a}	3.7	1.1
Neutral detergent fibre	712.8^{d}	594.1^{a}	681.4^{b}	695.0^{c}	7.6	2.2
Acid detergent fibre	479.9^{ab}	477.6^{a}	483.7^{b}	477.0^{a}	5.8	1.7

^{abcd} Means within a row bearing different superscripts are different ($P<0.05$)

Table 6.4: Digestible Nutrient intake of sheep fed selected forage sweet potato cultivars

	Nutrient intake (g /kg $W^{0.75}$)					
Parameter	K158	Marooko	Wagabolige	Mugande	LSD	SEM
Dry matter	71.9	72.6	70.1	69.8	4.4	1.3
Organic matter	63.7	64.4	61.3	61.7	3.6	1.1
Crude protein	11.8^{b}	13.9^{c}	11.6^{b}	7.0^{a}	0.6	0.2
Neutral detergent fibre	27.7^{c}	22.4^{a}	25.6^{b}	26.6^{bc}	1.6	0.5
Acid detergent fibre	13.7	13.3	13.2	12.9	0.8	0.2

^{abc} Means within a row bearing different superscripts are different ($P<0.05$)

Table 6.5: Nitrogen balance in sheep fed selected forage sweet potato cultivars

	Forage sweet potato cultivars					
Parameter	K158	Marooko	Wagabolige	Mugande	LSD	SEM
Nitrogen intake (g/day)	7.6^{ab}	8.4^{b}	7.9^{ab}	6.6^{a}	1.4	0.4
Faecal N output (g/day)	1.5^{a}	1.5^{a}	2.0^{b}	2.3^{b}	0.4	1.4
Urinary N output (g/day)	3.4^{b}	2.4^{a}	2.4^{a}	2.1^{a}	0.9	0.3
Retained N (g/day)	2.7^{ab}	4.5^{b}	3.5^{b}	2.2^{a}	1.2	0.4
N digestibility (g/kg)	802.6^{c}	821.4^{d}	745.9^{b}	651.5^{a}	0.4	0.1

^{abcd} Means within a row bearing different superscripts are different ($P<0.05$)

nitrogen by sheep fed on Marooko, Mugande and Wagabolige was similar (P>0.05) but lower than (P<0.05) that recorded in K158. The nitrogen digestibility differed (P<0.05) among sheep fed on all the four cultivars.

6.3.6. Rumen pH, NH_3-N, and VFA

The rumen pH, NH_3-N, total VFA and molar percentages of acetate, propionate, butyrate and other acids of the sheep were not affected (P>0.05) by the forage sweet potato cultivar (Table 6.6.). Acetate to propionate ratio was also not affected (P>0.05) by the cultivar.

6.3.7. Nutrient intake in performance study

The cultivar affected (P<0.05) the CP, NDF and ADL intake (g/kg $W^{0.75}$) but did not (P>0.05) affect DM, OM, ADF and ME intake of the sheep fed on the four cultivars (Tables 6.7). The CP intake recorded in sheep fed on Marooko and Wagabolige were similar (P>0.05) but higher than (P<0.05) in sheep fed on K158 and Mugande. The lowest CP intake was recorded in sheep fed on Mugande (P<0.05). Sheep fed on cultivars K158, Marooko and Mugande recorded similar (P>0.05) NDF intake. Also, the sheep fed on cultivars Marooko, Mugande and Wagabolige recorded similar (P>0.05) NDF intake but Wagabolige recorded higher (P<0.05) NDF intake compared to K158. Cultivars K158 and Mugande achieved a similar (P>0.05) intake of ADL in sheep which was lower than (P<0.05) in sheep fed on Marooko and Wagabolige.

6.3.8. Sheep growth and feed efficiency

The forage sweet potato cultivars affected (P>0.05) sheep growth and FCE (Table 6.8). Sheep fed on K158, Marooko and Wagabolige recorded similar growth rate (P>0.05) while sheep fed on Mugande grew the least (P<0.05). The mean ADG of the sheep were: 143.0, 158.6, 103.9 and 146.8 g on cultivars K158, Marooko, Mugande and Wagabolige, respectively. The FCE for sheep on cultivars K158, Marooko and Wagabolige were similar (P>0.05) and higher than (P<0.05) for sheep fed on Mugande. The FCE for sheep fed on cultivars K158, Marooko, Mugande and Wagabolige expressed in gain per 100 kg dry matter was 13.6, 13.4, 10.4 and 13.0 kg respectively.

Table 6.6: Rumen fermentation parameters in sheep fed selected forage sweet potato cultivars

	Forage sweet potato cultivars					
Rumen parameter	K158	Marooko	Wagabolige	Mugande	LSD	SEM
pH of rumen fluid	6.80	6.81	6.86	6.82	0.89	0.26
NH_3-N (mg/L)	66.50	66.23	63.30	63.87	4.82	1.40
Total VFA (mmol/mL)	124.43	124.75	125.03	124.55	1.95	0.56
Molar % of VFA:						
Acetate (A)	68.98	69.59	68.88	68.34	1.61	0.47
Propionate (P)	22.02	21.35	22.09	22.58	1.52	0.44
Butyrate	7.57	7.48	7.56	7.43	0.35	0.10
Other VFAs	1.41	1.58	1.48	1.41	0.34	0.10
Acetate: Propionate ratio	3. 14	3.20	3.12	3.03	0.31	0.90

Table 6.7: Nutrient intake, rumen parameters and performance of sheep fed selected forage sweet potato cultivars

	Forage sweet potato cultivars					
Nutrient, g/Kg W $^{0.75}$	Mugande	K158	Marooko	Wagabolige	LSD	SEM
Dry matter, (DMI)	113.1	107.1	116.6	119.4	12.4	3.9
Organic matter, (OMI)	99.6	94.5	101.8	103.7	10.0	3.4
Crude Protein, (CPI)	12.9^{a}	16.6^{b}	20.0^{c}	19.9^{c}	1.9	0.7
Neutral detergent Fibre intake (NDFI)	46.2^{ab}	42.6^{a}	43.9^{ab}	47.5^{b}	4.2	1.5
Acid detergent Fibre intake (ADFI)	31.5	31.6	32.9	33.9	3.3	1.1
Liginin intake (ADLI)	9.5^{a}	9.3^{a}	11.7^{b}	13.6^{c}	1.1	0.4
Metabolizable Energy (ME), (MJ per Kg W $^{0.75}$)	1.05	1.09	1.14	1.14	0.12	0.04

[abc:] Means within a row bearing different superscripts are different ($P<0.05$)

Table 6.8: Performance of sheep fed on selected forage sweet potato cultivars

Cultivar	Average Daily gain (ADG, g)	Feed efficiency, (Kg feed/gain)
Mugande	103.9[a]	10.4[a]
K158	143.0[b]	13.6[b]
Marooko	158.6[b]	13.4[b]
Wagabolige	146.8[b]	13.0[b]
LSD	30.8	2.5

[ab] Means within a column bearing different superscripts are different ($P<0.05$) for ADG and ($P<0.05$) for Feed efficiency.

6.4. Discussion

6.4.1. Nutrient composition

The forage sweet potato cultivars were of high nutritional quality. They had much higher CP than the 80g CP/kg DM below which forages are defined as low quality (Leng, 1990) and therefore may not limit microbial activity in the rumen (Van Soest, 1994). The NDF was below the 600g/kg DM usually considered as the threshold for ruminants (Meisser *et al.,* 1991). The low NDF was consistent with the general observation of lower NDF in non-grass forages (Minson, 1990). The four cultivars had adequate fibre, measured as NDF and defined as total cell wall content which is essential for rumination, saliva flow, rumen buffering and health of the rumen wall (Fox *et al.,* 1992). Furthermore, the high OM digestibility and energy enabled the sheep to obtain adequate ME required for incorporating nitrogen into microbial protein (Preston and Leng, 1987; Muia, 2000).

The chemical composition of the four forage sweet potato cultivars was in agreement with available literature on forage sweet potato (Snijders *et al.,* 1992; Kiragu and Tamminga, 1997; Larbi *et al.,* 2007). The DM level was in agreement with values reported by Chhay *et al.* (2007), Olorunnisomo (2007b) and Kebede *et al.* (2008). The OM values are within the range of those reported by Farrell *et al.* (2000); Iyeghe-Erakpotobor *et al.* (2006) and Chhay *et al.* (2007) for forage sweet potato. The CP values agree with those reported by Giang *et al.* (2004), Lam and Ledin (2004) and Kiragu *et al.* (2007).

The fibre content (NDF, ADF and ADL) are all in the range reported by Olorunnisomo, (2007a, b) and Kebede *et al.* (2008). However, their values were lower than

those reported in the current study and those by Snijders *et al.* (1992), Kariuki *et al.* (1998) and Kiragu *et al.* (2007). These higher values may be due to harvesting age, variety used and a site effect (Karachi, 1982a, b; Irungu *et al.*, 2000). The low NDF in forage sweet potato cultivars was consistent with the general observation of lower NDF in non-grass fodders (Minson, 1990).

Nonetheless, all the forage sweet potato cultivars in the current study had an NDF higher than 150g/kg DM recommended by Strasia and Gill (1990) as being suitable for growing ruminants. Furthermore, these cultivars contained lower than 600g NDF/kg DM beyond which a feed is classified as poor quality (Meissner *et al.*, 1991). According to Van Soest (1994) and Karachi and Dzowela (1990), the relatively high lignin levels were characteristics associated with forbs.

6.4.2. Nutrient Intake and digestibility

The DM, NDF and OM intake (g/kg $W^{0.75}$) were not affected by the cultivar indicating that these cultivars did not limit their intake in sheep. Hence the trend in CP, ADF and ME intake depended on their cultivar dietary composition. The high nutrient digestibility recorded showed that the four forage sweet potato cultivars were all good quality diets for the sheep. For example, OM digestibility was above the 500 to 600g/kg DM range where most tropical grasses fall (Minson, 1990; Kariuki, 1998; Muia, 2000), which compared favourably with 678 to 831g/kg DM recorded by Snijders *et al.* (1992) for forage sweet potato and 650 to 790g/kg DM reported by Chaparro and Sollenberger (1997) from well fertilized dwarf Napier grass. Likewise, CP and NDF digestibility were higher than 585 to 669 and 585 to 608 g/kg DM, respectively, obtained by Muia (2000) with sheep fed Napier grass.

Marooko had the highest CP and Mugande the lowest NDF digestibility, respectively. This was in agreement with the results reported by Minson (1990) who showed that nutrient digestibility rose with increased ME and a reduction in NDF. The author also showed that the nutrient digestibility was positively associated with OM digestibility which in turn was related to the energy available in the forage. The OM digestibility varied with the proportion of NDF. The NDF digestion depends on the degree of lignification, the activity of rumen microbes and the rumen retention time (Minson, 1990). The cellular structure and the inherent attributes of NDF and CP of the four cultivars were relatively similar as their OM digestibility did not differ (Hagerman *et al.*, 1992; Kaitho, 1997). The protein digestibility

and available energy seemed sufficient for ammonia incorporation into microbial protein (Preston and Leng, 1987).

To rank the nutritive value of forages, Norton and Poppi (1995) considered a combination of potential digestibility and voluntary intake. The high nutrient digestibility, nutrient intake and digestible nutrient intake observed classified the four forage sweet potato cultivars as highly nutritious forages. Sheep fed these cultivars maintained higher nutrient intake than those fed Napier grass, a common fodder in Kenya (Muia, 2000).

6.4.3. Nitrogen balance

The effect of the cultivars on daily nitrogen intake and digestibility, output of faecal and urinary nitrogen and retained nitrogen in sheep was due to the protein content and complexity of proteins in these cultivars which agreed with reports by Phillips *et al.* (1995); Phillips and Rao (2001) and Longo *et al.* (2008). The sheep fed on cultivars K158, Marooko and Wagabolige recorded higher N intake than Mugande because the three cultivars contained higher CP (Phillps *et al.*, 1995; Foster *et al.*, 2009a, b; Freeman *et al.*, 2009). The lower faecal N output in K158 and Marooko compared to Mugande and Wagabolige could have been due to higher N digestibility in sheep. The similarity in urinary N output by sheep fed on Marooko, Mugande and Wagabolige was in agreement with Bengaly *et al.* (2007), Freeman *et al.* (2008) and Freeman *et al.* (2009). The increased N digestibility and digestible OM with increased N intake is in agreement with other workers (Phillps *et al.*, 1995; Phillips and Rao 2001; Longo *et al.*, 2008).

6.4.4. Rumen pH, NH_3-N, and VFA

The four cultivars recorded rumen pH within the range of 6.0 to 7.0 which is considered optimal for the activities of cellulolytic microbes (Erdman, 1988; Foster *et al.*, 2009a, b; Hassen *et al.*, 2009) and VFA absorption (Dijkstra, *et al.*, 1993). The total VFA concentration and molar proportions of VFA were typical of the ruminal fluid of ruminants fed a forage-based ration (Bergman, 1990; Freeman *et al.*, 2009; Hassen *et al.*, 2009). The total VFA concentration exceeded the normal range, 100 to 120 mmol/L in forage fed ruminants, reflecting their greater fermentability (Bergman, 1990; Foster *et al.*, 2009a, b; Hassen *et al.*, 2009). Ruminal passage rates usually increase with DMI, and this can decrease the ruminal propionate proportion (Hristov *et al.*, 2004; Owens *et al.*, 2009). However, this did not occur in the sheep as they recorded similar DMI. The similarity in ruminal acetate and

propionate proportions and the attendant similarity in acetate: propionate ratio suggested that the four forage sweet potato cultivars attained similar efficiency of ruminal fermentation (Hassen *et al.,* 2009; Owens *et al.,* 2009). Forage sweet potato cultivars maintained ruminal NH_3-N concentration at similar level that exceeded the recommended concentration of 50 mg/L for maximizing microbial N synthesis (Satter and Slyter, 1974). However, the four cultivars also recorded ruminal NH_3-N concentrations above 20 mg/L below which is considered limiting in microbial N synthesis (Satter and Slyter, 1974).

6.4.5. Nutrient intake in performance study

Forage sweet potato cultivars have been reported to have high digestibility (Etela *et al.,* 2007; Larbi *et al.,* 2007; Olorunnisomo, 2007b) hence promote nutrient intake. This was also demonstrated in the current study. Forage sweet potato cultivars are known to have low NDF (Ouda *et al.,* 2004; Olorunnisomo, 2007a, b; Kebede *et al.,* 2008) hence will not limit nutrient and ME intake. The four cultivars used in this study had adequate fibre (Fox *et al.,* 1992). Adequate protein digestibility and available energy are essential for sufficient NH_3-N incorporation into microbial protein synthesis (Preston and Leng, 1987). Furthermore, these authors reported that the supply of soluble N and fermentable OM in the rumen should be synchronized for optimal microbial protein synthesis.

The CP intake depended on the cultivar fed to the sheep although it did not limit nutrient intake as the cultivars contained more than 80g CP/kg DM below which forages limit intake (Leng, 1990) but above which rumen microbial activities are stimulated (Van Soest, 1994), thus making such forages of better feeding value. Furthermore, the high OM may have enabled the sheep to obtain adequate ME to enable incorporation of NH_3-N and degradable protein into microbial protein (Preston and Leng, 1987). This was in agreement with the findings in the current study on digestibility, where the sheep ingested similar quantity of ME. These factors, therefore, may have culminated in the sheep attaining voluntary intake beyond which no further nutrient intake was possible. The high nutrients intake recorded in the current study are in agreement with findings of Kariuki *et al.* (1998) who showed that forage sweet potato can replace lucerne in the diets for weaned calves. Additionally, Semenye *et al.* (1989) and Orodho *et al.* (1993) successfully used forage sweet potato as milk replacer in goat kids and calves, respectively. This suggests that forage sweet potato can be considered as protein rich forages.

Kiragu and Tamminga (1987) recorded increased DM intake in pre-weaning Friesian calves supplemented with forage sweet potato compared to calves fed on milk alone and this reduced rearing cost by 50%. Supplementing Napier grass with forage sweet potato also increased DM intake in calves (Kiragu *et al.,* 2007; Kariuki *et al.,* 1998). Kariuki *et al.* (1998) likewise, reported that forage sweet potato met the DM and CP requirements of weaned calves. Wilman *et al.* (1999) reported higher DM intake in sheep fed forage sweet potato compared to those fed on millet leaves and straws, sorghum and maize stovers. Semenye *et al.* (1989) fed forage sweet potato as milk replacer in goat kids whereas Orodho *et al.* (1993) succeeded to replace milk with forage sweet potato in calf diets. Kebede *et al.* (2011) reported increased DM intake, ADG and economic returns with increased inclusion of forage sweet potato in goat diets.

6.4.6. Sheep growth and feed conversion efficiency

The nutrient intake by sheep recorded in the current study were higher than previously reported in sheep and goats studies by Lam and Ledin (2004), Olorunnisomo (2007b) and Kebede *et al.* (2008) which could have sustained the high ADG (56.9-86.4 g/day). Aregheore (2003) documented that the ADG of goats were affected by forage type and their ratio offered. Goats on sole forage sweet potato diet and those on mixed diets of forage sweet potato with batiki grass (*Ischaemum aristatum*) recorded higher ADG (59.5-60.1 g/day) and feed conversion efficiency (5.7-6.9) compared to a sole diet of batiki grass (Aregheore, 2003). The ADG and feed efficiency recorded in the current study were similar for all the sheep on the cultivars K158, Marooko and Wagabolige. The feed conversion efficiency was in agreement with values recorded by Lam and Ledin, (2004) and Olorunnisomo, (2007b). The characteristics of these cultivars indicated that the efficiency of nutrient incorporation into weight increase was promoted (Hagerman *et al.* 1992; Kaitho, 1997).

These cultivars are suitable diets to sheep and they have a potential to be utilized as livestock feed either as sole feed or as a protein supplements to poor quality roughages such as cereal crop residues. The cultivars K158, Marooko and Wagabolige should, therefore, be popularized among smallholder farmers to improve the nutrition of their livestock.

6.5. Conclusions and recommendations

The cultivars had similar DM, OM, ME and NDF intake and DM and OM digestibility. They also maintained similar rumen fermentation characteristics. These

cultivars, however, differed in CP intake, digestibility and nitrogen balance in sheep. The four cultivars provided good quality feeds to sheep as they contained high DM, OM and CP and less fibre. They also provided high ME, recorded superior intake of digestible OM, CP and NDF which classify them as high quality forages. Cultivar K158 had the highest nutrient digestibility and intake among the four cultivars whereas sheep fed Marooko had highest N digestibility and retention.

These cultivars can provide suitable nutrients to sheep both as sole diets and supplements hence have a potential to improve livestock production in Kenya. Cultivars K158, Marooko and Wagabolige are, therefore, recommended to livestock farmers as suitable forage. Additional research needs to be done on the performance of sheep and dairy goats fed on these sweet potato cultivars and their effect on animal products such as milk.

The four sweet potato cultivars were high quality diets for sheep and their intake did not vary widely probably indicating that the sheep may have attained maximum voluntary DM intake. Consequently the sheep fed on these cultivars attained ADG and feed efficiency beyond 143.0 g and 13.0 kg, respectively, which were considered high.

The ADG and feed efficiency were similar for the sheep on cultivars K158, Marooko and Wagabolige indicating that any one of them was recommended to feed growing sheep.

CHAPTER 7

NUTRIENT INTAKE, MILK YIELD, MILK COMPOSITION AND RUMEN FERMENTATION CHARACTERISTICS OF KENYA DUAL PURPOSE GOATS FED ON FORAGE SWEET POTATO CULTIVARS

7.0. Abstract

Increased world population, consumer preference and allergies to cow milk have escalated demand for goat milk. However, milk production is limited by high feeds cost and their seasonal distribution. The objective of the study was to evaluate three forage sweet potato cultivars on nutrient intake, digestibility and rumen fermentation characteristics and milk yield and milk composition in goats. Six lactating dairy goats were fed on cultivars K158, Marooko and Wagabolige for three successive 30-day periods in 3 x 3 Latin square design and data reported for days 21 to 27 of each period. The DM (113.4-114.3) and OM (98.5-100.1 g/kg $W^{0.75}$) intake was not affected by the cultivar but CP (17.6-19.5), fiber (NDF, 43.6-45.7; ADF, 32.0-33.6; ADL, 9.8-12.9 g/kg $W^{0.75}$) and metebolizable energy (1.10-1.17 MJ/kg $W^{0.75}$) were affected. Goats on Marooko and Wagabolige ingested similar CP (18.9-19.5), ADF (32.0-32.2) and ME (1.10-1.11 MJ/kg $W^{0.75}$). Cultivars influenced digestibility of CP (750.0-826.1) and NDF (627.4-682.2 g/kg DM); Cultivars did not influence intake of metabolizable energy (1.10-1.17 MJ/kg $W^{0.75}$); rumen pH (6.83-6.85), molar percentages of acetate (68.40-69.71), propionate (22.21-22.27), butyrate (7.70-8.05) and acetate to propionate ratio (3.08-3.30); cultivars affected milk yield (491.7-680 g/d) and composition (BF, 26.1-35.7; protein, 35.2-44.7; lactose, 51.1-53.9; total solids, 107.4-141.2 and solids non-fat 94.2-108.9 g/kg) but did not affect DM (742.5-744.3), OM (756.0-757.3) and ADF (483.2-487.8 g/kg DM) digestibility. Marooko and Wagabolige produced milk with similar butter fat (26.1-28.7) that was lower than in K158 (35.7 g/kg). K158 and Wagabolige yielded milk containing similar quantities of protein (44.4-44.7), lactose (53.0-53.9), solids-non-fat (105.6-108.9 g/kg) and freezing point depression (-0.62-0.63^{o}C) that were higher than in Marooko (35.2, 51.1, 107.4, 94.2 g/kg and -0.60^{o}C, respectively). Cultivar ranking in their ability to induce increased milk yield and quality in descending order was K158, Marooko and Wagabolige; K158, Wagabolige and Marooko respectively. Among the three forage sweet potato cultivar evaluated in the current study, K158 is the most suitable to feed dairy goats. This cultivar should be widely popularized among dairy goat producers in Kenya.

7.1. Introduction

Goat milk and its products are alternatives to cow milk. Milk production and composition in goats are affected by many factors namely type and amount of basal feed and concentrate supplementation affect milk fat, lactose, protein and total solids (Sampeleyo *et al.,* 1998; Park *et al.,* 2007; Oprean *et al.,* 2011). Mwandotto et al. (1992a) reported that mean lactation length was positively and highly correlated with lactation yield in goats. These authors studied Kenya indigenous goats (East African goats and Galla goats) and exotic goats (Toggenburg and Anglo Nubian) and their four way crosses (4-way crossbreds).

Crossbreds through use of Toggenburg and Anglo Nubian showed similar growth rates (Mwandotto *et al.,* 1990; Mwandotto *et al.,* 1992a). The greatest improvement in milk yield was at the F_1 level of crossing (Ruvuna *et al.,* 1988; Mwandotto *et al.,* 1990; Mwandotto *et al.,* 1992a). Mwandotto *et al.* (1991) showed that further improvement in milk yield at 4-way crossbred level was small due to loss of hybrid vigour. The 4-way crossbreds were named Kenya Dual Purpose Goats (KDPG). Semenye *et al.* (1989) and Mwandotto *et al.* (1991) showed that the F_1 crossbreds could be used for on-farm milk production due to their similar potential milk yield (2 l/day) to Kenya Dual Purpose Goats. It was projected that families that reared at least three KDPG does would satisfy their daily milk requirement (Mwandotto *et al.,* 1991). Ruvuna *et al.* (1988) demonstrated increased milk yield when does were milked in the presence of the kid which was attributed to the stimulation of milk let-down by the presence of the kids and the number of milkings daily also influenced the milk yield as reported by Akpa *et al.* (2001) and Akpa *et al.* (2003).

Globally, the goat is an important producer of milk and meat for sale or family consumption. This necessity is growing primarily due to increase in world population (Borges *et al.,* 2004; Mioc *et al.,* 2008; Strzalkowska *et al.,* 2009). In Kenya, goats are used to produce milk due to diminished arable land (Mwandotto *et al.,* 1992b; Semenye *et al.,* 1992). Goats are able to exploit land which cannot be used for other agricultural activities such as land that is mountainous and that has uneven landscape (Mmbengwa *et al.,* 2008). The other main reason for increased demand for goat milk is increased consumer interest in products made from goat milk. This is due to their superior nutritional value and absence of allergic reaction when compared to cow milk. However, large scale industrialization of dairy goat sector is limited by low volume and seasonal milk production (Borges *et al.,* 2004; Park *et al.,* 2007; Strzalkowska *et al.,* 2009). Another limitation is the high cost of feeds and their

seasonal distribution. It is, therefore, essential to evaluate various forages so as to identify those that can provide adequate nutrition to dairy goats.

Sweet potato cultivars have been reported as protein rich forages (PRF) (Aregheore, 2003; Lam and Ledin, 2004; Etela *et al.,* 2008). Sweet potato selection studies identified some superior cultivars on the basis of their forage characteristics, fast regeneration after harvest, ability to smoother weeds and tolerance to diseases and moisture stress (Ondabu *et al.,* 2005; Ondabu *et al.,* 2007). Thus there is potential in Kenya of availability of nutritious and high yielding forage sweet potato cultivars which can be used as cheap protein sources. This will improve dairy goat performance when fed either as sole feed or as a protein supplement to poor quality roughages such as crop residues. Most of the available forage cultivars have not been adequately studied in Eastern Africa (Peters, 2008; Andrade *et al.,* 2009; Kebede *et al.,* 2011). These knowledge gaps not withstanding, some of these forage cultivars are already being used as feed by some livestock farmers (Ashiono *et al.,* 2006; Rono *et al.,* 2006). There is, therefore, an urgent need to elucidate the feeding value of newly identified forage sweet potato cultivars.

The objective of the current study, therefore, was to determine the nutrient intake, milk yield, milk composition and rumen characteristics of dairy goats fed on three superior forage sweet potato cultivars.

7.2. Materials and methods

7.2.1. Study site

The study site was the same as in Chapter 3 detailed in section 3.2.1.

7.2.2. Cultivation of forage sweet potato

The cultivars, K158, Marooko and Wagabolige, were grown and harvested at the optimum maturity of 120 days as detailed in Chapter 3, section 3.2.2.

7.2.3. Experimental dairy goats and Feeding

Six lactating Kenya Dual Purpose dairy goats (KDPG, 4-way crossbred, 4 years old, mean weight, 37.8 $\pm$ 2.4 kg) at their eighth week of lactation were selected from a large flock for this study. The goats were de-wormed with Gardal, 10% (containing Ricobendazole, 10% w/v) before the start of the experiment and then they were allocated to individual pens at random. They were henceforth fed on the forage sweet potato cultivars for three successive

30-day periods in a 3 x 3 Latin squares design. The forage cultivars were harvested daily, chopped to 2.5 cm length and offered at 0900 hr daily to dairy goats in individual troughs. An allowance 15% above the previous day's intake was offered to cater for unexpected increased feed intake. Samples from each batch of sweet potato cultivar fed were collected between days 21 to 27 of each period and bulked. The refusals from previous day's feed were also weighed, sampled and recorded to determine feed intake. Total collection of faeces and urine was done. Faeces and urine were pooled separately, for each goat and sub-sampled for chemical analyses (AOAC, 1998). Water and mineral licks were on offer at all times.

7.2.4. Experimental design

Each of the dairy goats was allocated to the three forage sweet potato cultivars in random sequence for three successive 30-day periods in a 3x3 Latin square design. The dairy goats were milked twice daily, milk yield recorded, sampled and milk composition measured on two successive milkings (AOAC, 1998). Data on feed intake, milk yield and milk composition were collected for days 21 to 27 of each period. Rumen liquor was obtained from the dairy goats using suction through a tube inserted into the rumen through the mouth, on day 30 of each period as detailed in Chapter 6.

7.2.5. Chemical analyses

Samples of feed offered, feed refusals and faeces were collected, dried at 70^{o}C for 24 hr, ground through 1 mm sieve and stored in plastic containers for chemical analysis. Dry matter was determined according to AOAC (1998) and used to determine feed intake. Proximate analysis of faeces, feed offered and refusals was done according to AOAC, (1998). Neutral detergent fibre (NDF), acid detergent fibre (ADF) and acid detergent lignin (ADL) was determined using the method of Van Soest *et al.* (1991). The metabolizable energy (ME) content of the forage sweet potato cultivars was estimated using the equation of the Australian Agricultural Council (1990) for tropical forages. The rumen liquor was analyzed for total volatile fatty acids (VFA), individual VFA (acetate, butyrate and propionate) by gas chromatography and pH and ammonia concentration using AOAC (1998) procedures. Milk composition and freezing point depression were determined using MilkoScan Type 78110 (FOSS Analytical A/S, Denmark).

7.2.6. Statistical analyses

The data obtained on proximate composition, feed intake and digestibility; ME, milk yield and milk composition, rumen pH, ammonia and VFA concentration of the goats fed on the three sweet potato cultivars was subjected to analysis of variance using general linear model (GLM) of SAS (2003). The separation of means was done using least significant difference procedures.

The following statistical model was used:-

$Y_{ij} = \mu + \tau_i + \beta_k + \acute{\varepsilon}_{ijk}$

Where Y_{ij} = Estimated feed intake, milk yield and composition, rumen VFA, pH and ammonia concentration

μ = Overall mean feed intake, milk yield and milk composition, rumen pH, ammonia and VFA concentration

τ = Treatment (forage cultivar) effect on feed intake, milk yield and milk composition, rumen pH, ammonia and VFA concentration

β_k = Period effect on feed intake, milk yield and milk composition, rumen pH, ammonia and VFA concentration

$\acute{\varepsilon}_{ijk}$ = Residual treatment effect on intake, milk yield and milk composition, rumen pH, ammonia and VFA concentration

7.3. Results

7.3.1. Nutrient composition

The composition of forage sweet potato cultivars K158, Marooko and Wagabolige at 120 days' growth are as detailed in Section 6.3.1 and Table 6.1.

7.3.2. Nutrient Intake

The results on nutrient intake are shown in Table 7.1. The DM and OM (g/kg $W^{0.75}$) and ME (MJ/kg $W^{0.75}$) intake by goats was not affected ($P>0.05$) by the forage sweet potato cultivar unlike CP, NDF, ADF and ADL which were affected ($P<0.05$). The goats fed on Marooko and Wagabolige ingested similar quantity ($P>0.05$) of CP and ADF which was higher ($P<0.05$) than CP intake in K158. The NDF intake by goats fed on K158 and Wagabolige was similar ($P>0.05$) but higher than the NDF intake in Marooko. The ADF intake by goats fed on K158 was higher than in Marooko and Wagabolige. All the three

Table 7.1: Nutrient intake (g/kg $W^{0.75}$) of goats fed three forage sweet potato cultivars

	Forage sweet potato cultivars				
Nutrient intake	K158	Marooko	Wagabolige	LSD	SEM
Dry matter	114.3	113.4	113.5	3.8	1.0
Organic matter	100.1	99.0	98.5	3.2	0.8
Crude protein	17.6[a]	19.5[b]	18.9[b]	0.7	0.2
Neutral detergent fibre	45.7[b]	43.6[a]	45.1[b]	1.5	0.4
Acid detergent fibre	33.6[b]	32.0[a]	32.2[a]	1.1	0.3
Acid detergent lignin	9.8[a]	11.3[b]	12.9[c]	0.4	0.1
Metabolizable energy (MJ)	1.17	1.11	1.10	0.08	0.01

[abc] Means within a row with different superscripts are different (P<0.05)

cultivars differed in the amount of ADL ingested by goats with K158 and Wagabolige recording the lowest and highest ADL intake, respectively.

7.3.3. Nutrient digestibility

The results on nutrient digestibility are shown in Table 7.2. The forage sweet potato cultivar influenced (P<0.01) the digestibility of CP and NDF but did not affect (P>0.05) DM, OM and ADF digestibility in goats. The CP and NDF digestibility differed (P<0.05) among the cultivars. Marooko recorded the highest (P<0.05) CP digestibility and the lowest (P<0.05) NDF digestibility when fed to the goats. Wagabolige recorded the highest (P<0.05) NDF digestibility and the lowest (P<0.05) CP digestibility.

7.3.4. Digestible nutrient intake

The digestible DM and OM intake (g/kg $W^{0.75}$) in goats were not affected (P>0.01) by the forage sweet potato cultivar, however, the digestible nutrient intake of CP, NDF and ADF were affected (P<0.05) (Table 7.3). Goats fed on K158 and Wagabolige ingested similar (P>0.05) quantity of digestible CP and digestible NDF. Goats fed on Marooko recorded the highest (P<0.05) digestible CP intake and the lowest (P>0.05) digestible NDF intake. Marooko and Wagabolige recorded similar (P>0.05) digestible ADF intake that was lower than (P<0.05) in goats fed on K158.

Table 7.2: Nutrient digestibility (g/kg DM) by goats fed three forage sweet potato cultivars

	Forage sweet potato cultivars				
Nutrient intake	K158	Marooko	Wagabolige	LSD	SEM
Dry matter	744.3	742.8	742.5	3.4	0.9
Organic matter	757.3	756.3	756.0	4.3	1.1
Crude protein	782.9[b]	826.1[c]	750.0[a]	6.8	1.7
Neutral detergent fibre	660.9[b]	627.4[a]	682.2[c]	5.8	1.4
Acid detergent fibre	487.4	487.8	483.2	5.4	1.3

[abc] Means within a row with different superscripts are different (P<0.05)

7.3.5. Rumen pH, NH_3-N and VFA

The rumen pH, NH_3-N, total VFA and molar percentages of acetate, propionate, butyrate and other acids in goats were not affected (P>0.05) by the forage sweet potato cultivar (Table 7.4). Acetate to propionate ratio was also not affected (P>0.05) by the cultivar.

7.3.6. Milk yield and composition

The milk yield and composition were affected (P<0.01) by the sweet potato cultivar (Table 7.5). The amount of milk recorded for the forages sweet potato cultivars in descending order (P<0.05) was as follows: K158, Marooko and Wagabolige. The goat milk composition was affected (P<0.01) by the cultivar of sweet potato fed. The goats fed on Marooko and Wagabolige recorded milk containing similar amount (P>0.05) of butter fat that was lower than (P<0.05) the milk from goats fed on K158. The goats fed on K158 and Wagabolige recorded similar quantities (P>0.05) of protein, lactose, solids-non-fat and freezing point depression that were higher than (P<0.05) in Marooko. Although the freezing point depression value in milk produced from goats fed on K158 and Wagabolige; Marooko and Wagabolige was similar (P>0.05), the freezing point depression in Marooko was lower (P<0.05) than in K158. The goats fed on the three cultivars produced milk that differed (P<0.05) in total solids. The goats fed on K158 recorded the highest total solids and those fed on Marooko recorded the lowest.

Table 7.3: Digestible nutrient intake (g/kg $W^{0.75}$) of goats fed three forage sweet potato cultivars

	Forage sweet potato cultivars				
Nutrient	K158	Marooko	Wagabolige	LSD	SEM
Dry matter	86.5	84.3	84.2	2.9	0.7
Organic matter	75.8	74.9	74.5	2.4	0.6
Crude protein	13.8[a]	16.1[b]	14.2[a]	0.6	0.2
Neutral detergent fibre	30.2[b]	27.4[a]	30.8[b]	0.9	0.3
Acid detergent fibre	16.4[b]	15.6[a]	15.6[a]	0.5	0.1

[ab] Means within a row with different superscripts are different ($P<0.05$)

Table 7.4: Rumen fermentation parameters in goats fed three forage sweet potato cultivars

	Forage sweet potato cultivars				
Rumen parameters	K158	Marooko	Wagabolige	LSD	SEM
pH of rumen fluid	6.85	6.83	6.90	0.13	0.04
NH_3-N (mg/ L)	22.33	22.73	21.90	2.82	0.72
Total VFA (mmol/L)	121.22	121.82	119.28	3.89	0.99
Molar % of VFA:					
Acetate (A)	68.40	69.71	68.47	3.36	0.86
Propionate (P)	22.27	21.21	21.75	2.73	0.70
Butyrate	8.05	7.70	7.83	1.77	0.45
Other VFAs	1.50	1.56	1.51	0.37	0.09
Acetate: Propionate ratio	3.08	3.30	3.18	0.56	0.14

Table 7.5: Milk yield and composition by goats fed three forage sweet potato cultivars

Parameter	Forage sweet potato cultivars				
	K158	Marooko	Wagabolige	LSD	SEM
Milk yield (g)	680.0^{c}	585.0^{b}	491.7^{a}	8.7	2.2
Milk Composition (g/kg)					
Butter fat	35.7^{b}	26.1^{a}	28.7^{a}	5.4	1.3
Protein	44.7^{b}	35.2^{a}	44.4^{b}	3.0	0.8
Lactose	53.9^{b}	51.1^{a}	53.0^{b}	1.7	0.4
Total solids	141.2^{c}	107.4^{a}	132.9^{b}	5.7	1.6
Solids non-fat	108.9^{b}	94.2^{a}	105.6^{b}	4.5	1.2
Freezing point depression (^{o}C)	-0.63^{b}	- 0.60^{a}	-0.62^{ab}	0.03	0.01

abc: Means within a row with different superscripts are different (P<0.05)

7.4. Discussion

7.4.1. Nutrient composition

The three sweet potato cultivars were nutritionally high quality forages as discussed in details in Section 6.4.1.

7.4.2. Nutrient Intake and digestibility

The similarity in DM and OM intake by goats fed on the different forage sweet potato cultivars is in agreement with the observation by Sampelayo (1998). This tendency can be explained by the relatively higher fibre in K158 compared to Marooko (Sampelayo, 1998). The lower CP and ADF intake in K158 may be due to their relatively lower content in this cultivar.

The high nutrient digestibility indicated that the three cultivars provided adequate nutrients to the goats. For example, OM digestibility was above 500 to 600 g/kg DM range where most tropical grasses fall (Minson, 1990; Kariuki, 1998 and Muia, 2000). The OM digestibility compared favourably with the 678 to 831 g/kg DM recorded by Snijders *et al.* (1992) on forage sweet potato cultivars and 650 to 790 g/kg DM obtained by Chaparro and Sollenberger (1997) from well fertilized dwarf Napier grass. Likewise, CP and NDF

digestibility were higher than 585 to 669 and 585 to 608 g/kg DM, respectively, obtained by Muia (2000) with sheep fed Napier grass.

7.4.3. Rumen fermentation parameters, pH, NH_3-N, and VFA

The three sweet potato cultivars recorded ruminal fluid pH within the range of 6.0 to 7.0 considered optimal for the activities of cellulolytic microbes (Erdman, 1988; Foster *et al.,* 2009a, b; Hassen *et al.,* 2009) and VFA absorption (Dijkstra, *et al.,* 1993). The total VFA concentration and molar proportions of VFA were typical of the rumen fluid of ruminants fed a forage-based ration (Bergman, 1990; Freeman *et al.,* 2008; Hassen *et al.,* 2009). The total VFA concentration exceeded the normal range of 100-120 mMol/L for forages fed ruminants, perhaps reflecting their greater fermentability (Bergman, 1990; Foster *et al.,* 2009a, b; Freeman *et al.,* 2009). Ruminal passage rates usually increase with DMI, and this can decrease the ruminal propionate proportion (Hristov *et al.,* 2004; Owen *et al.,* 2009) but this did not occur in the goats as they recorded similar DMI. The similarity in ruminal acetate and propionate proportions and the attendant similarity in acetate: propionate ratio suggested that the three sweet potato cultivars attained similar efficiency of ruminal fermentation (Hassen *et al.,* 2009; Owens *et al.,* 2009). These cultivars maintained ruminal NH_3-N concentrations at similar level that was below the recommended concentration of 50 mg/L for maximizing microbial N synthesis (Satter and Slyter, 1974). However, the three sweet potato cultivars recorded ruminal NH_3-N concentrations above 20 mg/L which is considered to limit microbial N synthesis (Satter and Slyter, 1974).

7.4.4. Milk yield

The difference in milk yield by goats may be due to the apparent difference in ME intake by goats fed on the different sweet potato cultivars (Sampelayo, 1998). The goats fed on K158 yielded the highest amount of milk as they also ingested relatively highest ME. Adogla-Bessa and Aganga (2000) reported that energy intake accounted for 62 % of the variation in milk yield of Tswana goat in Botswana. The milk yield in the current study was lower than the 750 to 908 and 685 to 705 g/day reported in Kenya by Ruvuna *et al.* (1995), Mwandotto *et al.* (1992a), respectively; and 795 g/day reported by Banda *et al.* (1992) for goats in Malawi. However, the milk yield was higher than the 380 g reported by Khalid *et al.* (2013) in Nubian goats fed on sweet potato vines silage. Mioc *et al.* (2008), Mmbengwa et al. (2008) and Garcia-Peniche *et al.* (2012) reported that milk yield differed among breeds of

goats. For example, Ruvuna *et al.* (1995) and Mwandotto *et al.* (1992a) reported low milk yield in East African goats compared with their crosses with Anglo-Nubian and Toggenbug bucks. The greatest improvement in milk yield from the indigenous base was at the F_1 level of crossing (Ruvuna *et al.,* 1988; Mwandotto *et al.,* 1990; Mwandotto *et al.,* 1992a). Mwandotto *et al.* (1991) showed that further improvement in milk yield at 4-way crossbred level was only slight due to loss of hybrid vigour in subseguent generations. Hence the lower milk yield recorded in the current study may have been due to the proportion of F_1 and 4-way crossbred in the experimental goats. The reduced performance may have arisen due to unfavourable environmental influence on the flock over the years and the small flock size which limited the choice of experimental goats (Muasya *et al.,* 2006; Muasya *et al.,* 2008).

Banda *et al.* (1992) demonstrated hybrid vigour in crossing local Malawi goat with Boar goats. Mmbengwa et al. (2008) reported that Boer goats produced more milk than Nguni goats. The stage of lactation and the season affected milk yield as reported by Fekadu *et al.* (2005), Mioc *et al.* (2008) and Oprean *et al.* (2011) and Banda *et al.* (1992), Mwandotto *et al.* (1992b) and Zahraddeen *et al.* (2009) respectively. Milk yield estimation method affected yield as Ruvuna *et al.* (1988) demonstrated increased does' milk yield when milked in the presence of the kid which was attributed to the stimulation of milk let-down by the presence of the kids. Banda *et al.* (1992) reported that hand milking yielded 36.5 % less milk compared to yield estimated using the weigh-suckle-weigh of kids or using oxytocin injection before milking. The current study used hand milking without the doe stimulation by the kid. Correcting for the effect of hand milking according to Banda *et al.* (1992), shows the milk yield in the current study fell within the range of values reported by Mwandotto *et al.* (1992a) and Mwandotto *et al.* (1992b). The milk yield after conversion was 928.2, 798.5 and 671.2 g/day produced by goats fed on K158, Marooko and Wagabolige, respectively. The number of milkings daily tended to increase the milk yield but twice daily milkings in goats was found optimal and this was practised in the current study (Akpa *et al.,* 2001; Akpa *et al.,* 2003).

7.4.5. Milk composition

The composition of goat milk is affected by many factors including diet, breed and the stage of lactation (Mmbengwa *et al.,* 2008; Zahraddeen *et al.,* 2009; Hassan *et al.,* 2010). Goat milk lactose declined as lactation progressed and daily milk yield declined while protein increased with advancing lactation (Fekadu *et al.,* 2005; Mioc *et al.,* 2008; Oprean *et al.,*

2011). Butterfat and total solids decreased in midlactation and increased in late lactation. In ruminants, the pattern of ruminal fermentation that develops depends on the amount and quality of the fibre fraction in the diets (Adogla-Bessa and Aganga, 2000; Zahraddeen *et al.,* 2007; Hilario *et al.,* 2010). A decrease in fibre in the diet and a decrease in particle size of the fibre all tend to reduce the acetogenic to glucogenic VFAs ratio, which is the principal precursor of the fatty acids synthesized in the mammary gland (Sampelayo, *et al.,* 1998). As a result, the fat content of the milk tends to be depressed (Zahraddeen *et al.,* 2007; Hilario *et al.,* 2010). Hence, although the goats fed on K158 and Wagabolige ingested similar quantity of both NDF and digestible NDF, their intake of ADF were different causing a difference in butterfat (BF) between them. Moreover, the goats fed on Marooko and Wagabolige ingested similar quantity of ADF and hence they produced milk with similar BF. Furthermore, the energy balance in the goats has been shown to affect BF (Sampelayo *et al.,* 1998; Strzalkowska *et al.,* 2009; Oprean *et al.,* 2011) and in the current study goats fed on Marooko and Wagabolige ingested similar ME that was relatively lower than those fed on K158. This may have enabled goats fed on K158 to produce milk of higher BF than those fed on Marooko and Wagabolige which recorded similar BF.

Dietary characteristics that lead to a decreased BF in milk cause an increase in protein content (Sampelayo, *et al.,* 1998). Hence goats fed on Wagabolige increased their milk protein content to match goats fed on K158, although the protein content in milk produced by goats fed on Marooko was lower. Furthermore, Cannas *et al.* (1998) showed that an increase in dietary protein and a decrease in energy intake increased protein intake and milk protein content in sheep. Additionally, Oprean *et al.* (2011) showed that an increase in the plane of nutrition increased protein content in goat milk. These observations are in agreement with the results of the current study.

The lactose content in goat milk is affected by the plane of nutrition (Sampelayo, *et al.,* 1998; Cannas *et al.,* 1998; Oprean *et al.,* 2011). Sampelayo et al. 1998 and Cannas et al. 1998 fed nutritionally adequate test diets to goats which showed no effect on goat milk lactose content. However, by varying the energy and protein content in the diets they concluded that energy balance was the main cause of lactose variation in goat milk. In the current study goats fed on Marooko apparently ingested lower ME than those fed on K158. This may have enabled goats fed on K158 to produce milk containing higher lactose compared to those fed on Marooko.

The variations in butter fat, protein and lactose in goat milk due to the feeding of K158, Maroko and Wagabolige have direct effects on total solids (TS) and solids non-fat (SNF) content of goat milk (Strzalkowska *et al.,* 2009; Khalid *et al.,* 2013). Their increase caused higher values in TS and SNF in goat milk (Strzalkowska *et al.,* 2009). Park *et al.* (2007) reported the freezing point for goat milk to range between -0.540 and -0.570 ^{o}C which was slightly lower than the values recorded in the current study (Table 7.6). Solutes in milk, for example lactose, depress freezing point to about 0.5 ^{o}C below the freezing point of water. Addition of water raises the milk freezing point towards 0 ^{o}C and it is illegal to adulterate milk with water. The freezing point values in the current study are in agreement with Strzalkowska *et al.* (2009) and showed an increased concentration in individual milk components.

The protein and SNF content of milk in the current study were similar to those reported by Banda *et al.* (1992) but lactose was higher than that reported by Banda et al. (1992) and Zahraddeen *et al.,* (2007). However, the protein content was higher than the value reported by Khalid *et al.* (2013) as the Nubian goats were in early lactactation (Fekadu *et al.,* 2005; Mioc *et al.,* 2008; Oprean *et al.,* 2011). The higher lactose in the current study indicated that K158, Maroko and Wagabolige provided better diets than the grazing and the supplemental concentrate provided to goats by Banda *et al.* (1992) in Malawi; Zahraddeen *et al.* (2007) in Nigeria, and Hassan et al. (2010) in Bangladesh respectively. Fibre in the grazing may have increased the BF in the Bangladesh, Malawi and Nigerian goats as fibre type and amount has been reported to affect BF (Sampelayo *et al.,* 1998). The elevated BF may have increased the value of TS in milk from the Malawi goats (Strzalkowska *et al.,* 2007). The lower protein reported by Zahraddeen *et al.* (2007) and Hassan *et al.* (2010) were in agreement with Sampelayo, *et al.* (1998). Sampelayo *et al.* (1998) reported that dietary characteristics that led to an increased BF in milk caused a decrease in protein content; and in the study by Zahraddeen *et al.* (2007) and Hassan *et al.* (2010) fibre increased BF.

7.4. Conclusions and recommendations

The three forage sweet potato cultivars provided similar amount of OM which was utilized at relatively similar level by dairy goats. Marooko was the best source of CP which was highly digested and most effectively utilized by the dairy goats. Cultivar K158 recorded relatively higher fibre intake, higher digestibility and subsequently higher digestible fibre intake by dairy goats, making K158 a suitable source of fibre.

Dairy goats fed on cultivar K158 produced most milk, followed by goats fed on Marooko, then those fed on Wagabolige. The cultivar merit order changed when milk composition was considered, where goats fed on K158 were at the top, followed by Wagabolige and Marooko was in third position. Therefore, among the three forage sweet potato cultivar evaluated in the current study, K158 is the most suitable to feed dairy goats. This cultivar should be widely popularized among dairy goat producers to improve goat performance.

CHAPTER 8

GENERAL DISCUSSION

8.1. Introduction

There is little documentation on the management, nutritive value and suitability of forage sweet potato as livestock feed. Information on the management aspects of the cultivars for optimal fodder yield and nutritional quality, including the effect of harvesting age on DM yield and nutritional quality is scarce (Ondabu *et al.,* 2005; Ondabu *et al.,* 2007). In Kenya, there is a seasonal variation` in the quantity and quality of available forage in tandem with the rainfall distribution. As a result, inadequate nutrition is a major limitation to livestock productivity; causing high young stock mortality and reduced growth rate, low fertility in adult cattle and decreased milk production (Ouda *et al.,* 2001; Kiragu *et al.,* 2003; Ilatsia *et al.,* 2007). To even out this seasonal forage availability and quality, farmers should undertake forage conservation. Sweet potato cultivars can be conserved as silage in order to provide livestock with feeds all year.

8.2. Harvesting age, chemical composition, crude protein yield and *in vitro* digestibility

This study evaluated the effects of harvesting age on chemical composition, DM and CP yield and *in vitro* digestibility of forage sweet potato in order to select the three most superior cultivars. Harvesting age influenced chemical composition, DM and CP yield and *in vitro* digestibility of forage sweet potato. The cultivars differed in DM and CP yield and *in vitro* digestibility. The study showed that harvesting age was more important than the cultivar in affecting the CP and there was little change in NDF, ADF and ADL with increased harvesting age as detailed in Chapters 3. Cultivars K158, Marooko and Wagabolige were superior in DM and CP yield and their optimal yield and nutritional quality were recorded at 120 days. Consequently, these cultivars can be harvested at 120 days, which was considered an early age, without much reduction in yield. The CP yield recorded by K158, Marooko and Wagabolige at 120 days was higher than the yield reported by Snijders *et al.* (1992) at 180 days and Ruiz (1982) at 165 days showing a higher CP yield potential among these cultivars even at a younger re-growth. However, Snijders *et al.* (1992) and Ruiz (1982) evaluated different cultivars and tested different cutting regimes from those reported in the current study. As protein is a major limiting nutrient in Kenyan livestock production systems, K158, Marooko and Wagabolige are recommended as good supplements to poor quality roughages

such as cereal crop by-products and as sole feed (Semenye *et al.,* 1989; Orodho *et al.,* 1993; Kariuki *et al.,* 1998) to improve performance in livestock production. The three cultivars will also increase the diversity of forages available, which widens the farmers' choice (Claessens *et al.,* 2009). These cultivars could, therefore, be widely popularized among livestock farmers in Rift valley and Central Provinces where suitable cultivation conditions exist and these regions rear over 80% of dairy cattle in Kenya.

The apparently diminished IVOMD recorded among the cultivars beyond 120 days confirmed that this was the optimum harvesting age. This was also in agreement with available literature that at the optimal harvesting age cultivars record high IVOMD. The similarity in ME with extended harvesting age was in agreement with reported literature, which showed little difference in energy among various sweet potato cultivars. The climatic factors at the study area may be optimal for these cultivars and the harvesting age allowed adequate time for plants to accumulate optimal energy.

Cultivars K158, Marooko and Wagabolige were recommended as the three most superior forage sweet potato cultivars considering DM and CP yield, and their recommended harvesting age was 120 days for their optimal yield and nutritional quality.

8.3. Macro and microminerals in forage sweet potato cultivars

Majority of forage sweet potato cultivars in Eastern Africa have not been adequately evaluated in terms of their mineral content. The harvesting age influenced the concentration of macro and micro-minerals and their concentration decreased with increased harvesting age.

Cultivars 99/1 and K049 can be harvested at 90 days to provide highest levels of calcium and sodium; calcium, magnesium and sodium, respectively. Wagabolige can also be harvested at 90 days to provide potassium. Cultivars 99/1, Marooko and Mugande; 99/1, K049, Mugande and Wagabolige; 99/1, K049 and K158 can be harvested at 120 days for optimal concentration of magnesium, phosphorus and potassium respectively. The optimum concentration of calcium and sodium in K158, Mugande and Wagabolige was recorded at 180 days showing that they were characteristically different from the remaining test cultivars (Monamodi *et al.,* 2003; Magagula *et al.,* 2010; Agbede and Adekiya, 2011). However, K158 contained the highest concentration of both calcium and sodium. These results showed that macro minerals concentration in cultivars of forage sweet potato was affected differently by harvesting age (Monamodi *et al.,* 2003; Akinrinde, 2006; Olorunnisomo, 2007b). The macro

mineral optima recorded in cultivars probably indicated equilibrium between the rate of leaf initiation and leaf death (Snijders *et al.,* 1992; Monamodi *et al.,* 2003; Olorunnisomo, 2007a, b).

The recommended harvesting age was 120 days for optimum concentration of magnesium, phosphorus and potassium in K158, Marooko and Wagabolige whereas harvesting at 180 days was advocated for optimum calcium and sodium concentration in K158 and Wagabolige.

Cultivars K049 and Marooko; Marooko and Wagabolige; K158; 99/1, K049, K158, Marooko and Wagabolige; Marooko can be harvested at 90 days to provide cobalt, copper, iron manganese and zinc respectively. Cultivars 99/1 and Wagabolige; K049; 99/1 and K049 can be harvested at 120 days for optimal concentration of cobalt, copper and zinc respectively. The optimum iron concentration in K049, Marooko, Mugande and Wagabolige was recorded at 180 days showing that they were characteristically different from the remaining test cultivars (Monamodi *et al.,* 2003; Magagula *et al.,* 2010; Agbede and Adekiya, 2011). However, Marooko contained the highest concentration of iron. It was recommened that K158, Marooko and Wagabolige be harvested between 90 and 120 days to provide cobalt, copper, iron, manganese and zinc.

8.4. The Conservation Potential as Silage or Hay of Selected Forage Cultivars of Sweet Potato

The selection of the most promising forage cultivars of sweet potato and ensiling was done. The three molasses level (0, 5 and 10%) and cultivars influenced the silage pH and nutrient composition. The different forage preparation methods and cultivars, also, influenced the drying rate and nutrient composition of forage sweet potato hay.

The addition of molasses during making of silage from the cultivars benefited the silage fermentation as shown by the favourable pH. The 5% molasses rate seemed to provide adequate soluble fermentable sugar compared with no molasses addition. The cultivars produced silage containing the highest DM at 5% molasses and molasses tended to reduce NDF, ADF and ADL in silage as molasses enhanced silage fermentation. Also molasses improved silage quality through increased DM and OM, reduced ammonia and butyric acid. Five percent molasses rate was, therefore, recommended in making silage from sweet potato cultivars.

Sweet potato cultivars fermented into silage without molasses addition as they recorded pH values lower than 4.8 which has been reported as the threshold in typical tropical fodders. Their fermentation into silage without molasses addition has not been documented before and will require further research. This may have been achieved due to hydrolysis of starch in the cultivars to sugars boosting the supply of available sugars for fermentation (Kaiser *et al.,* 2000; Pitz *et al.,* 2000; Murugeswari *et al.,* 2006).

Marooko produced the best silage as it contained the highest DM, OM and CP and low NDF, ADF and ADL and relatively low NH_3-NH and butyric acid. Cultivars K158 and Wagabolige contained similar OM and CP but K158 had lower ADF and ADL and higher DM and NDF than Wagabolige. Wagabolige produced relatively poorer quality silage compared to K158 as it recorded higher NH_3-NH and lower TA.

Cultivars K158, Marooko and Wagabolige have high conservation potential as they can successfully be conserved into silage. Molasses application rate of 5% was suitable to produce silage with suitable pH, increased DM and OM, reduced NDF, ADF and ADL and silage of good quality. Silage making using forage sweet potato cultivars should be popularized to livestock farmers to enable them to avail highly nutritious diets to their livestock throughout the year hence improving livestock production performance.

Shredding increased the cultivar DM in all the five drying durations and may be considered more effective in exposing a larger surface for moisture loss (Pattey *et al.,* 1988; Seo *et al.,* 2000; Suttie, 2000) compared to leaving the cultivars whole or just chopping. There was no major advantage in chopping or leaving the cultivars whole and this may suggest that the cultivars were either insufficiently thinly spread or the study was not long enough for these benefits to be recorded (Savoie and Mailhot 1988; Pattey *et al.,* 1988; Enoh *et al.,* 2005). The observations recorded in this study showed that there were minimal losses due to spoilage under the applied experimental treatments. Mechanical treatment was essential to increase the drying rate in forage cultivars of sweet potato. Shredding was recommended as the best treatment to rapidly increase the DM in these cultivars.

Cultivars K158 and Wagabolige recorded similar DM, OM and ADF but differed in CP, NDF and ADL. Marooko contained the highest CP and the lowest DM and fibre. All the three cultivars contained similar OM and GE. Cultivars K158 and Wagabolige overall dried at similar rate which was higher than in Marooko. Wagabolige increased in DM most rapidly when dried whole or shredded compared to K158 and Marooko. Drying time only affected the DM without affecting other nutrients. The forage sweet potato hay had similar DM at 0

and 24 hr but the DM significantly increased at 48, 72 and 92 hr. However, hay making was a poor conservation method as it did not attain 800 g/kg DM after 96 h of drying.

8.5. Nutrient intake, digestibility, rumen fermentation characteristic and performance of sheep fed on forage sweet potato cultivars

The most promising forage cultivars of sweet potato were studied. The DM, OM, NDF and ME intake (g/kg $W^{0.75}$) was not influenced by the cultivar but the intake of CP, ADF and ADL was influenced by the cultivar (Chapter 6). The cultivars influenced the digestibility of CP, NDF and ADF but did not affect DM and OM digestibility. However, digestible nutrient intake of DM, OM and ADF (g/kg $W^{0.75}$) were not affected by the cultivars but digestible CP and NDF were affected. The rumen fermentation characteristics were not affected by the cultivars. The cultivar influenced the CP, NDF and ADL intake (g/kg $W^{0.75}$) but did not affect DM, OM, ADF and ME intake of sheep fed on the four cultivars in sheep performance study. The cultivar, also, influenced sheep growth and FCE.

The cultivars provided good diets to sheep as they contained high DM, OM and CP and less fibre (Snijders *et al.,* 1992; Kariuki, 1998; Muia, 2000). They also provided high ME, recorded high intake of digestible OM, CP and NDF and these characteristics enable them to be considered high quality forages (Norton and Poppi, 1995). Cultivar K158 had the highest nutritient digestibility and intake among the cultivars. These cultivars (K158, Marooko and Wagabolige) provided edequate nutrients to sheep both as sole diets and supplements hence have a potential to improve livestock production in Kenya (Claessens *et al.,* 2009).

The nutrient intakes, in sheep performance study, were higher than in sheep and goats studied by Lam and Ledin (2004), Olorunnisomo, (2007b) and Kebede *et al.* (2008) showing that the three cultivars were nutritionally superior. The feed conversion efficiency was in agreement with values recorded in the literature (Lam and Ledin, 2004; Olorunnisomo, 2007b). These cultivars' characteristics indicated the efficiency of nutrient incorporation into weight gain was promoted (Hagerman *et al.,* 1992; Kaitho, 1997). The nutritional superiority of sweet potato cultivars was also reported by Aregheore (2003) when he fed goats on sole forage sweet potato diets and mixture with batiki grass (*Ischaemum aristatum*). Those goats on mixed diets of sweet potato with batiki grass recorded higher ADG and feed conversion efficiency compared to a sole diet of batiki grass (Aregheore, 2003). The nutritional superiority of K158, Marooko and Wagabolige should be exploited to improve sheep diets

both as sole diets and supplements in Kenya. Livestock farmers should be trained on the benefits of K158, Marooko and Wagabolige to make these cultivars widely grown on Kenyan farms.

8.6. Nutrient intake and performance of dairy goats fed on forage sweet potato cultivars

The objective of the current study was to determine the nutrient intake, milk yield and composition of dairy goats fed on the most superior forage cultivars of sweet potato. The DM, OM and ME intake (g/kg $W^{0.75}$) by goats was not affected by the forage sweet potato cultivar unlike CP, NDF, ADF and ADL which were affected as detailed in Chapter 7. The cultivar influenced the digestibility of CP and NDF but did not affect DM, OM and ADF digestibility in goats. The digestible DM and OM intake (g/kg $W^{0.75}$) were not affected by the cultivar, however, the digestible nutrient intake of CP, NDF and ADF were affected. The milk yield and composition were, also, influenced by the sweet potato cultivar.

The digestibility study showed K158, Marooko and Wagabolige provided adequate nutrients to goats (Minson, 1990; Kariuki, 1998 and Muia, 2000) as detailed in Chapter 7. The similarity in DM and OM intake by goats fed on the different sweet potato cultivars is in agreement with Sampelayo (1998). The goats fed on Marooko tended to record lower fibre intake, while those on K158 had higher intake. This tendency can be explained by the relatively higher fibre in K158 compared to Marooko (Sampelayo, 1998). The lower CP and ADF intake in K158 may be due to their relatively lower content in this cultivar. The fact that Marooko and Wagabolige had the highest and lowest CP was in agreement with the findings of Minson (1990) who showed that nutrient digestibility rose with increased metabolizable energy. The author also showed that the nutrient digestibility was positively correlated with OM digestibility which in turn was related to the energy available in the forage. The inherent attributes of NDF and CP of the sweet potato cultivars were relatively similar (Hagerman *et al.,* 1992 and Kaitho, 1997). The protein digestability and available energy seemed sufficient for ammonia incorporation into microbial protein (Preston and Leng, 1987).

The goats fed on K158 yielded the highest milk volume as they also ingested highest ME followed by Marooko and Wagabolige. Adogla-Bessa and Aganga (2000) reported that energy intake accounted for 62 % of the variation in milk yield. The milk yield in the current study was lower than those reported in the literature (Mwandotto *et al.,* 1991; Banda *et al.,* 1992; Ruvuna *et al.,* 1995). Mwandotto *et al.* (1991) and Ruvuna *et al.* (1995) reported low

milk yield in East African goats compared with their crosses with Anglo-Nubian and Toggenbug. The greatest improvement in milk yield from the indigenous base was at the F_1 level of crossing as loss of hybrid vigour occurred in subsequent generations (Ruvuna *et al.,* 1988; Mwandotto *et al.,* 1990; Mwandotto *et al.,* 1991).

Although the goats fed on K158 and those on Wagabolige ingested similar quantity of both NDF and digestible NDF, their intake of ADF were different causing a difference in butterfat (BF) between them. The goats fed on Marooko and Wagabolige ingested similar quantity of ADF and they produced milk with similar BF. The energy balance in goats has been shown to affect BF (Sampelayo, *et al.,* 1998; Strzalkowska *et al.,* 2009; Oprean *et al.,* 2011). In the current study goats fed on Marooko and Wagabolige ingested similar ME that was relatively lower than in K158. This may have enabled goats fed on K158 to produce milk of higher BF than those fed on Marooko and Wagabolige which recorded similar BF (Adogla-Bessa and Aganga 2000; Hilario *et al.,* 2010).

A decreased BF in milk causes an increase in protein content (Sampelayo, *et al.,* 1998). Hence goats fed on Wagabolige increased their milk protein content to match goats fed on K158 although the protein content in milk produced by goats fed on Marooko was lower. Also, an increase in dietary protein and a decrease in energy intake increased protein intake and milk protein content in sheep. These observations are in agreement with the results recorded in the current study. Energy balance was the main cause of lactose variation in goat milk (Sampelayo, *et al.,* 1998 and Cannas *et al.,* 1998). In the current study goats fed on Marooko apparently ingested lower ME than those fed on K158. This enabled goats fed on K158 to produce milk containing higher lactose compared to those fed on Marooko. The variations in fat, protein and lactose in goat milk caused by K158, Maroko and Wagabolige had direct effects on total solids (TS) and solids non-fat (SNF) content of goat milk (Strzalkowska *et al.,* 2009). According to the superiority in milk composition qualities these cultivars were ranked in descending order as K158, Wagabolige and Marooko respectively.

8.7. Practical implications and conclusions

The shorter harvesting age of sweet potato will enable livestock farmers to increase the number of harvests annually with the resultant higher annual DM and CP yield. The three superior cultivars were ranked in increasing CP yield as Marooko, Wagabolige and K158, respectively, and these were the three promising forage cultivars recommended to farmers.

The ME did not widely vary with extended harvesting age and was in agreement with reported literature that there was little difference in energy among various sweet potato cultivars. The climatic factors at the study area may be optimal for these cultivars and the harvesting age allowed adequate time for plants to accumulate optimal energy. This may allow farmers to harvest these cultivars piece-meal over long periods without energy deterioration in these cultivars. Such spread in harvesting will contribute to the distribution of nutritious feed to livestock throughout the year with the resultant increased livestock productivity. There is, also, widespread mineral deficiency in Kenya hence these cultivars should be widely popularized as sources of macro and microelements in the livestock industry.

These cultivars fermented into silage without molasses addition will save money in silage production and can extend silage making in farming situations where silage additives are unavailable. Shredding was preferred as it increased the cultivar DM at all the five drying durations and was considered more effective in exposing a larger surface for moisture to evaporate compared to leaving the cultivars whole or just chopping. The cultivars should be thinly spread and the study drying period lengthened for the benefits arising from chopping and shredding to be realized.

These studies showed that the selected cultivars were nutritionally suitable feedstuffs to sheep and goats both as sole diets and supplements. They have a potential to improve livestock production in Kenya. Cultivars K158, Marooko and Wagabolige, therefore, should be popularized among livestock farmers through training and demonstrations.

8.8. Further research

The growth site and season of growth affect the yield and composition of these forage cultivars. These effects are through soil composition and climatic characteristics. The study should, therefore, be replicated in different ecological sites and during different seasons. Mineral bioavailability studies are required to ascertain the mineral adequacy in the selected forage sweet potato cultivars. Further research should, also, be done to analyze the mineral content in various parts (leaf, petiole, stem and the whole plant) of sweet potatoes cultivars to optimize the use of these cultivars as mineral sources in Kenya. Different sample handling methods such as avoiding harvesting too close-to-the ground and rinsing the sample with water to minimize contamination, should be studied**.**

There is need to study why the sweet potato cultivars fermented into silage without molasses. The effects of molasses application rate below 5% on silage fermentation characteristics and quality requires additional research. Future studies should ensure that the cultivars are sufficiently thinly spread and extend long enough for the full benefits in chopping and shredding compared to leaving the cultivars whole. There is need to explore other methods of enhancing rapid moisture loss when making hay from forage sweet potato such as forage pulverizing. Additionally, livestock performance evaluation studies that involve other cultivars of sweet potato and different livestock species are required.

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APPENDIX

LIST OF PUBLICATIONS

1. **Irungu, R.,** A.Y. Guliye, P.K. Migwi and J.N. Kariuki (2015). Effects of different mechanical preparation methods on drying rate and nutrient composition of forage sweet potatoes hay. *Journal of Biology, Agriculture and Healthcare, 5 (13): 112-118.*
2. **Robert Irungu,** P.K. Migwi, J.N. Kariuki and A.Y. Guliye (2016). Nutrient intake, digestibility and rumen fermentation characteristics of sheep fed on selected forage sweet potato cultivars. *East African Agricultural and Forestry Journal, 82:1-13. DOI 1080/0012835.2016.1164978.*
3. **Irungu, R.,** A.Y. Guliye, P.K. Migwi and J.N. Kariuki (2015). Effect of molasses on fermentation characteristics and nutritive value of silage from selected forage sweet potato cultivars. *Egerton Journal of Science and Technology, 15:74-92.*
4. **Irungu, R.,** P.K. Migwi, J.N. Kariuki and A.Y. Guliye (2016). The effects of feeding selected forage sweet potato cultivars on nutrient intake, milk yield and composition of lactating dairy goats. *Journal of Applied Animal Research,* Under Review.
5. **Irungu, R.,** P.K. Migwi, J.N. Kariuki and A.Y. Guliye (2016). Effects of different mechanical preparation methods on drying rate and nutrient composition of hay from sweet potato forage. *Tropical Grassland-Forraje Tropicale,* Under Review
6. **Irungu, R.,** P.K. Migwi, J.N. Kariuki and A.Y. Guliye (2016). Sweet potato forage grown as a vegetable to provide protein, carbohydrates and minerals on the Kenya central highlands. *African Journal of Food, Agriculture, Nutrition and Development,* Under Review