EFFECT OF STAGE OF GROWTH ON NUTRITIONAL VALUE OF DUAL PURPOSE SORGHUM

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DECLARATION

I, Patrick Githui Mwangi hereby declare that this thesis is my original work. It has not been presented for an award of degree in any other university.

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PATRICK GITHUI MWANGI (BSc) **Date**

This thesis has been submitted for examination with our approval as university supervisors

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DEDICATION

This work is dedicated to my dear wife Lucy, my son Mwangi and my daughter Wambui, each of whom has brought something fresh and new that has enabled me to successfully pursue my studies.

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LIST OF ABBREVIATIONS

ADF	Acid Detergent Fibre
ADL	Acid Detergent Lignin
AFRS	Agriculture Forecast Reporting system
AEASWW	Agricultural Extension and Advisory Services World Wide
AI	Artificial Insemination
ANOVA	Analysis of Variance
AOAC	Association of Analytical Chemists
ASDS	Agricultural Sector Development Strategy
BTA	Biotechnology Trust Africa
CAGR	Compounded Annual Growth Rate
CBEs	Collection and Bulking Enterprise
CAIS	Central Artificial Insemination Station
CIRAD	Centre for International Research for Agricultural Development
CP	Crude protein
DAFWA	Department of Agriculture and Food in Western Australia
DM	Dry matter
FAOSTAT	Food and Agriculture Organization Statistics
FAO	Food and Agriculture Organization of the United Nations
FEWNET	Famine Early Warning System Network
GDP	Gross Domestic Product
IDPS	Improved dual purpose sorghum
I C A R	Indian Council of Agricultural Research
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
INRA	Institute for National Research for Agriculture
IVDMD	*In vitro* Dry Matter digestibility
IFAD	International Fund for Agricultural Development
ECF	East Coast Fever

KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
KCC	Kenya co-operative creameries
KDB	Kenya Dairy Board
KLBO	Kenya Livestock Breeders Organization
KMDP	Kenya Market – led Dairy Programme
KNBS	Kenya National Bureau of Statistics
KNDMP	Kenya National Dairy Master Plan
KNSP	Kenya National Strategic Plan
KNAIS	Kenya National Artificial Insemination Service
LAB	Lactic Acid Bacteria
LRC	Livestock Records Centre
ME	Metabolizable Energy
MJ	Mega joules
MDGs	Millennium Development Goals
MoLD	Ministry of Livestock Development
MoLNSP	Ministry of Livestock National Strategic Plan
NDA	Netherlands Development Agency
NDF	Neutral Detergent Fibre
N	Nitrogen
NH_3N	Ammonia Nitrogen
NRC	National Research Council
TDN	Total Digestible Nutrients
PTT	Propensity to Tiller
USAID	United State Agency for International Development
WSC	Water Soluble Carbohydrates
QTL	Quantitative Trait Loci

ABSTRACT

The study was conducted to evaluate the effect of stage of growth on the quality of improved dual purpose sorghum *(Sorghum bicolor)* fodder and silage (IDPS). Six treatments based on physiological stage of growth of sorghum were assigned randomly in plots within a block and replicated three times. Treatments were bloom stage (PS1), soft dough stage (PS2), hard dough stage (PS3), physiological maturity stage (stalks with grains), (PS4), physiological maturity stage (stalks without grains) (PS5), and 1 month post grain harvest (PS6). The parameters determined were dry matter yield, nutrient composition, plant height, tiller count and effect of protein (cotton seed cake) supplementation on silage digestibility at different physiological stages of growth. Highest ($P< 0.05$) DM yield (18.01 ton/ha) was obtained at PS4 compared with 8.69, 12.75, 16.27 17.04 and 13.04 ton/ha for PS1, PS2, PS3, PS5 and PS6, respectively. CP declined ($P<0.05$) with maturity from 8.6 at PS1 to 7.98, 7.96, 7.61, and 6.77 to 6.72 at PS2, PS3, PS4, PS5 and PS6 respectively. NDF and ADF at PS1, PS2, PS3, PS4, PS5 and PS6 were 54.4, 60.8, 65.71, 65.93, 66.73 70.3 and 27.93, 35.96, 41.98, 41.97, 42.04, 46.05 respectively. ADL was 3.44, 5.03, 7.38, 7.39, 7.42, and 8.3 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively. Highest ($P<0.05$) silage IVDMD of 60.72 was at PS1 compared with 54.73, 53.82, 53.56, and 45.75 obtained at PS2, PS3, PS4, PS5 and PS6 respectively. Inclusion of cotton seed cake in silage increased ($P<0.05$) IVDMD at various growth stages. PS3 growth stage provided fodder material with higher ($P< 0.05$) nutritive for silage making while highest ($P< 0.05$) fodder yields were obtained at PS4. Harvesting at PS5 provided both fodder and grains for livestock and human consumption respectively. It was evident that yields and quality of IDPS was affected by age at harvesting.

CHAPTER 1.0: INTRODUCTION

1.1 Background

Roughages such as natural pastures and fodder form the main feedstuffs for ruminant livestock in Kenya (Kinyua, 2013). Pastures and fodder are considered the backbone of dairy industry and their year round availability in acceptable quality determines the competitiveness of the dairy sector (KMDP, 2013). In Kenya, dairying is mainly practiced in medium and high potential areas where forage production systems are rain-dependent and thus feed is readily available during rainy seasons and inadequate during dry spells (Shem *et al.,* 2001). High potential areas are agricultural land in ecological zone 1- 111, occupying 12% of proportion of total land area and receiving annual rainfall ranges of 850- 1400mm. Medium potential areas are marginal agricultural land in ecological zone 1V, occupying 6% of proportion of total land area and receiving annual rainfall ranges of 750- 850 mm 850-1400mm (Sombroek et al., (1982). Consequently, milk production follows similar seasonal trend with high and low yields during rainy and dry seasons, respectively (Le Van, 2003). Feed conservation during rainy season to even out feed supply during dry season is not practiced by majority of the small holder dairy farmers (KMDP, 2013). Limited awareness amongst farmers on feed conservation technologies and limited land resources have been cited as hindrance to feed conservation (Techno – Serve 2008).

About 75% of Kenya's population lives in medium and high potential areas where population density is six times the country's average (KMDP 2013). Family land size has reduced to below 1.2 acres and is likely to decline to less than 0.7 by the year 2020 **(**Jayne and Milu, 2012). This implies that the area that could be used for pastures and fodder production is progressively diminishing as it is replaced by cultivation of food crops in response to escalating population pressure (Nandwa *et al.,* 2013). Besides food crops, pastures and fodder production competes for the same space with perennial cash crops like coffee and tea

(KMDP, 2013). Consequently both food and feed shortages have been reported as a constraint affecting majority of the farm families (Techno - Serve, 2003).

To balance out both feed and food supply, there is need to identify a dual purpose fodder crop with high fodder and grains yields per unit area of the limited land resource. Improved dual purpose sorghum (IDPS) variety *Ikinyaruka* fits this description (KMDP, 2013).

1.2 Statement of problem

Availability of feed for livestock is a problem due to land scarcity and need for food. IDPS is dual purpose and can be used for feed and food if cut at different physiological growth stages i.e. bloom stage, soft dough stage, hard dough stage, physiological maturity stage (stalks with grains), physiological maturity stage (stalks without grains), and 1 month post grain harvest. However, yields and quality of the IDPS when harvested at those different stages is not known.

1.3 Justification

Land sub divisions in medium and high potential areas of Kenya in response to escalating population pressure has resulted to gradual decline in farm size rendering to land previously used for fodder and pasture production being replaced by cereal cultivation (Koskey *et al,* 2008). Consequently, feed and food shortages have become a common scenario to majority of the farm families as the land sizes for food and fodder crops production have reduced to less than 1.2 acres **(**Jayne and Milu, 2012).

To mitigate the shortages, use of dual purpose fodder crops that would balance out both feed and food supply throughout the year on the limited land resources could be used. Improved dual purpose sorghum (IDPS) would fulfill this requirement. IDPS is capable of providing cereals as well as adequate fodder materials all the year round when harvested at different stages of growth (Gachuki *et al.*, 2007). However, when harvested at those different growth stages, it is expected that the nutritional value of the fodder material will vary with the stages. Information on nutritional variations of IDPS at different growth stages is scanty. Therefore, this study was undertaken to evaluate the dry matter yield, the nutritive value and the silage quality of improved dual purpose sorghum (IDPS) variety, *Ikinyaruka* as well as the proportional changes in digestibility at different physiologic growth stages.

1.4 Objectives of the study

The main objective was to evaluate the effect of stage of growth on nutritive value of Improved Dual Purpose sorghum, variety, *Ikinyaruka*

The specific objectives were to:

1. Determine the dry matter (DM) yield of dual purpose sorghum at different physiological growth stages.
2. Assess the nutritive value of dual purpose sorghum harvested at different physiological growth stages.
3. Assess the nutritive value of the sorghum silage conserved at different physiological growth stages.
4. Assess the effect of protein supplementation on digestibility of the sorghum silage at different physiological growth stages.

1.5 Hypothesis of the study

H_0: The six physiological growth stages of dual purpose sorghum, variety, *Ikinyaruka* have same dry matter yield, nutritive value and silage quality.

H_0: Protein supplementation has no effect on digestibility of the sorghum silage at different physiological growth stages.

CHAPTER 2.0: LITERATURE REVIEW

2.1 Introduction

In Kenya, dairy production is dominated by the smallholder dairy farmers who keep an estimated 3.5 million dairy cattle and produce approximately 5 billion litres of milk annually (KNBS, 2009). Dairy products excluding sale of live animals contribute 30 percent of livestock GDP and more than 22 percent of livestock gross marketed products (Muriuki, 2011). The industry is quite dynamic and an important source of regular income for close to one million smallholder dairy farmers (KMDP, 2013).

Dairying provides milk, employment, cash income and manure among others (KNSP, 2012), with milk being the major product (Ministry of Livestock, 2010). Kenya population was 38.6 million people by the year 2009 and annual milk consumption was 4.5 billion litres (KNDMP, 2012). The population is estimated to hit 58 million in the year 2032 and the consumption is expected to be 12.76 billion litres (MDGs, 2012). The national average milk production level was estimated at 5 litres per cow per day and this being alarmingly low (KNDMP, 2012), to meet the future expected milk demand some factors which constrain milk production needs to be addressed.

2.2 Constraints to milk production

Several factors have been identified as constraints to milk production among them being feed (quantity and quality), poor breeding practices, livestock diseases, marketing and infrastructure, credit facilities and extension services (Muriuki, 2011). Feed (quantity and quality) has been ranked as the leading constraint to milk production.

2.2.1 Feed (Quantity and quality)

Quantity and quality feed is a key strategy in realizing increased milk productivity (Techno Serve, 2008). In Kenya, dairy cattle are mainly fed on natural grass pastures and planted fodder crops which are rarely available in required quality and quantity especially during the dry seasons (Ministry of Livestock, 2010). The quantity and quality of feed are greatly influenced by climate (seasons) and are high and low during rainy and dry seasons, respectively (Baker and Gray, 2003). Consequently, trends in milk production follow the same seasonal calendar with deficiencies occurring during dry seasons while milk glut is experienced during rainy seasons (KMDP, 2013). During rainy seasons cows produce 5- 9 litres of milk per cow per day and this may drop by over 50% during dry spells when fodder quality and quantity has declined (Ministry of Livestock, 2010).

Farmers rarely conserve surplus fodder to even out feed supply during lean seasons (Tolera *et al.,* 2007). Lack of conservation is mainly associated with limited awareness amongst farmers on feed conservation leading to lack of preparedness for dry periods feeding (KMDP, 2013). Low fodder production which is mainly associated with limited land resources have also been cited as an obstacle to feed conservation (Techno Serve, 2008).

Both the quality and the quantity of feed are determined by the availability of land for pastures and fodder production (Ministry of Livestock, 2010). Land sizes have decreased due to continuous land subdivisions brought about by increasing human population pressure (FEWS-NET, 2013). Majority of the farm families owns less than 1.2 acres of land and more of this land is allocated to cereal and cash crop cultivation on expense to pasture and fodder production (Koskey, 2008). Farmers integrate dairy with food and cash crop enterprises to maximize ever diminishing returns from declining farm sizes (KMDP, 2013). This reduction in land for fodder production has resulted in milk yields well below potential due to insufficient animal dry matter and nutrient intake (Techno Serve, 2008).

In small holder production system, cows are confined (zero-grazing) and fed through a cut-and-carry system in which inadequate feed materials and sometimes of unknown nutritional value are fed to the animals (Muriuki, 2011). The feed materials widely used in this system include Napier grass, maize crop residues and weeds and they are rarely supplemented with concentrates (proteins and minerals) (Techno Serve, 2008).

2.2.2 Poor breeding practices

Poor breeding practices constrain milk production because most of the smallholder dairy farmers use unproven bulls with low genetic value due to years of inbreeding (KNDMP, 2012). Artificial insemination (AI) is not readily available in some remote dairy farming areas (Muriuki, 2011). Some farmers have also stopped using AI regularly citing its prohibitive costs (KNDMP, 2012).

2.2.3 Animal diseases

Majority of animal diseases are tick borne diseases which have been reported to have impacted negatively dairy industry (BTA, 2010). These diseases include, East Coast Fever (ECF), Heart Water (Babesiosis) and Anaplasmosis (Ministry of Livestock, 2010). They result in high mortality rates in livestock and farmers incur high costs in their control through the use of acaricides and chemo-therapy (BTA, 2010).

Breakdown of management of communally owned dips following the withdrawal of government support in 1993 has largely contributed to increased incidences of tick borne diseases (KNDMP, 2012). Smallholder farmers now commonly use hand spraying which is less effective than plunge dip (KNSP, 2012). The number of communal dips has continued to decline and by the year 2010 it was estimated that less than 50% of the dips were operational (KNDMP, 2012). Other important diseases include black quarter, foot and mouth, mastitis, milk fever, lameness and parasitic diseases (internal and external) (BTA, 2010).

2.2.4 Market and infrastructure

Limited market and poor infrastructure imposes serious constraints in marketing of dairy produce and products (FAO, 2011). Majority of roads from rural areas to cooling centres are poor resulting to delay in milk deliveries and often high incidences of spillage and spoilage have been reported (NDA, 2005). Lack of cooling facilities, erratic payments to producers, low farm gate prices, and unreliable market outlets have been cited as constraints to dairy production (Muriuki, 2010).

2.2.5 Availability of credit

Majority of small holder dairy farmers' experience difficulties accessing credit due to stringent conditions and high interest rates (Ministry of Livestock, 2010). Some farmers find it difficult in repayment owing to uncertainties associated with farming enterprises (FAO, 2011). Such uncertainties include unpredictable weather conditions, livestock diseases and unreliable milk marketing channels.

2.2.6 Extensions services

Provision of government extensions services has declined considerably since the introduction of Structural Adjustment Programme (SAP) in the 1990s (AEASWW 2011). The private sector and dairy cooperatives societies have not been able to fill this gap (Techno-serve, 2005). As such, skills in fodder production and management (eg use of fertilizer, manure and chemicals) as well as testing of feeds to determine their nutritional value are sometimes lacking (KMDP, 2013). Extension budget together with number of staff has plummeted significantly over the last years and thus farmers not sufficiently advised (AEASWW 2011).

2.3 Common feed resources

Forages which include natural pastures and purposely grown fodders are the most important feed resources for livestock and include; Napier grass, sweet potato vines, green maize stalk, maize Stover, Rhodes grass and Kikuyu grass (Ministry of Livestock, 2010).

2.3.1 Napier grass *(Pennisetum purpureum)*

Napier grass is one of the most important fodder crop used by small holder dairy farmers in medium and high potential areas of Kenya in the cut and carry feeding system (Kariuki, 1998). Napier grass which is established through cuttings or splits is high yielding, palatable and highly nutritious when less than one metre tall. It is usually ready for harvesting three-four months after planting where harvesting can continue at an interval of six-eight weeks for three - five years (KARI, 2012).

At six-eight weeks, fresh napier has a CP, NDF, digestibility and metabolizable energy (MJ/Kg) of 8-12, 56-62, 54-60 and 7.5-9.5 respectively (Lukuyu *et al.*, 2013). Dry matter yields of Napier grass has been estimated at 23-28 tons per hectare per year (KARI, 2012).

Napier grass silage does not ferment well due to low levels of fermentable sugars (less than 50g/ kg) and requires addition of energy sources such as bran and molasses during ensiling to enhance fermentation and the quality of the silage (Mbuthia and Gachuiri, 2003).

2.3.2 Sweet potato vines *(Ipomoea batatas)*

Sweet potato vines are mainly used as dairy cattle feed in high potential areas in Kenya especially for the cut & carry feeding system (Kinyua, 2013). A sweet potato crop is established using storage roots, sprouts and cuttings and when fully established it spreads quickly forming a dense ground cover on the ground surface (Ondabu *et al.*, 2005).

Dual purpose cultivars of sweet potato vines (SPV) provides tubers for human consumption and vines for feeding livestock and thus suitable in areas where land is limiting (Kinyua, 2013). When harvested at age of 6-8 weeks the fresh vines had a CP, NDF, digestibility percentages and metabolizable energy (MJ/Kg) of 16, 46, 60 and 8.3 respectively on dry matter basis while silage (vines and roots) had a CP, NDF, digestibility percentages and metabolizable energy (MJ/Kg) of 16.2, 20, 69 and 13.3 respectively (Lukuyu *et al.*, 2013).

However, One of the limitations of SPV is high moisture content which is reported at 87 and 72 percent for fresh vines and silage (vines and roots), respectively. Controlling this moisture content when making silage is challenge to farmers (Lukuyu *et al.*, 2013). Yield and quality of forage vary with age of plant with dry matter yield of vines ranging from 4.3 to 6 tons DM/ ha (Ondabu *et al.*, 2005).

2.3.3 Maize (*Zea mays*)

Maize stalk have been reported as the best feed resource among other commonly used fodders as it contains sufficiently higher quantities of energy and is highly palatable (ICAR, 2012). Compared with other fodder crops, whole maize plant (inclusive of ear) produces better nutritional quality as well as higher biomass yields (KARI, 2012). Maize can be fed to cows as green chop or conserved as silage (Chaudhary *et al.*, 2012).

Maize harvested at silk, milk or dough stages of growth have a DM yield ranging between 20 – 30 % and therefore could be ensiled successfully at those growth stages (Chaudhary *et al.*, 2012). A range of various nutrient contents of maize harvested at soft or hard physiologic growth stages of growth have been reported by several researchers (Table 1)

Table 1: Nutrient content of maize harvested at soft or hard dough physiologic growth stages

Parameter	Unit	Content	Source
DM	% as fed	20-30	ICAR (2012)
CP	% DM	7- 8	Gupta *et al.*, (2005)
CF	% DM	23- 28.7	ICAR (2012)
NDF	% DM	64 -72.8	Chaudhary *et al.*, (2012)
ADF	% DM	40- 46.8	ICAR (2012)
Starch	% DM	18-20	ICAR (2012)
Ash	% DM	6-8.6	Chaudhary *et al.*, (2012)
IVDMD	% DM	52.8-65	Gupta *et al* .,(2005)

Maize has enough soluble sugars and nutrients and does not require a ferment starter like molasses to improve the process of fermentation and nutrient content (ICAR, 2012). In Kenya maize grains are mainly harvested at physiological maturity for human consumption and resultant fodder after grain harvest is used as livestock feed (KARI, 2012).

Unlike sorghum the quality of maize fodders materials deteriorates rapidly after grain harvest. Maize leaves and stems are soft and succulent at early growth stages of a plant but become hard and fibrous with maturity (ICAR, 2012). Shortly after grain physiological maturity, soluble solids in leaves and stems rapidly decrease and consequently lignin and xylan increases (Chaudhary *et al.,* 2012). The succulent fodder moisture content drops to 9-12 per cent as the fodder degenerates into dry stover (ICAR, 2012).

Maize stover which is commonly used as feed resource has low nutritional value containing 38, 26 and 19% cellulose, hemicellulose and lignin respectively (Woyengo *et al.,* 2004). Cellulose is digestible, hemicellulose is partially digestible and lignin is completely indigestible by ruminants (Chaudhary *et al.,* 2012).

2.3.4 Rhodes grass *(Chloris gayana)*

Rhodes grass is a perennial grass that once established, spreads quickly forming good ground cover, growing to a height of 0.5 metres tall (Lukuyu *et al.*, 2007). Rhodes grass is easily established using seeds at a rate of four to six Kilogrammes per hectare (KARI, 2012). It grows best in soils ranging from clays to sandy loams with pH range between 5.0 and 8.3 and annual rainfall of 24–40 inches (600–1000 mm) (Lukuyu *et al.*, 2007). Rhodes grass is highly palatable with crude protein content of about 8-11% (Ragoma, 2011). It is useful in cut and carry feeding systems, open grazing and is very suitable for making hay (Lukuyu *et al.*, 2007).

Ahmed *et al.,* (2014) compared yields and cutting regimes of Rhodes grass with forage sorghum cultivars as shown in Table 2. The first cut was done at 50 % flowering for both

Rhodes grass and sorghum cultivars while subsequently other cuttings were done at interval of 35 days. Yields of Rhodes grass increased while that of sorghum decreased with subsequent cuttings with Rhodes grass out yielding forage *Sorghum* cultivars over the two seasons.

Table 2: Fresh and dry matter yields (t/ha) of Rhodes grass and sorghum across four cuts

	Fresh matter				Dry matter			
Cuts	1	2	3	4	1	2	3	4
Rhodes grass	27.39	26.96	30.57	30.49	7.07	6.84	7.88	8.56
Sorghum	30.16	19.06	16.99	13.27	7.11	4.61	4.53	3.76

***Source:** Ahmed et al, 2014*

2.3.5 Kikuyu Grass *(Pennisetum Clandestinum)*

Kikuyu grass is a creeping sub-tropical grass that forms a dense turf and provides excellent forage for all grazing animals, beef, dairy, sheep, goat, horse and camel (Geoff, 2006). It is tolerant to heavy grazing and popularly used as pasture in dairy production (Marais, 2001; Donaldson, 2001).

Kikuyu grass originated from the highlands of East and Central Africa (i.e. Kenya, Ethiopia) (Geoff, 2006). It does well on deep, red loams of volcanic origin with high rainfall ranging from 1,000-1,600 mm annually and mild temperatures (DAFWA, 2006).

Common' kikuyu cultivar which is narrow-leafed does not produce seeds and thus are propagated using runners and usually forms a dense sward after establishment (Geoff, 2006). Under moisture stress, seedlings grows and establishes slowly but once established it is very tolerant to heavy grazing (Donaldson, 2001).

Young kikuyu grass has high crude protein levels of 18% - 20% and IVDMD of 70% but fall to 10–12% when mature (Geoff, 2006).Young grass is soft and palatable but this decline with maturity of crop (DAFWA, 2006). Presence of a legume in the sward increases utilization of the grass (Geoff, 2006).

Fertilization is recommended at every two months at 112 kg/ha of N after cutting or continuous grazing. Average yields of kikuyu grass harvested 4, 8 and 12 weeks after germination ranges between 829.92 to 1157.84, 1649.10 to 2110.76 and 2347.49 to 2401kgs/ hectare (DAFWA, 2006).

2.4 Sorghum *(Sorghum bicolor)*

There is need to identify types of fodder crops which can produce relatively high fodder and grain yields with fluctuating weather conditions (drought tolerance) from the limited available land (KMDP, 2013). Sorghum *(Sorghum bicolor)* could be the alternative to some previously grown fodder crops. Sorghum is increasingly being grown for livestock feeding and is becoming an important fodder crop in many regions of the world (Carmi *et al.*, 2005, Glamoclija *et al*., 2011). Sorghum has been widely accepted for grain and forage production mainly due to several factors such as resistance to drought, short maturity growth period, ratooning and tillering abilities (Cothren *et al*., 2000).

Generally, sorghum does well in hot, semi-arid tropical environments with 400 – 600 mm rainfall where the performance of other crops like maize is poor but it is also widely grown in high rainfall areas (Shewale, 2008). It grows in altitudes of up to 2300 m in the tropics and requires a warm temperature range of between 20–35 °C (Kimber, 2000). It grows on a wide range of soil types but well suited to soils with pH range of 5.0–8.5 (Shewale, 2008). Sorghum has been reported to produce reasonable amounts of grains, even in poor soils where many other crops like maize have failed (Yosef *et al*., 2009). As animal feed, sorghum plays a significant role in providing nutritious feed stuff to cattle both dairy and beef (Shewale, 2008). Dual purpose sorghum is capable of producing cereals for human food, and adequate fodder for livestock.

2.4.1 Origin and classification of sorghum

Sorghum is believed to have originated in equatorial Africa and domesticated in Ethiopia between 5000 and 7000 years ago before being distributed to other regions around the African continent along trade and shipping routes (Vavilov, 1951; Harlan, 1969). Classification of sorghum was done by Moench in 1794 who established the genus *Sorghum* and brought all the sorghums together under the name *Sorghum bicolor with* 52 species composed of 31 cultivated, 17 wild, and 4 weedy species (House, 1978; Clayton, 1961; Snowden, 1936).

Far much later, Harlan and de Wet De Wet combined the 52 species into a single species on the basis of the absence of genetic barriers among the *Sorghum* races (Shewale, 2008). In 1972, Harlan and de Wet used the criteria of inflorescence type and divided all the cultivated sorghum races into five races and fifteen sub races, under *S. bicolor* ssp. *Bicolor* (Shewale, 2008).

2.4.2 Plant morphology

Sorghum has three types of adventitious roots; those that develop from the basal node of the stem and occupy the soil depth of between 5 to15 cm; others which develop above the basal nodes and grow laterally to about a meter and then vertically; They act as nutrient feeders to plant and roots that arise from nodes above the ground and anchor the plant but not effective in water and nutrient uptake (Ashiono *et al.*, 1994). Stem varies in length from less than one to four meters and have nodes and internodes with the latter being shortest at the bottom of the plant and increases in length towards the top (Plessis,2008). The topmost internode bearing the panicle (earhead) is the peduncle which is longer than all the internodes and may be straight, wavy or curved (goose-necked) in shape (Shewale, 2008). Internodes are alternately grooved and from the grooves may arise axillary tillers (nodal tillers) while basal tillers arise from lower nodes (Ashiono *et al.,* 1994). Tillering is dependent on variety and environmental influence (Shewale, 2008). The white waxy coating on the surface of the internodes is called bloom and it is thought to impart drought tolerance to the plant (Ashiono *et al.,* 1994).

The number of leaves, length and width in well adapted plants may vary from 14 to 30, 0.3 to 1m and 0.5 to 15cm respectively (Plessis, (2008). The leaves are usually shorter and smaller towards the top (flag leaf). The leaf is divided into the leaf sheath and lamina. The stomata are found on both sides of the lamina. The midrib may be white, dull green, orange or brown. A white midrib is associated with the pithy stem, while a dull mid rib plant has juicy stem. Plants with a brown midrib will have lower lignin content in their stems and thus more easily digested by animals (Ouda *et al.,* 2005).

The leaf sheath of the flag leaf encloses the developing inflorescence at boot growth stage as primodia differentiates into floral parts and ultimately develops into an inflorescence (panicle); this will always have sessile (fertile) and pedicelled (male or sterile) spikelets and florets (Ashiono *et al* 1994). Flowers begin to open two to three days after the inflorescence is completely emerged from the boot (Ashiono *et al.,* 1994). Flowering takes place first in the sessile spikelets from top to the bottom of the inflorescence and takes about a week for the complete flowering of the inflorescence (Plessis, 2008) which is similarly followed by seed formation. Sorghum is self-pollinated but may often be cross pollinated at range of 0.6 to 50 % depending on variety; being high in loose panicle and low in compact panicle (Ashiono *et al.,* 2005).

Grain and dual purpose cultivars have compact heads while forage cultivars have loose heads (Ouma *et al.,* 2013). Grains are hardy, small in size, round or oval shaped and colour varies from white to brown and are said to be at physiological maturity when the attachment to the spikelet turns dark brown due to formation of a callus tissue (Plessis, 2008). Grains harvested at physiological maturity with moisture content of 25 to 30% are fully viable (Ashiono *et al.,* 2005).

2.4.3 Special inherent attributes of sorghum

Sorghum may have basic growth patterns of tillering and ratooning which are important growth attributes in influencing the growth, development and crop yields (ICRISAT, 2012). The tillering ability in sorghum has been reported to increase grain, forage and DM yields, as well as dry matter digestibility (Pholsen *et al.,* (1998). Generally, improved sorghum varieties compared with local landraces have higher grain and fodder yields and this was related to increased number of tillers (Tekle *et al*., 2014) Hammer (2006) and Kuraparthy *et al*., (2008) reported that tillering is an important trait that increases grain yield and biomass production. Tillering in sorghum is mainly dictated by genetics but could also be as a result of carbon supply demand balance of the plant (Hae *et al.*, 2010).

Another important inherent attribute of sorghum is its ‘stay green phenomenon’ where the plant maintains green stems and leaves for a long period after physiological maturity (delayed senescence) (Subudhi *et al.,* 2000). This phenomenon enables the plant to stay green long after the dry spell sets in and thus extending green chop feeding and conservation of forage materials when they are still green and fresh.

There is a relationship between stay green phenomenon and post-flowering drought tolerance which has been linked to quantitative trait loci (QTL) named as Stg2, Stg3 and StgB (Nagaraja *et al.,* 2014). Under terminal drought, stay green phenomenon associated with sorghum genotypes increased both grain and forage yield (Borrell *et al.,* (2000) and Kassahun *et al.*, (2009). Beside genetic factors, leaf senescence has also been associated with demand for nitrogen by plants during grain filling. This usually occurs when the plant begins breaking down chlorophyll and trans-locating N from its leaves to grain filling (Kassahun *et al.,* 2008).

Plant height is also another factor which has been reported to have an effect on grains and fodder yields (Peng *et al.,* 1999). Newbury (2003) reported that during the 1960s and 1970s, plant breeders substantially increased grain yield by developing dwarf varieties of cereal plants, a period known as the 'Green Revolution'. According to Quinby (1974), plant height in sorghum is mainly controlled by genetic factors both for shortness (dwarf) and tallness where tallness is being partially dominant to shortness. Accordingly, tall or zero-dwarf types grow to a height of three to four meters in height whereas dwarf plants may only attain a height one meter. Dwarf locus is generally associated with higher grain yield compared to tallness locus which has been associated with higher biomass yield (Peng *et al.,* 1999). Short type sorghum is early flowering unlike tall cultivars that enables plants to optimize their use of resources available in the environments before the onset of the stress syndrome (Laurie, 1997).

2.5 Development of improved sorghum varieties (IDPS) in Kenya

Research work on improvement of sorghum local landraces in Kenya was done in 1990s by International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) in collaboration with local research institutes. The objective was to develop sorghum varieties that are adaptable in semi-arid tropics with comparatively high grains and fodder yields. Local sorghum landraces in Kenya, Rwanda, Ethiopia, Burundi and Uganda were collected, and bred with improved varieties from ICRISAT (ICRISAT, 1992). As a result, several improved, grain, forage and dual purpose genotypes suitable for various regions of Kenya such as low altitude zones (Eastern, Coastal regions), medium altitude zones (Western Kenya) and high altitude zones (Rift Valley, Central Kenya) were developed (Ashiono *et al.,* 2005). Among the developed genotypes was a dual purpose sorghum variety, *Ikinyaruka* for high altitude zones which was released by KARI (Kenya gazette, 2006).

The variety was then introduced to farmers and became popular mainly because of its dual purpose characteristics and short growth period of five to five and a half months (Ouma *et al.,* 2013). This variety is multi tillering and regrows or ratoon after cutting. This makes the variety a suitable fodder crop in areas of land scarcity (Gachuki, 2007). Fresh fodder materials can be fed to cows in cut- and- carry production systems (zero grazing) or conserved as silage at various physiological stages of growth. For intensive land use, it can be intercropped with leguminous crop like beans for human consumption (Ashiono *et al*., 2005).

At physiological maturity, the variety has fresh fodder, dry matter and grain yields ranging from 57 to 63, 14 to 22 and 5 to 7 t/ha^{-}1 respectively (Gachuki *et al.,* 2007). According to Kitilit *et al*., (1998), the variety has gross energy ranging from17.33 to 20.5 MJ/kg, protein content of less than 8% and IVDMD of 58%,.

2.5.1 Nutrient composition of improved dual purpose sorghum (IDPS)

Nutrient composition of IDPS**,** variety, *Ikinyaruka* compared with other improved sorghum genotypes at physiological growth maturity is shown in Table 3. Compared with other sorghum genotypes, *Ikinyaruka* had the highest DM yields and CP within range of others. The CP content of most of these genotypes were too low (< 8.0%) required to sustain enough microorganisms population in the rumen.

Low protein content inhibits ingestion of sorghum resulting to low energy intake which might be too low for maintenance (Pretorius *et al.,* 1997). Forages containing < 8 % CP content show positive response with protein supplementation (Gregory & Felker, 1992).

Table 3: Nutrient content of sorghum genotypes (whole plant) harvested at physiological growth maturity

	Composition, %							
Genotype	DM	CP	NDF	ADF	ADL	EE	ASH	SOURCE
HC-136	-	5.38	65.53	36.54	4.32	-	5.86	Mahanta *et al*.,(2005)
Ikinyaruka	35.80	5.60	45.90	31.10	5.50	2.20	6.70	Kitilit *et al.,* (1998)
HD-15	-	8.20	66.18	35.35	3.83	-	9.10	Mahanta *et al*.,(2005)
E1291	34.53	5.50	45.80	27.00	5.90	2.30	6.50	Kitilit *et al.,* (1998)
J SEL-10	-	6.09	67.19	37.50	4.48	-	6.09	Mahanta *et al*.,(2005)
Lan-6	32.20	5.20	51.20	34.20	4.50	2.10	7.20	Kitilit *et al.,* (1998)
Lan-10	30.30	4.90	51.80	32.90	4.30	2.00	7.40	Kitilit *et al.,* (1998)

The sorghum variety under investigation (Ikinyaruka) had NDF content of (45.90 DM %) and this was relatively low compared with other genotypes

The NDF mainly consists of cell wall content and determines the fibres constituents in an ingredient (Pholsen *et al.,* 1998). This is because it estimates cellulose, hemicellulose, lignin, silica, tannins and cutin content of the feed material. Intake potential is predicted through NDF and its content is inversely correlated to digestibility and intake (Ruddell *et al.,* 2002). The higher the NDF value the poorer the quality of feedstuff as high NDF content affects digestibility and reduces feed intake (Pholsen *et al.,* 1998). As such, this variety ranks favorably compared to other fodders. The ADF and lignin content of Ikinyaruka was within range of the other genotypes. The ADF mainly approximates the crude lignin and cellulose fractions of plant material including silica and is negatively correlated with overall digestibility (Ruddell *et al.,* 2002). The prime factor influencing the digestibility is lignin which is indigestible plant structure (Hackmann *et al*., 2008).

2.5.2 Animal intake and performance

Animal intake is defined as the amount or quantity of feed voluntarily consumed by an animal and it is generally influenced by the palatability, availability, digestibility and the nutrient content of the feed (Jabbari *et al.,* 2011). Studies on animal intake of improved forage sorghum varieties have resulted in 20.5 - 23.5 and 10.4 – 13.5 g DM/kg LW in dairy cattle at early and later stages of growth respectively (Vignau- Loustau *et al.*, 2008). Slightly higher intake of 24.0 g DM/kg LW was reported by INRA (2007) on fodders harvested at early stages of growth.

Panwar *et al*., (2000) reported a wide variation of 1.60 to 3.20 kg/100 kg body weight in DMI depending upon the species of animals, physiological stages of maturity of plant. Emile *et al.*, (2005) observed that cows fed on sorghum silage harvested at hard dough stage had an intake comparable to maize silage harvested at the same stage of growth.

Fazaeli *et al.,* (2006) reported that the average daily weight gains were not significantly different in feedlot calves fed on maize or sorghum silage ensiled at hard dough stage. Jabbari *et al.*, (2011) reported that corn and sorghum silage both ensiled at late milk stage had similar effect of increasing average daily weight gain of calves.

Sorghums are known to contain prussic acid which is poisonous to animals. The acid concentration is high in young plants and freshly cut plants. Through selection and breeding acid concentration in this genotype has been reduced as compared with local landraces but it is always advisable to avoid rush grazing and also to wilt the fodder overnight before feeding. If planted during off season (no other cereals in the field) the sorghum is prone to bird damage and much more susceptible to pests and diseases attack. Stage at harvest affects fodder yield and nutritional quality and largely determines animal intake and animal performance (Vignau- Loustau *et al.,* 2008; Emile *et al.,* 2005; Jabbari *et al.*,2011). Effect of stage of growth on fodder yields, nutritional value and silage quality is discussed in subsequent topics

2.6 Effect of stage of growth on fodder yields, nutritional value and silage quality

Fodder yields, nutritional value and silage quality is dependent on many factors, the most important of which are forage species, stage of growth at harvest and soil fertility (Carmi et al.,2005) Among the given factors, stage of growth at harvest has been reported as the most important factor that affects fodder yields, nutritional value and silage quality (Ibrahim *et al.,* 2014; Sohail *et al.,* 2011).

2.6.1 Effect of stage of growth on fodder yields and nutritional quality

Stage of growth is remarkably one of the most important factors that dictate the nutritional quality of fodder (Fariani *et al.,* 1994). Yoana *et al.,* 2009 harvested hybrid forage sorghum at four stages of growth and obtained results as shown in Table 4.

Table 4: DM yields of hybrid forage sorghum at different growth stages

Maturity stage /Days after sowing)	Minimum	Maximum	Average
	DM tons/acre		
Flowering stage	3.99	4.42	4.15
Soft dough stage	3.72	6.16	5.64
Hard dough stage	3.92	6.65	5.83

Physiological maturity stage	7.26	7.40	7.36

Source: *Yoana et al., 2009*

They observed that maximum DM yields were obtained at maturity growth stage. Sorghum plant normally reach flowering (bloom), milk (soft dough), hard dough stage and physiological maturity growth stages at 84 -98, 97 -121, and 120 -148 and 147 -175 days after sowing respectively (Ashiono et *al.,* 1994).

Similarly, Sonon *et al*., (1990) reported effect of stage of growth at harvest on DM content and DM yields for six forage sorghum cultivars harvested at milk, hard dough and maturity stages as shown in Table 5.

They observed that dry matter content and yields increased as the crop advanced in age with highest dry matter content and yields being obtained at hard dough growth stage. They concluded that the most appropriate harvesting time for green feeding and silage making was at hard dough growth stage.

Table 5: DM content (%) and DM yields (t/acre) of six forage sorghum cultivars harvested at milk, hard dough and maturity stages of growth

	Dry matter content (%) and Dry matter (t/a^{-1}) yields					
	Milk stage		Hard dough stage		Maturity stage	
Cultivar	DM (%)	DM(t/a^{-1})	DM (%)	DM(t/a^{-1})	DM (%)	DM(t/a^{-1})
Agri Pro 1020-F	25.30	5.50	31.00	6.80	38.70	5.90
DeKalb FS5	24.80	5.40	30.20	7.90	34.00	7.20
DeKalb FS25E	25.10	7.50	27.10	8.20	29.90	6.20
Pioneer 843	31.40	5.10	40.00	8.00	38.80	5.60
Pioneer 931	32.70	8.30	34.30	6.30	38.30	6.10

Rox orange	22.00	4.50	27.20	5.70	33.00	5.40

***Source**: Sonon et al., 1990*

During this stage of growth they reported that the fibrous content in the fodder material was less compared to maturity growth stage and therefore more digestible.

However, protein content decreases as DM increases with advancing age of the crop as reported by Ibrahim *et al.*, 2012 (Table 6) for four forage sorghum cultivars harvested at milk stage (MS), hard dough (HD) and physiological maturity (PM) stages of growth (Ibrahim *et al.*, 2012). Cakmamakci et al., (1999) and Carmi et al.,(2005) also reported an increase in dry matter yields and a decrease in protein content for forage sorghum as the crop advanced to maturity. The NDF content has been reported to increase with age for forage sorghum variety (Pnina) from 628 to 645 (g kg¯1 DM) from milk stage to hard dough growth stage respectively (Carmi *et al.*, 2005).

Table 6: Dry matter yield and protein content of three forage sorghum cultivars harvested at milk (MS), hard dough (HD) and physiological maturity (PM) stages of growth

	Dry matter yield (t ha^{-1})			Protein content (gkg^{-1})		
Cultivar	MS	HD	PM	MS	DS	PM
E. Sumac	15.00	20.91	30.08	77.00	83.90	67.70
Leotti	15.64	19.74	29.99	70.60	84.30	64.90
Rox	16.67	21.78	29.63	87.00	65.70	64.10

***Source:** Ibrahim et al., 2012*

Increase of NDF and ADL content from 339 to 353 and 39.2 to 44.2 g/kg $^{-1}$ respectively from panicle emergence (PE) to milk (MS) growth stage of forage sorghum cultivar was also reported by Ibrahim *et al.,* (2012) Generally, fiber content (NDF, ADF and ADL) increases while quality and digestibility decreases as fodder advances in age (Ball *et al.*, 2001).

Heuve *et al.,* (2012) reported a decrease of IVDMD from 64.3 to 55% for forage sorghum with advancement of age from flowering to soft dough growth stage. Forage containing panicles with grains had higher IVDMD and more starch content and this counteracts the effect of high fibre as plants advances to maturity (Cakmakci *et al*., 1999;).

2.6.2 Effect of growth stage on the quality of sorghum silage

Several factors such as dry matter content, chopping length, crop digestibility, additives and stage of maturity at harvest determine silage quality (Ibrahim *et al.,* 2012). Among them, stage of maturity at harvest largely determines silage quality (Ball *et al.,* 2001).

Several studies have been done on the effect of growth stage on the quality of sorghum silage to determine the most appropriate time for ensiling (Ibrahim *et al.,* 2012) Researchers working on various varieties of forage sorghum have observed an increase in Dry Matter (DM) and a decrease in crude protein, ash, lipid and IVDMD with advancement of crop maturity at ensiling. In one such study, Sohail *et al.,* (2011) reported nutrient composition and silage characteristics of forage sorghum silage ensiled at booting (CS1), heading (CS2) and milk stage (CS3) as shown in Table 7.

Sorghum plant normally reach booting (CS1), heading (CS2) and milk stage (CS3) growth stages at 57- 75, 76-85, 97 – 121 days after sowing respectively (Ashiono *et al*.,1994). Dry Matter (DM), Neutral Detergent Fibre (NDF), Acid Detergent Fibre ADF and Acid Detergent Lignin ADL increased with the maturity of the crop at ensiling while Crude Protein (CP), Total Digestible Nutrients (TDN) and Metabolizable Energy (ME) decreased and concluded that the most appropriate time for harvesting the fodder materials for ensiling was milk growth stage (CS3) (Sohail *et al.,* 2011).

Carmi *et al.*, (2005) reported a decrease in IVDMD from 67.1 to 62.5 % of sorghum silage conserved at milk and hard dough stage respectively. Morphological and physiological changes as the crop advances in age determine both the nutritive value of the fodder and the silage quality (Miron *et al*., 2005). The cytoplasmic portion of the cell reduces and the quantity of protein, lipids, soluble carbohydrates and soluble minerals decrease with maturity of crop (Sohail *et al.,* 2011).

Table 7: Nutrient content (% DM) and silage characteristics of forage sorghum silage harvested at booting (CS1), heading (CS2) and milk stage (CS3) stages of growth

	Harvesting stages		
Nutrient content and silage characteristics	CS1	CS2	CS3
DM	15.78	19.60	29.79
CP	8.90	7.00	6.06
NDF	66.60	68.50	71.40
ADF	40.29	41.09	43.50
LDF	3.83	4.46	5.71
TDN	61.97	58.54	56.93
ME(Mcal/Kg)	2.31	2.16	2.08
WSC (%)	5.00	4.50	3.90
pH	4.30	4.23	4.10
Lactic acid (%)	3.00	5.83	6.80
NH_3-N (% of total N)	9.00	5.60	4.25

Source: *Sohail et al., (2011)*

Growth stage at harvest had an effect on pH and NH3-N (% of total N) of silage (Ibrahim *et al.,* 2013). Silage conserved from late milk stage to hard dough stage had optimum pH and

NH_3-N levels and therefore were the best harvesting stages for silage making (Carmi *et al.,* 2005; Sohail *et al.,* 2011).

Good silage has a pH of less than 5.0 and ammonia-N not exceeding 10 % of total nitrogen (Schukking, 1994). Higher ammonia-N exceeding 10% is an indication of extensive degradation of amino acid in the silo released through proteolysis (McDonald, 1981).

2.7 Effect of supplementing sorghum silage with protein on digestibility

Sorghum has low crude protein ranging from 5-7 % and as such, feeding sorghum as sole diet would not meet the protein requirements for a lactating cow (Kokkonen, 2000). Low protein content in feed results to reduced dry matter intake and low apparent digestibility and consequently gradual reduction in body weight (Preston and Levy, 1987).

Low protein content of sorghum therefore requires protein supplementation to increase both DM intake and microbial protein synthesis in the rumen (Huhtanen, 1998). Increased microbial protein synthesis leads to increased and balanced flow of amino acids in the rumen resulting to improved utilization of energy for more milk production (Tuori, 1992).

Protein rich fodders, some farm and agro-industrial by-products have been known to increase protein content in sorghum basal diets and thus improving feed intake and overall animal performance (Wekesa *et al.*, 2006*).* Mean silage DM intake and milk yield increased from 6.7 to 8.3 % and 10 to 14 litres/day respectively after supplementation with sweet potato vines (Ashiono *et al.,* (2003). Rams fed on sorghum stover supplemented with dried poultry litter increased feed intake, feed conversion ratio and gradually increased body weight gain (Abdulwaheed *et al.,* 2014).

Inclusion of up to 30% pyrethrum marc to sorghum silage in beef cattle feedlots improved dry matter intake and digestibility and produced better average carcass grades (Wekesa *et al.,* 2006*).* Friesian cows fed on fresh forage sorghum mixed with lablab legumes had higher roughage daily DM intake than cows fed on sorghum sole diet (Somkiert *et al.,* 2010).

Higher apparent digestibility was reported in steers fed on sorghum silage supplemented with cotton seed cake as compared to those fed singly on sorghum silage (Leupp *et al.,* 2006). Agro-industrial and farm by-products used as protein supplements include cotton seed cake, sunflower seed cake and pyrethrum marc. Table 8 shows protein content of some common agro-industrial by-products that can be used as protein supplements.

Cotton seed cake contains gossypol which is only tolerated by ruminants and thus not used to supplement non ruminants diets (Wekesa *et al.,* 2006. It has higher protein compared to sunflower and pyrethrum by - products and as such could readily supplement protein deficit (< 8) associated with sorghum feed materials. Sunflower meal has amino acid profile containing 1.14% lysine and 0.68% methionine but has relatively higher fiber content and therefore commonly used in formulating low cost diets (Yagoub and Talha, 2009).

Table 8: Agro-industrial by-products commonly used as protein supplements

Product	**CP (%DM)**	**Source**
Cotton seed cake	38.7 – 49.8	Wekesa *et al.*, 2006
Sunflower cake	29.3 -37.9	INRA (2012)
Cotton seed cake	39.8- 45.6	NRC (1984)
Sunflower cake	28.6 - 34.8	NRC (1984)
Cotton seed cake	41.3 – 44.6	FAO (2002)
Pymarc	20.2 - 23.5	Maina *et al.*, (2012)

Due to its relatively higher protein content, cotton seed cake may be best suited as protein supplement to raise low protein levels contained in sorghum diets.

CHAPTER 3.0: MATERIALS AND METHODS

3.1 Study site

The study was carried out at Kenya Agricultural and Livestock Research Organization (KALRO) station in Lanet, Nakuru County, Kenya. The station is located at latitude 0^o N 18^o S and longitude 36^oW 09^oE, 1920m Above Sea Level (ASL). The area has bimodal rainfall pattern with long rains being experienced from the month of March to June and short rains in the months of October, November and December. Annual rainfall is often below 800mm and unreliable both in quantity and distribution. Temperatures range between 8 to 30^oC. Soils are deep sandy loam with good water holding capacity with pH range of 5.5 to 6.5.

3.2 Experimental field

Experimental field was ploughed and hallowed prior to the onset of the rains. Large clods of soil were broken into finer particles using hoes and rakes to attain a fine tilth. Dual purpose sorghum seeds (*Ikinyaruka)* were sourced from the centre. The seeds were sown in a three block experimental plot containing eighteen plots using a completely randomized block design. Each block had six plots each measuring 5 x 4.8 m.

Six treatments based on the physiological stage of growth of the sorghum at harvest, were assigned randomly to plots within a block and replicated three times. The treatments were sorghum harvested stages and were specified as follows:

1., Bloom stage (PS1)

2., Soft dough stage (PS2)

3., Hard dough stage (PS3)

4., Physiological maturity stage (stalks with grains), (PS4)

5., Physiological maturity stage (stalks without grains) (PS5)

6., One month post grain harvest (PS6).

Shallow rows spaced at 60cm were dug and Di-Ammonium Phosphate (DAP) fertilizer applied in them at a rate of 80 kg/ha and thoroughly mixed with soil. Certified seeds were drilled in the rows at a rate of 6–8 kg/ha. and thinly covered with soil. Thinning was done when the crop was 20 cm high to achieve inter plant spacing of 20 cm. After thinning, CAN fertilizer at a rate of 80 kg/ha. was applied for top dressing. Weed control was done manually by use of hands during the growth period. Pesticides were used to control pests and diseases.

3.3 Harvesting, sampling and data collection

Growth stages were closely observed and number of days after sowing recorded prior to harvesting. PS1 was harvested at 87 days after sowing when estimated half the plants in the net plot had panicles bearing approximately 50% flowers. PS2 was harvested at 115 days after sowing when estimated half the plants in the net plot had panicles bearing approximately 50% soft milky grains. PS3 was harvested at 142 days after sowing when estimated half the plants in the net plot had panicles bearing approximately 50% hard grains. PS4 was harvested at 169 days after sowing when estimated half the plants in the net plot had panicles bearing approximately 50% mature grains. PS5 was harvested 169 days after grain harvest while PS6 was harvested 1month after grain harvest.

Harvesting and sampling was done on whole plant except at PS5 and PS6 where main stalk panicles were cut for grain harvesting. A net plot of 3.0 x 4.0 metres was measured within the six middle rows of each plot leaving 0.5 metres on either side of the row to cushion the border effect. Calibrated measuring iron bar was used to measure plant height in net plot while tillers were counted physically. Stalks in the net plots (treatments) were harvested (cut) at height of 3 inches above the ground at each growth stage and their fresh weight recorded. Harvested stalks were then chopped using a 'machete' into small irregular pieces of about 2-3cm in size and mixed thoroughly on a plastic sheet spread on the ground.

A sample of approximately 1kg sample of the chopped material was immediately placed in an air-dry oven for 3 days at a temperature of 60^0C for fresh fodder dry matter (DM) determination. Grains harvested at PS5 were sun dried to a moisture content of approximately 12.5% and their dry weight recorded. Samples of dried fresh stalk were ground in the Wiley Mill to pass a 1 mm screen for subsequent DM and nutrient analysis.

A 5kg portion of the fresh chopped fodder material was packed tightly in polythene bags measuring 36 by 64 cm and a thickness of 1000g. Packed bags were sealed tightly using sisal twine after expelling as much air as physically possible. Two silos were prepared for every replicate. The silos were then stored in a cool shaded, rodent free area. Each silo was opened after 90 days and checked for any deviation from the characteristic fermentation smell and any visibly spoiled materials were separated. A sample of 1kg was taken from each silo and placed in air-dry oven for 3 days at 60^0C. Samples of dried silage were ground in the Wiley Mill to pass a 1 mm screen for subsequent nutrient analysis.

After harvesting at PS1, farm yard manure was applied to harvested plot and ratoon crop was allowed to grow. The ratoon crop was later harvested at bloom stage and subjected to similar sampling and data collection procedure. Silage samples from PS3 and PS4 were mixed thoroughly with cotton seed cake (CSC) at levels of 0, 15, 20, 25, and 30 % for IVDMD determination.

3.3.1 Yields determination

Fresh fodder yield was obtained by weighing freshly harvested material from a net plot of 3.0 x 4.0 m^2 using field weighing balance and recording the yields. Area of the net plot was converted into hectare with corresponding plot yields converted to tons, followed by further calculations into yield t/ ha^{-1}. Similarly, dry matter (DM) and grain yield t/ ha^{-1} were calculated using net plot yields and DM content followed by conversions into yield t/ ha^{-1}.

3.3.2 Determination of Dry Matter (DM)

Determination of Dry Matter (DM) of fresh forage and silage was done by placing an air dried sample in an oven at 105^{0}C overnight, cooled in a desiccator and weight recorded. Weight loss for both forage and silage samples were calculated as percentage moisture of dried sample in accordance with the standard procedure 7.007 of the AOAC, (1998).

3.3.3 Crude protein and fibre determination

Determination of Nitrogen content was done using Kjeldahl procedure (AOAC,1990) while determination of neutral, acid detergent fibre and acid detergent lignin was done according to the sequential method of Van Soest *et al*. (1991) by adding α-amylase without sodium sulfite and using the ANKOM filter bag system with A220 fiber analyzer (ANKOM Technology, Fairport, NY), and expressed as exclusive residual ash.

3.3.4 Determination of in *vitro* dry matter digestibility (IVDMD)

IVDMD of air dried sorghum, sorghum silage and silage cotton seed cake (CSC) mixed samples were determined in accordance to the two - stage fermentation technique of Tilley and Terry (Tilley and Terry, 1963).

3.3.5 pH determination

Silage pH was determined by weighing 100g sample of silage and mixing with 1 litre of distilled water and then blended for 45 seconds. The mixture was left to stand for two hours in 1.5 litre glass jars covered with aluminum foil. The pH of silage extracts was determined using a grass electrode pH meter, standardized with buffer of pH 4 and 7. The blended material were squeezed through two layer of cheese cloth and centrifuged at 2500rpm for 30 minutes. A 20 ml aliquot was treated with 10ml of 20% sulphuric acid and frozen. This was later used for ammonia- nitrogen analysis

3.3.6 Ammonia nitrogen

Ammonia nitrogen was determined on a 5 ml sample aliquot alkalized with 40% sodium hydroxide by Kjeldal steam distillation and titration (AOAC, 1990). A sample of 5 ml was put into a Kjeldahl flask where 10mls of 40% sodium hydroxide was added and mixture was distilled. The distillate was then collected in 1 % boric acid and carefully titrated against 0.01 M hydrochloric acid.

3.4 Statistical analysis

One way analysis of variance was done using the GLM procedure of Statistical Analysis System (SAS) package version 9.1 (Statistical Software Version 9.1 [13]). Effects were considered significant in all statistical calculations if the P-values were < 0.05. Ranking of the means was done using Fisher's Least Significant Difference (LSD) test.

CHAPTER 4.0: RESULTS AND DISCUSSION

4.1 Tiller count and yields of IDPS at six different physiological growth stages

Tiller count and yields of improved dual purpose sorghum (IDPS) at six different physiological growth stages are shown in Table 9.

Table 9: Tiller count and yields of IDPS at six different physiological growth stages

Growth stage	Tillers/ plant	Fresh forage yield (t/ha^{-1})	DM content (gKg^{-1})	DM yield (t/ha^{-1})
Bloom stage (PS1)	2.60^{a}	41.39^{a}	210.00^{a}	8.69^{a}
Soft dough (PS2)	2.76^{a}	50.98^{b}	250.30^{b}	12.75^{b}
Hard dough stage (PS3)	3.86^{b}	59.61^{c}	273.00^{c}	16.27^{c}
Physiological grain maturity (stalks with grains) (PS4)	3.87^{b}	60.22^{c}	299.10^{c}	18.01^{c}
Physiological grain maturity (stalks without grains) (PS5)	3.89^{b}	58.96^{c}	289.00^{c}	17.04^{c}
1 month post grain harvest (PS6)	3.92^{b}	50.00^{b}	261.90^{b}	13.05^{b}
SEM	0.849	0.10	0.001	0.001
Stage effect	*	*	*	*

^{a,b,c},: *Means within the same column with different superscripts differ significantly (P< 0.05).*

**= Significant effect (P < 0.05). SEM = standard error of the mean.*

4.1.1 Tiller count

Tiller counts at six growth stages of IDPS are shown in Table 9. The number of tillers were significantly (P <0.05) affected by the stage of growth at harvest. Mean tiller counts per plant were 2.60, 2.76, 3.86, 3.87, 3.89 and 3.92 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively.

Tiller count in this study was in agreement with Tekle *et al*. (2014) who reported tiller counts of 3, 2.8, and 2.7 for three improved sorghum varieties at flowering growth stage. The number of tillers increased from PS2 to PS3 with no significant increase thereafter (Fig 1). Dual purpose sorghum varieties have inherent tillering ability and the numbers of tillers have been reported to increase with maturity (Gachuki *et al*., 2007).

Number of tillers did not increase after hard dough stage (PS2) and this might have been associated to non -production or dormancy of tillering buds as more energy could have been diverted to grain formation and filling. Tillering is a genetic trait that increases the number of tillers with maturity which consequently increases DM yield and as shown in Figure 1 (Kuraparthy *et al*., 2008) Tillering has also been reported to increase grain yield as well as biomass production (Hammer *et al*., 2006). Tillering is controlled by genetics or carbon supply demand (S/D) balance of the plant (Hae *et al*., 2010).

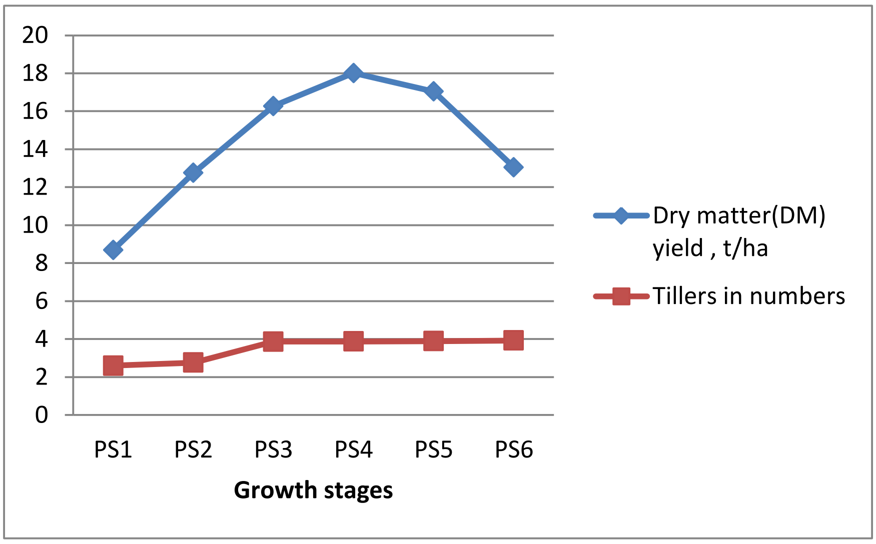

Figure 1: Effect of age on tiller counts and dry matter (DM) yield

4.1.2 Fresh fodder yield

The yields were significantly ($P<0.05$) affected by stage at harvest, increasing with advancing age of the plant (Table 9). Fresh fodder yields were 41.39, 50.98, 59.61, 60.22, 58.96 and 50.00 t ha^{-1} for PS1, PS2, PS3, PS4, PS5 and PS6 respectively. There was a significant increase from PS1 to PS2 and from PS2 to PS3 but it was not significant from PS4 and PS5 with reduction at PS6.

Highest fresh fodder yield were recorded at PS3, PS4 and PS5 respectively. This was in agreement with Ibrahim *et al.*, (2012) who reported increased fresh fodder yields of 60.87, 75.40, 84.69 and 91.90 t ha^{-1} for forage sorghum harvested at panicle emergence, milk, dough and physiological maturity stages of growth respectively.

Fresh fodder yields of 60 t ha-1 have been reported of dual purpose sorghum at physiological maturity stage in agreement with this study (Gachuki *et al*, 2007). Increased fresh fodder yields at PS3, PS4 and PS5 growth stages might be attributed to presence of mature tillers at later stages of maturity. Average number of tillers at those stages of growth ranged from three to four tillers per plant. The plants were also growing as evidenced by more accumulation of dry matter.

Plant height might also have contributed to increased fresh fodder yields. Maximum mean plant height of 132.2 cm was recorded at PS3, PS4 and PS5. Peng *et al.* (1999) reported that plant height has an effect on grains and biomass yields.

Increased forage yields at PS3, PS4 and PS5 might also be as a result of delayed leaf senescence. Delayed leaf senescence has been reported to increase both grain and fodder yield (Nagaraja *et al.*, 2014). Harvesting of grains from the main stalk at PS5 had less effect on fresh fodder yield. This might be attributed to minimal changes in leaf, stem, and head ratio after panicle harvest. Since growth of sorghum was rain fed, moisture stress with delayed harvesting at PS6 could have resulted to stunted growth of tillers, loss of leaves and weathering of main stalks. This might have caused a decline in fodder yields observed at PS6.

4.1.3 Dry matter (DM) content

DM contents of fresh forage and silage were significantly ($P<0.05$) affected by stage at harvest (Table 9). Dry matter contents were 210.00 250.30, 273.00, 299.10, 289.00 and 261.90 g Kg^{-1} for PS1, PS2, PS3, PS4, PS5 and PS6 respectively.

DM content was lowest at PS1, increased significantly at PS2 and was highest and similar at PS3, PS4 and PS5. DM increased with maturity of the crop in agreement with Carmi *et al* (2005) who reported increased DM content for three sorghum varieties of 269, 210 and 232gKg^{-1} at early milk stage respectively and 369, 271 and 264gKg^{-1} at dough stage respectively.

Increased DM with age could be attributed to increased accumulation of DM in the plant (leaves, stalks and tillers) with advancing maturity and could have reached maximum at PS3, PS4 and PS5. Ability of forage crop to accumulate DM content is important as this is required to maintain and to sustain productions in ruminants (Yoana *et al.*, 2009). Appropriate DM content of more than 250 g kg^{-1} is required in the forage for successful field ensiling (Carmi *et al.*, 2005).

Reduced DM content at PS5 might be attributed to the harvested grain having had higher DM than the forage. PS6 growth stage coincided with dry month of January and moisture stress resulted to stunted growth of tillers, loss of leaves and weathering of main stalks. This might have caused decline in DM content observed at PS6.

4.1.4 Dry matter yields

Yields were significantly (P<0.05) different for the various stages of growth and increased with age (Table 9). The DM yields for PS1, PS2, PS3, PS4, PS5 and PS6 stages were 8.69, 12.75, 16.27, 18.01, 17.04, and 13.05 t/ ha, respectively. Highest DM yields of 16.27, 18.01 and 17.04 t/ ha^{-1} were obtained at PS3, PS4 and PS5 growth stages respectively and coincided with the highest DM content of the crop and the highest fresh forage yield.

Increase in DM yields of sorghum with age was in agreement with Yoana *et al.*, (2009) who reported average DM yields of 4.42, 6.16, 6.65 and 7.40 ton/acre at flowering, soft dough, hard dough and maturity stages of growth respectively. Similarly, Ibrahim *et al.*, (2012) reported an increase in DM yields from 18.75 to 20.15 t ha^{-1}at panicle emergence to physiological maturity stages of growth. DM accumulation with increased proportions of stems, panicles and tillers might have contributed to increased DM yield at PS3, PS4 and PS5 growth stages.

4.2 Grain yields

Grain yield obtained at physiological maturity stage (PS4) was 3.02 t/ ha^{-1} which was comparable to yields obtained by Ouma *et al*., (2013) of 3.5 and 3.0 t/ ha^{-1} at Lanet and Koibatek experimental sites respectively.

4.3.1 Crude protein (CP)

Crude protein content at the six growth stages are shown in Table 10. The values for PS1, PS2, PS3, PS4, PS5 and PS6 stages were 8.60, 7.98, 7.96, 7.61, 6.77 and 6.72 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively. Crude protein contents was different (P<0.05) for different stages of growth and decreased with age. Highest CP content of 8.60 was obtained at PS1 then declined to less than 7.00 after grain harvest.

4.3 Nutrient content of IDPS at six different physiological growth stages

Nutrient content of IDPS at six different physiological growth stages is shown in Table 10

Table 10: **Nutrient content of IDPS at six different physiological growth stages**

Growth stages	%	% DM					
	DM	CP	NDF	ADF	ADL	ASH	IVDMD
Bloom stage (PSI)	21.00^{a}	8.60^{d}	54.40^{a}	27.93^{a}	3.44^{a}	8.52^{d}	60.72^{c}
Soft dough (PS2)	25.03^{b}	7.98^{c}	60.80^{b}	35.96^{b}	5.03^{b}	8.50^{d}	60.12^{c}
Hard dough (PS3)	27.30^{c}	7.96^{c}	65.71^{c}	41.98^{c}	7.38^{c}	7.90^{c}	54.73^{b}
Physiological grain maturity (stalks with grains) (PS4)	29.91^{c}	7.61^{b}	65.93^{c}	41.97^{c}	7.39^{c}	7.09^{c}	53.82^{b}
Physiological grain maturity (stalks without grains) (PS5)	28.90^{c}	6.77^{a}	66.73^{c}	42.04^{c}	7.42^{c}	6.48^{b}	53.56^{b}
1 month post grain harvest (PS6)	26.19^{b}	6.72^{a}	70.30^{d}	46.05^{d}	8.30^{d}	6.21^{a}	45.75^{a}
SEM	0.63	0.31	1.42	1.22	0.32	0.24	0.66
Stage effect	*	*	*	*	*	*	*

*a,b,c,: Means in the same column followed by different superscripts differ significantly at $P < 0.05$. *= Significant effect (at $P < 0.05$) of growth stage. NS = Lack of significant effect of growth stage, at $P < 0.05$. SEM = standard error of the mean.*

Decrease of CP with plant age in sorghum was in agreement with Ibrahim *et al.,* (2012) who reported a decrease from 9.2 from panicle emergence to 5.7 at physiological maturity growth stage. Similarly, Sohail *et al.*, (2012) reported a decrease from 7.00 to 6.00 from heading to milk growth stages respectively.

Decreased CP percentages with advancing maturity might be attributed to decreased proportion of leaves to stem with maturity. Leaves contain high contents of CP and are the main contributor of protein in the forage (Cakmakci *et al*., 1999). Decline in CP at PS5 could be attributed to loss of some crude protein that was contained in grains prior to harvesting. Crude protein (CP) content decrease as dry matter (DM) yield increases with advancing age of the crop (Figure 2)

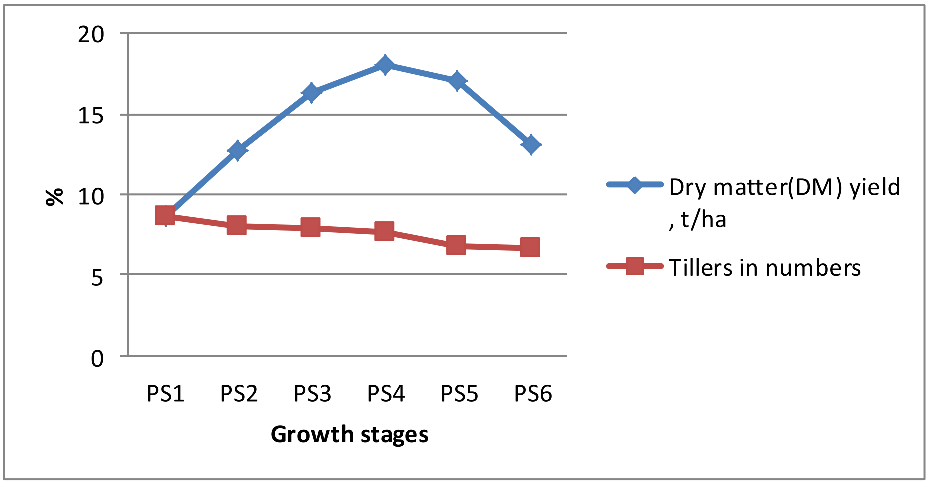

Figure 2: Effect of age on crude protein (CP) compared to dry matter (DM) yield

However, it was noted that protein of IDPS was inadequate to meet the thresh hold for optimal ruminal function for cellulolytic bacterial activity (Hennessy, 1980). Protein rich fodder crops, legumes and some agro- by products should be used as protein supplements in sorghum basal diets. Sweet potato vines have been reported to improve CP content in sorghum based diets (Ashiono *et al*., 2012). Supplementing sorghum with protein induced higher daily dry matter intake, increased digestibility and consequently increases milk production (Jumaa *et al*., 2014).

4.3.2 NDF, ADF and ADL

NDF, ADF and ADL content at the six growth stages are shown in Table 10. NDF values were, 54.4, 60.8, 65.71, 65.93, 66.73 and 70.3 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively. ADF values were, 27.93, 35.96, 41.98, 41.97, 42.04 and 46.05 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively while ADL was 3.44, 5.03, 7.38, 7.39, 7.42, and 8.3 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively. NDF, ADF and ADL content were different ($P<0.05$) for different stages of growth and the trend increased with age.

Increase in NDF was in agreement with Sohail *et al*., (2011) who reported an increase from 68.40, 69.01 to 71.70 of forage sorghum from pre-heading, boot and milk growth stages respectively. The ADF content increased from 339 to 353 g/kg $^{-1}$ for sorghum cultivar *Nes* from panicle emergence to milk growth stage and ADL content from 39.2 to 44.2 g/kg $^{-1}$ for sorghum cultivar *Nes* from panicle emergence to milk growth stage respectively (Ibrahim *et al*., 2012). Ashiono *et al., (*2005) reported ADF of 43.7 while Heuze *et al.*, (2012) reported ADL of 7.4 at physiological maturity growth stages. Figure 3 below shows correlation between NDF, ADF, ADL contents and DM yield as the crop advances age.

Synthesis and accumulation of fibre content as plant matured could be attributed to formation and thickening of secondary cell walls and could also be as a result of increase in cell wall content, lignification of stem and leaves as cellulose increases more than hemicellulose content (Ibrahim *et al*,2012). NDF, ADF and ADL content at PS3, PS4 and PS5 were similar. This might be attributed to the emergence of tillers which ameliorated the fibre content even with increase in age through the three growth phases.

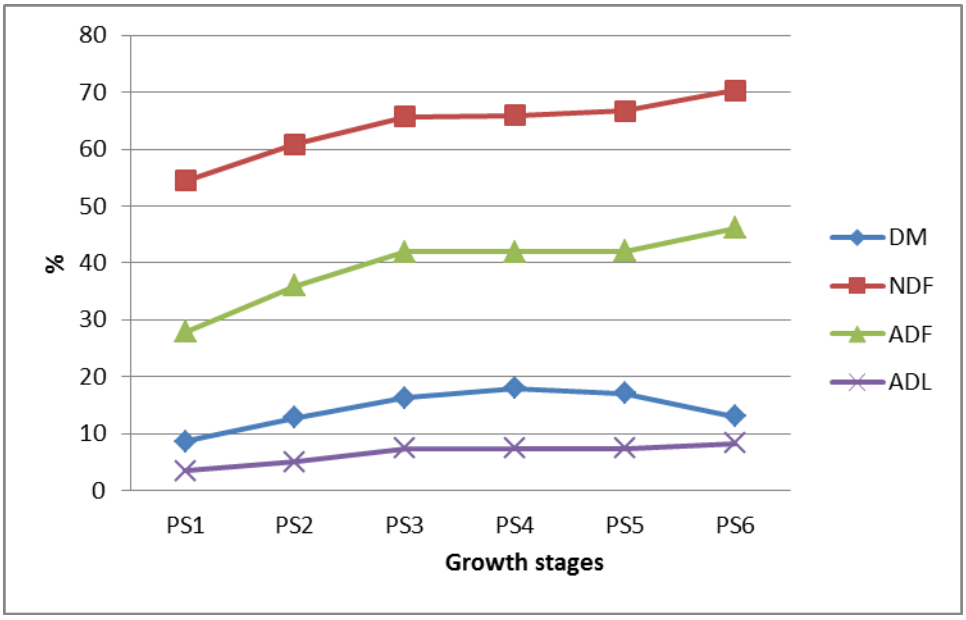

Figure 3: Correlation between NDF, ADF, ADL contents and DM yield

4.3.3 Ash

The ash content at the six growth stages are shown in Table 10. The values for PS1, PS2, PS3, PS4, PS5 and PS6 stages were 8.52, 8.5, 7.9, 7.09, 6.48 and 6.21 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively. The content were different ($P<0.05$) for different stages of growth and the trend decreased with age. Highest ash content was at PS1, PS2 and PS3 and could be attributed to rapid uptake of minerals during those early stages of growth.

According to Warrick *et al.*, (2011), about 80% of mineral uptake by plants takes place by flowering stage and beyond this stage the uptake reduces drastically. The absorbed minerals are used at later stages of plant growth for various physiological processes taking place within the plant like grain formation. This may explain the decline in ash content at later stages of plant growth.

4.3.4 *In vitro* dry matter digestibility (IVDMD)

The IVDMD of IDPS fodder harvested at six growth stages are shown in Table 10. The values were 60.72, 60.12, 54.73, 53.82, 53.56 and 45.75 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively. The values were differed ($P<0.05$) for various stages of growth and the decreased with age. IVDMD decreased as dry matter (DM) yield and NDF content increased with advancing age of the crop as shown in Figure 4.

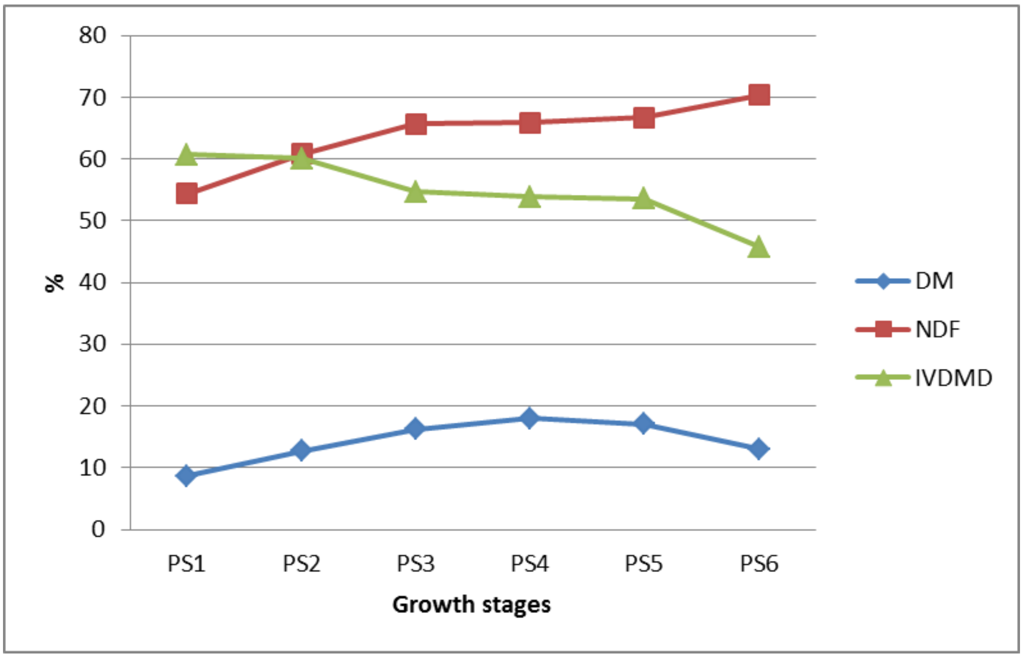

Figure 4: Effect of age on IVDMD compared to dry matter (DM) yield and NDF content

IVDMD of PS2 and PS3 (60.12 and 54.73 respectively) obtained in this study was comparable with Heuve *et* al (2012) findings of 60.30 and 55.00 at milk and dough growth stage respectively. Decrease in IVDMD from PS1 to PS6 growth stages could be attributed to lignification of leaves and stalks with increased cell wall contents with maturity. Increase in proportion of stems and consequent decrease of proportion of leaves with maturity could also be attributed to decline in IVDMD at later stages of growth. Soluble solids rapidly decrease and lignin and xylan increase shortly after physiological maturity (Chaudhary *et al.*, 2012).

High protein content at early growth stages could have enhanced the activities of rumen microbes and thus increasing IVDMD. Similarities in IVDMD at PS3, PS4 and PS5 could be attributed to similarities of their tillers which were at same growth stages (soft and hard dough stages). IVDMD levels obtained at all growth stages (PS1 to PS6) were above the 45%. This is the minimum acceptable level for sustaining performance of cattle in the tropics (Youngquist *et al.*, 1990)

In conclusion, the DM yield of IDPS increased while the quality deteriorated with advancing age. The balance between the two is mainly achieved at age between PS3 to PS4 days as shown in Figure 3. Therefore, IDPS should be utilized as livestock feed (fresh fodder feeding or silage making) within this period which is mainly within hard dough stage to physiological grain maturity growth stages.

4.4 Nutritional value of IDPS silage at different physiological growth stages.

4.4.1 Dry matter

Dry matter content of IDPS silage at different growth stages is shown in Table 11. The contents were 22.00, 26.00, 29.60, 30.60, 29.50 and 27.10 for PS1, PS2, PS3, PS4, PS5 and PS6, respectively. Silage DM was higher than fresh fodder DM. Under normal silage making, there is wilting and loss of effluent from the forage material in the silo thus higher silage DM compared to fresh fodder material. According to Castle and Watson (1973), minimum DM content for suitable ensilage condition is 247 g kg-1 and below this level may result in excessive effluent and high chance of spoilage and dry matter loss from the silo. Minimal content of 50 g kg−1 DM of water-soluble carbohydrate (WSC) is also required for successful ensiling.

Table 11: Nutritional content of IDPS silage at six different physiological growth stages

Growth stages	%	% DM					
	DM	CP	NDF	ADF	ADL	ASH	IVDMD
Bloom stage (PSI)	22.00^{a}	7.72^{d}	56.50^{a}	29.46^{a}	3.54^{a}	8.58^{c}	56.06^{d}
Soft dough (PS2)	26.00^{b}	7.01^{c}	62.80^{b}	36.49^{b}	5.50^{b}	8.56^{c}	53.70^{c}
Hard dough (PS3)	29.60^{c}	7.00^{b}	65.97^{c}	41.82^{c}	7.35^{c}	7.94^{b}	52.47^{b}
Physiological grain maturity (stalks with grains) (PS4)	30.60^{c}	7.00^{b}	66.24^{c}	41.95^{c}	7.47^{c}	7.90^{b}	52.32^{b}
Physiological grain maturity (stalks without grains) (PS5)	29.50^{c}	6.71^{a}	67.20^{c}	42.76^{c}	7.52^{c}	6.58^{a}	52.21^{b}
1 month post grain harvest (PS6)	27.10^{b}	6.68^{a}	70.76^{d}	46.37^{d}	8.50^{d}	6.33^{a}	42.52^{a}
SEM	1.93	0.20	1.42	1.23	0.24	0.24	0.73
Stage effect	*	*		*	*	*	*

*a,b,c,: Means in the same column followed by different superscripts differ significantly at P<. 0.05. *= Significant effect (at P < 0.05). NS = Lack of significant effect of growth stage, at P < 0.05. SEM = standard error of the mean*

4.4.2 Crude protein (CP)

Crude protein content of IDPS silage at six growth stages is shown in Table 11. The content for PS1, PS2, PS3, PS4, PS5 and PS6 stages was 7.72, 7.01, 7.00, 7.00, 6.71, and 6.68 respectively and decreased with the advancing age of the crop. CP values of silages were lower than fresh fodder material in agreement with Kung and Shaver (2001) who attributed the loss to CP seepage in the silo. Loss of CP could also be attributed to denaturing of some amino acids by intensive heat produced in the silo while others could have been lost through deamination process (Kung and Muck, 1997). In the silo large proteins fractions are broken by proteolytic enzymes into simple nitrogenous compounds such as peptides, amino acids and ammonia (Mciteka, 2008).

Crude protein of the silage at all growth stages was averaged 7% which is the critical threshold level for maintenance of ruminants and thus for increased milk production requires protein supplementation (Gregory and Felker, 1992). Supplementation with protein rich fodder crops, legumes and some agro- by products is recommended for sorghum silage basal diet in agreement with (Ashiono *et al.*, (2012). Supplementation induces ingestion of silage which results to high energy intake (Gregory & Felker, 1992).

4.4.3 NDF, ADF and ADL

Fibre components of the silage namely, NDF, ADF and ADL at six growth stages are shown in Table 11. NDF contents were, 56.50, 62.80, 65.97, 66.24, 67.20 and 70.76 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively. ADF percentages were, 29.46, 36.49, 41.82, 41.95, 42.76, and 46. 37 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively while ADL percentages were 3.54, 5.50, 7.35, 7.47, 7.52, and 8.50 for PS1, PS2, PS3, PS4, PS5 and PS6 respectively. Fibre content was lower for silages made at younger stages of growth (PS1, PS2 and PS3).

The values were not different (P>0.05) for fibre content for silage and fresh fodder materials. Mciteka (2008) reported that fermentation processes, such as enzymatic and bacterial breakdown of the forage has less or no effect on fibre content and usually fibre fraction of the silage remains same as the fresh fodder material.

4.4.4 Ash

Ash contents for IDPS silage ensiled at six growth stages are shown in Table 11. The percentages for PS1, PS2, PS3, PS4, PS5 and PS6 stages were 8.58, 8.56, 7.94, 7.90, 6.58 and 6.33 respectively. Ash content was higher for silages made at younger stages of growth (PS1, PS2 and PS3). The values were not different (P>0.05) for ash content for silage and fresh fodder materials. No significant difference (P>0.05) was observed in ash content for silage and fresh fodder materials. Silage obtained at all six growth stages had green colour, pleasant smell and good texture and fitted the physical description of a good silage according to Kung and Shaver (2001.

4.4.5 *In vitro* dry matter digestibility (IVDMD)

IVDMD for IDPS silage at six growth stages are shown in Table 11. IVDMD for silage at PS1, PS2, PS3, PS4, PS5 and PS6 stages were 56.06, 53.70, 52.47, 52.32, 52.21, and 42.52 and was higher for silages made at younger stages of growth (PS1, PS2 and PS3). There was no apparent difference in IVDMD of the silage compared with the fresh fodder as there chemical composition was similar.

4.4.6 pH and Ammonia-N

Mean pH and NH_3-N values for IDPS silage at six growth stages are shown in Table 12. pH is an estimate of the level of acidity within silage and provides an indication of the level of preservation of the silage (Kung and Shaver, 2001). Amount of NH_3-N present in silages is a reliable indicator of the extent of proteolytic clostridial activity. Total nitrogen in the form of ammonia is an indication of extensive degradation of amino acid released through proteolysis (McDonald, 1991).

The pH values obtained at PS2, PS3, PS4, PS5 were between 3.8- 4.2 while mean NH_3-N values for PS1, PS2, PS3, PS4, PS5 and PS6 stages were 6.30, 5.90, 5.20, 4.90, 5.20 respectively. Well preserved silage should have a pH between 3.8 – 4.2 and below this range it is considered to be very acidic, while above this range the silage is poorly preserved (Catchpole & Henzel, (1971).

Kung and Shaver (2001) classified silage quality as follows; pH < 4.0 (excellent), between 4.1 and 4.3 (good), between 4.4- 5.0 (average) and > 5.0 (bad). Based on this classification, the silage obtained at all the six harvesting stages was of good quality. This may be an indicator that IDPS fodder material contains adequate levels of water-soluble carbohydrates (WSC) needed for adequate fermentation and is of low buffering capacity which readily accepts changes in pH (Kung and Shaver, 2001).

Table 12: Mean pH and NH_3-N (%Total - N) of IDPS silage at six stages of growth

Growth stage	pH	NH_3N content (% of total N)
Bloom stage (PSI)	4.39^c	6.30^c
Soft dough (PS2)	3.88^a	5.90^c
Hard dough (PS3)	3.85^a	5.20^b
Physiological grain maturity (stalks with grains) (PS4)	3.86^a	4.90^c
Physiological grain maturity (stalks without grains) (PS5)	4.18^b	5.20^b
1 month post grain harvest (PS6)	4.38^c	5.50^c
SEM	0.269	0.07
Stage effect	*	*

*a,b,c,: Means in the same column followed by different superscripts differ significantly at P < 0.05 *= Significant effect (P < 0.05). SEM = standard error of the mean.*

The NH_3-N content decreased with age in agreement with Garcia *et al*., (1989) who reported that increase in the concentration of NH_3-N was inversely proportional to the DM content of the fodder ensiled. Low NH_3-N at PS3 and PS4 therefore might be attributed to high DM content of the silage at those later stages of growth. Ammonia-N in silage is generally expressed as a percentage of total nitrogen which should not exceed 10 % of total nitrogen in good silage (Schukking, 1994). Maximum total nitrogen % obtained in this study was below 6.3 indicating that good quality silage was obtained at all the six stages of harvesting.

4.5 Practical implication of growth stages on utilization of IDPS.

Farmers who intend to utilize the fodder material when at optimum yields and balanced nutrient combinations for fresh fodder feeding and silage making should wait until the crop is at hard dough stage (PS3). At this growth stage the fodder material is ensiled with ease as it contains moderate moisture content and appropriate DM content.

In areas where land sizes are small and limited spaces are available for pasture and fodder production PS5 offers the best harvesting stage. At this growth stage grains are harvested for human consumption while fodder materials are fed to livestock as green chop or conserved as silage.

In most cases farmers may not be able to utilize post grain harvest fodder material at once and intends to use it gradually for a considerable period of time. Depending on prevailing weather conditions (wet or dry), IDPS unlike maize fodder materials (stover) after grain harvest can remain standing in the field for a reasonably longer period of time while still green and fresh with minimal changes in yields and nutrients content (Gachuki *et al.,* 2007).

In this study, one month post grain harvest (PS6) coincided with dry month of January which stunted tillers growth resulting in decline in fodder yields and nutrient content. However, the fodder materials remained largely fresh and green at harvest due to presence of relatively younger tillers.

Fodder material after grain harvest (PS5) was still appropriate for field ensiling as it had DM content of above 250 g kg^{-1} (Carmi *et al*, 2005). IVDMD at this growth stage was above 50 % and therefore far above the acceptable levels of 45% recommended by Youngquist *et al.,* (1990).

Soft dough stage (PS2) offered good harvesting stage for green chop feeding especially in cut and carry feeding system however, the DM and nutrient accumulation in leaves and stalk might not have reached maximum levels. Moisture content in leaves, stalks and grains might be relatively high and silage making might not be done with ease. Ensiling at this growth stage may result to some nutrient being lost in the silo through seepage of excess moisture. Fodder material at bloom stage (PS1) had not accumulated enough DM content required to sustain animal growth and productivity. The fodder materials are watery, tender and less fibrous and therefore might not be suitable for use as livestock basal diet.

4.6 Plant height, tiller count, fodder and DM yields of PS1 ratoon crop.

Plant height, tiller count, fodder and DM yields of PS1 ratoon crop are shown in Table 13. Both parent and ratoon crop were harvested at the same age. The parent crop was taller ($P<0.05$) than the ratoon crop while the latter had more tillers.

Table 13: Plant height, tiller count, fodder and DM yields of IDPS ratoon crop at PS1 growth stage

	Plant height (cm)	Tillers/ plant	Fresh forage yield (t/ha^{-1})	DM yield (t/ha^{-1})
PS1- Parent crop	130.36^{b}	2.6^{a}	41.39^{a}	9.10^{a}
PS1- Ratoon crop	100.78^{a}	5.18^{b}	47.71^{b}	9.54^{b}
SEM	3.980	0.142	0.231	0.114
Stage effect	*	*	*	*

*^{ab}: Means in the same column followed by different superscripts differ significantly at $P < 0.05$. *= Significant effect (at $P < 0.05$) of growth stage. SEM = standard error of the mean.*

Ratoon crop had higher DM yield than parent crop in agreement with Irungu *et al.,* (1993) who reported higher DM yield from 1st ratoon crop. The higher fresh forage and DM yield from the 1st ratoon crop could be attributed to increased tillering after 1st cutting.

Cutting of main stem stimulates emergence of basal nodes (Ashiono *et al.,* 2005) while application of farm yard manure after cutting enhances tiller emergency from the basal nodes (Gachuki *et al.,* 2007).

4.7 Nutrient composition of IDPS ratoon crop at PS1 growth stage

Nutrient composition of IDPS ratoon crop at PS1 growth stage is shown in Table 14. The values were not different (P>0.05) for nutrient content on IDPS parent and ratoon crop at bloom growth stage (PS1).for ash content for silage and parent fodder materials.

Nutrient content of dual purpose sorghum 1st ratoon crop and parent crop has been reported to be similar but declines steadily afterwards with subsequent ratoon crops (Irungu *et al.*, 1993). Similar reports on dual purpose sorghum have been reported at KARI Lanet experimental field trials (KARI- Lanet 2012).

Similarly, Pholsen *et al.,* (1998) reported CP, NDF and ADF of sorghum cultivar UT786-B of 4.84, 69.04 and 36.93 respectively harvested 90 days after emergency and 4.54, 62.74 and 34.49 respectively of its ratoon crop harvested 70 days after 1st harvesting. They reported lower CP, NDF and ADF contents on ratoon crop than the parent crop. They recommended for protein supplementation when both the ratoon and the parent crop is used as the basal diet.

Table 14: Nutrient content of IDPS ratoon crop at PS1 growth stage

Growth stages	% chemical composition					
	CP	NDF	ADF	ADL	ASH	IVDMD
(PS1) parent crop	8.60	54.40	27.93	3.44	8.52	60.72
(PS1) Ratoon	8.48	53.95	27.90	3.33	8.98	60.69
SEM	0.209	0.741	0.598	0.035	0.035	0.209
Ratoon effect	NS	NS	NS	NS	NS	NS

NS = Lack of significant effect, SEM = standard error of the mean.

Ratoon crop harvested at bloom stage (PS1) had not accumulated DM and nutrients and should be allowed to grow beyond this growth stage and preferably to harvest at hard dough stage to balance DM yield and quality.

4.7 Effect of cotton seed cake (CSC) supplementation on IVDMD of IDPS silage

IVDMD increased significantly ($P<0.05$) on addition of varying levels of cotton seed cake for both PS3 and PS4 growth stages (Table 15). The IVDMD values for PS3 and PS5 were 52.47, 54.31, 57.01, 58.29, 60.07 and 52.21, 52.66, 54.66, 55.71, 57.72 respectively at supplementation levels of 0, 15, 20, 25 and 30. Increase in IVDMD at PS3 was higher than at PS5 at every supplementation level. The digestibility increased gradually as the level of cotton seed cake (CSC) increased and the response was higher at PS3 compared to PS5 as shown in Figure 5.

Table 15: IVDMD of two growth stages IDPS silage at varying levels of cotton seed cake (CSC) supplementation

% CSC	% IVDMD	
	PS3	PS5
0	52.47 ^{a}	52.21^{a}
15	54.31 ^{b}	52.66 ^{a}
20	57.01 ^{c}	54.66 ^{b}
25	58.29^{c}	55.71^{c}
30	60.07^{d}	57.72^{c}
SEM	0.220	1.987
F- Pr	*	*

*a,b,c,: Means in the same row followed by different superscripts differ significantly (P < 0.05). *= Significant effect (at P < 0.05.) SEM = standard error of the mean.*

Increased digestibility with corresponding increase in cotton seed cake (CSC) could be attributed to increased nitrogen (N) supply to microorganisms in the rumen. The microorganisms require N supply for their growth and multiplication and in the process enhances breakdown of the feed materials in the rumen to release various nutrient components that are needed by the animal for growth, reproduction and production.

Sorghum has high levels of water-soluble carbohydrates (WSC) which might be the source energy needed to capture N from CSC (Kitilit *et al* 1998). According to Woyengo *et al.* (2004) capturing of N requires a synchronized and sufficient supply of energy. Amount of fermentable organic matter in the diet determines the level of energy supplied to microorganisms and hence digestion in the rumen (Ørskov & Grubb, 1978).

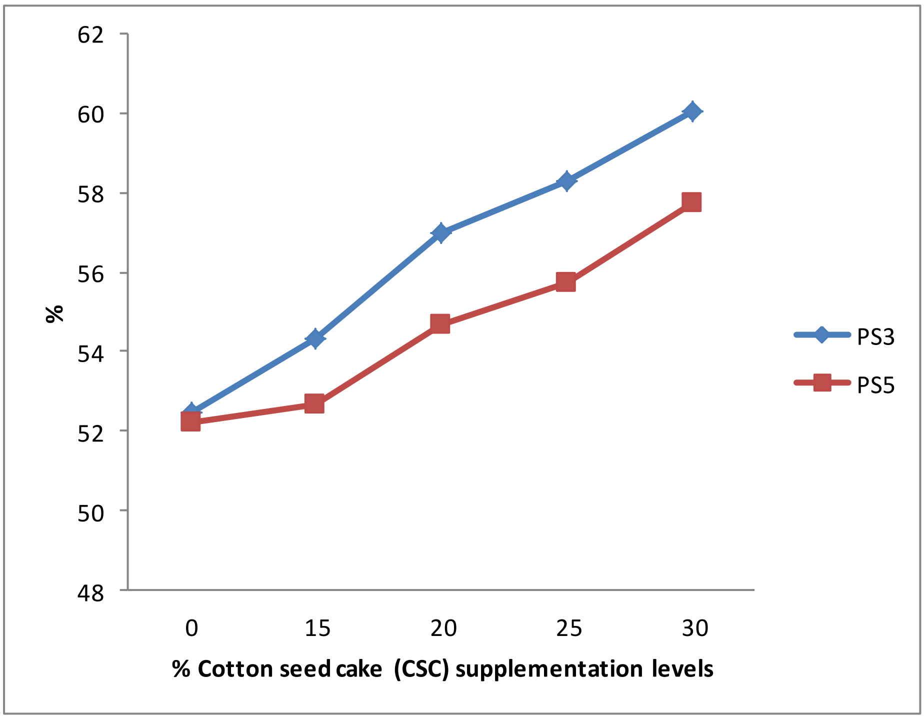

Figure 5: IVDMD of two growth stages IDPS silage at varying levels of cotton seed cake (CSC) supplementation

CP at PS3 and PS5 was below 8%, and therefore supplementation raised the N level which consequently optimized rumen function and thus improving digestibility. Responses to protein supplementation depend on the amount of the energy and CP supplied and thus explaining higher digestibility responses at PS3 than PS5 (Woyengo *et al.* 2004)

4.8 Summary

Figure 6 below shows a summary of nutritional values of IDPS fodder at various growth stages

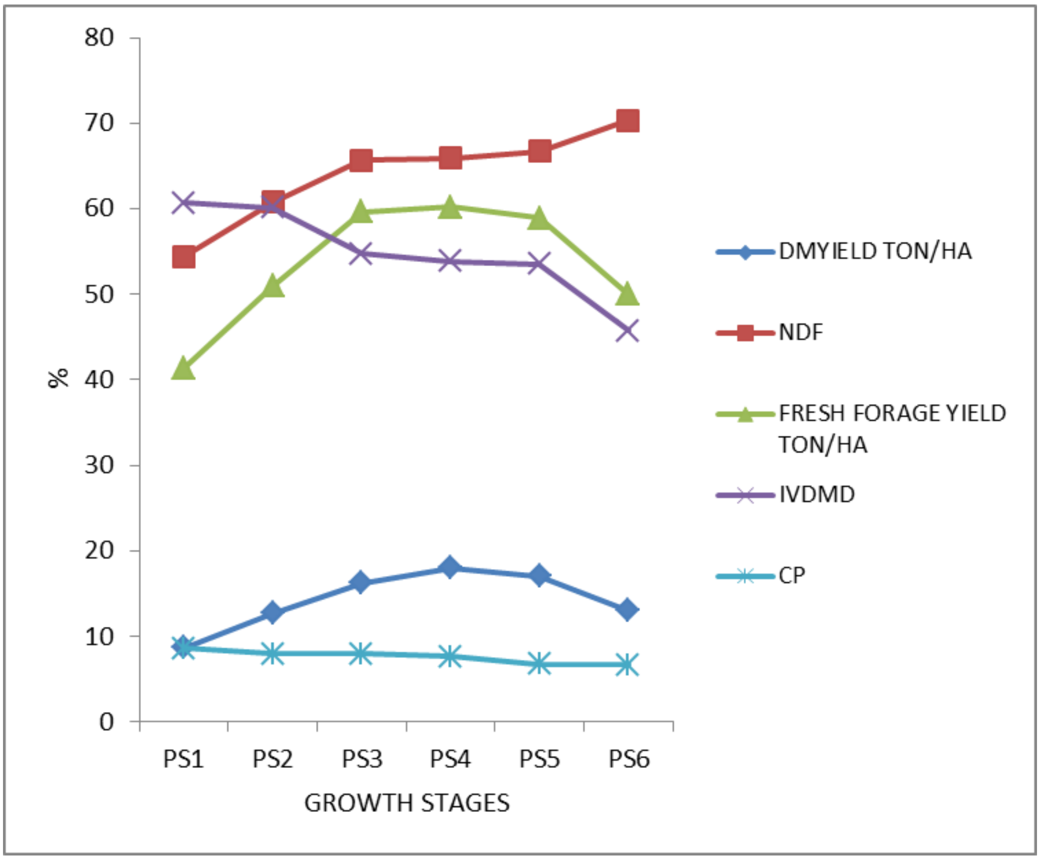

Figure 6: Summary of nutritional values of IDPS fodder at various growth stages

Dry matter yield (t/ha) at six growth stages were significantly (P<0.05) affected by growth stage at harvest and increased with plant maturity. Dry matter yield was highest and stabilized at hard dough stage (PS3), maturity stage (PS4), and post grain harvest stage (PS5) growth stages.

Crude protein content was significantly affected by growth stages, P<0.05. High CP content was obtained at early stages of growth. CP decreased gradually as the crop matured and stabilized at hard dough stage (PS3), maturity stage (PS4), and post grain harvest stage (PS5). CP content of below 7% was observed towards the last two growth stages (PS5 andPS6).

Neutral detergent fibre (NDF), and IVDMD at six growth stages were significantly (P<0.05) affected by growth stage at harvest and increased with plant maturity. Optimum NDF was obtained at hard dough stage (PS3), maturity stage (PS4), and post grain harvest stage (PS5) growth stages.

Invitro Dry Matter Digestibility (IVDMD) was significantly affected by growth stages, $P < 0.05$. High IVDMD was obtained at early stages of growth. IVDMD decreased gradually as the crop matured and almost stabilized at hard dough stage (PS3), maturity stage (PS4), and post grain harvest stage (PS5). IVDMD content of below 55 was observed towards the last two growth stages (PS5 andPS6).

Hard dough stage (PS3), maturity stage (PS4), and post grain harvest stage (PS5) growth had the highest DM yields (t ha^{-1}) and optimum fibre content combinations. Best quality silage was obtained at hard dough stage (PS3). IDPS harvested at PS5 growth stage offered both human food (cereals) and livestock feed (fodder).

CHAPTER 5.0: CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

- The DM yield of the IDPS increased with age at harvesting while forage quality deteriorated with advancing age. The balance between quality and quantity was achieved at harvesting between 142 to 169 days.
- The highest DM yield was obtained at physiological grain maturity (stalks with grains) stage of growth at 18.01 t ha^{-1}
- The nutritive value was highest at hard dough physiological stage of growth
- Protein supplementation using cotton seed cake (CSC) increased IVDMD of the dual sorghum silage at all stages of growth.

5.2 Recommendations

- The optimum period for utilization of IDPS as livestock fodder should be within the hard dough to physiological grain maturity growth stages.
- The low CP content in IDPS requires protein supplementation.
- The ratoon crop of the IDPS yielded higher DM compared to parent crop and farmers should be encourage to allow for ratooning.
- IDPS could be harvested at physiological maturity stage to provide grains for human consumption and thereafter, fodders materials could be fed to cows as green chop or conserved as silage for dry season feeding.

5.3 Further work

The following is recommended for further investigation

- Feeding trials to assess the intake and milk production of a dairy cows when fed on IDPS (fresh fodder or silage material) harvested or ensiled at various stages of growth and after supplementing with protein rich feed materials
- Feeding trials to assess intake, weight gain and carcass quality of beef animals when fed to IDPS silage harvested at various stages of growth

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