EVALUATION OF ECONOMIC PRODUCTIVITY FODDER AND GRAIN YIELD OF SORGHUM (*Sorghum bicolor* (L) Moench) AS INFLUENCED BY VARIETY AND CUTTING TIME UNDER SEMI-ARID ENVIRONMENTS

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EGERTON UNIVERSITY

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DECLARATION AND RECOMMENDATION

This thesis is my original work and has not been presented in this form or any other for the award of a degree in any other University.

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DEDICATION

I hereby wish to dedicate this work to my Sons, Roy and Brian for enduring my absence despite their tender age during the course of my training.

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ABSTRACT

The potential of sorghum to meet food, feed and farm income needs of smallholder farmers in arid areas of Kenya relies on the identification and cultivation of appropriate varieties. Sorghum cultivation for food grain and quality fodder from the same crop is not well established among varieties in Kenya. The fodder– cum–grain yield potential of important varieties required to be identified to enable farmers in semi-arid areas to select appropriate varieties and crop management programs to maximize economic returns. Field trials were conducted at Kenya Agricultural and Livestock Research Organization, Kiboko, Kenya during season 1 (October – December 2013) and season 2 (March -May, 2014). The objectives of the trials were; to determine the fodder and grain yield in sorghum varieties cut at different times, the effect of cutting time on yield components of sorghum varieties and the sorghum cutting time that maximizes economic returns to farmers. The experimental design was split plot in a randomized complete block design and replicated thrice. The main plot treatments were four cutting times; No cut, Cutting 40 days after sowing, Cutting 75 days after sowing and Cutting 40 then 75 days after sowing respectively. The sub-plot treatments were four varieties Gadam El Hamam (Vg), Mexico R Line 5 (Vm), KAT 369 X F6 YQ 212 (VK_3) and KAT 487 (VK_4) respectively. Parameters studied included physiological growth and yield aspects. The results indicated that cutting time and variety significantly affected sorghum grain and fodder yield. Variety Mexico R Line 5 produced the highest mean fodder yield of over 16 t/ha and net income of above KEs.190, 000 under C_{75}in season 1 that had higher rainfall. KAT 487 produced the largest amount of grain up to a maximum of 2.66 t/ha and the highest net income of over KEs. 140,000 from a combination of grain and fodder underC_{40} in season 2 that had poorer rainfall. Sorghum harvested at 40 days after sowing produced fodder and grain within the same growing season. From the results, KAT 487 is the best sorghum variety recommended for growing as a dual purpose crop. Mexico R Line 5 is the most suited for fodder production. This study indicates that it would be possible for sorghum farmers to obtain high incomes from sorghum. It is also evident that the same crop can be harvested as fodder at 40 days after sowing and also produce grain for human consumption within the same growing season.

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LIST OF ACRONYMS AND ABBREVIATIONS

ASAL	Arid and Semi- arid lands
DAS	Days after sowing
GTA	Global Trade Atlas
ICRISAT	International Crops Research Institute for the Semi-arid Tropics
ILRI	International Livestock Research Institute
KIRDI	Kenya Industrial Research and Development Institute
MoA	Ministry of Agriculture
MoA- ERA	Ministry of Agriculture – Economic Review of Agriculture
MoDP	Ministry of Devolution and Planning
UNDP	United Nations Development Program
WUE	Water use efficiency

CHAPTER ONE
INTRODUCTION

1.1 Background information

Sorghum (*Sorghum bicolor* L. Moench) is grown predominantly as a food crop under rainfed conditions in the semi-arid tropics. It also provides nutritious fodder to millions of livestock in Asia and Africa. Development of high yielding dual purpose varieties for both grain and fodder could mitigate the demand for grain and fodder (Mohanraj *et.al.* 2011).

It is estimated that about 84 % of the country is arid or semi-arid and therefore unsuitable for rainfed agriculture due to low and erratic rainfall. These areas often exhibit frequent crop failures and low crop and animal productivity (GoK, 2010).In the last several years, droughts have led to persistently unstable and declining agricultural productivity in semi-arid areas of Kenya. Coping strategies such as growing alternative crops that are drought tolerant in place of traditional crops of maize and beans need to be given serious consideration. Research has indicated that sorghum (*Sorghum bicolor* L. Moench) has the potential to alleviate food insecurity in ASALs due to its tolerance to drought and ability to thrive under a wide range of soils (GoK, 2010).

Sorghum is ranked third among cereals after maize and wheat in Kenya (GoK, 2010). Recently, sorghum has found increasing popularity in beer brewing by major companies in the region. Generally, the very low sorghum grain yields of about 500–800 kg/ha on small scale farms are obtained in semi-arid regions as a result of biotic and abiotic factors. The crop also has untapped potential in bio-energy production. Sorghum production and productivity could be enhanced by use of improved high yielding varieties among the resource poor farmers (Ashiono *et al*, 2005a).

Despite the growing population in Kenya, the contribution of sorghum to the cereal diet is below potential. From past studies, it is evident that inadequate attention has been given to the sorghum sub-sector (KIRDI, 2011). In Kenya, only 18 hybrids of sorghum had been released as compared to 164 improved maize varieties up to the year 2011(KIRDI, 2011). The sorghum sub-sector faces an image problem where it is considered to be a food crop for the poor and vulnerable communities in the ASALs. Its consumption in the urban areas is extremely low and many urban dwellers prefer maize thus lowering the market potential of sorghum (Miano *et al*, 2010).

The most important ruminant feed on many of the small crop-livestock farms of Asia and Africa is composed of stalks, leaves and other remains of crop plants after harvesting. Smaller quantities come from planted forages and often poorly managed pastures. Expensive concentrates which is the mainstay of livestock production in developed countries—are used only occasionally in the less developed tropics.

While crop residues (straw and stover) have become a main feed for farm animals in the semi-arid tropics, crop breeders until recently continued to focus solely on increasing grain yields. Research efforts in the recent past have incorporated fodder quality traits in crop breeding trials (ILRI, 2008).Through this effort, sorghum varieties with high yields of grain and stover as well as improved stover quality are identified.

Sorghum fodder contains 7 to 12% protein, 70% carbohydrates, minerals, crude fat and nitrogen free extract (Amanullah *et al*, 2007).The nutritional quality of sorghum fodder decreases rapidly as the crop matures. The average palatability decreases as plants get older and taller with an increase in fiber content and a reduced animal intake (ICRISAT, 2006a). The practice of cutting dual purpose sorghum within the growing period and allowing the crop to re-grow for grain production would enable livestock farmers to meet their livestock feed needs during critical drought periods and yet have the possibility of obtaining grain to meet their dietary requirements.

Sorghum is essential to diets of poor people in the semi-arid tropics where droughts cause frequent failures of other crops. Sorghum contributes to the food security of many of the world's most food-insecure agro-ecological zones (FAO, 1996). Poverty alleviation has been a principal objective of technology development strategies in sub-Saharan Africa focusing on drought tolerant crops, such as sorghum, chickpea, millet, peanuts, and cowpeas.

Production trends for the main cereal crops in Kenya have indicated a decline over the years with maize showing a decline of 19 percent from 32.5 million bags to 26.3 million bags between 2007 and 2008 against an estimated consumption level of 36 million bags. Wheat and rice production declined by 5.1 percent and 53.7 percent respectively while the area under sorghum production declined by 33.1 per cent during the same period (MoA, 2008)

A number of regional and national studies on the possible negative impacts of current climate variability and future change on agricultural productivity have emphasized the need to develop improved coping and adaptation strategies. Developing countries are particularly vulnerable to the impacts of current variability and future changes in climate due to the high dependency of the population and economies on rainfed agriculture and their limited capacity to adapt (Huq *et al,* 2004; Sivakumar *et al,* 2005; Kurukulasuriya *et al,* 2006; Adger *et al,* 2007; Lobell *et al,*2008; Schlenker & Lobell, 2010).

The low average farm size in the study area (2.87 ha) with 17% of the farmers holding less than one hectare coupled with lack of inputs and casual labor is a major constraint to increased productivity (Rao *et al,* 2011).Increasing the productivity of crops associated with tolerance to conditions of low and unreliable rainfall and high evapo-transpiration rates common to the semi-arid areas of Kenya should be of urgent concern to crop breeders and agronomists in the country. The objective of this study is to evaluate the yield advantage and effectiveness of cutting time on the biomass and grain yield of sorghum in the marginal areas of Kenya and recommend it as an alternative agronomic practice for improving food and fodder the productivity in the semi-arid regions.

Sorghum grain is mostly used for human consumption. It can be utilized as whole, de-husked or as flour (MoA, 2006). Other products include; de-hulled boiled Sorghum, stew, pilau, Sorghum green grams pilau, Sorghum ugali, Sorghum ginger biscuits, bread, queen cakes, Sorghum cake, Sorghum chapatti, porridge and beverage (MoA, 2007). Sorghum grain has high levels of iron and zinc at (>70 ppm) and (> 50 ppm) respectively. It therefore has potential to reduce micronutrient malnutrition globally (ICRISAT, 2006b). In Africa, Sorghum is grown mainly as a subsistence food crop.

1.2 Statement of the Problem

Though the production of the main cereals grown in Kenya showed a significant increase between 2011 and 2012, the acreage under sorghum declined due to low adoption by farmers and low use of certified seed. Area under maize, wheat and rice increased from 2.13 million ha to 2.27 million ha, 1.48 million ha to 2.98 million ha, and 0.26 million ha to 1.49 million ha, respectively between 2011 and 2012. Area under sorghum under the same period declined from 0.25 million ha to 0.22 million hectares respectively MoA, 2013). Growth in the agricultural sector decelerated in 2013 to 2.9 per cent from a revised growth of 4.2 per cent in 2012 partly due to inadequate rainfall received in some grain growing regions (MoDP, 2014)

Livestock farmers in the semi-arid areas of Kenya have solely depended on poorly managed communal grazing lands and crop residues to feed their livestock. The increasing human population and recurrent drought has made it difficult for the areas to support large numbers of livestock which often leads to deaths of livestock in large numbers every year.

Although different crop varieties have been developed for cultivation in the dry areas especially in the Rift Valley and Eastern Kenya, so far little effort has been put to the development of dual purpose sorghum varieties. Studies on the possibility of cutting sorghum periodically for fodder and yet obtain substantial grain from the same crop need to be carried out in Kenya especially for the semi-arid regions of Makueni.

1.3 Objectives

1.3.1 Broad Objective

The broad objective was to enhance fodder and grain yield of sorghum in semi-arid areas of Kenya through use of varying time of forage harvesting.

1.3.2 Specific Objectives

1. To determine the fodder and grain yield in sorghum varieties cut at different times.
2. To determine the effect of cutting time on yield components of sorghum varieties.
3. To determine the sorghum cutting time that maximizes economic returns to farmers.

1.4 Research Hypotheses

1. There is no difference in fodder and grain yield of sorghum varieties due to cutting time.
2. There are no differences in yield components in sorghum due to cutting time.
3. There are no differences in economic returns among sorghum varieties due to time of cutting.

1.5 Justification

The need to increase food and fodder production in the semi-arid regions of Kenya cannot be over emphasized. This can only be possible through innovative approaches that mitigate effects of increased drought occurrences precipitated by climate variability and change. One approach would be identification and selection of crops that are drought tolerant and can efficiently utilize the environmental resources. Sorghum would be a choice crop towards contributing to this endeavor. Crop intensification to alleviate food and feed scarcity through increased food grain and fodder productivity per unit area is essential in an endeavor to contribute to the food security of the semi-arid areas of Kenya.

The effect of the selected sorghum lines / varieties could be amplified through the use of appropriate agronomic management practices. Failure to do this would lead to increased frequency of crop failure and an increased dependence on famine relief and a sense of helplessness amongst the resource poor farmers in semi-arid areas. Understanding the productivity related morphological traits of newly released sorghum varieties and their response to varying cutting time is important in evaluating the dual purpose potential of sorghum in semi-arid environments.

Information on the effects of cutting time and cutting height of sorghum on fodder and grain yield is either sparse or lacking in Kenya. Therefore, this study focuses on the effects of different cutting times and varieties on sorghum in an experiment to be established in the dry areas of Makueni County.

CHAPTER TWO
LITERATURE REVIEW

2.1 Distribution and Economic Importance of Sorghum

Sorghum (*Sorghum bicolor (*L.) Moench) belongs to the family *Poaceae* and is an important forage crop in many regions of the world affected by drought occasioned by climate change (Zerbini & Thomas, 2003).Its resistance to drought makes it suitable as a food and fodder crop in semi-arid areas especially due to its ability to produce under dry conditions compared to corn (Tabosa *et al*, 1999). Sorghum has great potential to provide food, feed and fodder for human, poultry and cattle respectively. The present fodder production does not meet the fodder requirement in terms of both quantity and quality (Ahmad *et al*, 2007).

Sorghum is a drought resistant cereal and can withstand periods of high temperature. It grows in areas where the annual rainfall is in the range 500-700 mm per year and can withstand periods of water logging (Taylor, 2010). In semi-arid regions sorghum serves as the staple food and source of animal feed and fodder (M'Ragwa *et al*, 1997).

The yield and quality of sorghum is affected by a wide array of biotic (pests and diseases) and abiotic stresses (drought, low temperature and poor soils). The major biotic constraints include shoot fly, stem borer and head bug among insect pests; grain mould and anthracnose among the diseases, while terminal drought and low temperature (post-rainy season) and soil salinity are the major abiotic constraints (M'Ragwa *et al*, 1997). Due to production constraints and the use of low yielding traditional cultivars coupled with traditional production practices, sorghum grain productivity is still low in the semi- arid areas of Kenya.

2.1.1 Role of Sorghum in Food Security and Development in Kenya

Food security is likely to remain a chief development concern in Sub-Saharan Africa in the foreseeable future. The effects of sharp increases in food prices in 2007 up to mid-2008 and the global economic downturn of 2009 have reversed the decline in the proportion of undernourished population in developing countries experienced in the late 1960s to 2004-2006 (FAO, 2009).

Sorghum can contribute to food and nutrition security, job creation and sustainable economic development, especially for communities in ASALs. Sorghum is rich in carbohydrates, iron, magnesium, potassium, calcium and phosphorus. Bio-fortification of the cereal with essential minerals, vitamins and other nutrients could be a cost-effective tool in the battle against malnutrition among food deficient communities (Taylor & Taylor, 2011; Lipkie *et al*., 2013). In addition to being important for human consumption, sorghum has potential for use in animal feed and beverage industries.

In Kenya, declining growth of the agricultural sector has been a major concern facing policy makers and stakeholders in the sector. This is likely to have negative impact on employment and income inequality as well as food security for the country (UNDP, 2002). Enhancing agricultural productivity in Kenya is necessary as the yields of major crops are far below the potential yield (Karugia, 2003).Studies of sorghum as fodder crop in terms of production pattern, comparative economics with other competing commercial crops, marketing and processing, has not attracted sufficient attention of researchers in the past (Nagpal, 1981; Wylie, 2007; Sharma, *et al*, 2009).

Areas under crop production require to be expanded by venturing into dry areas. Drought tolerant crops like sorghum have great potential in this regard. Sorghum is a very important source of food and farm income for smallholder farmers, which can be enhanced especially if linked to new markets (Hamukwala, 2010).

Although in the early 1990s a large part of sorghum output was used as human food, its importance has declined since then. Use of sorghum as animal feed has more than doubled from 30 to 60% since the early 1990s (FAO, 1995).

2.2 Fodder Sorghum

Increased livestock production can only be achieved through the cultivation of high-quality forages with high yielding ability that are adapted to biotic and abiotic environmental stresses (Muia *et al*, 2001; Tessema *et al*, 2002;Kahindi*et al*, 2007). Sorghum stover is a source of dry season feed for livestock. Forage sorghum provides alternative feed for ruminants as fresh-cut feeding, grazing and silage (Skerman & Riveros, 1990).The quality of forage sorghum at the first cut, usually 60DAS is low in protein content (4-6%) (Hennessy, 1980).

Sorghum fodder contains more than 50% digestible nutrients which consist of 8% protein, 2.5% fat and 45% nitrogen-free extract. The nutritional value of sorghum fodder varies with the stage of growth (Pedersen *et al*, 1983; Vanderlip, 1993; Snyman & Joubert, 1996). The

DM and crude fiber content increase as the crop matures while protein content, digestibility and the energy content decrease. Presence of cyanogenic glycosides which yields HCN on hydrolysis is poisonous to livestock (Collet, 2004). Sorghum breeding efforts to improve grain yield as well as stay green traits, which delays stover senescence, have been intensified (Rooney 2005). Stay-green sorghum cultivars maintain their leaves alive and mature slowly with gradual decline in whole-plant quality (Singh *et al*, 2009).

2.2.1 Effect of Variety on Sorghum Growth Parameters and Fodder Yield

Demand for quality stover and a growing economic value has resulted in cereal breeding programs focusing on the improvement of stover yield (Reddy *et al*., 1995; Hash *et al*., 2000). Dry matter yields of sorghum are significantly higher when cut at a height of 7 cm as compared to 14 and 21 cm at the first cutting. Multi-cut sorghum is capable of producing high-quality forage when other perennials have low production (Undersander *et al*, 1990).

The fodder quality of sorghum depends on many factors such as fertilization, irrigation, genotype, plant density and harvesting time (Pholsen *et al*, 1998; Saeed & El-Nadi, 1998; Cakmakci *et al*, 1999; Pholsen *et al*, 2001; Zulfiqar & Asim, 2002; Carmi *et al*, 2006; Miron *et al*, 2006; Glamoclija *et al*, 2011). Time of harvesting is the most important factor affecting quality of forage. Maturity of forage crops influence forage digestibility and consumption by animals with increase in fiber while quality and digestibility decreases as aging prolongs (Ball *et al*, 2001). Appropriate harvesting time is therefore a crucial factor for a successful forage sorghum production.

Stage of growth is one of the most important factors influencing nutritional quality of fodder (Fariani *et al*, 1994). The nutritive value of a fodder and its silage depends upon the morphological and physiological changes. As the fodder matures, the cytoplasmic portion of the cell reduces and the quantity of protein, lipids, soluble carbohydrates and soluble minerals decrease. To maintain high production and quality of fodder, harvesting at appropriate cutting heights and defoliation frequencies is recommended (Butt *et al*, 1993; Muia *et al*, 2000; Tessema *et al*, 2003; Jφrgensen *et al*, 2010).

Cutting height influences plant vigour, re-growth and plant stability within the soil (Butt *et al*, 1993; Leininger & Clary, 2000; Jφrgensen *et al*, 2010). Very frequent cutting affects the growth and development of the fodder crop. Delayed defoliation frequency may enhance the growth and development of the crop (Butt *et al,* 1993; Nyaata *et al,* 2002; Tekletsadik *et al,* 2004). Cutting height was observed to have effect on number of tillers per plant, number of leaves per tiller, total number of leaves per plant, leaf length per plant and basal circumference per plant. Leaf-to-stem ratio increased as the frequency of defoliation increased (Tessema *et al,* 2010).

Studies carried out in Pakistan on different sorghum cultivars showed significant differences in plant height, stem diameter, leaf weight per plant, leaf area per plant, fresh weight per plant, dry weight per plant, forage yield, dry matter yield and ash percentage(Yousef *et al,* 2009). Significant differences were reported among sorghum cultivars in protein contents (Yousef *et al,* 2009; Sarfraz *et al,* 2012). Varieties that produced bigger plants, more leaves and thicker stem resulted in increased forage and dry matter yield (Amir *et al,* 2014).

Significant variation among sorghum cultivars for fresh forage yield and yield components were reported in various studies. Average dry fodder yield ranges of between 8.3t/ha and 20.8 t/ha were recorded among five different sorghum varieties (Ammanullah *et al,* 2007). Chohan *et al,* (2003), Hussain *et al,* (2011) and Ghasemi *et al,* (2012) also reported significant differences in the fresh forage yield of various sorghum forage cultivars. In a study of sorghum varieties for forage yield and quality, significant differences were reported in forage and dry matter yield associated with plant density, plant height and stem thickness. Ayub *et al,* (2010) reported differences in plant height ranging between 169.4 cm and 182.1 cm among four varieties. In the same study, the number of leaves per plant and fodder dry matter yields was found to be significantly different among the varieties. Similar findings were reported by Amir *et al, (*2014). In a different study, varietal differences were also reported with respect to quality parameters; crude protein percentage, total ash percentage and ether extractable fat percentage (Muhammad *et al,* 2010).

An evaluation of the performance of 15 forage sorghum cultivars with respect to green fodder yields, plant height and dry matter yield significant differences were observed among the cultivars with respect to the above parameters (Ghasemi *et al,* 2012). A study of sorghum genotypes in the dry highlands of Kenya showed significant differences in varietal performance with respect to yield, days to flowering, plant height, 100- seed weight and agronomic score among the 28 varieties in the study (Ouma & Akuja 2013). Differences were also observed among five sorghum varieties for dry fodder yield (Parameswarappa & Lamani, 2005).

According to preliminary yield trials carried out during the long rains of 2005 at KARI Katumani, the four entries in this study exhibited differences in agronomic characteristics with respect to average height, grain yield and days to 50% flowering.

2.3 Grain Sorghum Production

Sorghum is essential to the diets of poor people in the semi-arid tropics where droughts cause frequent failures of other crops. Sorghum contributes to the food security of many of the world's most food-insecure agro-ecological zones (FAO, 1996). Poverty alleviation has been a principal objective of technology development strategies in sub-Saharan Africa focusing on drought tolerant crops, such as sorghum, chickpea, millet, peanuts, and cowpeas.

A number of regional and national studies on the possible negative impacts of current climate variability and future change on agricultural productivity have emphasized the need to develop improved coping and adaptation strategies. Developing countries are particularly vulnerable to the impacts of current variability and future changes in climate due to the high dependency of the population and economies on rainfed agriculture and their limited capacity to adapt (Huq *et al,* 2004; Sivakumar *et al*, 2005; Kurukulasuriya *et al,* 2006; Adger *et al,* 2007; Lobell *et al,* 2008; Schlenker & Lobell, 2010).

2.3.1 Effect of variety on sorghum grain yield

Studies on sorghum indicate significant differences among varieties with respect to grain yield. Growth traits such as head length, head weight, grain yield per head, straw yield and grain yield per hectare were found to differ significantly among cultivars (Atokple *et al,* 2014). Motagally, (2010) reported differences in head length, head weight and straw yield among two varieties with variety shandweel having a head length of 32.28 cm, head weight of 96.53 and straw yield of 26.11 kg per plot as being higher that the variety Giza variety. A study of eight varieties in Pakistan revealed that varieties differed significantly for grain yield. Among the varieties studied, sorghum variety SPV-462 (4120 kg/ha), CSV-15 (3898 kg/ha), Johar (3857 kg/ha) and Rari S-4 yielded (2858 kg/ha) (Nazir *et al,* 2011). Other studies showed similar results (Alagrasamy, 1993;Osmanzai, 1994).

An evaluation of dual purpose Kharif varieties showed significant variability in grain yield. Among the varieties tested, BH-9704-1-3 (SPV-1600) recorded highest average grain yield of 5257 kg/ha followed by BH9706-1-1 (41.26 kg/ha), BH- 9709-1-3 (3822 kg/ha) and BH-9702-9-1 (3651 kg/ha) as compared to the check DSV-2 (2788 kg/ha) and CSV-15 (2667 kg/ha) (Parameswarappa & Lamani, 2005).

In a study of different varieties in upper midlands and lower highlands of Kenya, significant differences in grain yield were observed among varieties. Among the varieties studied, variety Seredo (KAK) produced 0.83 t/ha, Seredo (KSC) 0.28 t/ha, Serena KSC) 0.72 t/ha, E 525HR 0.81 t/ha, while Livoywa produced 2.11 t/ha in Chobosta, North Rift (Kute *et al.*, 1997). Differences in grain yields among varieties were reported among 28 varieties in the dry highlands of Kenya (Ouma& Akuja 2013).

2.4 Effect of Cutting Time on Sorghum Growth Parameters, Fodder and Grain Yield

Cutting time has been reported to influence the growth parameters, fodder and grain yield in sorghum. Differences in grain yield, 1000 seed weight, number of panicles and panicle length were reported among three varieties of sorghum, common Sudan grass, Sudan grass hybrid GII and Sudan grass hybrid and Grazer N2, at seeding rate of 20kg/ha and four cutting frequencies; no cutting, cut once, cut twice and cut thrice. From the study, cutting negatively affects growth and yield of sorghum. Common Sudan grass that was not cut yielded 2.97 t/ha of grain, 1000 seed weight of 13.8 g. Plants cut once yielded 1.03 t/ha of grain and 1000 seed weight of 16.0 g. Plants cut twice yielded 0.29 t/ha of grain and 1000 seed weight of 4.5 g. Similar results were observed for the other varieties (Akash & Saoub, 2002).

In a study on cutting management in Oat variety Sabzar, it was reported that cutting time resulted in significant differences in plant height, number of tillers, green fodder and dry matter yield. Single cut plants recorded an average plant height of 58.04 cm; double cut plants recorded an average height of 58.01cm. The numbers of tillers per sq meter were 328.48 and 330.34 for single and double cut plants respectively. Green fodder and dry matter yield was 15.68t/ha and 17.99t/ha for single and double cut plants respectively while dry matter yield was 3.97t/ha and 3.08 t/ha for single and double cut plants respectively (Intikhab *et al,* 2013)

Cutting time was also reported to have significant effect on plant height, fodder and dry matter yield of sorghum. Green fodder and dry matter yields were reduced during subsequent cuts. Sorghum cut at 15 DAS, 30 DAS, 45 DAS and 60 DAS had plant height of 25.81 cm, 41.10 cm, 81.21cm and 132.41 cm respectively. In the same experiment, the green fodder yields were

23.75 t/ha and 2.66 t/ha respectively during the first cut and second cut respectively (Roy &Khandaker, 2010).

Nutritional composition of fodder was also found to differ with cutting time. In a study of cutting time in sorghum carried out at Bangladesh Agricultural University, the chemical composition was found to differ with cutting time. The composition for fodder cut at 15 DAS were recorded as 6.61 %, 37.05 % , 3.38 %, 42.64 %and 0.4 % per 100g DM, for crude protein, crude fiber, ether extract, nitrogen free extract and phosphorus respectively. In the second cut (30 DAS) the composition was 6.69 %, 34.51 %, 3.01 %, 48.87 % and 0.11 % per 100g DM for crude protein, crude fibre, ether extract, nitrogen free extract and phosphorus respectively (Roy & Khandaker, 2010).

Nutritional value of fodder was found to decline with advanced plant maturity. In a study of four forage sorghum cultivars (Early Sumac, Leotti, Nes, Rox) carried out at Mustafa Kemal University in Turkey, fresh forage yield, dry matter content, protein yield, lignin content and relative feed value (RFV) tended to increase with advanced plant maturity (Atis *et al*, 2012).In the same study, neutral detergent fiber (NDF), acid detergent fiber (ADF), cellulose and hemi-cellulose content tended to decrease. Green forage yields were recorded as 60.67 t/ha, 75.40 t/ha, 84.69 t/ha and 91.90 t/ha at panicle emergence (PE), milky stage (MS), dough stage (DS) and physiological maturity (PM) respectively. Dry matter yield was 10.26 t/ha, 16.23t/ha, 21.05 t/ha and 30.01t/ha for PE, MS, DS and PM respectively. Crude protein content of forage was recorded as 83.4 g/kg, 75.2 g/kg, 76.9 g/kg and 63.5 g/kg for PE, MS, DS and PM respectively (Atis *et al*, 2012).Sorghum for hay making is best cut at about 80 cm (40 DAS) which produces better quality hay that is easier to cure (Undersander *et al*, 2003; Suttie, 2000). However, the best stage for ensiling sorghum fodder is the medium dough stage (Undersander, 2003)

CHAPTER THREE
MATERIALS AND METHODS

3.1 Study Site Description

The study was conducted at Kenya Agricultural and Livestock Research Organization (KALRO), Kiboko Field Station (1^{o} 31'S, 37^{o}16'E) which lies at an altitude of 1260m above sea level and is classified as Lower Midland IV Agro ecological zone (Jaetzold *et al*, 2006). The area receives an average annual rainfall of 500-1300 mm, which is bi-modal with long rains (March-May) and short rains (October-December). The mean minimum and maximum annual temperatures are between 11.9^{o}C and 25.5^{o}C, respectively. The soils are Pellic Vertisols that are imperfectly drained, moderately deep, friable, dark grayish brown to black, very firm, gravelly cracking clay on gentle slopes (Jaetzold *et al*, 2006). The average minimum and maximum temperatures in the field during the trial were14^{o}C and 32.9^{o}C respectively.

3.2 Experimental Design and Treatment Application:

The experimental design was a split plot arrangement laid out in a Randomized Completely Block Design with cutting time as the main plots and variety as the sub-plots. Each treatment was replicated three times. The experimental layout covered an area of 45 m by 20 m. (Fig. 1).Plot size was 4.0 m x 3.0 m. Spacing was 60 cm between rows and 20 cm within rows. The main plot treatments consisted of no cutting (Co), cutting at 40DAS (C_{40}), cutting at 40then 75DAS (C_{40}-$_{75}$) and cutting at 75 DAS (C_{75}) respectively. The varieties in the study (Mexico R. Line 5 (Vm), KAT 487 (VK_4) and KAT 369 X F6 YQ 212 (VK_3) are at various levels of evaluation and performance trials at the Kenya Agricultural and Livestock Research Organization (KALRO) while Gadam el Hamam (Vg) is a common variety.

According to preliminary yield trials carried out during the long rains in 2005 at KALRO Katumani, the entries had the following basic agronomic characteristics;

- Mexico R Line 5 is a white seeded entry with relatively short days to 50% flowering at 60 days. Plant height was an average of 181 cm. The panicle exertion was relatively small at 10 cm. The average grain yield was 1.5 t/ha.

- KAT 487 is a white seeded entry with short days to 50% flowering at 58 days. Plant height at maturity was an average of 148 cm. Panicle exertion was 12 cm. Average grain yield was 2.5 t/ha.
- KAT 369 X F6 YQ 212 is a white seeded entry with short days to 50% flowering duration of 55 days. Plant height at maturity was an average of 163 cm. Panicle exertion was 10 cm. Average grain yield was 1.31 t/ha.
- Gadam el Hamam is a common variety that produces white seeds. The days to 50% flowering were an average of 55. Plant height was an average of 136 cm. Panicle exertion was 15 cm while the average yield was 2.1 t/ha.

3.3 Experimental Layout (Split-plot design)

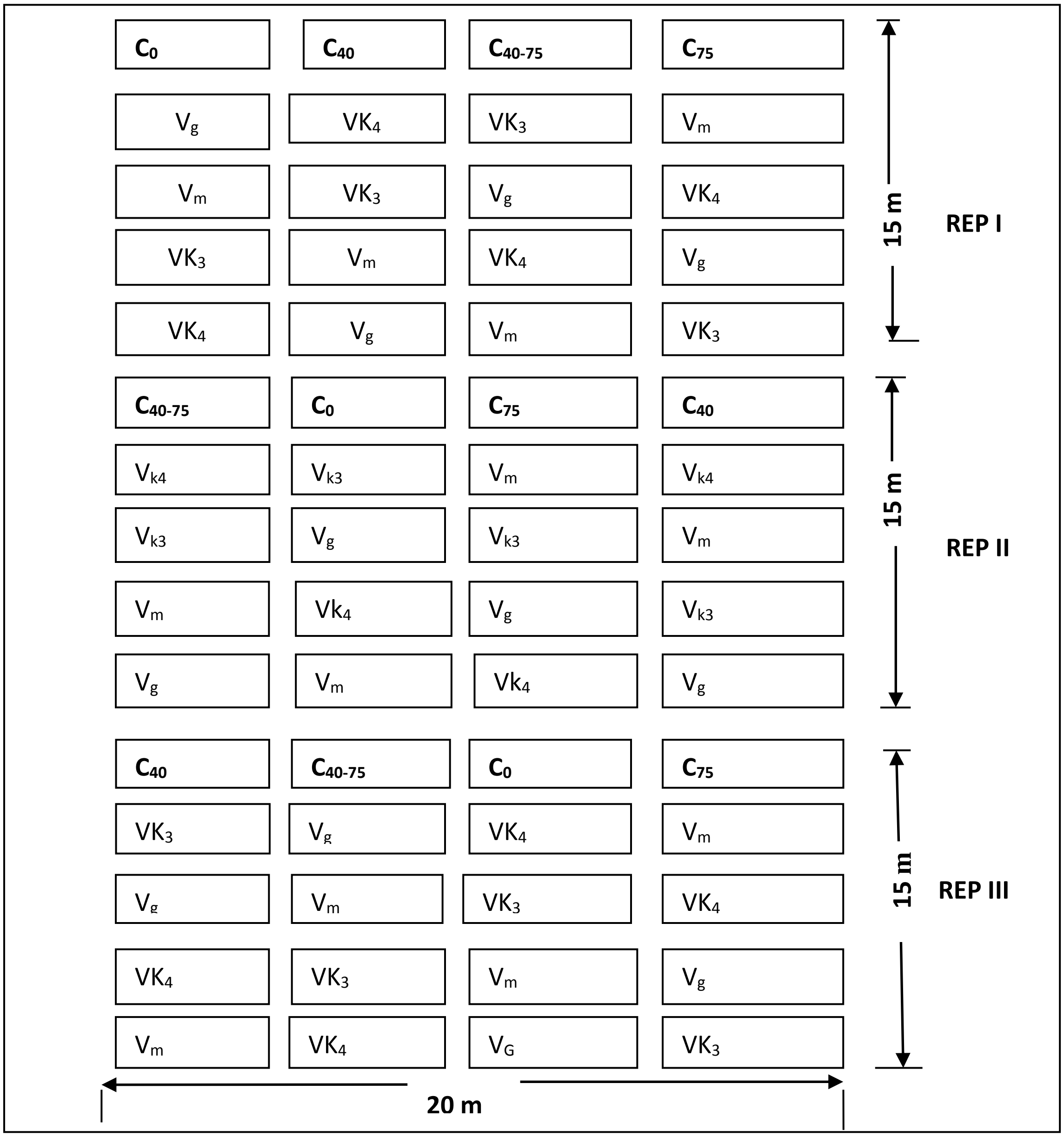

Figure 1: The experimental layout showing the treatment combinations for the four varieties

KEY:

Variety	**Designation**	**Cutting time**	**Designation**
Gadam El Hamam	V_g	No Cut	C_0
Mexico R. Line 5	V_m	Cut at 40 DAS	C_{40}
KAT 369 X F6 YQ 212	VK_3	Cut at 40 then 75 DAS	C_{40-75}
KAT 487	VK_4	Cut at 75 DAS	C_{75}

3.4 Land Preparation and Planting

The experimental site was ploughed, harrowed using tractor drawn implements and finally hand leveled to ensure a fine tilth. Furrows were made by manually dragging a stick along a string used to mark rows at the onset of the rains. Phosphorous was applied at the recommended rate of 30 kg P/ha (Ashiono *et al,* 2005b) in the furrows and mixed with the soil.

Sorghum seeds were treated using SEEDPLUS (Imidachloprid 10% + Metalaxy 10% + Carbendazim 10%), thinly broadcast along the furrows at a spacing of 60 cm between rows and then thinly covered with soil. Thinning was carried out two weeks after emergence to attain the recommended spacing of 20 cm between the plants. The plots were irrigated twice a week at 27 mm of water per session during the first 30 DAS and once per week afterwards until 90 DAS. The total amount of irrigation water applied was about 432 mm.

3.4.1 Routine Plant Maintenance Practices

Nitrogen was applied six weeks after sowing at the recommended rate of 40 kg N per hectare (Ashiono *et al.* 2005a). Plots were kept weed free by hand weeding as weeds appeared. Thiamethoxam 25 WG insecticide was sprayed to control soil borne pests at 200g per hectare. Imidacloprid 200SC was sprayed to control aphids and *Heliothes armigera* at 0.5 Litres per hectare between 40 and 75 DAS. Birds were controlled by people strategically placed around the field on raised platforms.

3.5 Data Collection

The following growth parameters were measured:

Plant height readings were taken at 20; 40 and 75 DAS respectively. Plant height of four plants per plot in each of the middle rows randomly selected was taken and the mean calculated and recorded.

Dry fodder weight was determined 40, 40 then 75, 75 and 118 DAS respectively. Plant samples were obtained from sorghum plants cut randomly along 0.8m one inner row per plot. The rest of the plants in the plot were cut and discarded. The samples were sun dried to constant weight and weighed on an electronic balance. Number of tillers was taken 40, 75 and 118 DAS. The tillers were physically counted from randomly selected plants within the inner 2 meter rows of each plot and the mean calculated.

Grain was harvested from sorghum plants per 0.8m row of each plot, threshed and sun dried. The grain sample weight was determined using an electronic weighing balance. One thousand grains from each plot were harvested and physically counted. The 1000-grain weight was determined using an electronic weighing balance.

3.6 Economic Evaluation

The market price data of sorghum grain and fodder respectively, was collected from the surrounding markets of Nairobi and Machakos and Makueni. Gross margin was calculated for each variety and cutting time to establish the profitability of the sorghum enterprise for each treatment. Fodder costs were established in the surrounding area of Machakos and Makueni Counties. The Gross margin of cut versus un-cut plots was compared at the end of the growing period (118 DAS). The Gross Margin was calculated using the formula below (Baiyegunhi & Fraser, 2009);

Formula for calculation of gross margin

$$GM = Q_y P_y - \sum X_i P_{Xi}$$

Where,

GM =Gross Margin   *Y Q* =Total output of crop (kg)

Y P =Unit price of product (KEs)   *i X* =Quantity of the input used (kg)

Xi P =Price per unit of the input (KEs)   *Y Y Q P* =Total revenue associated with the *ith* input (KEs)

$\sum X_i P_{Xi}$ = Summation (overall inputs, *i-n* to give   Total Variable Cost –*TVC*)

Thus,

GM = *GFI* - *TVC* (ii)

Where,

GM =Gross Margin (KEs/ha)   *GFI* =Gross Farm Income (KEs/ha)

TVC=Total Variable Cost (KEs/ha)

Source; Baiyegunhi and Fraser, 2009

3.7 Data Analysis

The data collected was subjected to Analysis of Variance (ANOVA) using GENSTAT 14th Edition (Anon, 1993). The treatments which were found to be significant were separated with Fisher's protected Least Significant Difference (LSD) at 5% level of probability.

The Linear Model fitted for the experiment was;

$Y_{ijk} = \mu + \rho_i + \alpha_j + \gamma_{ij} + \beta_k + (\alpha\beta)_{jk} + \varepsilon_{ijk}$

i = 1, 2, 3; j = 1, 2, 3, 4 k = 1,2,3,4

Where, Y_{ijk}– Grain or Fodder Yield, μ - grand mean, ρ_i is i^{th} blocking effect, α_j is effect cutting time, γ_{ij} is main plot error (error a), β_k is k^{th} variety, $(\alpha\beta)_{jk}$ is effect of interaction between variety and cutting time, ε_{ijk} is random error component (error b) and γ_{ij} and ε_{ijk} were normally and independently distributed about zero means with a common variance σ^2.

CHAPTER FOUR
RESULTS

Weather Data at Experimental Site

The total amount of rainfall received at the experimental site for season 1 (October – December 2013) and season 2 (Mar – May 2014) was 245.40 mm and 188.50 mm, respectively. The average relative humidity was 87.18 and 86.8 in season 1 and 2 respectively (Fig. 2). During the period of study, rainfall over the two seasons was erratic with some months (September and October 2013) receiving below 2.0 mm of rainfall. The highest amounts were received in November 2013 and March 2014 (102 mm and 186.50 mm, respectively) (Fig.2). The mean maximum temperatures for season 1 and season 2 were 30.8 ^{o}C and 30.6 ^{o}C, respectively (Fig. 3). The Mean minimum temperatures for season 1 and season 2 were 17.325 ^{o}C and 17.725 ^{o}C, respectively.

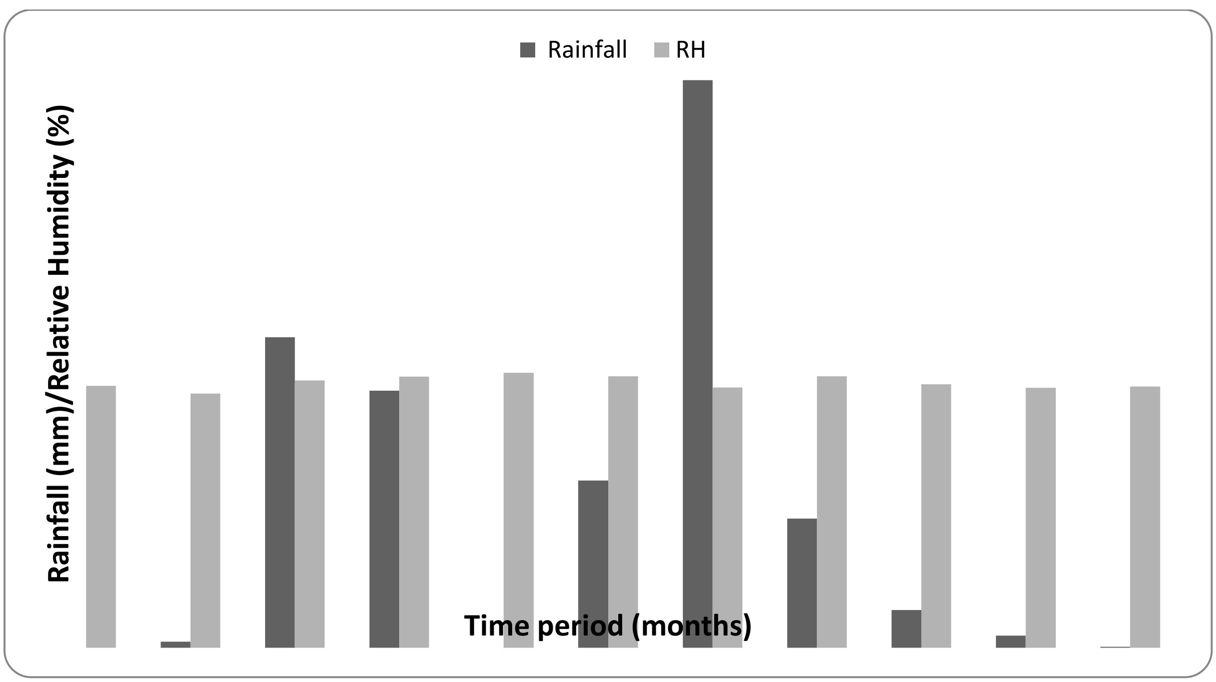

Figure 2: Rainfall and Relative Humidity data for KALRO, Kiboko during the study period. (Source- ICRISAT Kiboko field weather station 2013/2014)

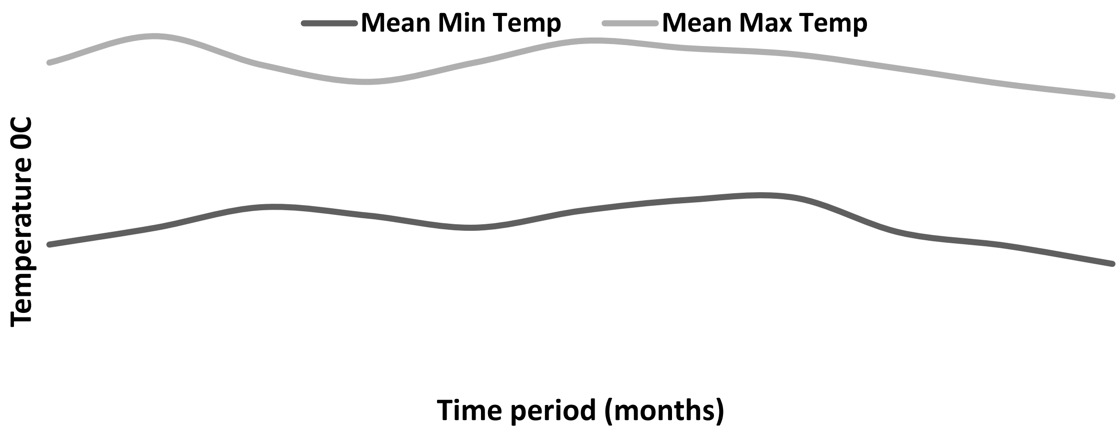

Figure 3: Minimum and maximum temperature data for KALRO, Kiboko during the study period. (Source - ICRISAT Kiboko Field weather station 2013/2014)

4.1 Effect of Cutting Time and Variety on Sorghum Plant Height

4.1.1 Effect of Cutting Time on Sorghum Plant Height

Cutting time had significant effect on plant height only at 75 and 118 DAS for all cutting time treatments in both seasons. Plant height increased progressively with the growing periods of sorghum varieties from a range of 45.7cm at 20 DAS to a maximum height of 177.7 cm for the no cut (C_0) treatment followed by 124.0 cm, 90.9 cm and 87.7 cm for crops cut at 40 DAS (C_{40}), 40 then 75 DAS (C_{40-75}) and 75 DAS (C_{75}) respectively in season 1(Table 1). The corresponding sorghum heights for season 2 were 44.8 cm at 20 DAS to a maximum of 167.9 cm for the no cut (C_0) treatment followed by 115.2 cm, 115.2 and 79.1cm for plants cut at 40 DAS (C_{40}), 40 then 75 DAS (C_{40-75}) and 75 DAS (C_{75}) respectively for season 2. Cutting later in the crop growth cycle resulted in a decline in sorghum re-growth in height in season 1. Cutting time appeared to severely affect sorghum height for plants cut at 40 then 75 (C_{40-75}) DAS and 75 DAS (C_{75}) respectively that declined from an average of 125.7 cm and 129.1 cm to 82.4 cm and 74.1 cm for both cutting time treatments in season 1. This trend was observed in season 2 for all cutting time treatments (Table 1).

4.1.2 Effect of Variety on Sorghum Plant Height

Sorghum varieties exhibited significant differences in height at all stages of growth. Sorghum height increased progressively for all varieties with increase in maturity. The varieties were tallest at 75 DAS with Mexico R Line 5 being significantly the tallest (158.6 cm) followed by KAT 487 (144.6 cm), KAT 369 (140.9 cm) and last was Gadam (114.3 cm). It was apparent that at maturity (118 DAS), the varieties were shorter compared to height at 75 DAS due to the imposed cutting treatments. The same trend was observed in season 2 (Table 1).

4.1.3 Interactions between Cutting Time and Variety on Sorghum Plant Height

Interactions between cutting time treatments and variety were significant for plants cut at 75 DAS (C_{75}) and 118 DAS only for both seasons (Table 1). At no cut (Co), treatment. Mexico R was the tallest at 211 cm by 118 DAS (Table 1). This was followed by KAT 369 and KAT 487 which had equal height in both seasons. Under C_{40}treatment, Mexico R and KAT 487 had significantly taller crops compared to KAT 369 and Gadam. Sorghum cut twice at 40 and 75 DAS (C_{40-75}), revealed a severe decline in height ranging between 77cm and 96 cm and 67.5cm to 88.5 cm which were statistically equal in season1 and season 2 respectively. Sorghum varieties cut at 75 DAS (C_{75}) had significantly shorter crops ranging between 75cm and 99.6 cm in season 1 and 67.5 and 90.8 cm in season 2. Those heights were not significantly different from those subjected to cutting twice at 40 and 75 DAS (C_{40-75}).

Table 1: Effect of cutting time and variety on sorghum height (cm) at Kiboko, Kenya during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014)

	Sorghum height (cm)							
	20 DAS		40 DAS		75 DAS		118 DAS	
	Season							
Cutting treatment	**1**	**2**	**1**	**2**	**1**	**2**	**1**	**2**
No Cut	46.00	47.80	89.20	76.00	172.29a	147.18a	177.7a	167.9a
Cut 40 DAS	46.47	48.81	89.60	79.30	131.20b	118.33b	124.0b	115.2b
Cut 40 - 75 DAS	45.69	44.82	93.20	81.60	125.86b	125.68b	90.9c	82.4c
Cut 75 DAS	46.03	46.58	96.70	79.30	129.07b	121.02b	87.7c	79.1c
LSD P≤ 0.05	**NS**	**NS**	**NS**	**NS**	**10.754**	**13.746**	**12.98**	**13.28**
Variety								
Gadam	38.10b	40.06b	82.90	69.10c	114.32c	109.93c	96.6c	88.3d
Mexico R	47.77a	50.87a	94.60	84.60a	158.59a	139.05a	136.0a	127.0a
KAT 369	49.32a	48.35a	97.00	84.60a	140.93b	131.15b	118.1b	109.0c
KAT 487	49.00a	48.73a	94.40	78.00b	144.57b	132.06b	129.5a	120.2b
LSD P≤ 0.05	**2.884**	**3.882**	**NS**	**6.230**	**5.127**	**3.211**	**6.57**	**6.60**
CV %	**6.0**	**8.3**	**8.7**	**8.4**	**3.9**	**5.4**	**5.4**	**6.0**

Means followed by the same letters or no letters within a column are not significantly different according to Fisher's protected Least Significant Difference (LSD) at $P \leq 0.05$

Table 2: Interaction between cutting time and variety on sorghum plant height 75 DASat Kiboko, Kenya during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014)

Cutting treatment	Variety		Season 1 (Oct 2013 - Jan 2014)		Season 2 (April - Jul 2014)			
	Gadam	**Mexico R**	**KAT 369**	**KAT 487**	**Gadam**	**Mexico R**	**KAT 369**	**KAT 487**
No Cut	130.00de	206.23a	175.03b	177.90b	120.43cd	165.23a	154.20ab	148.83b
Cut 40 DAS	109.70f	151.80cd	126.10e	137.20de	102.33d	126.13c	120.87c	123.97c
Cut 40-75 DAS	106.27f	142.33cd	127.43e	127.40e	106.80d	130.40c	121.77c	125.10c
Cut 75 DAS	111.33f	134.00de	135.17de	137.77de	110.17d	134.43c	127.77c	130.33c
LSD P≤ 0.05		**12.887**				**14.104**		
CV %		**4.4**				**3.0**		

Means followed by the same letters or combination of letters are not significantly different according to Fisher's protected Least Significant Difference (LSD) at $P \leq 0.05$

Relationship between Cutting Time with Sorghum Height

Sorghum height increased with maturity as depicted by the mathematical functions given in Figure 4. The functions have high coefficients of determination where R^2> 98.4%. In treatment C_0(no cut), the sorghum plants reached a height of about 180 cm at about 100 DAS, followed by treatment C_{40} (one cut at 40 DAS) at 130 cm., then C_{75} and C_{40-75}plants which attained an average height of 117 cm at 85 DAS. Beyond those days of maturity, the height apparently declined as defined by the developed function. This was true for all cutting treatments except for no cut (Co) where the height remained constant after 105 DAS until harvest. These functions can be useful in predicting sorghum height subjected to various cutting regimes.

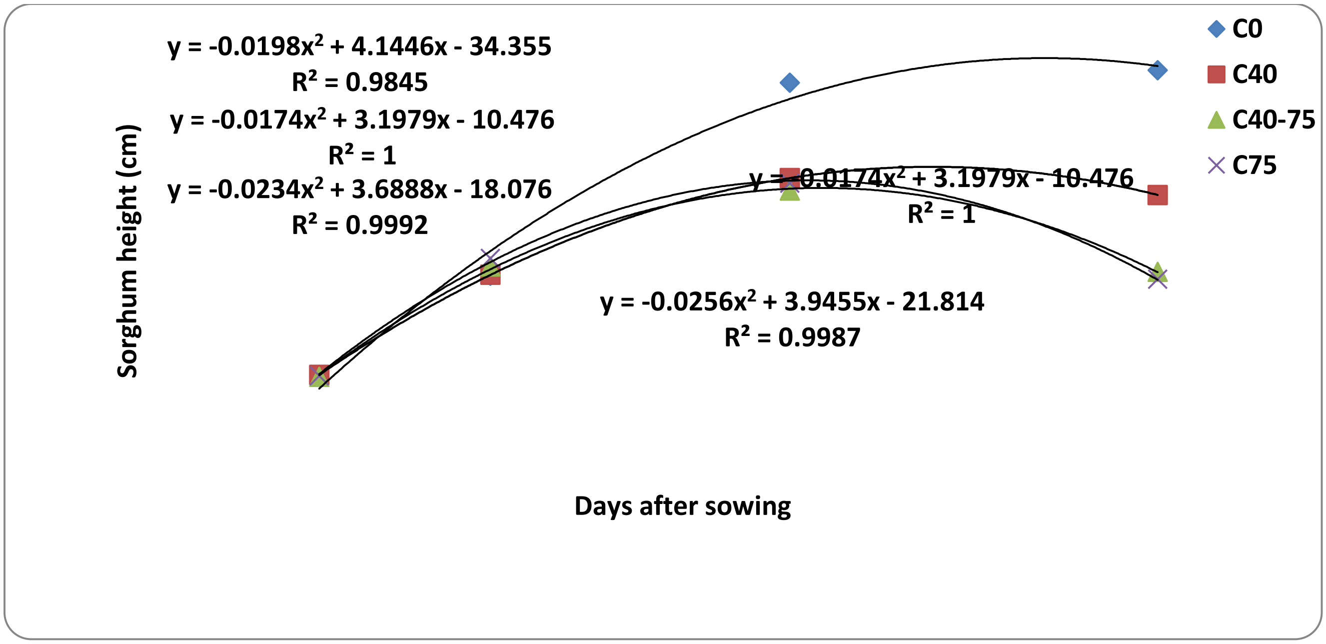

Figure 4: Relationship between sorghum heights with maturity of sorghum varieties as affected by cutting time in Kiboko, Kenya

Table3: Interaction between cutting time and variety on sorghum height 118 DAS at Kiboko, during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014)

	Variety	**Season 1**			**Season 2**			
Cutting treatment	Gadam	Mexico R	KAT 369	KAT 487	Gadam	Mexico R	KAT 369	KAT 487
No Cut	133.7c	211.0a	183.3b	182.7b	125.3c	200.6a	173.6b	172.2b
Cut 40 DAS	99.9de	147.5c	109.9d	138.7c	91.5de	139.2c	100.7d	129.3c
Cut 40-75 DAS	77.3e	88.2e	88.3e	96.9de	68.9e	79.5e	79.3e	88.5de
Cut 75 DAS	75.6e	97.2de	91.1e	99.6de	67.5e	88.6de	82.6e	90.8de
LSD P≤ 0.05		**15.95**				**16.20**		
CV %		**6.5**				**7.1**		

Means followed by the same letters or combination of letters are not significantly different according to Fisher's protected Least Significant Difference (LSD) at P ≤ 0.05.

4.2 Effect of Cutting Time and Variety on Number of Leaves for Sorghum 75 Days after Sowing

No differences were observed in vegetative growth of sorghum (number of leaves) for all cutting time treatments in season1 and season 2. The average number of leaves per plant across all cutting times was 9 and 8 in season 1 and 2, respectively. Sorghum varieties did not exhibit differences in number of leaves in either season. Vegetative growth (number of leaves) for each variety was slightly higher in season 1 across all sorghum varieties.

4.3 Effect of Cutting Time and Variety on Tillering in Sorghum

4.3.1 Effect of Cutting Time on Tillering in Sorghum

Irrespective of cutting time treatments, tillers per plant were observed to increase with maturity of crops. Differences in tillering of sorghum due to cutting time treatments were observed only in Gadam in season 2 with plants producing an average of 2 tillers each. There were no effects due to interaction of cutting time and variety on sorghum tillering in either season.

Relationship between number of Tillers per Plant with Time of Maturity of Sorghum

The number of tillers per plant increased with increase in maturity for all varieties as given by the linear and quadratic functions $y = -3.3725 + 0.101x$; $y = 4.349 – 0.129x + 0.001x^2$ and $y = -3.240 + 0.094x$; $y = 4.594 + 0.139x + 0.001x^2$ in season 1 and 2 respectively (Fig. 5a and Fig. 5b). The quadratic function was a better fit with $R^2 = 0.862$ compared to the linear function with $R^2 = 0.783$. Irrespective of cutting time treatments effects on the sorghum varieties, it is possible to predict tiller number with 86.2% confidence level using the quadratic function.

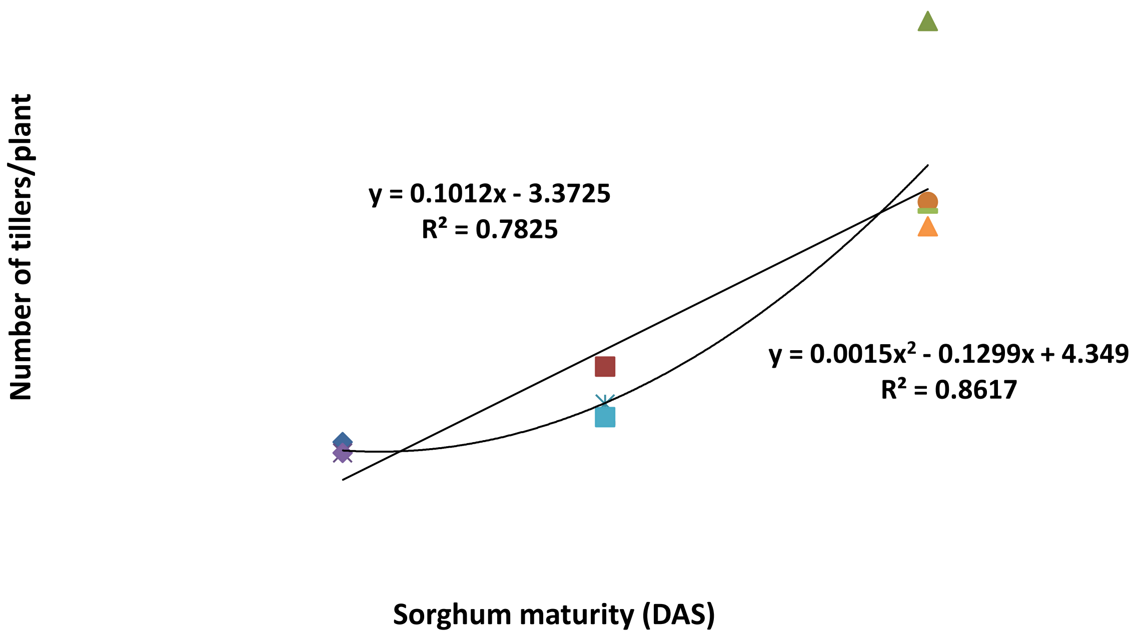

Figure 5a: Relationship between number of Tillers per plant with Time to maturity of sorghum varieties as affected by Cutting Time in Season 1 in Kiboko, Kenya

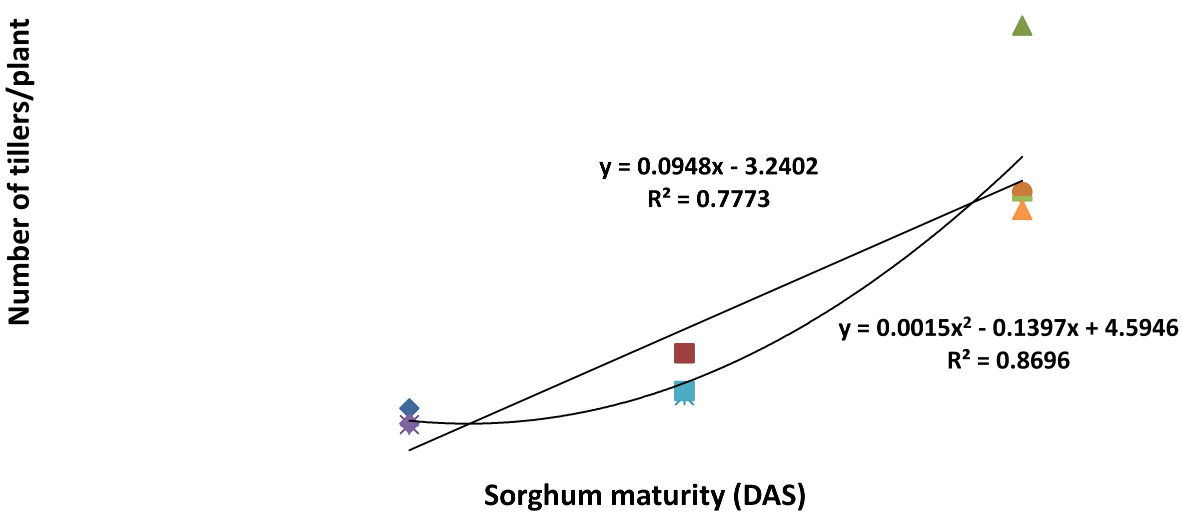

Figure 5b: Relationship between number of Tillers per plant with Time to maturity of sorghum varieties as affected by Cutting Time in Season 1 in Kiboko, Kenya

4.3.2 Effect of Sorghum Variety on Tillering

Significant differences in tiller production in sorghum due to varieties were observed in all varieties at 75 and 118 DAS in season 1 and season 2. Differences in tillering at 40 DAS for all sorghum varieties were only significant in season 2. Tillering was observed to increase with age of the sorghum. All sorghum varieties had the highest tiller numbers at 118 DAS. Gadam produced the highest average number of tillers at 40, 75 and 118 DAS in season 1 and season 2. The other three varieties did not differ significantly in tillering in either season (Table 5). Gadam variety had the highest number of tillers per plant at all cutting times followed by Mexico R Line 5, KAT 369 X F6 YQ 212 and KAT 487 which did not differ significantly with respect to number of tillers per plant (Table 3). However, the higher number of tillers per plant for variety Gadam did not confer advantage in terms of DM yield when compared to other varieties.

Table4: Effect of cutting time and variety on tillering in sorghum at Kiboko, Kenya during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014)

	Days after sowing					
	40		75		118	
Cutting treatment	**Season 1**	**Season 2**	**Season 1**	**Season 2**	**Season 1**	**Season 2**
No Cut	1.40	1.34	2.60	2.13b	8.99	8.32
Cut 40 DAS	1.40	1.39	3.06	2.50ab	9.47	8.89
Cut 40 - 75 DAS	1.60	1.43	2.84	2.71a	9.94	9.17
Cut 75 DAS	1.50	1.28	2.57	2.25b	8.48	7.94
LSD P≤ 0.05	**NS**	**NS**	**NS**	**0.361**	**NS**	**NS**
Variety						
Gadam	1.70	1.70a	3.75a	3.21a	13.13a	12.20a
Mexico R	1.40	1.25b	2.73b	2.04b	8.22b	7.63b
KAT 369	1.40	1.22b	2.21bc	2.17b	7.97b	7.45b
KAT 487	1.40	1.28b	2.38b	2.17b	7.56b	7.14b
LSD P≤ 0.05	**NS**	**0.086**	**0.4793**	**0.236**	**2.197**	**2.113**
CV %	**28.3**	**22.6**	**14.5**	**12.9**	**28.2**	**24.9**

Means followed by the same letters or no letters within a column are not significantly different according to Fisher's protected Least Significant Difference (LSD) at P ≤ 0.05

4.4 Effect of Cutting Time and Variety on Sorghum Fodder Yield

4.4.1 Effect of Cutting Time on Sorghum Fodder Yield

Sorghum fodder dry matter yield differed significantly across all cutting times at 40 DAS in both seasons. Sorghum cut at 40 then 75DAS (C_{40-75}) produced the lowest mean yield of 0.65 t/ha in season 1 while Cut 40DAS (C_{40}) had the second lowest mean fodder dry matter yield (0.69 t/ha) in season 2.Sorghum plants that were left to grow to maturity (C_0) produced the highest fodder DM yield of 11.87 t/ha and 9.54 t/ha at harvest in season 1 and season 2 respectively. Sorghum cut at 75 DAS (C_{75}) produced the lowest amount of DM of 3.19 t/ha and 2.45 t/ha at harvest in season 1 and 2 respectively (Table 4).

4.4.2 Effect of Sorghum Variety on Fodder Yield

Varieties showed significant influence on dry matter yield of sorghum at 40, 75 and 118 DAS in both seasons except during season 2 at 75 DAS (C_{75}). Variety Mexico R 5 produced the highest fodder DM yield in both seasons at all harvest intervals with a minimum DM fodder yield of 0.11 t/ha for cut 40 then 75 DAS (C_{40-75}) and a maximum of 7.15 t/ha for cut 75 DAS. Gadam had the lowest average fodder DM yield across all cutting time treatments (Table 4).

4.4.3 Effect of interaction between Cutting Time and Sorghum Variety on Fodder Yield

Significant interaction effects were observed for cutting time and sorghum variety on fodder yield for all cutting times in seasons 1and 2. Sorghum crops left to grow to maturity without cutting (C_0) produced the highest fodder DM yield among all varieties. Mexico R out yielded the other varieties with a fodder DM yield of 15.0 t/ha and 12.57 t/ha followed by KAT 487 in season 1 and 2 respectively. Gadam variety under no cut produced the lowest fodder DM yield of 9.2 t/ha and 7.0 t/ha in season 1 and 2, respectively. The treatment C_{75} produced the second highest quantity of fodder DM across all varieties and seasons. Mexico R Line 5under C_{75} was the highest yielding variety with a yield of 12.73 t/ha in season 1. Treatment C_{40} produced the lowest fodder DM yield among all varieties with Mexico R producing the highest amount of fodder DM of 0.74 t/ha in season 1(Table 5). A similar trend was observed in season 2.

4.4.4 Effect of Cutting Time on Cumulative Fodder Yield

Fodder yields under varying cutting times was combined for all cutting times at final harvest (118 DAS) i.e. cut once at 118 DAS under C_0, Cut twice at 40 and 118 DAS under C_{40}, cut twice at 75 and at 118 DAS under C_{75} and cut three times at 40 DAS, 75 DAS and 118 DAS underC_{40-75} respectively. The highest cumulative sorghum DM yields were obtained under C_{75} (12.5 t/ha) (Fig. 6a and Fig. 6b), followed by Co (11.9 t/ha) and C_{40} (5.4 t/ha) and C_{40-75} produce the lowest amount of fodder DM, in season 1. A similar trend was observed in season 2. Season 2 DM for all cutting treatments were slightly lower compared to season 1. This was attributed to poorer rainfall conditions in season 2 (Fig. 2).

4.4.5 Effect of interaction between Variety and Cutting Time on Cumulative Sorghum Fodder DM Yield

Cumulative fodder DM yield was computed for each sorghum variety at varying cutting time treatments (Table 9). For all cutting times, Mexico R Line 5 yielded the highest cumulative amount of fodder DM for no cut (C_0) treatment with yield of 15 t/ha and 12.57 t/ha followed by KAT 369 X F6 YQ 212 that yielded 11.67 t/ha and 9.4 t/ha in season 1 and 2, respectively. Variety Gadam produced the lowest quantity of fodder DM of 9.2 t/ha and 7.0 t/ha in seasons 1 and 2, respectively.

Cumulative fodder yield for C_{75} was observed to be slightly higher than that for C_0. This is because the cumulative fodder yield for C_{75} was computed from fodder cut at 75 DAS plus that cut at final harvest (118 DAS). Fodder yields for C_{40-75} and C_{40} were relatively lower as the crop for these cutting time treatments were cut either early in the growing season or re-growth.

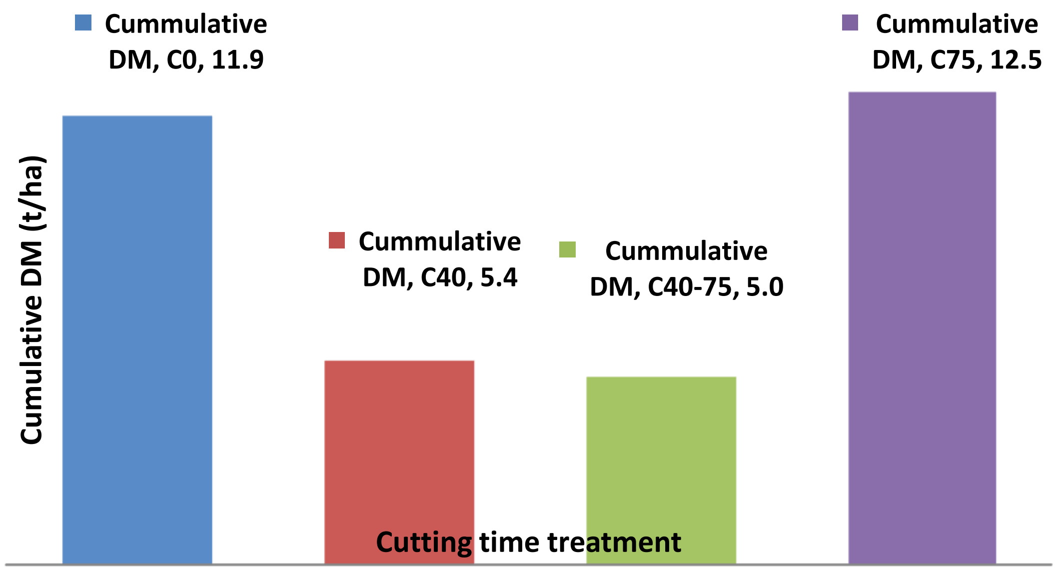

Figure 6a: Cumulative DM yield per cutting time treatment during S1 (Oct-Dec, 2013) and S1 (Mar-May, 2014) in Kiboko, Kenya

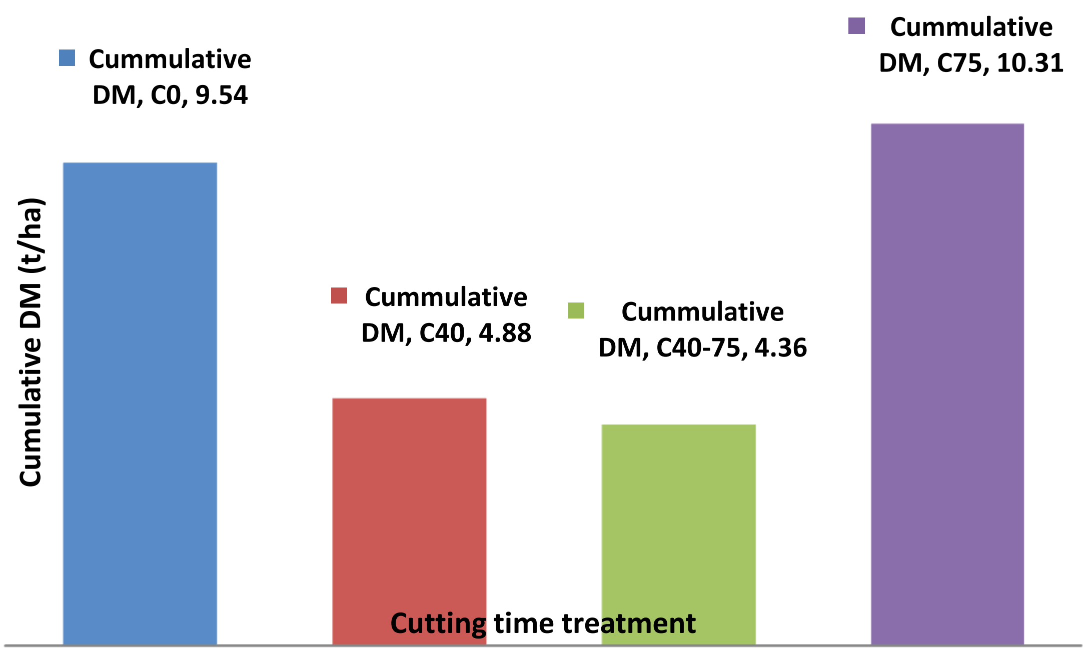

Figure 6b: Cumulative DM yield per cutting time treatment during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014) in Kiboko, Kenya

Relationship between Sorghum Varieties and Fodder Yield at Various Stages of Growth

The effect of varieties on fodder dry matter yield of sorghum at various stages of growth (DAS), when subjected to varying cutting time treatments is shown in Figure 9. Fodder DM increased with progress towards maturity of sorghum for all varieties. However, as growth progressed and by the 80th DAS, Mexico R Line 5 had significantly the highest fodder yield followed by KAT 487 and KAT 369 X F6 YQ 212 respectively. Gadam produced the lowest fodder yield by 118 DAS of only 4.56 t/ha and 3.52 t/ha in season 1 and season 2 respectively. Mexico R Line 5 significantly out yielded the other three varieties producing 7.15 t/ha and 6.02 t/ha in seasons 1 and 2 respectively. This was followed by KAT 487 (6.13 t/ha and 5.02 t/ha), KAT 369 X F6 YQ 212 (5.92 t/ha and 4.82 t/ha) in seasons 1 and 2 respectively. Mexico R Line 5 also produced the tallest plants from 75 DAS which accounted for the higher DM yield (Table 5).

Growth rate with respect to DM yield was observed to be highest for Mexico R Line 5 at 0.0868 t/ha/day followed by KAT 487 at 0.758 t/ha/day. Gadam had a dry matter accumulation rate of 0.0558 t/ha/day (Fig. 9). The production functions developed had coefficient of determination (R^2) of over 0.98 meaning they have high predictive value for determining fodder productivity for the four varieties (Fig. 9). The C_{40-75} treatment was removed from the fitting of the functions to avoid scattering of data. Furthermore, cutting sorghum twice at 40 then 75 DAS severely curtailed its growth and development for all the varieties.

Relationship between Sorghum Height and Dry Matter Yield at 118 DAS

Linear curves were fitted for each variety in season 1 and 2 to relate sorghum height at 118 DAS with above ground DM yield at 118 DAS. The R^2 values for Gadam were R^2 = 0.924 and 0.961for season 1 and season 2 respectively. KAT 487 had R^2 values of 0.909 and 0.940; Mexico R Line 5 had R^2 values of 0.807 and 0.812 while KAT 369 X F6 YQ 212 had R^2 values of 0.995 and 0.990 for season 1 and season 2 respectively (Fig.7). It therefore implies that the DM yield of sorghum for each respective variety can be estimated from known plant height at harvest (118 DAS) using these functions with over 92 % and 96 % reliability for Gadam; 91 % and 94 % reliability for KAT 487; 81 % and 81 % reliability for Mexico R Line 5 and 99.5 % and 99 % reliability for KAT 369 X F6 YQ 212 for season 1 and season 2 respectively.

Relationship between Varieties' Heights at 75 DAS with DM Yield at 118 DAS

Regression analysis was done to evaluate the relationship between height at 75 DAS with fodder DM yield at harvest (118 DAS) for each variety (Fig. 8a and Fig.8b). Results show that sorghum height at 75 DAS positively influences DM production at harvest. The rate of fodder production (t/ha) per unit increase in height (cm) was 0.284 and 0.246 for Gadam, 0.160 and 0.234 for Mexico R, 0.158 and 0.183 for KAT 369 X F6 YQ 212 and 0.159 and 0.258 for KAT 487 in season 1 and 2, respectively. The regression functions could account for more than 81% of the variations for all the varieties except Gadam in season 2. The rate of dry matter increase as influenced by height appeared to be highest for Gadam. Gadam however was the shortest (106 cm– 130cm) and produced the lowest quantity of fodder. Mexico R Line 5 was the tallest variety (134 cm – 206 cm) and out-yielded the other varieties. Crops were observed to be tallest under the no cut (C_0) treatment for all varieties and yielded the highest DM followed by C_{40}. It was evident that cutting later in the crop growth cycle interfered with re-growth and thus fodder DM production. C_{40} produced higher fodder DM at harvest (118 DAS) of between 3.1t/ha to 5.2 t/ha compared to C_{75} that produced between 1.9 t/ha and 3.7 t/ha of fodder DM. Extrapolation of linear regression for Gadam to a height of approximately 150 cm reveals that DM yields of up to 15 t/ha can be obtained if the variety was altered genetically to grow taller plants (Fig. 8a).

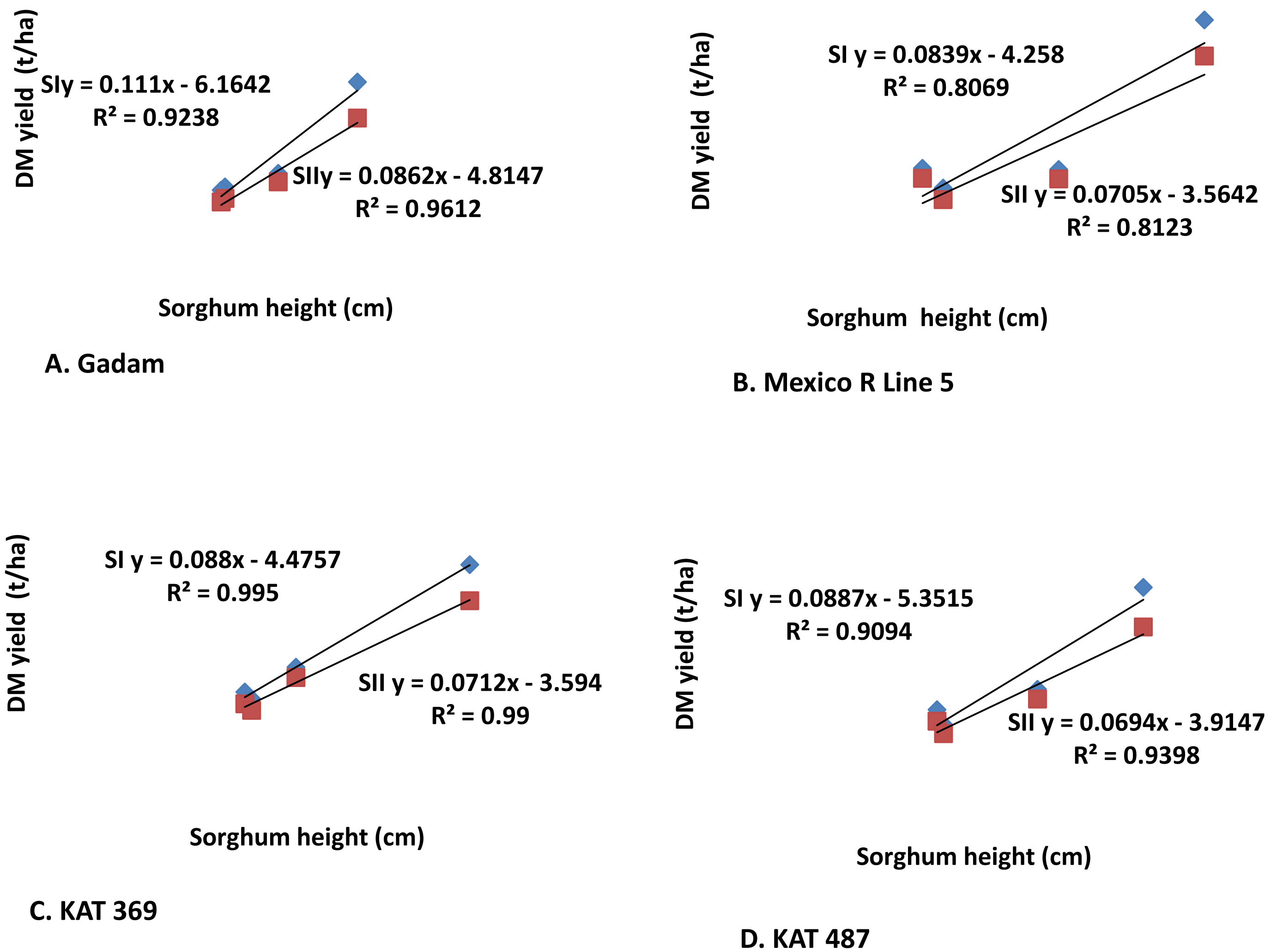

Figure 7: Relationship between sorghum height to DM yield by variety at 118 DAS during S1 and S2 at Kiboko, Kenya

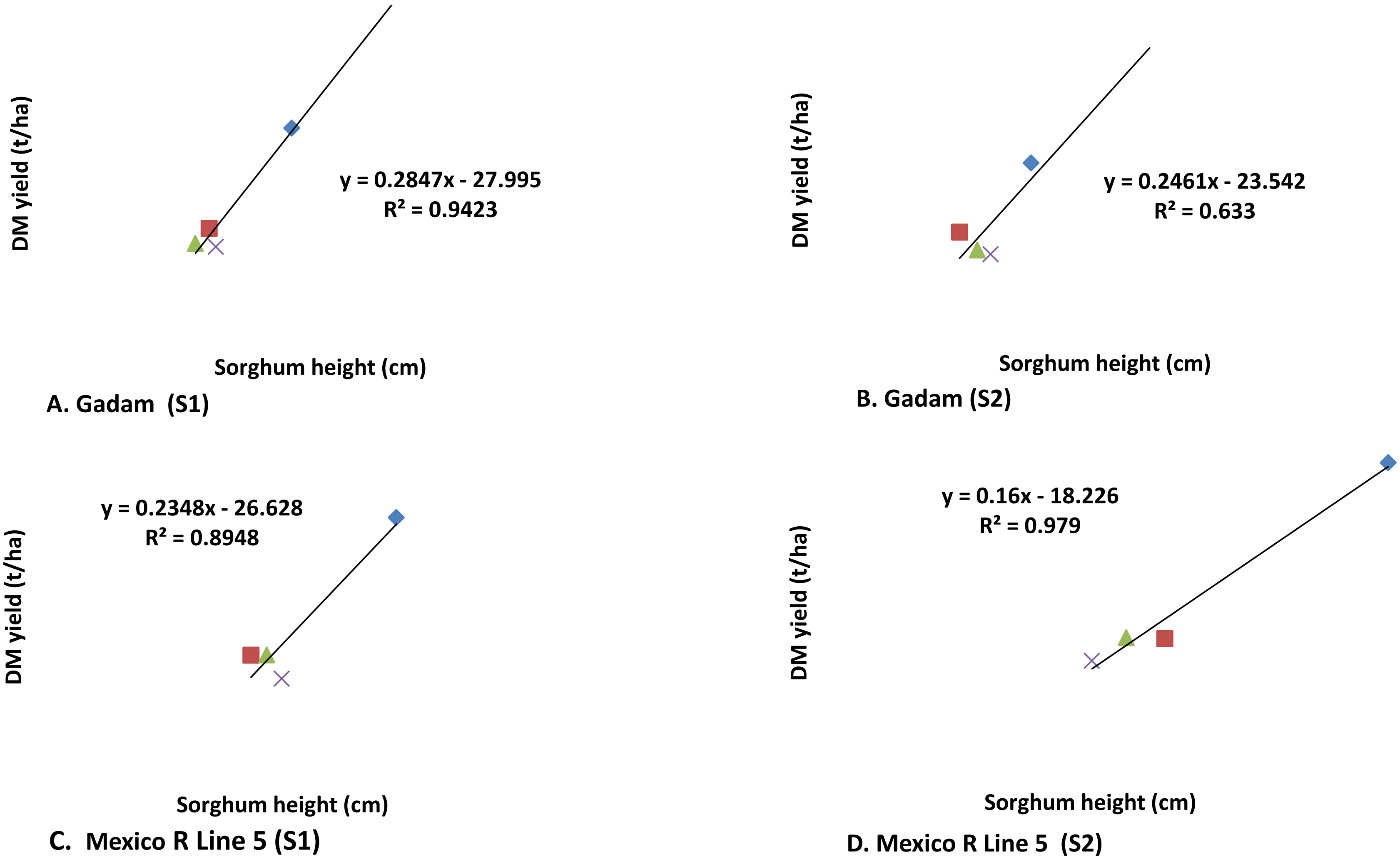

Figure 8a: Relationship between sorghum varieties' Gadam and Mexico R line 5 height at 75 DAS to DM yield at 118 DAS at Kiboko, Kenya

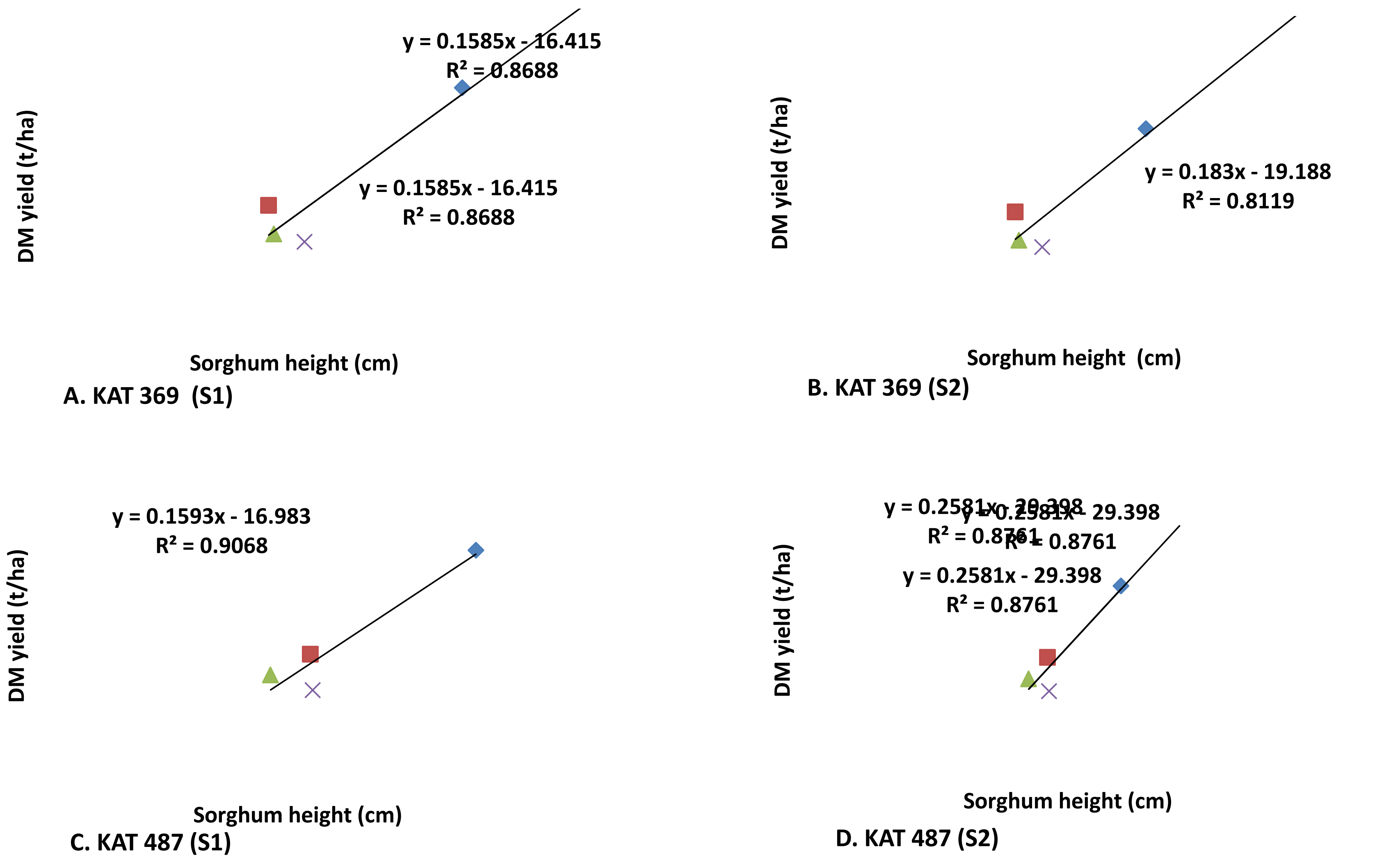

Figure 8b: Relationship between sorghum varieties KAT 369 X F6 YQ 212 and KAT 487 height at 75 DAS to DM yield at 118 DAS in Kiboko, Kenya

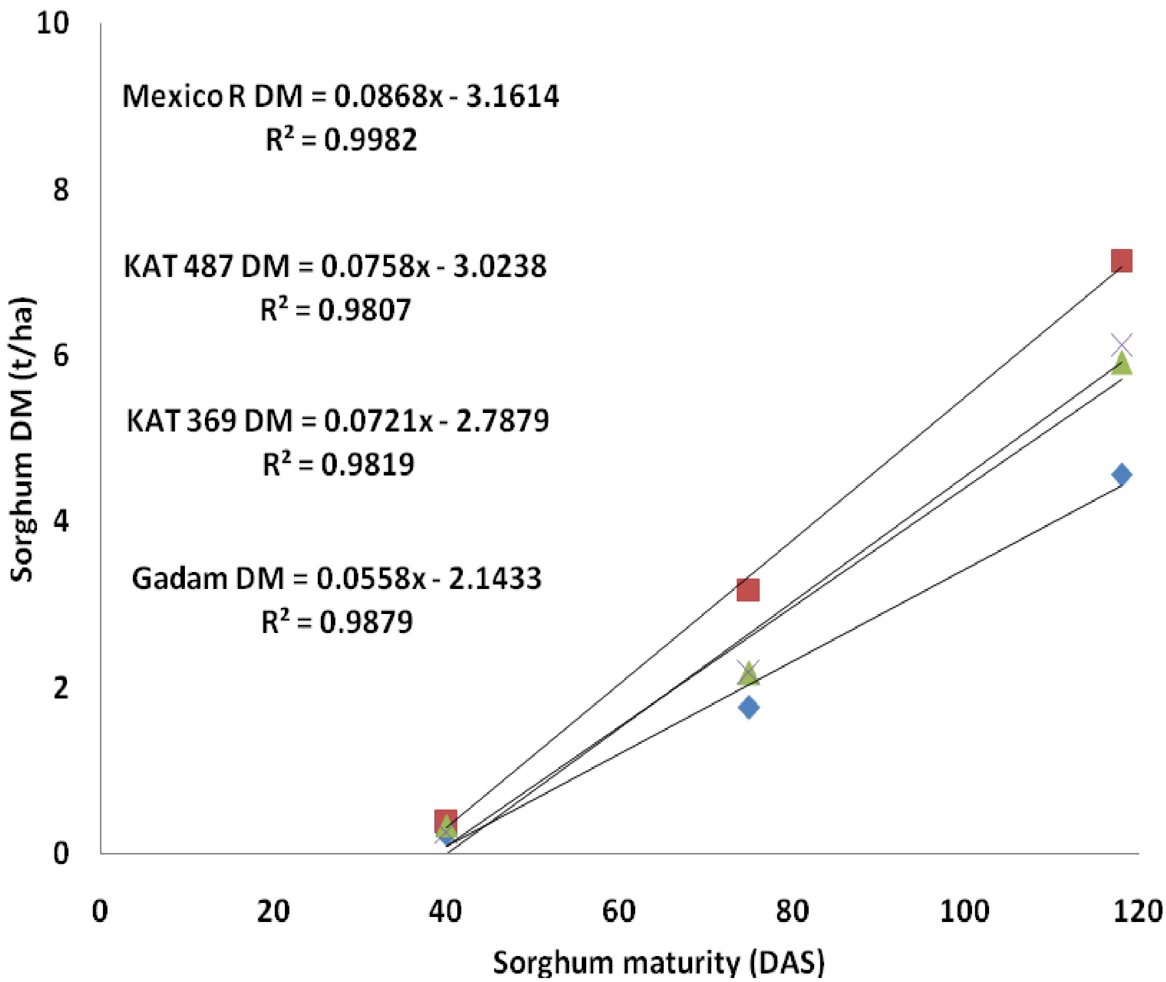

Figure 9: Relationship between sorghum varieties and DM yield under varying cutting time treatments

Table 5: Interaction between cutting time and variety on sorghum fodder dry matter yield (t/ha) 40 DAS at Kiboko, Kenya during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014)

	Variety		**Season 1**		**Season 2**			
Cutting time	Gadam	Mexico R	KAT 369	KAT 487	Gadam	Mexico R	KAT 369	KAT 487
No Cut	0.00f	0.00f	0.00f	0.00f	0.00	0.00	0.00	0.00
Cut 40 DAS	0.49e	0.74b	0.66bc	0.50e	0.56	0.78	0.74	0.70
Cut 40 - 75 DAS	0.47e	0.85a	0.69b	0.59d	0.67	0.68	0.68	0.61
Cut 75 DAS	0.00f	0.00f	0.00f	0.00f	0.00	0.00	0.00	0.00
LSD P≤ 0.05		**0.051**				**NS**		
CV %		**8.4**				**37.8**		

Means followed by the same letters or no letters within a column are not significantly different according to Fisher's protected Least Significant Difference (LSD) at P ≤ 0.05

Table 6: Interaction between cutting time and variety on sorghum fodder dry matter yield 40 and 75 DAS (t/ha) at Kiboko, Kenya during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014)

Cutting	**Variety**		**Season 1**		**Variety**		**Season 2**	
treatment	Gadam	Mexico R	KAT 369	KAT 487	Gadam	Mexico R	KAT 369	KAT 487
No Cut	0.00d	0.00d	0.00d	0.00d	0.00	0.00	0.00	0.00
Cut 40 DAS	0.00d	0.00d	0.00d	0.00d	0.00	0.00	0.00	0.00
Cut 40-75 DAS	0.35c	0.56a	0.36b	0.38b	0.48	0.45	0.50	0.49
Cut 75 DAS	0.00d	0.00d	0.00d	0.00d	0.00	0.00	0.00	0.00
LSD P≤ 0.05		**0.026**				**NS**		
CV %		**43.4**				**48.4**		

Means followed by the same letters or no letters within a column are not significantly different according to Fisher's protected Least Significant Difference (LSD) at P ≤ 0.05

Table7: Interaction between cutting time and variety on Sorghum fodder dry matter yield (t/ha) 75 DAS at Kiboko, Kenya during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014)

Cutting treatment	**Variety**		**Season 1**			**Season 2**		
	Gadam	Mexico R	KAT 369	KAT 487	Gadam	Mexico R	KAT 369	KAT 487
No Cut	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d
Cut 40 DAS	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d
Cut 40 -75 DAS	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d	0.00d
Cut 75 DAS	7.03c	12.73a	8.73b	8.73b	6.95c	9.66a	7.49b	7.33b
LSD P≤ 0.05		**0.801**				**0.245**		
CV %		**14.4**				**22.1**		

Means followed by the same letters within a column are not significantly different according to Fisher's protected Least Significant Difference (LSD) at P ≤ 0.05

Table8: Interaction between cutting time and variety on Sorghum fodder dry matter yield (t/ha) 118 DAS at Kiboko, Kenya during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014)

Fodder dry matter yield (t/ha)								
Cutting treatment	**Variety**		**Season 1**				**Season 2**	
	Gadam	Mexico R	KAT 369	KAT 487	Gadam	Mexico R	KAT 369	KAT 487
No Cut	9.20c	15.00a	11.67b	11.60b	7.00c	12.57a	9.40b	9.20b
Cut 40 DAS	3.63e	4.93de	5.20d	5.43d	3.10e	4.30de	4.53d	4.83d
Cut 40-75 DAS	2.80e	5.00d	3.63e	4.20de	2.10e	4.33de	2.87e	3.50bde
Cut 75 DAS	2.60e	3.67d	3.20e	3.30e	1.87e	2.90e	2.47e	2.75e
LSD P≤ 0.05		**1.289**				**1.335**		
CV %		**10.6**				**14.7**		

Means followed by the same letters within a column are not significantly different according to Fisher's protected Least Significant Difference (LSD) at P ≤ 0.05

Table 9: Interaction between cutting time and variety on cumulative fodder DM yields (t/ha) of sorghum varieties at varying cutting time treatments in S1and S2 at Kiboko, Kenya

	Variety							
Cutting Time Treatment	Gadam		Mexico R		KAT 369		KAT 487	
	S1	**S2**	**S1**	**S2**	**S1**	**S2**	**S1**	**S2**
C0	9.20	7.00	15.00	12.57	11.67	9.40	11.60	9.20
C40	4.12	3.66	5.67	5.08	5.86	5.27	5.93	5.53
C40-75	3.62	3.25	5.08	5.46	4.68	4.05	5.17	4.60
C75	9.63	9.05	16.40	12.56	11.93	9.66	12.03	10.08

4.5 Effect of Cutting Time and Variety on Sorghum Grain Yield

4.5.1. Effect of Cutting Time on Sorghum Grain Yield

Sorghum grain yield varied significantly with imposed cutting time treatments. Plants subjected to no cutting and cut 40 DAS (C_{40}) produced grains at harvest (118 DAS). Sorghum under no cut produced an average grain yield of 2.01 t/ha and 1.92 t/ha followed by cut 40 DAS with an average yield of 1.82 t/ha and 1.64 t/ha in season 1 and season 2 respectively. Plants subjected to cutting twice at 40 then 75 DAS (C_{40-75}) and those cut once at 75 DAS (C_{75}) did not produce grain at harvest (table 11). Season 2 grain yield for C_0 was significantly different while that in season 1 was not. The better performance of season 1 crop was attributed to the favorable rainfall distribution (Fig. 2) received after 40 DAS. This would have enabled better re-growth and thus recovery of the C_{40} crop.

4.5.2 Effect of Variety on Sorghum Grain Yield

Sorghum variety effect on grain yield was significant in season 1 only. KAT 487 was the highest yielding variety with an average grain yield of 1.27 t/ha and 1.22 t/ha followed by variety Gadam that yielded an average of 1.10 t/ha and 0.99 t/ha in season 1 and 2 respectively. KAT 369 had the lowest average yield of 0.69 t/ha and 0.65 t/ha in season 1 and 2 respectively.

4.5.3 Effect of Interaction between Cutting Time and Variety on Grain Yield

Interactions between sorghum variety and cutting time on grain yield were observed to be significant in both seasons. Variety KAT 487 produced the highest quantity of grain (2.66 t/ha and 2.59 t/ha) under no cut (C_0) treatment followed by variety Gadam (2.24 t/ha and 2.15 t/ha) in season 1 and 2 respectively (Table 10). Sorghum cut at 40 DAS (C_{40}) also produced grain at final harvest. Variety KAT 487 produced the largest quantity of grain under C40 of 2.42 t/ha and 2.27 t/ha, followed by Gadam (2.16 t/ha and 1.80 t/ha) in seasons 1 and 2 respectively. Sorghum cut at 75 DAS (C_{75}) and crop cut at 40 then 75 DAS (C_{40-75}) did not produce grain (Table 10).

4.6 Effect of Cutting Time and Variety on Sorghum 1000 Grain Weight

Cutting time affected 1000 grain weight in both seasons. Sorghum plants subjected to no cut treatment produced grain with an average weight of 29.83g and 28.67g per 1000 grains in season 1 and 2 respectively. Plants cut at 40 DAS produced grains with an average weight of 30.33 g and 28.33 g per 1000 grains in season 1 and 2 respectively. Sorghum subjected to cutting at 40 then 75 DAS and 75 DAS did not produce grain at harvest. There were no differences in 1000 grain weight of sorghum among the four varieties. Main effects of cutting time treatment led to a reduction in 1000 grain weight from 28.8g to 14.17g for variety KAT 487 and Gadam respectively.

Table 10: Interaction between cutting time and variety on Sorghum grain yield (t/ha) at Kiboko, Kenya during S1 (Oct-Dec, 2013) and S2 (Mar-May, 2014)

Cutting treatment	Variety		Season 1			Season 2		
	Gadam	Mexico R	KAT 369	KAT 487	Gadam	Mexico R	KAT 369	KAT 487
No Cut	2.24a	1.62c	1.49c	2.66a	2.15c	1.54e	1.41f	2.59a
Cut 40 DAS	2.16b	1.42c	1.28c	2.42a	1.80d	1.29g	1.20g	2.27b
Cut 40 - 75 DAS	0.00d	0.00d	0.00d	0.00d	0.00h	0.00h	0.00h	0.00h
Cut 75 DAS	0.00d	0.00d	0.00d	0.00d	0.00h	0.00h	0.00h	0.00h
LSD P≤ 0.05		**0.249**				**0.098**		
CV %		**7.9**				**5.7**		

Means followed by the same letters within a column are not significantly different according to Fisher's protected Least Significant Difference (LSD) at $P \leq 0.05$

4.7 Effect of Cutting Time and Variety on Economic Productivity of Sorghum

For purposes of computing the net incomes, the average price for sorghum grain was KEs. 3,600 per 90 kg bag for Nairobi, Machakos and Kitui markets as obtained from the monthly market prices by Kenya's Ministry of Agriculture. The prices of fodder were, KEs.5, 000 under C_0, KEs. 20,000 under C_{40} and C_{40-75} and KEs. 15,000 under C_{75} per tonne of dry fodder (Table 11). The economic productivity was calculated for a combination of cumulative fodder dry matter harvested at different times and grain harvested at the end of the growing season. The grain and fodder were converted into tonnes per hectare. From the study, cutting time and variety had effect on economic productivity of sorghum. Under C_0 and C_{40}, sorghum produced both fodder and grain. However, for crops harvested at 75 DAS, i.e., C_{40-75} and C_{75} treatments, the crop did not produce any grain.

When subjected to varying cutting time treatments, sorghum variety Mexico R Line 5 was observed to generate the highest net income of KEs. 198,990 and that translated to a Benefit: Cost ratio of 5.23 under C_{75}; followed by KAT 487 that generated a net income of KEs. 158,890 and a Benefit: Cost ratio of 3.81 under C_{40}, in season 1. Gadam generated the lowest net income and Benefit: Cost ratio of KEs. 24,190 and 1.50 respectively (Table 12a). Mexico R Line 5 produced the highest quantity of fodder DM of 16.40 t/ha under C_{75}in season 1.The large quantity of fodder generated under this cutting time treatment generated higher returns compared to a combination of fodder and grain that was produced under C_0 and C_{40} for KAT 487 that produced the highest grain yield of 2.66 t/ha in season 1 (Table 12a).

In season 2 however, KAT 487 under C_{40} was observed to generate the highest net income of KEs. 144,890 followed by Mexico R Line 5 with a net income of KEs. 141,390 under C_{75}.This is because fodder for KAT 487 under C_{40} generated higher returns compared to that for Mexico R under C_{75} due to differences in fodder costs. Mexico R Line 5 however, had higher Benefit: Cost ratio of 4.01, followed by KAT 487 with a Benefit: Cost ratio of 3.56 under C_{40} (Table 12b). The Benefit: Cost ratio for KAT 487 under C_{40} was lower than that for Mexico R Line 5 under C_{75} due to higher production costs for handling grain in KAT 487 under C_{40}. Gadam had the lowest net income of KEs. 16,790 and a Benefit: Cost ratio of 1.35 under C_{40-75}.

The respective benefit: cost ratios of Mexico R Line 5 cut at 75 DAS were higher than those of KAT 487 cut at 40 DAS in season 1 and season 2. This is because KAT 487 cut at 40 DAS produced grain. The extra costs incurred in bird scaring, harvesting and grain storage led to reduction in Benefit: Cost ratio of KAT 487 when compared to Mexico R Line 5 cut at 75 DAS which produced only fodder.

Table 11: Mean Prices of Sorghum Fodder and Grain

Cutting Time	**Harvesting time (DAS)**	**Sorghum Fodder(KEs / kg DM)**	**Sorghum Grain(KEs / 90 kg bag)**
C_0	118	5.00	3,600
C_{40}	40	20.00	3,600
C_{40-75}	40 and 75	20.00	-
C_{75}	75	15.00	-

Table 12a: Economic analysis of sorghum varieties fodder and grain productivity under varying cutting times in Kiboko, Kenya in season 1 (Oct-Dec 2013)

Variety	Cutting time	Fodder Yield t/ha	Grain Yield t/ha	Income from Grain (KEs)	Income from fodder (KEs)	Gross income (KEs)	TVC (KEs)	Net Income (KEs)	Benefit: Cost Ratio
Gadam	C_0	9.20	2.21	88400	46000	134400	54110	80290	2.48
	C_{40}	4.12	2.16	86400	82400	168800	56510	112290	2.99
	C_{40-75}	3.62	0.00	0.00	72400	72400	48210	24190	1.50
	C_{75}	9.63	0.00	0.00	144450	144450	47010	97440	3.07
Mexico R Line 5	C_0	15.00	1.62	64800	75000	139800	54110	85690	2.58
	C_{40}	5.67	1.42	56800	113400	170200	56510	113690	3.01
	C_{40-75}	5.08	0.00	0.00	101600	101600	48210	53390	2.11
	C_{75}	16.40	0.00	0.00	246000	246000	47010	198990	5.23
KAT 369X F6 YQ 212	C_0	11.67	1.49	59600	58350	117950	54110	63840	2.18
	C_{40}	5.86	1.28	51200	117200	168400	56510	111890	2.98
	C_{40-75}	4.68	0.00	0.00	93600	118600	48210	70390	2.46
	C_{75}	11.93	0.00	0.00	178950	77550	47010	30540	1.65
KAT 487	C_0	11.60	2.66	106400	58000	164400	54110	110290	3.04
	C_{40}	5.93	2.42	96800	118600	215400	56510	158890	3.81
	C_{40-75}	5.17	0.00	0.00	103400	103400	48210	55190	2.14
	C_{75}	12.03	0.00	0.00	180450	180450	47010	133440	3.84

TVC: Total Variable Cost

Table 12b: Economic analysis of sorghum varieties fodder and grain productivity under varying cutting times in Kiboko, Kenya in season 2 (Mar-May 2014)

Variety	Cutting time	Fodder Yield t/ha	Grain Yield t/ha	Income from Grain (KEs)	Income from fodder (KEs)	Gross income (KEs)	TVC (KEs)	Net Income (KEs)	Benefit: Cost Ratio
Gadam	C0	7.00	2.15	86000	35000	121000	54110	66890	2.24
	C40	3.66	1.80	72000	73200	145200	56510	88690	2.57
	C40-75	3.25	0.00	0.00	65000	65000	48210	16790	1.35
	C75	9.05	0.00	0.00	135750	135750	47010	88740	2.89
Mexico R Line 5	C0	12.57	1.54	61600	62850	124450	54110	70340	2.30
	C40	5.08	1.29	51600	101600	153200	56510	96690	2.71
	C40-75	5.46	0.00	0.00	109200	109200	48210	60990	2.27
	C75	12.56	0.00	0.00	188400	188400	47010	141390	4.01
KAT 369X F6 YQ 212	C0	9.40	1.41	56400	47000	103400	54110	49290	1.91
	C40	5.27	1.20	48000	105400	153400	56510	96890	2.71
	C40-75	4.05	0.00	0.00	81000	81000	48210	32790	1.68
	C75	9.66	0.00	0.00	144900	144900	47010	97890	3.08
KAT 487	C0	9.20	2.59	103600	46000	149600	54110	95490	2.76
	C40	5.53	2.27	90800	110600	201400	56510	144890	3.56
	C40-75	4.60	0.00	0.00	92000	92000	48210	43790	1.91
	C75	10.08	0.00	0.00	151200	151200	47010	104190	3.22

TVC: Total Variable Cost

CHAPTER FIVE

DISCUSSIONS

5.1 Effect of Cutting Time and variety on Morphology, Yield, Yield Components and Economic Productivity of Sorghum

Cutting was observed to reduce sorghum height and consequently fodder DM productivity. This agreed with Roy & Khandaker (2010) who reported a reduction in plant height and fodder DM yield in sorghum during subsequent cuts. Height was also found to be strongly correlated with fodder DM yield. Taller crops yielded significantly higher fodder DM irrespective of cutting time treatment. Cutting slowed down the rate of vegetative growth by between 24 % and 50.6 % for sorghum cut at 40 DAS and 40 then 75 DAS respectively.

The correlation between cutting time to sorghum height was found to have high coefficients of determination of over 0.98. The greatest sorghum height of about 180 cm was measured for C_0 at 90 DAS followed by C_{40} with 130 cm by 95 DAS. Beyond 100 DAS height declined for the cut sorghum plants. The findings of Jorgensen *et al,* (2010) recorded that cutting influences sorghum vigor and re-growth. Sorghum cut more than once (C_{40-75}) and that cut close to maturity (C_{75}) at post -anthesis would produce shorter crops and lower fodder DM yield due to interference in composition of biomass during grain filling (Pasquale & Rosella, 2005). Height of sorghum subjected to varying cutting time treatments was observed to be significantly different at final harvest (118 DAS). Sorghum that was cut more than once (C_{40-75}) produced relatively shorter plants compared to those cut once i.e., 40 or 75 DAS, regardless of cutting time. This agreed with Akash & Saoub (2002) who found that cutting time influences growth parameters and fodder yield of sorghum. Cutting closer to maturity was observed to reduce sorghum height. Therefore at maturity, crops cut at 40 DAS that had a longer re-growth period of about 80 days, were significantly taller than those cut at 75 DAS. This implies that cutting interferes with vegetative growth and re-growth in sorghum leading to reduction in overall height and fodder DM yield.

Regression analysis to evaluate relationship of sorghum height at 75 DAS to fodder DM yield at final harvest (118 DAS), indicated a positive relationship between height and DM yield with a confidence of more than 81 %. Ayub *et al.*, (2010), reported that taller sorghum varieties produced higher fodder yields compared to shorter varieties. The rate of increase in fodder DM per unit increase in height (cm) ranged between 0.16 t/ ha / cm and 0.284 t /ha / cm across all the sorghum varieties. Extrapolation of the linear regression for Gadam variety to a height of 150 cm revealed that fodder production of up to 15 t/ha can be obtained; if it can be improved genetically to grow to that height.

From regression analysis developed to evaluate relationship between sorghum height and fodder DM yield potential, it can be concluded that selection of sorghums for fodder production should preferably be of taller genetic stature at over 175 cm height by the 75^{th}DAS.This would guarantee the farmer over 9-11 tons $ha^{-1}$of fodder depending on rainfall, other environmental and management factors such as cutting. Breeding for taller sorghum crop varieties that have a fast growth rate of over 240kg DM/ha/cm height for increased DM production is therefore worth consideration.

Based on relationships developed for sorghum height and DM yield, it was observed that sorghum height at 75 DAS is positively related to fodder yield at final harvest (118 DAS). Such relationships can be used to predict sorghum fodder yield potential at final harvest to enable the farmers to plan for effective fodder utilization such as storage, feeding management, preservation or sale.

Sorghum fodder yield differed significantly among cutting times in both seasons. The quantity of fodder increased with increase in age to maturity of sorghum. As the crop matures there is increase in size and number of yield components such as leaves and stems. Subsequent increase in lignin, cellulose and hemi-cellulose coupled with decreasing amounts of plant water content leads to increase in dry matter (Atis *et al,* 2012).Crops cut early in the growing season (C_{40}) produced low amounts of fodder compared to those that were cut later in the season (C_0 and C_{75}). Akash &Saoub (2002) and Intikab *et al,* (2013), reported a negative effect of cutting on growth and fodder yield in sorghum due to interference in the crop physiological processes.

Sorghum fodder DM yield was observed to differ significantly among varieties. Variety Mexico R consistently produced the highest fodder yields followed by KAT 369. These varieties also produced taller varieties compared to KAT 487 and Gadam. Gadam which is a short variety produced the lowest quantities of fodder. Yousef *et al.,* (2009), Safraz *et al,* (2012) and Amir *et al,* (2014), reported fodder yield advantage among varieties that produced bigger, taller plants with more leaves and thicker stems. Ammanullah *et al,* (2007), Hussain *et al,* (2011) and Ghasemi *et al,* (2012) observed significant differences in fodder yield among sorghum varieties.

It is therefore preferable to grow taller sorghum varieties such as Mexico R Line 5 and KAT 369 in order to maximize fodder production.

When cumulative sorghum fodder DM yield was computed for each cutting time treatment plus final harvest, yield differentials were observed to follow a similar pattern to the differences among varieties.

Mexico R Line 5 had the highest cumulative fodder DM yield of 16.4 t/ha. Fodder DM yield increased with the increase with maturity which agreed with Atis *et al,* (2012). Therefore, cutting later at75 DAS (C_{75}) yielded higher than cutting at 40 DAS. The highest cumulative fodder yield was the no cut (C_0) harvested at 118 DAS. Roy & Khandaker (2010) also reported an increase in fodder DM in crops harvested in subsequent cuts.The combined yield of sorghum cut at varying times produced higher fodder yields compared to that cut only at maturity under the no cut treatment. Roy &Khandaker, (2010) and Intikhab *et al,* (2013) reported increases in green fodder and dry matter yield among double cut plants as compared to single cut plants. Treatment C_{40-75} yielded the lowest quantity of fodder DM.

Tiller counts for three sorghum plants were determined just before cutting time treatments were imposed and the average computed for tillers per plant. It was observed that cutting tended to enhance tillering. Crops subjected to C_0 were observed to have lower tiller numbers per plant compared to the other cutting treatments. This is in agreement with the findings of Intikhab *et al,* (2013) who reported increased tillering due to cutting. Tillering however, did not increase DM and grain yield production for the cultivars under study.

Though no significant effects of cutting time or variety on number of tillers per sorghum plant were observed, tiller numbers generally increased with maturity of crop from less than two to approximately 9 tillers per plant by 118 DAS. The rate of increase was evident after 80 DAS. This is the period of grain filling; implying that for the crop to support significant reproductive growth, sufficient nutrition and watering should be available. Therefore, further trial to evaluate the effect of varied levels of nutrition after cutting sorghum is recommended, particularly for Mexico R Line 5 which produced the highest cumulative fodder DM yield (12-16 t/ha) and KAT 487 (10-12 t/ha).

Subjecting sorghum to cutting at 75 DAS becomes detrimental to further growth and development. This resulted in the suppression of continued growth, from the point of decapitation, which on the other hand, enhanced tillering. This enhanced tillering when sorghum is cut at 75 DAS did not apparently confer advantage on Gadam variety in relation to above ground biomass. Varieties Mexico R Line 5, KAT 369 and KAT 487 which had lower tillering ability compared to Gadam had a higher rate of growth and thus higher DM production which was attributed to their tall stature (Ayub *et al,* 2010).

Significant differences in 1000 grain weight were observed among cutting time treatments. This was attributed to the fact that sorghum cut at 40 followed by a second cut at 75 DAS (C_{40-75}), and one cut treatment at 75 DAS (C_{75}),respectively did not produce grain. Sorghum cut at 40 DAS (C_{40}) and the crop that was not cut produced grain that did not significantly differ in the test weight. However, sorghum that was subjected to no cut produced slightly heavier grain compared to that cut at 40 DAS. This would indicate that cutting sorghum slightly reduces the test weight and consequently the grain weight of cut crops. This is in agreement with Akash & Saoub (2002), who reported significant differences in 1000 seed weight due to the effect of cutting. This finding informs that cutting early in the growth period of sorghum does not significantly affect the physiological process of grain formation. This is because the flowering period for sorghum occurs after 55 DAS, thus cutting at 40 DAS would not affect grain formation and consequently the test and grain weight as compared C_0crops that are left to grow to maturity without cutting. Grain filling is dependent on photosynthetic assimilates produced and stored in the leaves and stem biomass. Therefore, crops with higher biomass (and height) have higher assimilates (sources) for use in grain filling (sink) than shorter crops.

Kat 487 produced significantly higher grain yields while Mexico R Line 5 was observed to produce the highest quantities of fodder DM under all cutting time treatments. Therefore these two varieties differ in their productive ability of the respective economic yields, that is, grain and fodder. These findings concur with those of Cleto *et al,* (2014) who reported a highly significant effect of varieties on fodder and grain yield in a study of four different varieties.

Despite its short stature, Gadam is a prolific grain producer compared to the taller varieties. This means that it mines less quantity of soil nutrients to produce higher grain yields but lower dry matter yield. On the other hand KAT 487 has the ability to produce both high DM and grain yield, implying that it has a higher nutrient up take which it concentrates in its bulkier biomass. This gives it advantage as a fodder crop when harvested at either 40 or 75 DAS for fodder production.

Farmers whose objective would be fodder production would maximize their returns if they harvested fodder at 75 DAS (C_{75}). Cutting at this time would provide nutritious fodder for livestock with reasonable economic returns of over 500% (Table 12a). The Sorghum fodder dry matter yield when cut at 75 DAS is comparable to that harvested at maturity. Fodder harvested at 75 DAS is however more nutritious and is therefore likely to compensate for fodder loss in terms of increased productivity from livestock. This is because the protein content, digestibility and the energy content decrease as the crop matures (Atis *et al,* 2012).

On the other hand farmers who would wish to produce fodder for livestock and grain for human consumption can produce both within the same growing season with higher rainfall by cutting fodder 40 DAS (C_{40}) and allowing the crop produce grain at maturity. Though cutting 40 DAS compromises on fodder productivity, the practice is likely to produce fodder of high nutritional value for livestock at 40 DAS, whose benefits would be observable during livestock growth and productivity.

Sorghum trade in Kenya is generally limited due to low biomass production volumes as majority of farmers produce to meet their subsistence needs only, with little surplus to sell (Ochieng, 2011). Selection of high yielding sorghum cultivars is likely to reverse this situation and lead to increase in farm incomes and productivity among sorghum farmers. The quantity and range of processed Sorghum products sold in local supermarkets such as sorghum flour is in great demand also (Chemonics, 2010).The sorghum varieties particularly Mexico R and KAT 487 evaluated in the current study have the capacity to produce large quantities of fodder (over 10 t/ha) and while KAT 487 and Gadam have capacity to produce large quantities of grain (over 2.2 t/ha) and thus have potential to generate high incomes for farmers in semi arid Makueni region of Kenya.

Though the differences in 1000 grain weight were not significant among varieties, variety Mexico R produced slightly larger grains followed by Gadam in season 1. KAT 369 and KAT 487 however had slightly larger grains in season 2. This concurred with the findings of Abdel-Motagally (2010) and Atopkle *et al,* (2014) who opined that grain weight significantly, differed among sorghum varieties. This implies that the varieties KAT 369 and KAT 487 may be more drought tolerant compared to Mexico R and Gadam as the rainfall distribution in season 2 (188.5 mm) was poorer than season 1 (245.4 mm). Sorghum grain yields varied significantly with imposed cutting time treatments. This was attributed to the fact that crops cut at 40 then 75 DAS (C_{40-75}) and 75 DAS (C_{75}) did not produce grain at final harvest (118 DAS).

This is due to the interference with flowering which takes place at approximately 55 DAS by cutting at 40 DAS and again at 75 DAS for C_{40-75} and C_{75}. The crop cut at 75 DAS for both cutting treatments (C_{40-75} and C_{75}) would have flowered by 75th day after sowing thus the grain producing ears are cut as fodder. This was attributed to the crops inability to produce vegetative growth because the reproductive growth phase had commenced and the sink for assimilates was not being translocated to the vegetative material. The sink for photosynthetic assimilates is the grain during the reproductive to maturity stages in cereals. Therefore, growth was inhibited hence there was no grain. The findings of Akash & Saoub (2002), reported a negative effect of cutting on growth and yield of sorghum. Cutting after 55 DAS interferes with the reproductive cycle of sorghum thus no further grain can be produced by the plants within the remaining period of the growing season (43 days). Sorghum that was left to grow to maturity without cutting (C_0) produced higher grain yield compared to C_{40}. Grain yield in season 2 was lower than season 2 due to poorer distribution of rainfall during the season.

There were significant differences in grain yield among sorghum varieties. Variety KAT 487 out-yielded the other varieties followed by Gadam. The average yields for each variety were slightly higher in season 1 compared to season 2 due to a better distribution of rainfall in season 1. Selection of KAT 487 and Gadam varieties is advisable to maximize grain yield. Both varieties produced significantly shorter crops. This may suggest that shorter sorghum crops are suitable for grain. Further studies are recommended to establish whether productivity potential for grain is correlated with height of sorghum. The findings were in agreement with those of Parameswarappa & Lamani (2005), Nazir *et al*,(2011), Ouma & Akuja (2013) and Atokple *et al*, (2014) who reported significant differences in grain yield among sorghum varieties.

From the analysis of economic productivity of sorghum varieties under varying cutting time treatments, it was apparent that Mexico R Line 5 variety under C_{75} produced the highest net income and Benefit: Cost ratio of 5.23. Though the crop under C_{75} yielded only fodder, Mexico R Line 5 produced a large quantity of fodder from cutting at 75 DAS and re-growth cut at final harvest (118 DAS). It was apparent that the season I (Oct – Dec 2013) crop gave better economic returns than the season II (Mar – May 2014) crop. This was attributed to better rainfall (245.4 mm) in SI than in SII (188.5mm). Crops grown under higher rain environment of in season 1 had better re-growth and therefore gave subsequent higher yields of either grain or fodder biomass. Farmers in better rainfall environments should grow Mexico R Line 5 for fodder production cut at 75 DAS in order to get a higher benefit: cost ratio of 5.23. In drier environments, KAT 487 may prove a better variety if cut at 40 DAS compared to cutting Mexico R Line 5 at 75 DAS that resulted to a lower net income.

By 75 DAS, the crop has completed grain formation and therefore produces high quantities of fodder. KAT 487 however produced relatively high net incomes from a combination of fodder cut at 40 DAS and grain. The extra costs of harvesting grain, handling and storage of grain increased production costs for KAT 487 under C_{40} leading to a lower net income compared to fodder only for Mexico R Line 5 in season 1.

This implies that for farmers interested in producing fodder for livestock feed and grain for human food, KAT 487 is preferable as a dual purpose variety. Allowing sorghum to grow to maturity without cutting produces a large quantity of fodder. The fodder is however of low nutritional quality and is composed of woody stems and low leaf: stem ratio. Such fodder is unlikely to attract good returns compared to fodder cut earlier in the growing season. Reddy *et al*, (1995) and Hash *et al*, (2000), reported that nutritional quality of sorghum fodder decreases as the crop matures. This is because the protein content, digestibility and the energy content decrease as the crop matures (Atis *et al*, 2012).

Comparison of the net incomes and Benefit: Cost ratio for season 1 and season 2 reveals that while production costs were the same, the returns were higher for season 1 (October-December) crop. This was attributed to better seasonal rainfall in season 1 (245.4 mm) compared to season 2 (March-May) of 188.5 mm. Availability of moisture during the growth period and more so after cutting is considered to be essential in the growth and subsequent post-cutting re-growth and grain production in sorghum.

CHAPTER SIX
CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

This study demonstrated the significance of selecting appropriate sorghum (*Sorghum bicolor* (L) Moench) varieties to maximize grain and fodder yield in semi arid Makueni. Effects of fodder cutting time and sorghum variety were determined for four varieties. Fodder and grain yield suitability as well as the economic productivity of each cutting time and variety was determined. Based on the findings, the following conclusions can be made:

i. Variety Mexico R Line 5 was found best for fodder production yielding a maximum cumulative fodder DM of 16.4 t/ha under the C_{75} cutting time treatment while variety KAT 487 was found to be the best for production of both fodder and grain due to its potential to produce large quantities of grain (2.27-2.66 t/ha) at harvest under C_0 and C_{40}as well as high quantity of fodder DM (10-12 t/ha) under C_{75} cutting time treatments respectively.

ii. Delayed cutting time was observed to enhance dry matter accumulation. For this reason, the no cut treatment C_0 produced the highest fodder DM for all sorghum varieties followed by the 75 DAS and 40 DAS cutting respectively. The highest fodder DM yields under no cut ranged between 9.54-11.87 t/ha.

iii. Plant height is a useful trait in selecting for fodder yield potential as taller plants with or without cutting produced higher quantity of fodder compared to shorter varieties.

iv. Mexico R Line 5 gave the highest net income of over KEs. 190,000 in season I (Oct-Dec 2013) that had a better rainfall with a Benefit: Cost ratio of 5.23 from fodder production only, harvested at the 75th DAS.KAT 487 gave the highest net income of over KEs. 140,000 with a Benefit: Cost ratio of 3.56 in the drier season 2 (Mar – May) from a combination of both grain and fodder yield when cut 40 at DAS.

6.2 RECOMMENDATIONS

From this study, the following recommendations can be made:

i. Farmers in should grow Mexico R Line 5for fodder and harvest preferably after 75 days after sowing to maximize fodder production or KAT 487 for both fodder and grain among the four varieties and cut for fodder at 40 DAS, then harvest grain at maturity.

ii. Farmers should select and grow taller sorghum varieties such as Mexico R Line 5 and KAT 487 that have the potential to produce large quantities of fodder. Sorghum Breeders should also focus on breeding for taller varieties with potential for higher fodder yield.

iii. To obtain high net income from sorghum farming, either variety Mexico R should be grown for fodder and cut at 75 days after sowing or variety KAT 487 and cut at 40 days after sowing for fodder and harvest grain at maturity.

iv. Further studies to determine the effect of cutting time and variety on fodder, grain yield and economic productivity of sorghum under varying water environments should be carried out.

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APPENDICES

Appendix 1: Variable production costs for sorghum in season 1 (Oct-Dec 2013) and season 2 (Mar-May 2014) at Kiboko, Kenya

SNo.	Activity/item	No of units	Rate/unit (KEs)
1	Land Ploughing	1 ha	4500
2	Sowing labor	10 md	300
3	NPK	30 kg	80
4	CAN	40kg	60
5	Seed cost	6kg	150
6	Weeding labor	50md	300
7	Pesticides cost (various)	various	6000
8	Crop protection labor	3md	300
9	Irrigation	8 sessions	626
10	Bird scaring labor	Monthly wage	5000
11	Grain harvesting labor	10	300
12	Gunny bags	30	50
13	Fodder cutting labor	C_0 = 15 md; C_{40} = 23 md; C_{40-75} = 27 md; C_{75} = 23 md	300

md = Man days

Appendix 2: Sorghum trade and production in Kenya 2005-2011

Unit	2005	2006	2007	2008	2009	2010	2011
Production (T)	150,127	131,188	147,365	54,262	94,955	164,066	159,877
Imports (T)	10,948	16,691	5,105	3,301	58,822	10,035	37,613
Exports (T)	734	97	919	892	1,503	49,709	276
Trade Balance (T)	-10,213	-16,594	-4,186	-2,409	-57,320	39,674	-37,337
Self-Sufficiency Ratio %	94%	89%	97%	96%	62%	132%	81%

Source MOA-ERA 2009 & 2012, UN Comtrade 2010; GTA 2012

Appendix 3: Temperature, Relative Humidity and Rainfall data during the growing season at Kiboko, Kenya

YEAR: 2013

Month	Mean Min Temp	Mean Max Temp	RH	Rainfall
January	18.1	31	89.5	29.50
February	17.3	33.1	81.4	0.00
March	20.1	33	82.4	58.30
April	19.5	31.7	91.8	228.20
May	16.5	30	90.6	36.00
June	14.8	27.8	90.9	0.00
July	14.2	27.5	87.5	3.00
August	14.9	27.5	84.8	0.00
September	15.6	30.7	86.1	0.00
October	17	32.9	83.6	2.00
November	18.7	30.5	87.9	102.00
December	18	29.1	89.1	84.50

YEAR: 2014

Month	Mean Min Temp	Mean Max Temp	RH	Rainfall
January	17	30.7	90.4	0.00
February	18.4	32.5	89.2	55.00
March	19.3	31.9	85.6	186.50
April	19.5	31.4	89.2	42.50
May	16.6	30.2	86.6	12.40
June	15.5	28.9	85.4	4.00
July	14	27.9	85.9	0.40
August	14.2	29.5	80.7	0.00

Source: ICRISAT field station, Kiboko Kenya