ADAPTABILITY OF PEARL MILLET (*Pennisetum glaucum* (L.)R.Br) VARIETIES IN THE SEMI-ARID KITUI COUNTY OF KENYA

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DECLARATION

I understand that plagiarism is an offence and I therefore declare that this thesis report is my original work and has not been presented to any other institution for any other award.

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DEDICATION

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ABBREVIATION AND ACRONYMS

%	Percentage
ANOVA	Analysis of Variance
ANOVA	Analysis of Variance
ASALS	Arid and semi-arid lands
B. C.	Before Christ
CEC	Cation Exchange Capacity
cm	Centimeter
CSO	Cooperatives and central statistical office
DFF	Days to fifty (50) percent flowering
DFM	Days to fifty (50) percent maturity
DMRT	Duncan multiple range test
DTA	Days to Anthesis
ECA	East and Central Africa
ERA	Economic Review of Agriculture
et al.	et alia (with other people)
FAO	Food Agricultural Organization
g	gramme
GoK	Government of Kenya
GY	Grain yield
H	Height
HA	Hectare
HI	Harvest Index
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics
IFAD	International Fund for Agricultural Development
IPGRI	International Plant Gentic Resources Institute
KALRO	Kenya Agricultural and Livestock Research Organization
KARI	Kenya Agricultural Research Institute
lsd	least significance difference
MACO	Ministry of Agriculture and central statistical office
MoA	Ministry of Agriculture

NCR	National Research Council
PM	Pearl Millet
PVS	Participatory variety selection
RUE	Rainfall use efficiency
SAT	Semi Arid Tropics
SEKU	South Eastern Kenya University
SSA	Sub-Saharan Africa
USAID	United States Agency for International Development

ABSTRACT

Cereals are important crops grown and consumed globally, regionally and locally. However, world cereal yields have declined due to frequent droughts, erratic and unreliable rainfall especially in sub-saharan Africa. Pearl millet accounts for almost half of the global production of the millet species. Therefore, identifying high yielding pearl millet genotypes with farmer preffered traits and adapted to drought stress is key for food security. The objective of the field study was to determine the adaptability of pearl millet varieties for the arid and semi-arid lands (ASALs). Field experiments were carried out in South Eastern Kenya University. The experiment was laid out in a Randomized complete block design with three replications. Data on growth and yield parameters were collected over the three seasons. The data were analyzed statistically and means were compared at 5% level of probability. The results indicated that genotype PVS-PM 1005 recorded significantly ($P<0.05$) for grain yield compared to other five genotypes. The average grain yield ranged from 835kgha^{-1} (Kimbeere) to 1453kgha^{-1} (PVS-PM 1005). There was a significant and positive correlation between grain yieldha^{-1} and days to emergence (0.5366), days to anthesis (0.641), days to flowering (0.0098), height (0.0685), Spike length (0.0145), tillers per plant (0.385) and 1000 grain weight (0.01533). The study therefore recommends PVS-PM 1005, PVS-PM 1006 and PVS-PM 1003 for seed bulking and distribution to farmers. In overall, the hybrids out yielded the landraces for grain productivity. The study confirmed that even under well managed, but rainfed, arid zone environments, current hybrids offer farmers more advantage over their traditional landrace.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background to the study

Pearl millet *(Pennisetum glaucum* (L) R. Br.) is a neglected and under-utilized traditional dryland crop that is grown in the drier parts of arid and semi-arid tropics (Obilana, 2003). It is one of the most important and reliable cereal crop in rainfed regions of the semi-arid tropics (Uzom *et al.*, 2010: FAO, 2010: Dave, 1987). These areas are characterized by low rainfall, sandy soils with low fertility (Krogh, 1997; Buerkert *et al.,* 2002: Gandah *et al.*, 2003), where other coarse cereals such as sorghum and maize fail to produce assured yields (Basavaraj *et al.,* 2010; FAO, 1996 and ICRISAT, 1996). The crop is grown by millions of resource-poor, subsistence level farmers (IFAD, 1999) and its percentage domestic consumption is rising steadily in Africa (World Bank, 1996). The main challenges for farmers within the semi-arid and arid tropics and sub-tropics are food insecurity, risk of crop failure and yield instability (CCN Kenya, 2013). These challenges are as a result of erratic and unreliable rainfall during the growing season (Kasei, 2001).

Changing weather patterns are leading farmers around the world to consider shifting crops, particularly to varieties that are resistant to worsening droughts, floods, high temperatures and salt intrusion (Bernier *et al.,* 2007). As such, there is need for identification, evaluation, production and dissemination of drought resistant crops like pearl millet which is a very important food security crop in the ASALs (CGIAR, 2011). Development and cultivation of improved farmer-preferred pearl millet cultivars with specific adaptation to the environments can significantly contribute to food security in Africa and the world at large (CGIAR, 2011). This will overcome Africa's stagnant dryland food production trends and growth (CGIAR consortium, 2011). Pearl millet is a cereal that is grown globally and is unique due to its tolerance to drought, low pH, low soil fertility and high temperatures (Ntare, 1990; Hajor *et al.,* 1996). In fact it is the only suitable and efficient crop for arid and semi-arid conditions because of its efficient utilization of soil moisture, high level of heat tolerance and low fertility than sorghum and maize (Shah *et al.,* 2012).

Due to its tolerance, pearl millet can be grown in areas where other cereal crops such as maize and wheat would not survive (Basavaraj *et al.*, 2010) and can yield in areas that receive rainfall as low as 200 to 250 mm (Bidinger and Hash, 2003).

Pearl millet accounts for almost half of the global production of the millet species from amongst different species of cultivated millets (National Research Council, 1996). Global millet production estimate is broken down into pearl millet (50%), finger millet (10%) and other millets (40%). Pearl millet is widely grown in Asia and Africa (Khairwal *et al.*, 1999). The area planted with pearl millet is estimated at 15 million hectares annually in Africa and 14 million hectares in Asia (National Research Council, 1996). Global production of pearl millet exceeds 10 million tons a year (National Research Council, 1996). It is by far the most important millet in Africa and worldwide (ICRISAT/FAO, 1996). Production in Africa accounts for almost half of its global production (FAO & ICRISAT, 1996). In Africa it is entirely a subsistence crop and production varies from one region to another with an average yield of 600kg per hectare (IFAD, 1999). In other continents it is grown under intensive cultivation as a forage crop (IFAD, 1999).

In Kenya pearl millet is a traditional crop, which is grown in many parts of the country especially in the arid and semi-arid regions of Makueni, Machakos, Kitui, Embu, Mbeere, Coast and Kirinyaga (Maundu *et al.*, 1999). It is grown mainly for subsistence use, but the crop lost favour with farmers when maize became the preferred crop and staple food after its introduction by the white settlers (Raschke & Cheena, 2007). Over the decades most farmers have abandoned pearl millet for maize (Nuss & Tanumihardjo, 2011). However, due to the desire to stabilize food security in the country there is now renewed interest in promoting drought-tolerant crops such as pearl millet and sorghum, which are known to be well adapted to harsh environments (GoK, 2009).

Current grain yields of pearl millet among small-scale farmers in Kenya are very low. It ranges between 500–700kg/ha (FAOSTAT, 2013). This is because farmers have continued to use landraces and varieties that are low yielding (KARI, 2013).

Pearl millet productivity has been declining due to many factors including climate change (FAO, 2008). Declining pearl millet productivity has in turn resulted in increased food insecurity in the country (GoK, 2007). Despite its suitability in the semi-arid areas, the area under pearl millet production is still low and farmers attain low yields in eastern Kenya (KARI, 2007; GoK, 2007; KARI, 2008; MoA, 2008). Most farmers still opt to grow maize which is frequented by crop failures (Raschke & Cheena, 2007). Consequently, there is a renewed interest in promoting drought-tolerant crops such as pearl millet, which are known to perform well in the arid and semi-arid lands of the developing world (Raschke & Cheena, 2007). Owing to its ability to thrive in drought prone and low input conditions, pearl millet production has been widely promoted among smallholder farmers in the arid and semi-arid parts of Kenya (GoK, 2007). However, performance of the crop is still low (KARI, 2007; GoK, 2007; KARI, 2008; MoA, 2008)).

The crop is believed to have descended from a West African wild grass which was domesticated more than 40,000 years ago (National Research Council, 1996). It spread from there to East Africa and then to India (National Research Council, 1996). Pearl millet is a crop of hot and dry climates (Dave, 1987). The crop has high water use efficiency, fast growth and tolerance to heat (Dave, 1987). The crop can survive and reliably produce reasonable yields on marginal soils and at rainfall levels as low as 300mm per annum, where other crops will fail (Dave, 1987). Primarily a tropical plant, pearl millet is often referred to as the "Camel" or the "arid giant" because of its exceptional ability to tolerate drought (Ong, 1983a). Even with minimal rainfall millet will typically still produce reasonable yields (Ong, 1983a). In many areas where millet is the staple food, nothing else will grow (Dave, 1987).

Extreme and recurrent droughts associated with climate change in ECA region have increased the urgency with which national policy makers are considering drought tolerant crops (Omamo *et al.,* 2006). Pearl millet can grow in these environments that are prone to drought and most vulnerable to climate change (Omamo *et al.,* 2006).

The area where pearl millet is important in ECA falls within low agricultural potential, low market access, and low population density production domain according to Omamo *et al*. (2006). These areas include some lowland areas of Eritrea, Ethiopia, Western and Northern Sudan, Eastern Kenya and the central plateau of Tanzania (Omamo *et al.,* 2006). Pearl millet forms an important staple food for more than 500 million households living in arid and semi-arid lands of Asia and Africa (National Research Council, 1996). Owing to its importance for food, feed and fodder (Sathya *et al.,* 2013), considerable global efforts have gone into improving its productivity through genetic enhancement.

The crop contributes to both rural food security and livelihood systems by providing good nutritional supplies and income sources to small-scale farmers (Rai *et al.,* 2012). Pearl millet is nutritionally superior for human growth when compared to maize and rice (Obilana and Manyasa, 2002; Yang *et al.*, 2012). The protein content of pearl millet is higher than maize and has a relatively high vitamin A content (Velu *et al.,* 2011; NIN, 2003). In Eastern and Central Africa, over thirty percent of the population (over 100 million people) live in these semi-arid areas and rely on agriculture and livestock as their main livelihood (Omamo *et al.*, 2006). The households in these areas depend on millets as the main staple crop providing source of food, feed for livestock and source of income (Omamo *et al.,* 2006). Besides providing food for human, millet stems are used for a wide range of purposes, including: the construction of hut walls, fences and thatches, and the production of brooms, mats, baskets and sunshades (IFAD, 1999).

South eastern Kenya is characterized by increasingly frequent drought occurrences sometimes extending for two to three years in a stretch (UNEP, 2009). Over the decades, there have been repeated maize crop failures in many parts of eastern Kenya especially because of droughts (Nagarajan and Audi, 2007). Coupled with improved production technologies, improved Pearl millet varieties if grown in semi-arid areas like the eastern province, can survive and yield well in such unreliable climatic conditions (Karanja *et al*., 2009).

To promote the crop, Kenya Agricultural and Livestock Research Organization (KALRO) have developed HYPMVs with accompanying supporting production technologies for higher yields (Karanja *et al*., 2009). In recognition of the role pearl millet can play in food security especially in ASALs, the Government of Kenya through the Ministry of Agriculture (MoA) initiated projects such as the Eastern Province Horticulture and Traditional Food Crops project, an International Fund for Agricultural Development (IFAD)-funded project, and Orphan Crops project in these regions to promote pearl millet, among other crops (Karanja *et al*., 2009). The main aim of this project was to encourage farmers to adopt these improved varieties in order to improve food security and rural incomes. Therefore the objective of the study was to determine the adaptability of six pearl millet varieties for arid and semi arid areas.

1.2 The statement of the problem

Pearl millet is an under-utilized crop that could play an important role in the food security, income generation and food culture of the rural poor in ASALs (Larson *et al.*, 2006: ASARECA, 2004). Production of the crop has been characterized by low yields due to failure to adopt new improved early maturing varieties and appropriate management practices (ASARECA, 2014). In Kenya, the areas under pearl millet have reduced from 115,302.6 ha (2007) to 100,143.9 ha (2011).

Areas that have experienced this drastic fall in hectares under pearl millet include: Eastern province (Tharaka, Mbeere, Mwingi, Kitui, Makueni Districts) and Rift valley Province (Baringo, Elgeyo-Marakwet and west Pokot districts (GoK; 2007, KARI; 2008, MoA; 2008). Pearl millet yield have also declined from 1,610 kilograms per hectare in 1980 to an estimated 200-800 kilograms in 2008 against the estimated global potential of 1,500 - 3,000kg ha^{-1} (KARI, 2007; GoK, 2012). These negative trends have resulted in imports from Tanzania and Uganda at 1,560 metric tons annually (USAID, 2010).

This decreasing trend in the production of this cereal crop despite its vital role in food security in this area is of great concern to planners and policy makers in the county.

Therefore identification of the most adaptable pearl millet variety will help enhance food security in the ASALs, Kitui County included. Variety improvement should therefore remain a major goal of both national and international agencies and breeders (Wilson *et al*., 2008).

1.3 Objectives of the study

1.3.1. General Objective

To determine the adaptability of six pearl millet varieties for arid and semi arid areas with a view to meeting food security.

1.3.2 Specific Objectives

i. To determine the growth and yield of the six pearl millet varieties.
ii. To determine the number of days to maturity of the six pearl millet varieties.
iii. To establish relationship between number of days to maturity and yields of the six pearl millet varieties.

1.4 Hypothesis

i. There is no difference in growth and yield of the six pearl millet varieties.
ii. There is no difference in maturity period of the six pearl millet varieties.
iii. There is no difference in relationship between maturity period and yields for the six pearl millet varieties.

1.5 Justification

Pearl millet is a potential alternative food crop in ASALs of eastern Kenya that can offer immediate food and nutritional security to food insecure rural population if proper research on its adaptability is established (ECARSAM, 2005). Realizing the multiple use potential of pearl millet grain, there is need to develop varieties and hybrids for high grain yield (Obeng *et al.,* 2010). Previous research carried out in a number of countries such as Sudan, Uganda and Tanzania produced impressive results but shows a gap in adaptability of pearl millet in the ASALs. According to Boyer (1982), drought is a major limiting factor to agriculture generally leading to reduction in crop yield. He therefore indicated that identifying genetic factors involved in plant response to drought stress is very significant and relevant for plant breeding.

Therefore, knowledge of pearl millet adaptability to ASALs will provide valuable information to breeders, farmers and policy makers about the potential opportunities for improving the welfare gains from this valuable dryland crop. This study if adopted will play a vital role in food production especially through subsistence farming. This will help to alleviate food insecurity which continues to prevail within the County.

1.6 Scope of the study

The study was conducted on pearl millet varieties in the semi arid Kitui County. The study focused on the adaptability of pearl millet genotypes that are high yielding and have farmer - preffered traits grown under rainfed conditions with a view of meeting food security. The study did not capture the effects of soil fertility levels in the study area.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Pearl millet taxonomy and origin

Pearl millet (*Pennisetum glaucum* (L.) R. Br.) is an annual, allogamous and diploid cereal which belongs to the family *Poaceae*, subfamily *Panicoideae*, tribe *Paniceae*, subtribe *Panicinae*, section *Pennicillaria* and genus *Pennisetum* (Rai *et al.,* 1997). Pearl millet is a predominantly cross-pollinated crop with 75–80% out-crossing (Rai *et al.,* 1999). It is a highly tillering diploid tropical C4 cereal crop. It bears grains on the surface of erect candle shaped terminal spikes. Grain size varies from 0.5 to over 2.0g/100, and, depending on the size of the spike, grain number per spike ranges from 500 to 3,000 (Andrews, 1990). The four cultivated forms of pearl millet are *typhoides* (found mainly in India and Africa), *nigritarum* (dominant on the eastern Sahel), *globosum* (dominant in the western Sahel) and *leonis*, dominant on the West African coast (The Syngenta Foundation for Sustainable Agriculture, 2006).

The geographical origin and the centre of domestication of pearl millet are situated in Western Africa (Brunken *et al.,* 1977; Rai *et al.,* 1997; Syngenta, 2006). The crop was subsequently introduced to India, where the earliest archeological records date back to 2000 B. C. (Oumar *et al.,* 2008).

2.2 Utilisation and nutritional value of pearl millet

Pearl millet is a staple food crop in arid and semi-arid regions of Africa and Asia (Khairwal *et al.,* 1999). The crop is also grown for feed and fodder purposes in many parts of the world (Ghazy *et al.,* 2010). In Africa and the developing countries of Asia, it is estimated that over 95% of pearl millet grains are used mostly for human consumption (http:// vasat. icrisat. org /crops/ pearlmillet/ pmproduction/ html/ m22. 2/ resources /2111. Html - Sept 2013). Traditionally, these grains are used in such diverse food types as leavened and unleavened flat breads, porridges, steamed foods, and rice-like boiled products and in alcoholic as well as non-alcoholic beverages (Yang *et al.,* 2012; Kumar, 1995). Pearl millet flour can be substituted for up to 20% of the wheat flour in making leavened bread (Rai *et al.,* 1999).

It is also grown as a fodder crop, e.g. in Brazil, the United States of America, South Africa and Australia. In addition to grain and forage uses, pearl millet crop residues and green plants also provide sources of animal feed, building material, and fuel for cooking, particularly in dry land areas (IFAD, 1999). Pearl millet grain has high levels of protein (12 - 15%) content with balanced amino acids, carbohydrates (60–70%), and fats (5–10%) which are important in the human diet, and its nutritive value is considered to be comparable to rice and wheat (Lakshmana, 2008). Pearl millet grains are usually made up of 70% carbohydrates and consist almost exclusively of starch. It accounts for 24% of total calorie intake as compared to 23% for maize and 13% for wheat (Hulse *et al*., 1980).

2.3 Millet Consumption in Kenya

Kenya imports an average 2000 MT/year to augment its production. Exports are only in some years. The consumption is shown in Table 2.1.

Table 2.1 Consumption of Millet and Surpluses and Deficits

Year	**2004**	**2005**	**2006**	**2007**	**2008**
Production(MT)	75,171	59,481	79,207	119,601	53,165
Net Imports(MT)	2,065	3,578	65	254	2,000
Consumption	77,236	63,059	79,272	119,853	55,165
Population(mi)	34.2	35.1	36.1	37.2	38.3
Per capita(Kg/ca)	2.25	1.8	2.2	3.2	1.4
Surplus/Deficit(MT)	2,065	3,578	65	252	2,000

Source: MOA - ERA, 2009

Consumption ranges from 1.4kg per capita to 3.2kg per capita and averages at 2.2kg per capita which is about a half of sorghum consumption. Imports show that Kenya is not sufficient in millet and offers a potential market from neighbouring countries. It experiences deficits ranging from 65 - 3,578MT averaging at 1,592MT (MOA, 2009)

2.4 Millet Utilization Analysis

In 2008, Kenya did not export any millet but imported a total of 10,580 MT from Zambia (10.8MT), Uganda (5,430MT) and Tanzania (5,042MT) (Economic Survey, 2007). Total domestic supply was estimated at 55,000MT of which 2,000MT was imported (Econ. Survey 2007).

Feed accounted for 7.3% (4,000MT), seed for 3.6% (2,000MT), processing for 20% (11,000MT), waste for 10.9% (6,000MT) and food for 58.2% (32,000MT). The per capita consumption is low at 0.9kg/ca based on population of 34.5 million (Econ. Survey 2007).

2.5 Pearl millet production

Pearl millet is one of the most extensively cultivated cereals in Africa after maize, sorghum and wheat particularly in arid and semi-arid regions (Table 2.2).

Table 2.2 Africa major grain crops during 2012

Crop	Production(Mt)
Maize	64.1
Sorghum	26.9
Wheat	24
Millet	20.1
Rice	17.3
Barley	6.1

Source: FAO, (2012)

According to FAO (2012), pearl millet is the fourth most grown cereal in the Africa. It is grown annually and production is about 20.1 million ton in the arid and semi-arid tropical regions. India is the largest producer of pearl millet in Asia, both in terms of area (about 9 million ha.) and production (8.3 million tons) with an average productivity of 930 kg/ha during the past three years (Mula, *et al.,* 2010). It is cultivated on 26 million ha, mainly by resource-poor and subsistence farmers in Asia and Africa (Rai *et al.,* 2007) and accounting for about 95% of the production and acreage with almost half of global millet production, with 60% of the cultivation area in Africa, followed by 35% in Asian countries (Basavaraj *et al.,* 2010). Pearl millet area in Africa is about 14 million ha with annual production of 13 million tonnes (Velu, 2006; FAO, 2003)

European countries represent 4% of millet production and North America only 1% mainly for forage. Global production exceeds 10 million tons per year (National Research Council, 1996). It is estimated that over 11.36 million tons of pearl millet grain are produced in 17.4 million ha globally (FAO, 2003).

In Sub-Saharan Africa, pearl millet is the third major crop with the major producing countries being Nigeria, Niger, Burkina Faso, Chad, Mali, Mauritania, and Senegal in the West and Sudan and Uganda in the East (National Research Council, 1996). In Southern Africa, maize has partially or completely displaced millet cultivation because of commercial farming (Basavaraj *et al.,* 2010).

India is the largest producer of pearl millet, both in terms of area (9.3 million ha) and production (9.3 million metric tons) with an average yield of 1044kg/ha. The trend in area, production and productivity of pearl millet suggest that area has increased marginally (2%) and productivity has gone up by 19% (Yadav, 2011). In Zambia, millet production declined by 22% to 37,644 metric tons in the 2010/2011 growing season from 47,997 metric tonnes in the 2009/2010 growing season. The total area planted for 2010/2011 decreased by 25% to 42,663 hectares from 53,789 hectares during the 2009/2010 season. The average yield during the 2010/2011 growing season ranged from 500 - 650kg/ha (MACO & CSO, 2011). Millet production in Africa has been on a downward trend partly due to high demand and profitability of competing crops, although, pearl millet still account for almost 87 percent of the total area planted with millets (ICRISAT, 1996; Bennetzen, 2003).

2.5.1 Pearl Millet Production in Kenya

Kenya produced about 53,155 metric tonnes of millet in the year 2008 (MOA, 2009). Regions which mostly produce millet in Kenya include central, Western (7.5%), Nyanza (17.5%), South Rift (9.7%), Eastern (65%) and coastal areas (0.5%). Table 2.3 shows the area and yield of pearl millet by regions that produced most pearl millet in Kenya during the 2008/2009 season. In the past years evaluation of pearl millet production was complicated by the failure of national statistics to distinguish pearl millet from other millets (MOA, 2009). Pearl and finger millet were collectively classified as millets (MOA, 2009).

Table 2.3 Pearl millet production in the provinces in Kenya in 2008

Parameter	Eastern	Nyanza	Rift Valley	Western	Others	Total
Crop area (ha)	34,426	9,315	5,141	3,983	290	53,155
Output (Metric Tonnes)	11,931	14,092	5,839	6,443	118	38,423
Yield (t/ha)	0.35	1.51	1.14	1.62	0.41	0.72
Yields (bags/ha)	4	17	13	18	5	13
% of Area	64.8	17.5	9.7	7.5	0.5	100
% of Output	31%	36.70%	15.20%	16.80%	0.30%	100%

Source : MOA ERA, 2009

In Kenya the area under pearl millet production has decreased by 6% from 100,143ha (2011) to 93,310ha in 2013 (MoA, 2013). Areas that have experienced this drastic fall in hectares under millet include: Eastern province (Tharaka, Mbeere, Mwingi, Kitui and Makueni districts) and Rift Valley province (Baringo, Elgeyo-Marakwet and West Pokot districts) (GoK, 2007 MoA, 2008). Pearl millet yield also has been declining since 1980 from 1,610kg ha^{-1} to an estimated 200 - 800kg ha^{-1} in 2008. The current yield is low against the estimated global potential of 1,500 to 3,000 kg ha^{-1} (KARI, 2007; GoK, 2007; KARI, 2008).

2.5.2 Farmers in Millet Production

The estimated holding under millet averages at 0.65ha per household in major millet areas (Stable Food Value Chain Analysis, 2010). In 2007, about 127,114 ha were under millet indicating about 195,560 growers (Stable Food Value Chain Analysis, 2010). These farmers produced 119,601 metric tonnes (t) of millet. Based on figures for the 2005 food balance sheet, 7.2% is used as feed (8,600 t), seed 3.6% (4,300 t), waste at 11% (13,156t), processing 20% (23,920 t) and food 58.3% (69,726 t). Per capita consumption is estimated at 1kg/ca and this translates to 1,173 t consumed by growers (Stable Food Value Chain Analysis, 2010).

2.6 Adaptation and climatic requirements of pearl millet

Like any grain crop, pearl millet yields best on fertile, well drained soils. However, it performs relatively well on sandy acidic soil conditions, and when available moisture and soil fertility are low (Myers, 2002).

This adaptation reflects pearl millet origin in the Sahel regions of Africa, where growing conditions are difficult (Myers, 2002). It is tolerant to sub-soils that are acidic (pH 4-5) and high in aluminium content (Oushy, 2010). Pearl millet is usually a short-day plant, although some varieties are day length neutral (Hannaway and Larson, 2004). It is generally sensitive to low temperatures at the seedling stage and at flowering. It germinates well at soil temperatures of 23^{o}C to 30^{o}C (www. nda. agric. za/ docs/ Brochures/ Pearlmillet). Emergence occurs in 2 to 4 days under favorable conditions (www. nda. agric. za/ docs/Brochures/Pearlmillet).

High daytime temperatures are needed for the grain to mature. It can grow in areas receiving 200–1500mm of rainfall (Oushy, 2010). Despite its drought tolerance, pearl millet requires evenly distributed rainfall during the growing season (Oushy, 2010). According to Wilson (2011), drought stress during flowering through to grain fill results in low and unstable yields. Yadav (2010) also pointed out that post flowering drought stress is one of the most important environmental factors reducing pearl millet grain yield as much as 70%. Too much rainfall at flowering can also cause crop failure (Oushy, 2010).

Ouendeba *et al.* (1995) measured the phenotypic correlations among thirteen characters in pearl millet. They showed that grain yield significantly correlated with spike length, spike circumference, leaf width, stem diameter, spike number, non productive tillers, plant height, spike yield, but not significantly correlated with days to flowering. Inheritance of vegetative growth index and related characters in pearl millet was reported (Lynch *et al.,* 1995). Fewer studies, however, were conducted on variability and relationship among characters of pearl millet especially under late summer sowing condition (Lynch *et al.*, 1995).

2.7 Importance of pearl millet in climate change and food security

Agriculture is facing declining water availability, reduction in arable land and strongly increasing demand for harvested products (Brisson *et al.,* 2010).

Predictions of climate change indicate an increased variability of rainfall in the next 40 years and increased risk of high temperature (Battisti and Naylor, 2009), that will cause appreciable limitations of yield (Brisson *et al.*, 2010). Food security requires investments in this domain, in particular with new genotypes that can at least maintain an acceptable productivity under reduced water availability (Tardieu, 2012).

With regard to this, pearl millet has been identified as one of the crops that are useful in overcoming the adverse effects of climate change, and thereby reinforcing food and income security of the poor (http://climateiisd.org/news/icrisat-develops-resilie Sept 2013). This has prompted ICRISAT to boost the production of pearl millet through hybrid development (http://climateiisd.org/news/icrisat-develops-resilie Sept 2013).

2.8 Production constraints in pearl millet crop

Pearl millet production faces several constraints including lack of quality seeds, birds, insect pests and diseases like downey mildew, blast, stemborers, incomplete understanding of farming systems, poor soil fertility and financial limitations of farmers in purchasing agricultural inputs. In eastern and southern Africa, it is primarily a crop of resource-poor, small-scale farmers and is typically produced under adverse conditions (ASARECA, 2004). The major challenges in these areas are low moisture, low input use and poor seed for planting (Jaetzold *et al*., 2006). In East and Central Africa, pearl millet is grown without any significant use of improved seed, early maturing varieties, agro-chemicals and farm implements (ASARECA, 2004).

2.9 Pearl millet biomass accumulation and partitioning

The key parameter in the quantification of biomass partitioning before anthesis is the pattern of dry matter allocation between leaves and stems (Jones and Kiniry, 1986). In general, the fraction of current assimilates that is partitioned to the leaf blades is high early in the season, but declines gradually as stem elongation starts, until it is zero at the end of leaf growth (van Keulen and Seligman, 1987; Borrell *et al.*, 1989). The grain filling period (GFP) of pearl millet can be divided into three phases (Fussell and

Pearson, 1978; Bieler *et al.*, 1993): (1) an initial lag phase between anthesis and the start of grain growth, (2) a period of near - linear increase in individual grain mass, and (3) a brief period just before physiological maturity of the grain during which the grain growth rate drops. The significant genotypic differences in grain mass which have been reported for pearl millet, are predominantly due to differences in the grain growth rate, rather than in the duration of the grain filling period (GFP) (Fussell and Pearson, 1978; Craufurd and Bidinger, 1988b; Bieler *et al.*, 1993).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 The study site

The field experiment was conducted on six pearl millet genotypes (PVS-PM 1005, PVS-PM 1006, PVS-PM 1002, PVS-PM 1003, PVS-PM 1004 and Kimbeere) at the Teaching and Research farm of the South Eastern Kenya University main campus, Kitui (Figure 3 1). This area is in eco-zone V (Jaetzold and Schmidt 1983). It is a semi-arid area with the annual rainfall amount ranging between 400mm - 800mm, temperature ranging between 14^{o}C - 34^{o}C latitude 1^{o}2257 S, longitude 38^{o} 00 19 E and 1152m above sea level (Conty government of Kitui website www.kitui.go.ke).

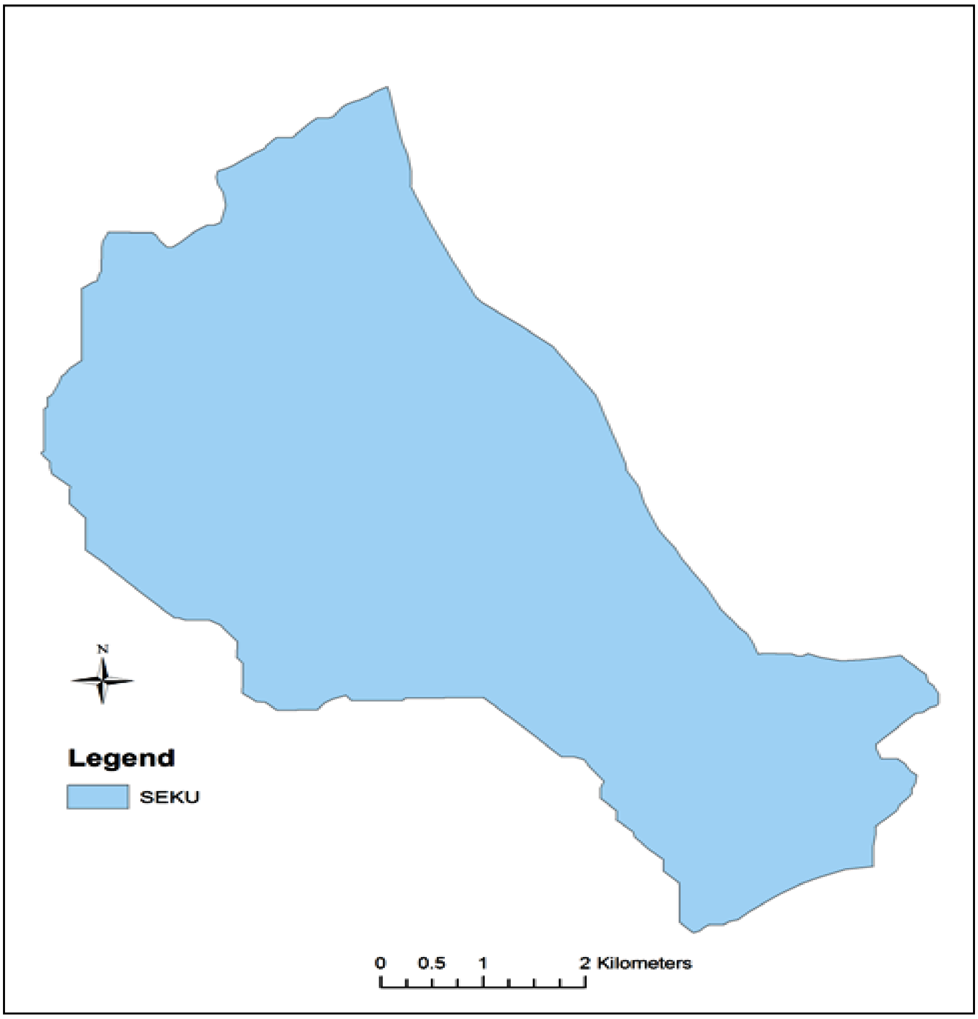

Figure 3.1 Map showing Study area.

3.2 Experimental design

The experiment was laid out in a randomized complete block designs (RCBD) with three replications (Figure 3.2).

5m

BLOCK 1 5.25m	5		3		4		1		2		6
1.5m Path											
BLOCK 2 5.25m	2		4		6		3		1		5
1.5m Path											
BLOCK 3 5.25m	1		2		5		4		6		3

Figure 3.2 Experimental layout of the pearl millet trial. Each plot is 5.25 m long by 5 m wide.

KEY

1-PVS-PM 1005

2-PVS-PM 1006

3-PVS-PM 1002

4-PVS-PM 1003

5-PVS-PM 1004

6-Kimbeere–Local check

3.3 Field preparation

The experiment was established on a piece of land previously ploughed using a tractor. The land was leveled to provide a medium fine tilth for the growth of the crops. Measuring and marking of the plot and sub plots was done thereafter. Gross plot size was 41m by 15.75m.

The plot was further divided into subplots of 5m by 5.25m. One and half meter alley ways were created between blocks and the subplots. The inter and intra-row spacing was 75cm row and 30 cm, respectively. The seeds were sown by drill and later the plants were later thinned to one plant per hole two weeks after of emergence. Weed management was taken care of throughout the experiment.

3.4 Data collection

Rainfall records were taken during plant growth and records on different plant characteristics were taken using standard guidelines as recommended by the International Board for Plant Genetic Resources (IBPGR) and International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) (1993). Data collection was done on the three inner rows to avoid influence from neighbouring plots. This was done in each plot on the following plant characteristic (Izge *et al. (*2005) and Nwasike *et al. (*1989).

- **Days to emergence (DTE)** - The number of days to emergence was recorded on the basis of visual observation.
- **Days to anthesis (DTA)** - Number of days from planting to the date when the first flower opened in a plot.
- **Days to 50% flowering (DFF)** – This was taken by counting the number of days from planting to when half (50%) the plants in a plot reached 50% stigma emergence.
- **Plant height (PH) in cm** - This was recorded by measuring from the base of the plant to the tip of the panicle before lodging in a plot.
- **Panicle length (cm) -** This was measured from base to the tip of 5 randomly selected panicles from a plot heap at harvest.
- **Days to 50 % Maturity** - Number of days from planting to the date when 50 % of the plants in a plot attained physiological maturity.
- **Number of tillers per plant** - The total number of tillers plant^{-1} at harvest were counted in each plot from five tagged plants and divided by five to calculate average number of tillers plant^{-1}.

- **Millet above ground biomass (t/ha) -** The stover yield for each plot was worked out by weighing the dry fodder yield from individual plot and it was computed in t ha^{-1}
- **One thousand (1000) Grain mass (TGM) -** A random sample of grain was drawn from the produce of each plot. 1000 - grains from each sample were counted and their weight was recorded.
- **Grain yield per net plot - Mass of harvested grains per plot (g) -** This was taken from threshed and winnowed grain for each plot.
- **Harvest index (%) -** Harvest index (HI) for each treatment was computed by using the formula of Donald and Hamblin, 1976.

$$\text{Harvest index} = \frac{\text{Economic yield (grain)}}{\text{Biological yield (grain + stover)}} \times 100$$

- **Dry matter production and its partitioning -** Five randomly selected plants from each plot were used to record the dry matter production at various growth stages. These plants were separated into leaves, stem and panicle. The plant parts were cut into small pieces and dried in oven at 80 ^{0}C until constant weight was attained. The dry weight of the leaf, stem and panicle at vegetative, reproductive, grain filling and harvest was recorded separately. Total dry matter was calculated by adding the dry weight of different plant parts and expressed in gram $plant^{-1}$ (Goering *et al.*, 1970).

The total mass of plants from the three middle rows in each plot (kg) at harvest, total number of heads from three middle rows per plot at harvest, grain yield per (kg) was determined from the threshed and winnowed grain for each plot (Goering *et al.*, 1970).

3.5 Data analysis

GenStat 15th Edition (VSN-International, 2012) was used in analyzing data and the least significant difference (LSD) at 5% was used to separate means. Analysis of Variance (ANOVA) was used to check for the differences in yield and yield components among treatments.

CHAPTER FOUR

4.0 RESULTS

4.1 Baseline characterization

The soil at the experimental area is sandy loam and slightly acidic, low in nitrogen, calcium and magnesium. The soil is acidic, sandy and has high level of potassium (Table 4 1). However other nutrients required for plant growth were inadequate for enhanced cereal production.

Table 4.1 Physiochemical properties of soils at the experimental site

Physiochemical properties of soils at the experimental site (0-15cm)			
Soil pH	5.62	Sand	81.4
Organic C(%)	0.41	Silt	15
Total N(%)	0.08	Clay	3.6
Available P($mgkg^{-1}$)	12.85	Textural class	Loamy sand
Ca (ppm)	0.09		
Mg (ppm)	0.06		
K (ppm)	60.75		
CEC	3.82		

4.2 Rainfall Distribution in the study area

The rainfall distribution of the study area is presented in figure 4.1. The three cropping seasons were characterized by different rainfall patterns. The area received 390.8 mm as rain in 2012 cropping season, 300.8mm in 2013 cropping season and 177.6 mm in 2015 cropping season. The crop was planted in three seasons, 12th November 2012 (short rains), 21st November 2013 (short rains) and 14th April 2015 (long rains) for season 1, 2 and 3 respectively. Harvesting was done on 20th February 2013, 25th February 2014 and 10th July 2015 for season 1, 2 and 3 respectively.

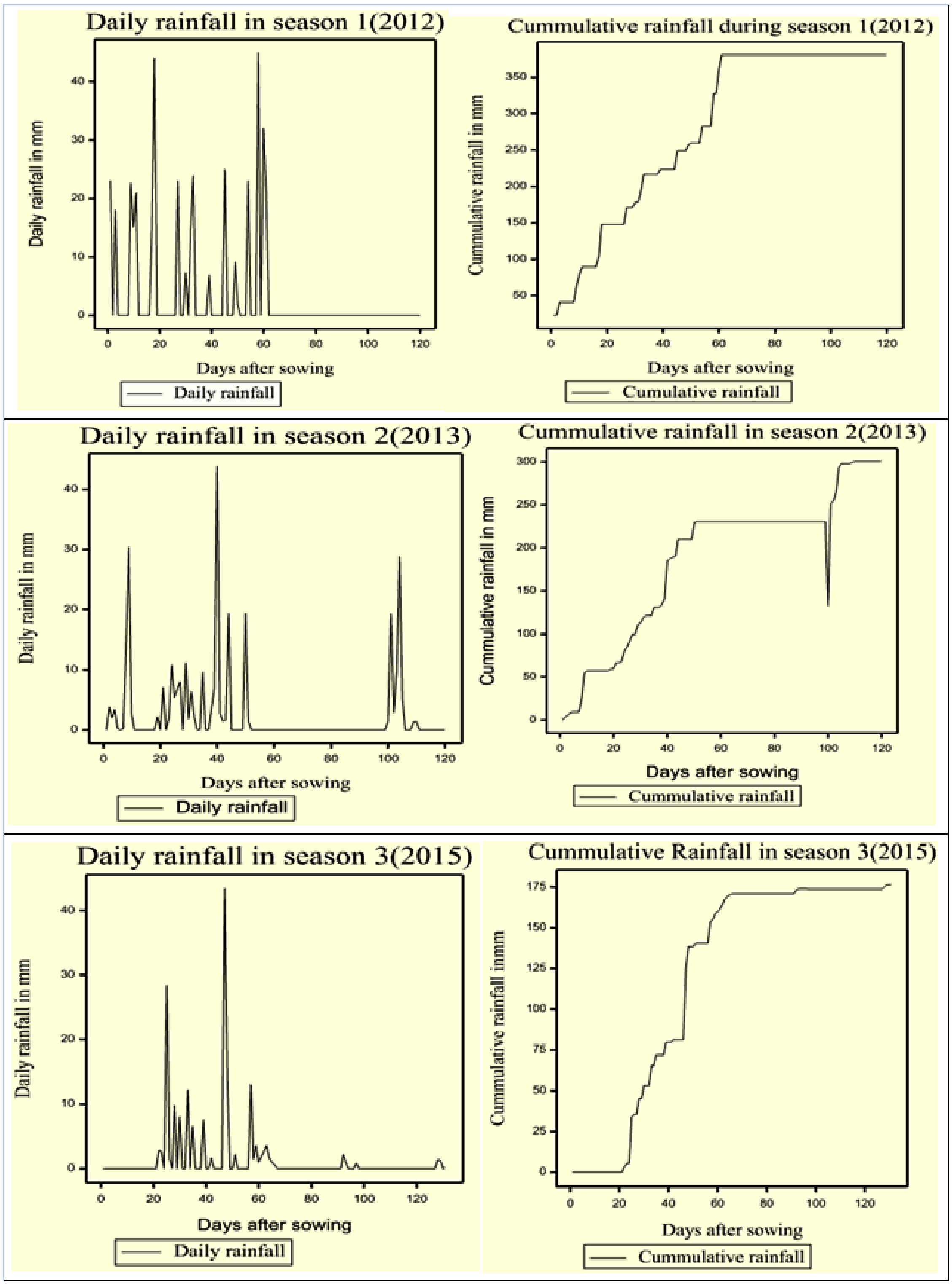

Figure 4.1 Rainfall Distribution in the study area.

4.3 Growth, yield and yield components

4.3.1 Growth components

4.3.1.1 Plant Height

Plant height was measured from the base of the stem to tip at harvest. The mean height from the 5 randomly selected plants was taken in each plot. The height of the six pearl millet genotypes was comparable (Table 4.2). However plant height varied significantly ($p<0.05$) among the seasons, plants were tallest in the first season and shortest in the third season; i.e. 160.5 cm, 154.0 cm and 148.3cm in the first, second and third season, respectively (Figure 4.2). The variation in the height of the pearl millet was attributed by variation in rainfall among the seasons and genetic constitution of the genotypes. Variety PVS-PM 1006 was the tallest with mean plant height of 157.9cm, whereas the local variety, Kimbeere, was the shortest (150.1cm). Overall results (Table 4.2) showed that there were no significant differences in plant height among the six millet genotypes for the period of evaluation.

Table 4.2 Mean plant height for each variety in three seasons

Pearl millet genotypes	**Season 1 (12th November to 20th March 2013)**	**Season 2 (21st November 2013 to 25th February 2014)**	**Season 3 (14th April 2015 to 10th July 2015)**	**Mean Plant height for each pearl millet in three seasons**
PVS-PM 1005	52.5_{ab}	156.1_{ab}	150.9_{ab}	153.2
PVS-PM 1006	166.2_{b}	154.2_{ab}	153.4_{ab}	157.9
PVS-PM 1002	167.8_{b}	161.4_{ab}	141.1_{a}	156.7
PVS-PM 1003	164.3_{b}	154.5_{ab}	148.6_{ab}	155.8
PVS-PM 1004	155.9_{ab}	149.4_{ab}	150.4_{ab}	151.9
Kimbeere	156.4_{ab}	148.4_{ab}	145.4_{ab}	150.1
Mean	**160.5**	**154**	**148.3**	**154.2**
LSD	19.2	19.2	19.2	

Values followed by the same subscript letters in the same column are not significantly different ($P<0.05$) from each other at 5% level according to ANOVA protected LSD test.

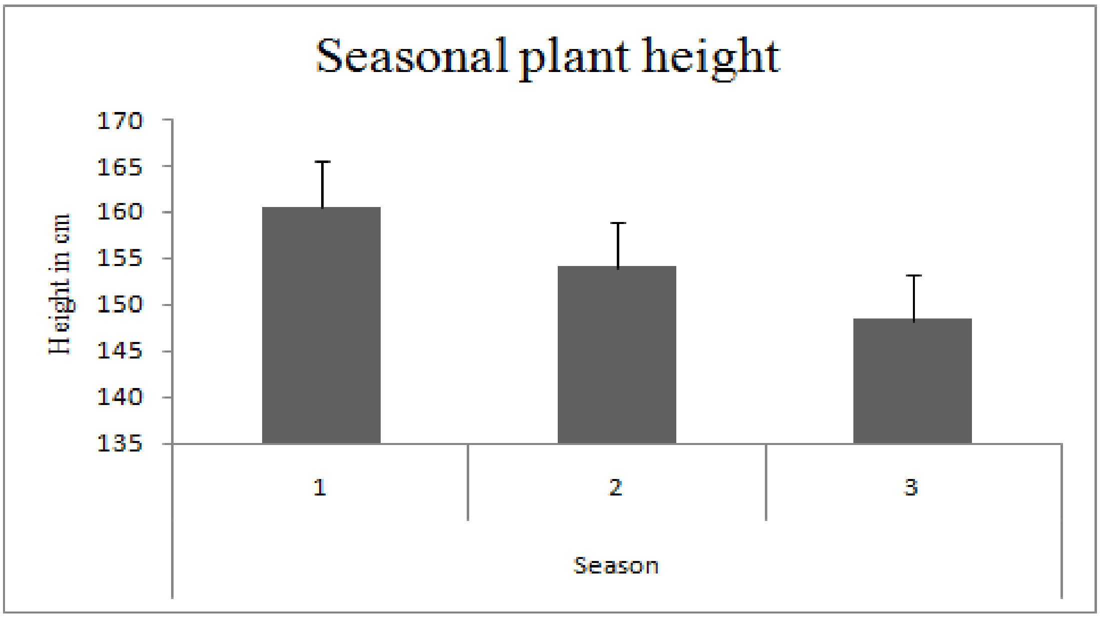

Figure 4.2 Variation of plant height of pearl millet varieties in the three seasons.

4.3.1.2 Number of Tillers

Data on number of tillers per plant is presented on Table 4.4. There were significant ($p<0.05$) variation in the numbers of tillers per plant among the six genotypes in the three seasons but they did not vary appreciably among the seasons (Table 4.3). Season one had the highest mean number of tillers per plant (7.3) compared to season two and three which had 6.6 and 6.7 tillers per plant respectively (Table 4.4). Kimbeere had the highest number of tillers per plant (7.6) followed by PVS-PM 1003 (7.2), PVS-PM 1004 (6.9), PVS-PM 1002 (6.9), PVS-PM 1006 (6.7), PVS-PM 1005 (5.8) (Table 4.4).

Table 4.3 ANOVA table for tillers per plant of Pearl Millet varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2.7778	1.3889	3.97	
Season	2	5.4444	2.7222	7.79	0.002
Treatment	5	16.3889	3.2778	9.37	<.001
Season.Treatment	10	3	0.3	0.86	0.579
Residual	34	11.8889	0.3497		
Total	53	39.5			

Table 4.4 Number of tillers per plant among six genotypes of pearl millet in three seasons

Pearl Millet Genotypes	Season 1 (12th November to 20th February 2013) Tillers/Plant	Season 2 (21st November 2013 to 25th February 2014) Tillers/plant	Season 3 (14th April 2015 to 10th July 2015) Tillers/plant	Mean tillers per plant for each pearl millet genotype in three seasons
PVS-PM 1005	6.3_{ab}	5.7_{a}	5.3_{a}	5.8
PVS-PM 1006	7.3_{bc}	6.3_{ab}	6.3_{ab}	6.7
PVS-PM 1002	7.3_{bc}	6.3_{ab}	7_{bc}	6.9
PVS-PM 1003	7.3_{bc}	7_{bc}	7.3_{bc}	7.2
PVS-PM 1004	7.3_{bc}	6.3_{ab}	7_{bc}	6.9
Kimbeere	8_{c}	7.7_{c}	7_{bc}	7.6
Mean	**7.3**	**6.6**	**6.7**	**6.8**
LSD	0.98	0.98	0.98	

Values followed by the same subscript letters in the same column are not significantly different ($P<0.05$) from each other at 5% level according to ANOVA protected LSD test.

4.3.1.3 Total dry matter accumulation in grammes per plant

Data on total dry matter accumulation (DMA) of the pearl millet genotypes at vegetative phase, reproductive phase, grain filling phase and at harvest is presented in Table 4.5. The increase in total dry matter accumulation plant^{-1} was more between reproductive phase and grain filling phase of the crop growth cycle. The rate of dry matter accumulation was slow between vegetative and grain filling phase to harvesting time of the crop. Total dry matter accumulation plant^{-1} was significantly more in season two at all the stages of crop growth except harvest time. The different pearl millet genotypes varied significantly ($p<0.05$) at vegetative, reproductive, grain filling phase and harvest in term of total dry matter accumulation plant^{-1}. At harvest, hybrid PVS-PM 1005 recorded significantly highest dry matter plant^{-1} (77.4) than all other genotypes while Kimbeere recorded the lowest dry matter (57.4).

Generally all the hybrids perfomed better than the local Kimbeere variety in total dry matter accumulation per plant in all the phases (Table 4.5).

Table 4.5 Total dry matter accumulation (gPlant^{-1}) of pearl millet at vegetative phase, reproductive phase, grain filling phase and at harvest.

Genotype	Vegetative phase				Reproductive phase			
	S1(2012)	S2(2013)	S3(2015)	Mean	S1(2012)	S2(2013)	S3(2015)	Mean
PVS-PM 1005	2.77	2.82	2.79	**2.79**	38.20	39.76	39.72	**39.23**
PVS-PM 1006	2.61	2.65	2.61	**2.62**	35.13	36.76	36.47	**36.12**
PVS-PM 1002	2.49	2.64	2.56	**2.56**	32.11	30.99	30.78	**31.29**
PVS-PM 1003	2.43	2.46	2.46	**2.45**	29.86	30.67	30.18	**30.24**
PVS-PM 1004	2.38	2.39	2.35	**2.37**	29.26	28.00	27.74	**28.33**
Kimbeere	1.96	2.13	1.95	**2.01**	26.22	26.28	25.93	**26.14**
Mean	**2.44**	**2.52**	**2.45**		**31.80**	**32.08**	**31.80**	
	Grain filling phase				**At Harvest**			
	S1(2012)	**S2(2013)**	**S3(2015)**	**Mean**	**S1(2012)**	**S2(2013)**	**S3(2015)**	**Mean**
PVS-PM 1005	61.9	63.26	62.67	**62.61**	76.35	78.14	77.60	**77.4**
PVS-PM 1006	55.47	57.33	57.02	**50.61**	68.93	71.07	70.14	**70.1**
PVS-PM 1002	50.48	51.66	51.44	**51.91**	65.95	67.22	67.00	**66.7**
PVS-PM 1003	49.34	49.08	48.85	**49.09**	59.76	60.30	59.83	**60.0**
PVS-PM 1004	48.95	47.07	46.74	**47.59**	59.33	58.23	57.90	**58.5**
Kimbeere	46.31	46.06	45.65	**46.01**	58.02	55.57	58.52	**57.4**
Mean	**52.08**	**52.41**	**52.06**		**64.72**	**65.09**	**65.17**	

S1-Season 1, S2-Season 2, S3-Season 3.

4.3.1.4 Dry matter partitioning (g plant^{-1})

The data on dry matter partitioning is presented in Table 4.6 and 4.7 Seasons had no significant effect on dry matter partitioning of various genotypes plant parts (leaves, stem and earhead). This followed a similar trend of total dry matter accumulation (Table 4.5). Dry weight of earhead was recorded at vegetative phase in the three seasons since it had not developed (Table 4.6). Among all the genotypes, leaves constituted major portion of dry matter at vegetative phase contributing between 62.37 to 71.14. Kimbeere variety recorded the highest percentage (71.14) from leaves in all the three seasons (Figure 4.3). Stem contributed lower dry matter accumulation at this stage and it ranged from 28.40 to 37.63 in all the varieties (Figure 4.3).The data on dry matter partitioning at reproductive phase (Table 4.6) showed that leaf and stem almost contributed equally towards total dry matter accumulation.

The range of contribution from the leaves was 46.29 to 44.98 percent and 40.08 to 44.35 percent from stem, respectively (Figure 4.4). Earhead contribution ranged between 12.67 to 14.19 percent in all the genotypes (Figure 4.4).

The dry matter partitioning at grain filling phase showed lower dry matter production in the leaves, stem and earhead in all the three seasons (Table 4.7). Leaves stem and earhead contributed towards the total dry matter in the range of 22.71 to 25.89, 37.27 to 39.13 and 35.55 to 40.01 percent, respectively (Figure 4.5). Stem and earhead contributed almost equally in total dry matter accumulation in all the pearl millet genotypes (Figure 4.5). At harvest, contribution of earhead was 33.51 to 35.52 percent followed by 33.45 to 34.95 per cent by stem and least by the leaves (31.03 to 33.03 percent) in total dry matter production (Figure 4.6).

Table 4.6 Dry matter partitioning (gplant^{-1}) of different plant parts of pearl millet genotypes at each phase in three seasons

Genotype	Vegetative phase											
	Leaves				Stem							
	S1(2012)	S2(2013)	S3(2015)	Mean	S1(2012)	S2(2013)	S3(2015)	Mean				
PVS-PM 1005	1.73_{cd}	1.77_{d}	1.73_{cd}	**1.74**	1.04_{g}	1.05_{g}	1.06_{g}	**1.05**				
PVS-PM 1006	1.67_{cd}	1.70_{cd}	1.67_{cd}	**1.68**	0.94_{f}	0.95_{f}	0.94_{f}	**0.94**				
PVS-PM 1002	1.63_{cd}	1.70_{cd}	1.70_{cd}	**1.68**	0.86_{ef}	0.94_{f}	0.86_{ef}	**0.89**				
PVS-PM 1003	1.60_{bc}	1.63_{cd}	1.63_{cd}	**1.62**	0.83_{de}	0.83_{de}	0.83_{de}	**0.83**				
PVS-PM 1004	1.70_{cd}	1.63_{bcd}	1.67_{cd}	**1.67**	0.68_{bc}	0.76_{cd}	0.68_{bc}	**0.71**				
Kimbeere	1.40_{a}	1.50_{ab}	1.40_{a}	**1.43**	0.56_{a}	0.63_{ab}	0.55_{a}	**0.57**				
Mean	**1.62**	**1.65**	**1.63**	**1.64**	**0.82**	**0.86**	**0.82**	**0.83**				
	Reproductive phase											
	Leaves				Stem				Earhead/Panicle			
	S1(2012)	S2(2013)	S3(2015)	Mean	S1(2012)	S2(2013)	S3(2015)	Mean	S1(2012)	S2(2013)	S3(2015)	Mean
PVS-PM 1005	16.73_{cd}	18.03_{d}	18.17_{d}	**17.64**	16.55_{f}	16.70_{f}	16.59_{f}	**16.61**	4.92_{e}	5.03_{e}	4.96_{e}	**4.97**
PVS-PM 1006	15.37_{bc}	16.80_{cd}	16.70_{cd}	**16.29**	15.22_{e}	15.33_{e}	15.22_{e}	**15.26**	$4.54d_{e}$	$4.63d_{e}$	4.55_{de}	**4.58**
PVS-PM 1002	15.27_{bc}	14.03_{ab}	13.97_{ab}	**14.42**	12.50_{d}	12.59_{d}	12.52_{d}	**12.54**	4.34_{cd}	4.37_{cd}	4.29_{cd}	**4.33**
PVS-PM 1003	13.40_{ab}	13.87_{ab}	13.80_{ab}	**13.69**	12.26_{d}	12.28_{d}	12.23_{d}	**12.26**	4.20_{bcd}	4.52_{de}	4.15_{bcd}	**4.29**
PVS-PM 1004	14.10_{ab}	12.67_{a}	12.60_{a}	**13.12**	11.44_{abc}	11.50_{c}	11.44_{bc}	**11.46**	3.73_{ab}	3.83_{abc}	3.70_{ab}	**3.76**
Kimbeere	12.10_{a}	12.07_{a}	11.90_{a}	**12.02**	10.71_{ab}	10.71_{abc}	10.67_{a}	**10.74**	3.41_{a}	3.50_{a}	3.36_{a}	**3.42**
Mean	**14.49**	**14.58**	**14.52**	**14.49**	**13.11**	**13.20**	**13.11**	**13.14**	**4.19**	**4.31**	**4.17**	**4.22**

S1-Season 1, S2-Season 2, S3-Season 3. Values followed by the same subscript letters in the same column are not significantly different ($P<0.05$) from each other at 5% level according to ANOVA protected LSD test.

Table 4.7 Dry matter partitioning (gplant^{-1}) among different plant parts of pearl millet genotypes in three seasons

Genotype	Grain filling Phase											
	Leaves				Stem				Earhead/Panicle			
	S1(2012)	S1(2013	S3(2015)	Mean	S1(2012)	S2(2013)	S3(2015)	Mean	S1(2012)	S2(2013)	S3(2015)	Mean
PVS-PM 1005	15.70_{e}	16.53_{e}	16.41_{e}	**16.21**	24.08_{e}	24.20_{e}	24.12_{e}	**24.14**	22.12_{bc}	22.53_{c}	22.14_{bc}	**22.26**
PVS-PM 1006	12.70_{abcd}	14.30_{de}	14.19_{cde}	**13.73**	22.08_{d}	22.23_{d}	22.15_{d}	**22.15**	20.69_{abc}	20.80_{abc}	20.68_{abc}	**20.73**
PVS-PM 1002	11.67_{abc}	12.73_{abcd}	12.66_{abcd}	**12.35**	19.71_{c}	19.76_{c}	19.68_{c}	**19.72**	19.10_{ab}	19.17_{ab}	19.10_{ab}	**19.12**
PVS-PM 1003	12.33_{abcd}	12.00_{abcd}	11.92_{abcd}	**12.08**	18.43_{b}	18.46_{b}	18.39_{b}	**18.43**	18.58_{a}	18.62_{a}	18.54_{a}	**18.58**
PVS-PM 1004	12.90_{bcd}	10.87_{ab}	10.76_{ab}	**11.51**	18.14_{ab}	18.20_{ab}	18.11_{ab}	**18.15**	17.91_{a}	18.00_{a}	17.87_{a}	**17.93**
Kimbeere	10.80_{ab}	10.33_{ab}	10.21_{a}	**10.45**	17.13_{a}	17.23_{a}	17.09_{a}	**17.15**	18.38_{a}	18.50_{a}	18.35_{a}	**18.4**
Mean	**12.68**	**12.79**	**12.69**	**12.72**	**19.93**	**20.01**	**19.92**	**19.96**	**19.46**	**19.60**	**19.45**	**19.50**
	At Harvest											
	Leaves				Stem				Earhead/Panicle			
	S1(2012)	S2(2013)	S3(2015)	Mean	S1(2012)	S2(2013)	S3(2015)	Mean	S1(2012)	S2(2013)	S3(2015)	Mean
PVS-PM 1005	23.91_{de}	25.17_{e}	25.11_{e}	**24.73**	26.67_{d}	26.77_{d}	26.69_{d}	**26.71**	25.77_{ef}	26.20_{f}	25.80_{ef}	**25.92**
PVS-PM 1006	21.17_{c}	22.47_{cd}	22.36_{cd}	**22.00**	24.03_{c}	24.43_{c}	24.01_{c}	**24.16**	23.73_{cdef}	24.17_{def}	23.77_{cdef}	**23.89**
PVS-PM 1002	20.23_{bc}	21.40_{c}	21.33_{c}	**20.98**	23.31_{c}	23.36_{c}	23.28_{c}	**23.32**	22.41_{bcde}	22.46_{bcde}	22.39_{bcde}	**22.42**
PVS-PM 1003	18.81_{ab}	19.00_{ab}	18.92_{ab}	**18.91**	20.59_{b}	20.63_{b}	20.59_{b}	**20.60**	20.36_{abc}	20.67_{abcd}	20.32_{abc}	**20.45**
PVS-PM 1004	20.21_{bc}	18.93_{ab}	18.82_{ab}	**19.32**	19.56_{ab}	19.63_{ab}	19.54_{ab}	**19.58**	19.56_{ab}	19.67_{ab}	19.54_{ab}	**19.59**
Kimbeere	17.41_{a}	18.03_{ab}	17.95_{ab}	**17.80**	19.16_{a}	19.27_{a}	19.14_{a}	**19.19**	21.45_{abcd}	18.27_{a}	21.43_{abcd}	**20.38**
Mean	**20.29**	**20.83**	**20.75**	**20.62**	**22.22**	**22.35**	**22.21**	**22.25**	**22.91**	**22.61**	**22.91**	**22.11**

S1-Season 1, S2-Season 2, S3-Season 3. Values followed by the same subscript letters in the same column are not significantly different (P<0.05) from each other at 5% level according to ANOVA protected LSD test.

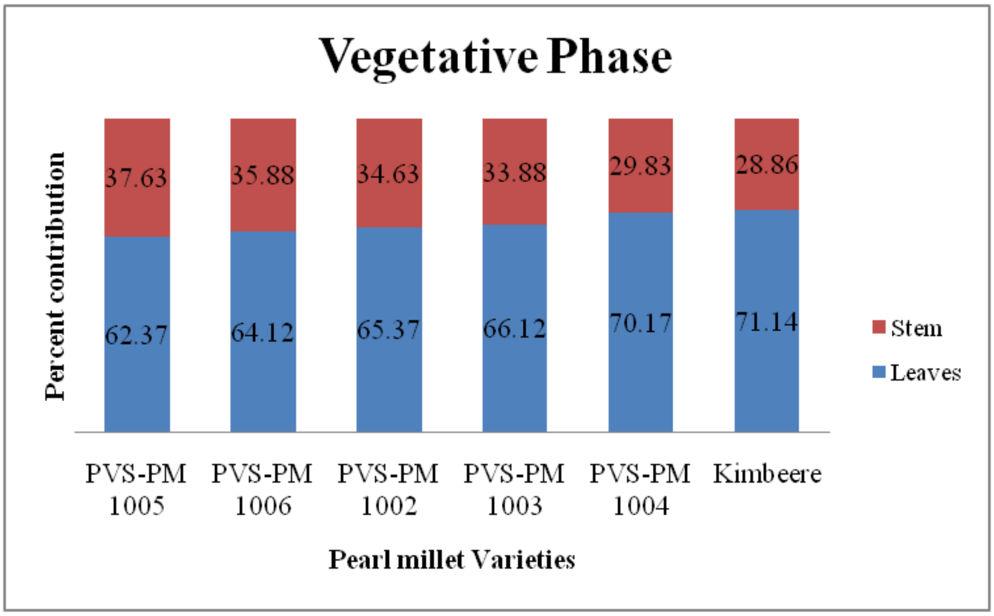

Figure 4.3 Percent contribution in total dry matter accumulation of pearl millet genotypes at vegetative phase.

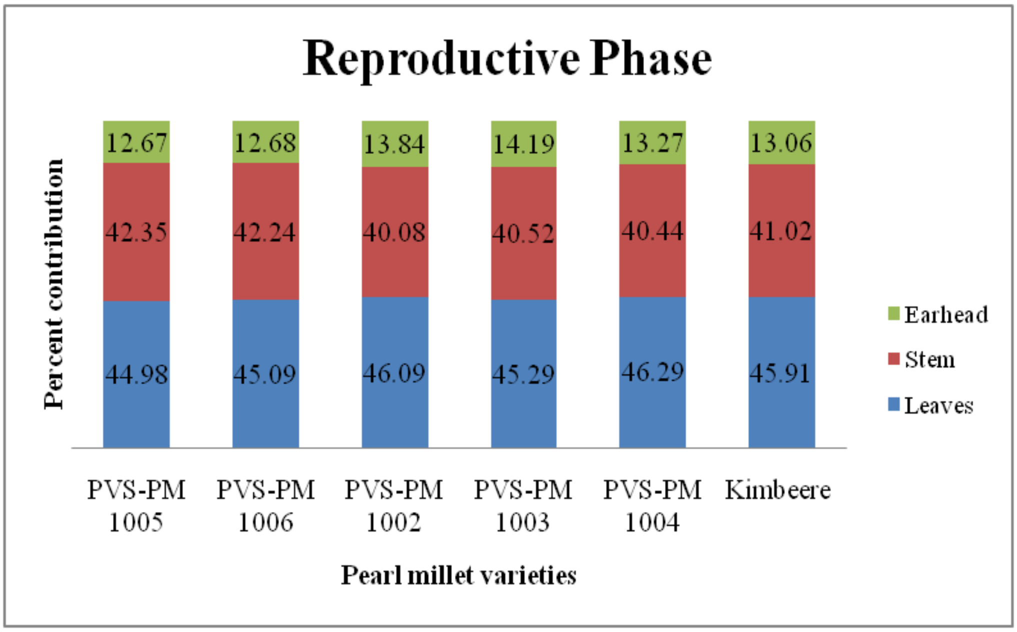

Figure 4.4 Percent contribution in total dry matter accumulation of pearl millet genotypes at reproductive phase.

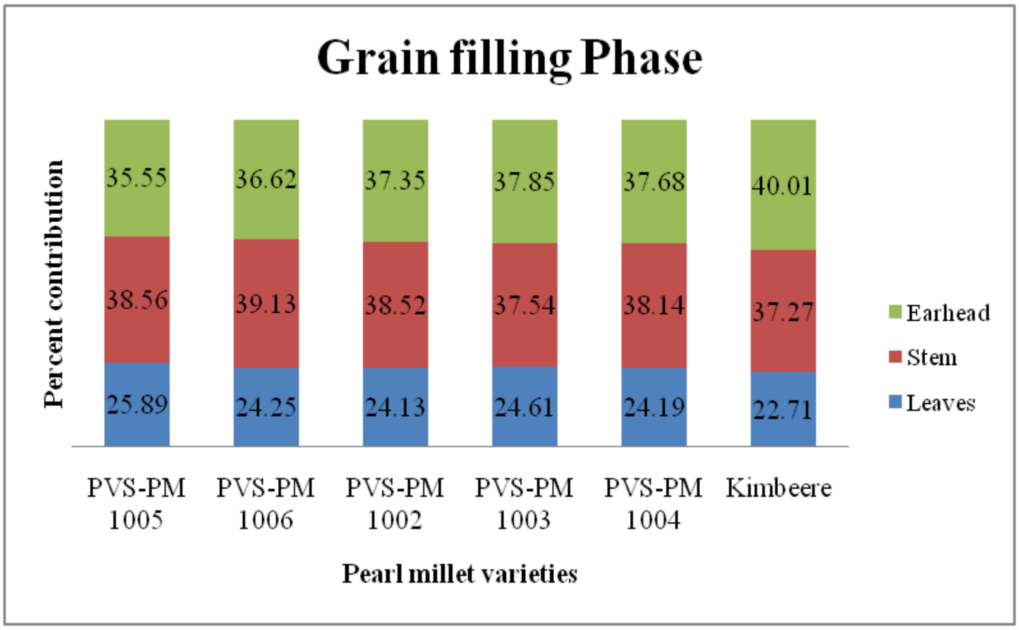

Figure 4.5 Percent contribution in total dry matter accumulation of pearl millet genotypes at grain filling phase.

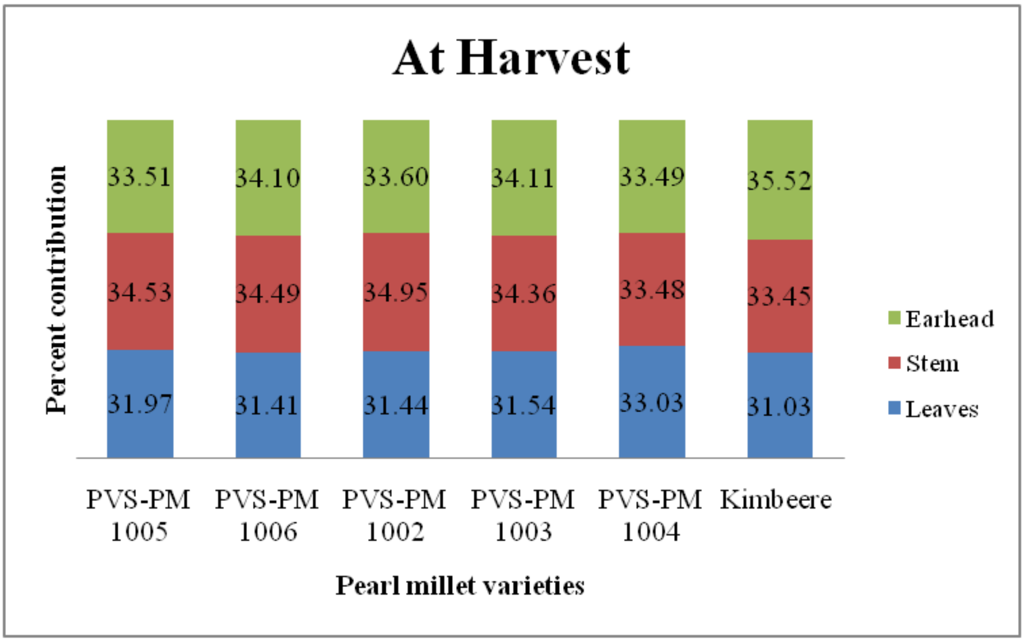

Figure 4.6 Percent contribution in total dry matter accumulation of pearl millet genotypes at harvest.

4.3.2 Yield and Yield Components of six pearl millet genotypes in three seasons.

4.3.2.1 One thousand Grain Mass (1000 Grain mass)

The data on 1000-grain mass of the pearl millet varieties is presented in Table 4.7. The 1000-grain mass varied significantly ($p<0.05$) among the pearl millet genotypes. Kimbeere had significantly lower 1000-grain mass compared to other five genotypes. There is a notable trend in weight of 1000-grain mass across the three season which were significantly ($p<0.05$) different from each other with the season 1 (2012) recording higher weight of 1000-grain mass compared to season two and three. The trend in 1000-grain mass in all the three seasons reveals that PVS-PM 100, PVS-PM 1002, PMS-PM 1006 and PVS-PM 1003 had higher grain mass (>11g) (Table 4.7).

4.3.2.2 Millet above Ground Biomass

The above ground biomass was significantly ($p<0.05$) different in terms of season*treatment interactions (Table 4.8). The data on above ground biomass of the pearl millet varieties is presented in Table 4.10 and 4.11. Kimbeere consistently had low above ground biomass yield (12.14 tonha^{-1}) compared to all the other pearl millet varieties (15.5tonha^{-1}, 10.6tonha^{-1} and 10.3tonha^{-1} in season 1, 2 and 3, respectively). The pearl millet above ground biomass varied significantly among varieties and seasons and was highest in first Season (23.66 tonha^{-1}) and lowest in third season(13.97 t/ha) for the six pearl millet varieties (Table 4.10). PVS-PM 1005 recorded the highest above ground biomass in the first and second season (30.3 tonha^{-1} and 14.6 tonha^{-1} respectively) while PVS-PM 1002 had significantly ($p<0.05$) high above ground biomass in season 3. Stover biomass was highest in season one and lowest in season 3 (Table 4.10).

Table 4.8 ANOVA table for Stover Yield of Pearl Millet varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2.9959	1.498	2.13	
Season	2	1055.9915	527.9957	749.74	<.001
Treatment	5	634.0059	126.8012	180.05	<.001
Season.Treatment	10	74.3841	7.4384	10.56	<.001
Residual	34	23.9441	0.7042		
Total	53	1791.3215			

4.3.2.3 Grain Yield

The grain yield varied significantly ($p<0.05$) in all the varieties, seasons and their interactions (Table 4.9). Based on the data computed for grain mass of pearl millet varieties, PVS-PM 1005 had significantly ($p<0.05$) higher grain yield compared to other 5 genotypes of pearl millet variety while it was PVS-PM 1003 that recorded significantly ($p<0.05$) more grains in season 3 compared to other pearl millet varieties (Table 4.10).

Table 4.9 ANOVA table for Grain yield of Pearl Millet genotypes

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	60538	30269	6.87	
Season	2	4902098	2451049	556.38	<.001
Treatment	5	1845842	369168	83.8	<.001
Season.Treatment	10	4466044	446604	101.38	<.001
Residual	34	149782	4405		
Total	53	11424303			

Table 4.10 Yield and yield components of six of pearl millet genotypes in three seasons

Pearl Millet Genotype	Season 1 (12th November 2012 to 20th February 2013)			Season 2 (21st November 2013 to 25th February 2014)			Season 3 (14th April 2015 to 10th July 2015		
	1000-grain mass (g)	Stover Yield(t/ha)	Grain yield (kg/ha)	1000-grain mass (g)	Stover Yield (t/ha)	Grain yield (kg/ha)	1000-grain mass (g)	Stover Yield (t/ha)	Grain yield(kg/ha)
PVS-PM 1005	15_{e}	30.3_{e}	2131_{e}	13.1_{c}	18.9_{d}	1224_{d}	8.7_{b}	19.23_{d}	1005.7_{b}
PVS-PM 1006	13.5_{d}	27.63_{d}	1330_{b}	10.9_{b}	17.4_{d}	1834.3_{c}	9.5_{bc}	14.97_{bc}	1012.7_{b}
PVS-PM 1002	8.7_{a}	23.23_{c}	2022_{d}	15.1_{d}	15.13_{c}	952.3_{ab}	10.8_{bc}	15.3_{c}	1188.3_{c}
PVS-PM 1004	8.9_{a}	21.37_{b}	2069_{d}	11.4_{b}	12.8_{b}	921.3_{ab}	7.3_{a}	10.67_{a}	1123.7_{c}
PVS-PM 1003	11.1_{c}	23.93_{c}	1482_{c}	13.6_{c}	12.8_{b}	682_{a}	8.7_{b}	13.33_{b}	1334.7_{c}
Kimbeere	9.9_{ab}	15.5_{a}	1132_{a}	6.2_{a}	10.6_{a}	680.3_{a}	6.7_{a}	10.33_{a}	704_{a}
Mean	**11.2**	**23.66**	**1694**	**11.7**	**14.6**	**1049**	**8.6**	**13.97**	**1061**

Values followed by the same subscript letters in the same column are not significantly different ($P<0.05$) from each other at 5% level according to ANOVA protected LSD test.

Table 4.11 Average stover, grain yield and Harvest index of six pearl millet genotypes for a period of three seasons.

Varieties	**Average stover yield (kg/ha)**	**Average Grain yield (kg/ha)**	**Harvest Index**	**1000-grain mass (g)**
PVS-PM 1005	22,810	1,453	6%	12.3
PVS-PM 1006	20,000	1,392	7%	11.3
PVS-PM 1002	17,887	1,387	7%	11.5
PVS-PM 1004	14,947	1,371	8%	9.2
PVS-PM 1003	16,687	1,166	7%	11.2
Kimbeere	12,143	839	6%	7.6
Mean	**17,412**	**1,268**	**7%**	**10.5**

The average stover biomass was highest in PVS-PM 1005 and lowest in Kimbeere, the local check (Table 4.11). Grain yield was comparable among PVS-PM 1005, PVS-PM 1006 and PVS 1002 but was substantially lower in PVS-PM 1004, PVS-PM 1003 and least in Kimbeere. Although the PVS-PM 1005 had the highest stover and grain yield, it had the lowest harvest index while PVS-PM 1003 had the highest harvest index (Table 4.11). The one-thousand grain mass varied from 7.6g in Kimbeere to 12.3g in PVS-PM 1003 (Table 4.11).

4.3.2.4 Millet Harvest Index

Harvest index variation was comparable in all the varieties and seasons (Table 4.12). A three-season summary on the pearl millet harvest index indicates a seasonal difference ($P < 0.05$) with the highest HI in Season 3 (8 %) and lowest in Season 1 and 2 (7 %) (Table 4.13). Crops that have poor water supply during grain filling may produce a large biomass but be unable to match that with a good harvest index (Passioura and Angus, 2010).The harvest index varied among the six pearl millet genotypes (Table 4.13). PVS-PM 1004 had significantly ($p<0.05$) higher harvest while it was Kimbeere which was the lowest.

PVS-PM 1006, PVS-PM 1002 and PVS-PM 1003 had comparable HI. The harvest Index of PVS-PM 1006 varied from 5% to 11%.

Table 4.12 ANOVA table for harvest index of Pearl Millet varieties

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	2	448.84	224.42	11.31	
Season	2	129.66	64.83	3.27	0.05
Treatment	5	1026.97	205.39	10.35	<.001
Season.Treatment	10	143.32	14.33	0.72	0.698
Residual	34	674.7	19.84		
Total	53	2423.49			

Table 4.13 Harvest index of pearl millet genotypes in three seasons

Pearl millet genotype	**Season 1**	**Season 2**	**Season 3**	**Mean**
PVS-PM 1005	7%	6%	5%	**6%**
PVS-PM 1006	5%	11%	7%	**7%**
PVS-PM 1002	8%	6%	8%	**7%**
PVS-PM 1003	6%	5%	10%	**7%**
Kimbeere	7%	6%	7%	**7%**
PVS-PM 1004	9%	7%	11%	**9%**
Average	**7%**	**7%**	**8%**	**7%**

4.3.2.5 Rainfall Use Efficiency

Rainfall use efficiency (RUE) was computed by dividing the grain yield of all the 6 pearl millet varieties with the total rainfall received between sowing and harvesting of millet in each of the 3 season (Table 4.14). Higher RUE was recorded by PVS-PM 1005 in first season (5.5kg/ha/mm), PVS-PM 1006 in the second season (6.2kg/ha/mm) and PVS-PM 1003 in season 3(7.5kg/ha/mm) (Figure 4.7).

Despite lower than expected rainfall in third season other factors such as light use efficiency may have played a critical role in increased rain water use efficiency by PVS-PM 1003 recording the highest RUE in the third season (Table 4.14).

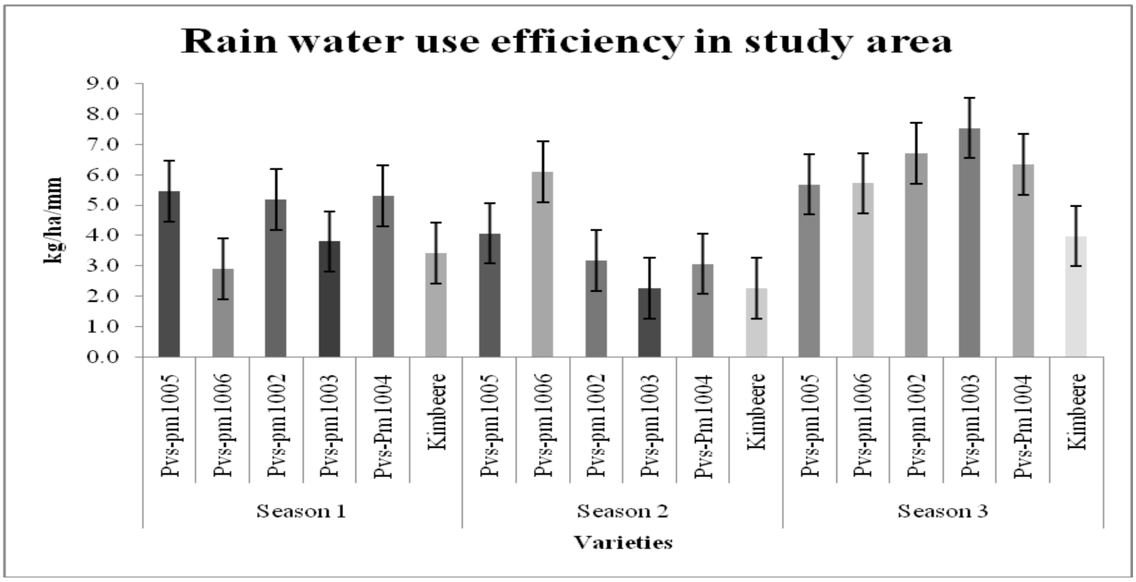

Figure 4.7 Rain water use efficiency in the study area for six pearl millet varieties in three cropping seasons

Table 4.14 Water use efficiency of six pearl millet genotypes in three seasons

Pearl Millet Genotype	Season 1 (12th November to 20th February 2013) Water use effiency(kg/ha/mm)	Season 2 (21st November 2013 to 25th February 2014) Water use efficiency(kg/ha/mm)	Season 3 (14th April 2015 to 10th July 2015 Water use effiency(kg/ha/mm)	Mean water use efficiency for each pearl millet genotype in three seasons
PVS-PM 1005	5.5	4.1	5.7	5.1
PVS-PM 1006	2.9	6.1	5.7	4.9
PVS-PM 1002	5.2	3.2	6.7	5.0
PVS-PM 1003	3.8	2.3	7.5	4.5
PVS-PM 1004	5.3	3.1	6.3	4.9
Kimbeere	3.4	2.3	4.0	3.2
Mean	**4.3**	**3.5**	**6.0**	**4.6**

4.3.2.6 Spike Length

Spike length varied significantly ($p<0.05$) in all the varieties and seasons (Table 4.16). The spike length varied among the varieties and was longest in PVS-PM 1006 (28.8

cm), followed by PVS-PM 1003 (27.1cm), PVS-PM 1005 (26.4cm), PVS-PM 1002 (26.0cm), PVS-PM 1004 (25.5cm) and shortest in Kimbeere (17.5 cm) (Table 4.15). The farmer variety recorded the shortest panicle (17.5cm) among the six genotypes and PVS- PM 1006 had the longest panicle. Panicle length was comparable among the seasons (Table 4.15). Yields can be increased by identifying varieties with long spike lengths.

Table 4.15 Spike length for six genotypes of pearl millet in three seasons

Pearl Millet Genotype	**Season 1 (12th November to 1st March 2013st)**	**Season 2 (21st November 2013 to 25th February 2014)**	**Season 3 (14th April 2015 to 3rd July 2015**	**Mean spike of each pearl millet genotype in three seasons**
	Spike length	**Spike length**	**Spike length**	
PVS-PM 1005	24.3_i	29.0_e	25.8_e	26.4
PVS-PM 1006	31.1_h	28.1_d	27.1_c	28.8
PVS-PM 1002	24.7_g	26.8_c	26.6_c	26.0
PVS-PM 1003	25.3_g	28.1_b	27.9_b	27.1
PVS-PM 1004	26.6_f	$22._4$	27.6_a	25.5
Kimbeere	16.3_c	16.1_a	20.0_a	17.5
Mean	**24.7**	**25.1**	**25.8**	**25.2**
LSD	1.4	1.4	1.4	

Values followed by the same subscript letters in the same column are not significantly different (P<0.05) from each other at 5% level according to ANOVA protected LSD test.

Table 4.16 ANOVA table for spike length of Pearl Millet varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	86.69	43.35	3.72	
Season	2	3392.86	1696.43	145.54	<.001
Treatment	5	3907.56	781.51	67.05	<.001
Season.Treatment	10	5296.58	529.66	45.44	<.001
Residual	34	396.31	11.66		
Total	53	13080			

4.4 Days to maturity (Phenology) of the six pearl millet varieties

4.4.1 Days after Emergence

The time to emergence varied appreciably (p<0.05) among varieties and seasons (Table 4.17). Kimbeere emerged in 5.3 days compared to the duration in the other five genotypes (Table 4.18). The time to emergence also varied among the three seasons and was 6.6 days, 4.1 days and 3.7 days in the first, second and third season, respectively. PVS-PM 1005 was the earliest to emerge (4.2 days) and Kimbeere was the latest (5.3 days) to emerge (Table 4.18). In general Kimbeere took the longest time to emerge in all the three seasons compared to other five varieties (Table 4.18). Days to emergence ranged between 4.2 to 5.3 among the six pearl millet genotypes.

Table 4.17 ANOVA table for days to emergence of Pearl Millet varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.4444	0.2222	1	
Season	2	92.1111	46.0556	207.25	<.001
Treatment	5	9.3333	1.8667	8.4	<.001
Season.Treatment	10	5.8889	0.5889	2.65	0.017
Residual	34	7.5556	0.2222		
Total	53	115.3333			

Table 4. 18 Days to emergence for six genotypes of pearl millet in three seasons

Pearl Millet Genotype	Season 1 (12th November to 20th February 2013) Days to emergence	Season 2 (21st November 2013 to 25th February 2014) Days to emergence	Season 3 (14th April 2015 to 10th July 2015 Days to emergence	Mean days to emergence for each pearl millet genotype in three seasons
PVS-PM 1005	6.0_{c}	3.3_{a}	3.3a	**4.2**
PVS-PM 1006	6.0_{c}	4.0_{a}	4.0_{a}	**4.7**
PVS-PM 1002	6.3_{cd}	3.3_{a}	3.3_{a}	**4.3**
PVS-PM 1003	7.0_{de}	3.7_{a}	4.0_{a}	**4.9**
PVS-PM 1004	7.0_{de}	5.0_{b}	3.7_{a}	**5.2**
Kimbeere	7.3_{e}	5.0_{b}	3.7_{a}	**5.3**
Mean	**6.6**	**4.1**	**3.7**	**4.8**
LSD	**0.7**	**0.7**	**0.7**	

Values followed by the same subscript letters in the same column are not significantly different (P<0.05) from each other at 5% level according to ANOVA protected LSD test.

4.4.2 Days to anthesis

Results for days to anthesis were significantly different (p<0.05) among the six pearl millet varieties over the three cropping seasons (Table 4.19). Kimbeere recorded significantly (p<0.05) more days (45.9 days) compared to other 5 genotypes of pearl millet variety while it was PVS-PM 1005 that recorded significantly (p<0.05) less days to anthesis compared to other pearl millet varieties (Table 4.20). Season 1 recorded significantly (p<0.05) more mean days to anthesis (44.9 days) compared to season 2 and 3 which recorded 39.9 and 40.4 days respectively (Table 4.20). Days to anthesis ranged between 34.6 to 45.9 days among the six pearl millet genotypes.

Table 4.19 ANOVA table for days to anthesis of Pearl Millet varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	90.704	45.352	4.65	
Season	2	276.704	138.352	14.2	<.001
Treatment	5	702.37	140.474	14.42	<.001
Season.Treatment	10	48.185	4.819	0.49	0.882
Residual	34	331.296	9.744		
Total	53	1449.259			

Table 4.20 Days to anthesis for six genotypes of pearl millet in three seasons

Pearl Millet Genotype	Season 1 (12th November to 1st March 2013st)	Season 2 (21st November 2013 to 25th February 2014)	Season 3 (14th April 2015 to 3rd July 2015	Mean days to anthesis for each pearl millet genotype in three seasons
	Days to anthesis	Days to anthesis	Days to anthesis	
PVS-PM 1005	38.7_{bc}	33.3_{ab}	31.7_{a}	34.6
PVS-PM 1006	44.3_{cdef}	38.7_{bc}	39.0_{bc}	40.7
PVS-PM 1002	45.3_{def}	38.3_{bc}	42.0_{cde}	41.9
PVS-PM 1003	47.0_{ef}	43.3_{cdef}	42.7_{cdef}	44.3
PVS-PM 1004	$45.7d_{ef}$	40.0_{cd}	43.0_{cdef}	42.9
Kimbeere	48.3_{f}	45.3_{def}	44.0_{cdef}	45.9
Mean	**44.9**	**39.9**	**40.4**	**41.7**
LSD	**5.1**	**5.1**	**5.1**	

Values followed by the same subscript letters in the same column are not significantly different (P<0.05) from each other at 5% level according to ANOVA protected LSD test.

4.4.3 Days to 50% Flowering/Booting

The plants were monitored daily and the number of days taken in each plot for 50% of the millet plants to flower recorded.

Days to 50% booting/flowering among the six pearl millet genotypes and seasons was comparable ($p<0.05$) as shown in (Table 4.21). The number of days to 50% booting ranged between 45.44 and 57.89 days (Table 4.22). The average days to flowering were 53.54 days. The interaction between seasons and varieties was not significant (Table 4.21).

Table 4.21 ANOVA table for days to 50% flowering of Pearl Millet varieties

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	2	24.481	12.241	2.46	
Season	2	302.926	151.463	30.5	<.001
Treatment	5	912.815	182.563	36.76	<.001
Season.Treatment	10	66.407	6.641	1.34	0.251
Residual	34	168.852	4.966		
Total	53	1475.481			

Table 4.22 Days to 50% flowering of six genotypes of pearl millet in three seasons

	Season 1 (12th November to 1st March 2013st)	**Season 2 (21st November 2013 to 25th February 2014)**	**Season 3 (14th April 2015 to 3rd July 2015**	**Average days to 50% flowering for each pearl millet genotype in three seasons**
Pearl Millet Genotypes	**Days to 50% flowering**	**Days to 50% flowering**	**Days to 50% flowering**	
PVS-PM 1005	50.7_{bc}	42.0_{a}	43.7_{a}	45.44
PVS-PM 1006	56.3_{efgh}	48.0_{b}	$51.0b_{cd}$	51.78
PVS-PM 1002	57.0_{efgh}	50.7_{bc}	53.3_{cde}	53.67
PVS-PM 1003	59.0_{gh}	55.3_{efg}	54.7_{cdef}	56.00
PVS-PM 1004	57.7fgh	55.3_{efg}	55.0_{defg}	56.33
Kimbeere	60.3_{h}	57.3_{efgh}	56.0_{efg}	57.89
Mean	**51.44**	**52.28**	**56.83**	**53.52**
LSD	**3.6**	**3.6**	**3.6**	

Values followed by the same subscript letters in the same column are not significantly different ($P<0.05$) from each other at 5% level according to ANOVA protected LSD test.

4.4.4 Days to 50% Maturity

Results for days to 50 percent (%) maturity are summarized in Table 4.23. Significant differences in days to 50% maturity ($p<0.05$) were observed among pearl millet genotypes in all the three seasons (Table 4.24). Days to 50% maturity ranged from 66.1 days for PVS-PM 1005 to 80.33 days for Kimbeere. There were no differences in days to 50% maturity between genotypes and seasons (Table 4.24).

Table 4.23 Days to 50% maturity for six genotypes of pearl millet in three seasons.

Pearl Millet Genotype	Season 1 (12th November to 1st March 2013st)	Season 2 (21st November 2013 to 25th February 2014)	Season 3 (14th April 2015 to 3rd July 2015	Mean days to 50% maturity for each pearl millet genotype in three seasons
	Days to 50% maturity	Days to 50% maturity	Days to 50% maturity	
PVS-PM 1005	70.7_{b}	64.7_{a}	64.0_{a}	66.1
PVS-PM 1006	76.3_{cde}	72.7_{bc}	73.7_{bc}	74.2
PVS-PM 1002	77.0_{cde}	74.0_{bcd}	74.0_{bcd}	75.0
PVS-PM 1003	79.7_{de}	76.0_{bcd}	74.7_{bcd}	76.8
PVS-PM 1004	82.7_{ef}	77.0_{cde}	75.3_{bcd}	78.0
Kimbeere	86.0_{f}	77.7_{cde}	77.3_{cde}	80.3
Mean	**78.6**	**73.5**	**73.2**	**75.07**
LSD	**4.8**	**4.8**	**4.8**	

Values followed by the same subscript letters in the same column are not significantly different ($P<0.05$) from each other at 5% level according to ANOVA protected LSD test.

Table 4.24 ANOVA table for days to 50% maturity of Pearl Millet varieties

Source of variation	**d.f.**	**s.s.**	**m.s.**	**v.r.**	**F pr.**
Block stratum	2	38.481	19.241	2.25	
Treatment	5	1081.704	216.341	25.29	<.001
Season	2	328.259	164.13	19.19	<.001
Treatment.Season	10	54.407	5.441	0.64	0.773
Residual	34	290.852	8.554		
Total	53	1793.704			

4.5 Correlation of selected traits in six pearl millet varieties

The correlations among the traits are presented in Table 4.25. There was a significant and positive correlation between grain yield ha^{-1} and days to emergence (0.5366), days to anthesis (0.641), days to flowering (0.0098), height (0.0685), Spike length (0.0145), tillers per plant (0.385) and 1000 grain weight (0.01533).

Table 4.25 Correlation coefficients of selected traits in pearl millet varieties

	DTE	DTA	DTF	HGT	SL	DTM	T/P	1000 GW	SY	GY	HI
DTE	-										
DTA	0.5416	-									
DTF	0.5945	0.9008	-								
HGT	0.0482	-0.0882	-0.0898	-							
SL	-0.2358	-0.3033	-0.3646	0.1709	-						
DTM	0.5868	0.8077	0.8685	-0.1127	-0.3037	-					
T/P	0.4889	0.9084	0.7939	-0.119	-0.3118	0.7201	-				
1000 GW	0.0152	-0.2769	-0.295	0.2784	0.3472	-0.249	-0.2619	-			
SY	0.5265	-0.0275	-0.0744	0.0775	0.2682	-0.1059	-0.061	0.4844	-		
GY	0.5366	0.0641	0.0098	0.0685	0.145	0.0612	0.0383	0.1533	0.6823	-	
HI	0.123	-0.1994	-0.1839	0.3969	0.5286	-0.2139	-0.2245	0.4102	0.4452	0.4133	-

DTE-days to emergence, DTA-days to anthesis, DTF-days to flowering, HGT-height, SL-Spike length, DTM-days to maturity, T/P-Tillers per plant, 1000 GW-1000 grain weight, SY- stover yield, GY-grain yield, HI-harvest index.

CHAPTER FIVE

5.0 DISCUSSION

5.1.1 Soil characteristic and Crop ecology

The soil properties and fertility status of the field typified the situation of South Eastern Kenya-loamy-sand and acidic soil (pH 5.62) which is ideal for Pearl millet cultivation (Spencer and Sivakumar, 1987). The low pH in the study area could be attributed to low Ca (0.09) and Mg (0.06) contents of the soil. According to Whalen *et al.* (2000), most agricultural crops produce well in the pH range of 5.6 to 7.5 in sandy soils. However, the percentage Organic Carbon (OC) was observed to be below (0.41%) in the evaluation field compared with the global outlook of 1.1-2.5% (Whalen *et al.,* 2000). Landon (2014) rated soil containing organic carbon > 20 % as very high, 10–20 % high, 4–10 % medium, 2–4 % low and < 2 % very low. With reference to these ranges, the percent organic carbon of the study area was very low. The initial total nitrogen content (0.01 %) was very low. Landon (2014) rated percent total N content in soil > 1.0 as very high, 0.5–1.0 high, 0.2–0.5 medium, 0.1–0.2 low and < 0.1 very low. With reference to these ranges, the total N content of the study area was very low (0.08) due to the low organic matter content since nitrogen is an essential component of organic matter. The available P content of the study area is low but around the value of 12.85 mg kg^{-1} which according to Manu *et al.* (1991) has been determined to be the critical P level required to obtain 90 % of the maximum millet yield. Buchholz *et al.* (2004) provided available P ranges as: < 3 mg kg^{-1}-very low, < 10 mg kg^{-1}-low, between 10 - 20 mg kg^{-1}-medium, > 20 mg kg^{-1}-high. The cation exchange capacity (CEC) (3.82 cmol+ kg^{-1} of soil) of the study area was very low and could be explained by the low pH and soil organic matter content. Arthur (2009) reported that low CEC value could be due to low pH (5.62). According to the rating given by Landon (2014), CEC value (i.e. in cmol+ kg^{-1}) > 40 is very high, 25–40 is high, 15–25 is medium, 5–15 is low and < 5 is very low.

Constant decline in the annual precipitation amounts has been blamed on climate change over the years affecting the ecology of the crop (Kasei, 2001). This is an indication that the seasons are getting shorter by the day. According to KFSSG (2013) South Eastern Kenya experiences a bimodal rainfall pattern with long rains falling from late March to June and short rains between late October and November.

The climate change effect has rather reinforced the need to concentrate more efforts at developing and conserving the early maturing and drought tolerant accessions for the ecology of South Eastern Kenya (Kasei, 2001).

5.1.2 Influence of Rainfall

Pearl millet requires an evenly distributed rainfall during the growing season despite its drought resistance (South African Department of Forestry and Fisheries, 2011). Excess rain at flowering can also cause a crop failure. Water is an essential input to ensure good seed yield. The most critical stages requiring adequate rainfall for pearl millet seed crop are tillering, flowering and seed development. Moisture stress at any of these stages reduces seed yield considerably (Khairwal *et al.,* 2007). Rainfall during the cropping seasons showed different rainfall patterns with 390.8 mm of rain in 2012 cropping season, 300.8mm in 2013 cropping season and 177.6 mm in 2015 cropping season. This must have impacted the overall growth of the crop. But during the three cropping seasons, low and erratic rainfall was registered especally during the developmental stage which surely affected the crop perfomance.

5.1.3 Variation among pearl millet genotypes for growth, yield and yield components selected important traits

Significant variability among the six peral millet genotypes for most of the characters studied in the three cropping seasons offer an opportunity for genetic improvement as superior ones can be isolated from the rest (Table 4.10). Genetic variation has been found to be an important prerequisite to improvement of those traits showing variation (Lakshmana, 2008). Increasing grain yield and yield stability is a major breeding objective to improving pearl millet (Baskaran *et al.* 2009). Considerable variation in grain yield was observed among the six genotypes ranging from 1453.6Kg/ha to 904.8 Kg/ha in all the three cropping seasons. PVS-PM 1005 had the highest grain yield (1453.6Kg/ha) in all the three seasons, followed by PVS-PM 1002 (1387.6Kg/ha, PVS-PM 1004 (1371.3Kg/ha, PVS-PM 1006 (1326.3Kg/ha), PVS-PM 1003 (1166.2Kg/ha) and Kimbeere which had the least yield (904.8Kg/ha). (Table 4.7).

The highest average grain yield for the six varieties was observed in season 1 (1694.3Kg/ha), followed by season 3 (1061.5kg/ha) and lowest was season 2 (1049.1kg/ha).

It is evident from the results that high yielding genotypes were the hybrids and the farmer variety gave the lowest yields Seasonal grain yield variations was due to low and unreliable rainfall during the three cropping seasons. Similar results were reported by Premsagar and Kapoor,1988.

5.1.3.1 Plant Height

The results showed that on the average, hybrid varieties are taller than the local check. Plant height is an important component which helps in the determination of growth (Muranyi and Pepo, 2013). The plant height results presented reviewed that all the six varieties did not differ significantly at 5% level of confidence. Variety PVS PM 1006 was the tallest with plant height of 157.2cm, whereas the local variety was the shortest in height (150.1cm) (Table 4.2). There were positive correlations between plant height with pearl millet grain yield. Similar results have been reported in earlier evaluation of pearl millet varieties in Ghana (Nutsugah *et al.*, 2000) and across seven countries in West Africa (Wilson *et al.*, 2008). Overall results in Apendix 1.2 showed that plant height among the six millet genotypes for the period of evaluation was comparable.

5.1.3.2 Number of tillers

The number of tillers were significantly ($p<0.05$) different in terms of genotypes and seasons. However, season*genotype interactions was not significant for number of tillers per plant (Table 4.3) Significant variation ($p<0.05$) on the number of tillers per plant was noted amomg the genotypes and seasons (Table 4.3). This may be due to varying soil fertility gradient, genetic factors and, varying rainfall conditions creating a difference in number of tillers between rich and poor soils. The main yield contributor towards a good crop of pearl millet is mainly from the earheads of the main stalk, primary tillers and some of the secondary tillers (Rangaswami Ayyangar *et al.*,1935)**.**

5.1.3.3 Total dry matter accumulation

The results showed that total dry matter accumulation varied among different plant parts among the pearl millet genotypes. In terms of dry matter partitioning, leaf contribution was highest in total dry matter at vegetative and reproductive phase. At grain filling phase, earhead and stem contributed the highest in total dry matter than leaf. The contribution of earhead was highest in the total dry matter at harvesting stage in all the pearl millet genotypes. Crop plants have several drought resistance mechanism which yield could be augmented under rainfed conditions (Chaves,1991). The short duration and early maturing genotypes, which mature before the rain ends or the soil is depleted have the drought escaping ability. These genotypes can mobilize stem reserves stored before anthesis to the developing grain.

5.1.3.4 Dry matter partitioning (gplant^{-1})

Results on dry matter partitioning varied at different stages clearly reflecting higher contribution of leaves in the total dry matter upto reproductive phase and thereafter contribution of earhead in the total dry matter started and continued to increase upto maturity. Dry matter matter contribution to different plant parts (leaf, stem and earhead) within genotypes also varied within the genotypes and seasons. Similar results were reported by Maiti and Bidinger, 1981. Increased dry weight in leaves and stem dry weight was due to increase in plant height with the increased number of leaves and internodes. Decline in leaf and stem weight at reproductive phase and maturity might be due to translocation of pre anthesis assimilates stored in these plant parts to the developing sink. There was poor partitioning of dry matter to earhead in the plants during the three seasons. This might be due to rapid senescence of foliage and adverse effect of moisture stress on seed setting and development of grains and hence, only little allocation of assimilates to grains (de Souza et al., 1997). This might be due to genetic composition of the genotypes and erratic rainfall during the three cropping seasons.

5.1.3.5 One thousand grain mass (1000 grain mass)

The results showed that 1000 grain weight varied significantly ($p<0.05$) across all the 6 pearl millet genotypes. Kimbeere recorded significantly low weight of 1000 grain weight compared to other five genotypes. There was a notable trend in weight of 1000 grains across the three season which were significantly ($p<0.05$) different from each other with the season 1 (2012) recording higher weight of 1000 grain weight compared to season two and three. The trend in 1000-grain mass in all the three seasons reveals that PVS-PM 100, PVS-PM 1002, PMS-PM 1006 and PVS-PM 1003 had higher grain mass (>11g) in all the three seasons (Table 4.10). This is an indication that the seasonal rainfall distribution affected 1000 grain mass among millet varieties since the rainfall was low during the grain filling stages almost in all the three seasons. The results are in agreement with findings of Abraham *et al.* (1989) and Yadav *et al.* (2001).

5.1 3.6 Millet above Ground Biomass

The data recorded on Stover yield reveals that Kimbeere consistently recorded low above ground biomass yield compared to all the other pearl millet varieties (15.5, 10.6 and 10.3t/ha in season 1, 2 and 3 respectively). A diminishing trend of above ground biomass yield was noted across the three seasons in all the 6 pearl millet varieties and this was attributed to the low and unreliable rainfall. PVS-PM 1005 recorded the highest above ground biomass in the first and second season (30.3 t/ha and 14.6 t/ha respectively) while it was PVS-PM 1002 that recorded significantly ($p<0.05$) high above ground biomass in season 3. Stover yield followed a trend like that of grain yield with the better performers also producing higher straw yields compared to their lower yielding counterparts. The results showed that the five hybrid varieties yielded more dry matter in comparison with the local variety (Kimbeere). Similar results were reported by Gupta et al. (2015). Kimbeere variety has shown poor performance with respect to dry matter yield because of its poor growth at the time of germination.

5.1.3.7 Grain yield

The yield should not be considered as a single trait but rather a group of traits, composed of the many components and is the final result of a plant life cycle (Borojevic, 1990).

The total grain yield varied considerably among the genotypes. Gravois (1994) reported similar results in rice and in maize. Identifying of high yielding hybrids of pearl millet is helpful because approximately one third of the world's pearl millet are grown in Africa and 70% of that is in arid semi-arid regions of this great continent (Kumar, 1989).

It has been found that about 50% of yield variation under drought stress conditions could be explained by differences in the yield potential of genotypes and their flowering time (Bidinger *et al.*, 1982, 1987a). Hybrids identified in this study for having yielded higher total grain yield per hactare could further be subjected to selectetion to obtain high yielding varieties because pearl millet cultivars grown by farmers are still producing lower total grain yield compared to other cereals. The greater perfomance of the hybrids could be as a result of hybrid vigor existing among the hybrid. The varieties which ripened earlier yielded more grain and the ones which ripened lately yielded more dry matter content. Other characters like spike length and number of tiller per plant were also in favour of grain yield. Similar results were reported by Sachdeva (1981).

5.1 3.8 Physiological importance of Harvest index

According to Maobe *et al.* (2010), the magnitude of the pearl millet harvest index is not highly heritable and varies with season, management and environment. It shows that how plant allocates its assimilates to harvestable organs. Highest pearl millet HI were obtained generally in season 3(8%) which recieved the lowest amount of rainfall but well distributed.

Sinclair and Weiss (2010) reported that significant improvement in yield of new varieties has been attributed to the increases in HI. The higher values of pearl millet HI observed in 2015 could be due to the lower haulm production as a consequence of low rainfall (Table 4.13) particularly torward the end of the cropping season. In those plants that manage to send more photosynthetates are transferred to economic organs, grain in cereals, harvest index will be higher.

Failure of treatments to impact on the pearl millet HI in the seasons is usually credited to poor distribution of rainfall especially at the grain filling stage. Crops that have poor water supply during grain filling may produce a large biomass but be unable to match that with a good harvest index (Passioura and Angus, 2010). The yield components approach is based on the empirical observation that growth during a critical window of time around anthesis is related to the number of grains per plant or per unit area (Fischer, 1985; Kiniry *et al.,* 2002).

5.1.3.9 Rainfall use efficiency

Rainfall use efficiency (RUE) is a measure of how efficiently the genotype uses rain water. RUE varied among the genotypes with PVS-PM 1005 recording the highest RUE followed closely by PVS-PM 1006. Despite lower than expected rainfall in third season other factors such as light use efficiency may have played a critical role in increased rain water use efficiency by PVS-PM 1003 recording the highest RUE in the third season. Generally Kimbeere did not show good RUE compared to other improved millet varieties and this was attributed to improved ground cover that may have reduced loss of soil moisture through evapo-transpiration. In addition improved ground cover results in improved soil structure and reduced water loss through soil erosion. Similar findings have been reported by (Cakir, 2004).

5.1.3.10 Spike/panicle Length

Panicle length and structure is an important agronomic trait in the acceptance of variety by farmers in arid and semi-arid regions of Africa (Ouendeba *et al.,* 1996). The results showed appreciable variation ($p<0.05$) among the varieties but the interaction between season and varieties was not significant. This may have being attributed to genetic factors and low and erratic rainfall during the three cropping seasons. The panicle length for most genotypes was significant (Table 4.15). The mean Spike length for the three seasons ranged from 24.7cm (season 1), 25.1cm (season 2) and 25.8cm (season 3). Teare, Wright, and Pudelko (1994) emphasized of head length being the primary factor in pearl millet productivity. This study found that the farmer variety has the shortest panicle among the six genotypes and PVS-PM 1006 as having the longest panicle.

Good potentials also exist for PVS-PM 1005, PVS-PM 1002, PVS-PM 1003 and PVS-PM 1004 for production of longer panicle length. They can further be subjected to selection for improved panicle length. Ouendeba *et al.* (1996) reported that farmers were found to select seeds based on spike length, spike compactness and seed size for susequent planting. Comperative perfomance of the hybrids clearly potrayed their superiority over the farmer local variety.

5.1.4 Phenological cycle (Days to maturity)

5.1.4.1 Days to emergence

The time to emergence varied appreciably ($p<0.05$) among varieties and seasons (Table 4.17). Delays in germination and plant emergence, lengthens the crop cycle and increases production costs and reduced yields (Otubo *et al.,* 1996). Kimbeere which emerged in 5.3 days had the lowest yields (839Kg/ha) compared to the duration in the other five genotypes (Table 4.11). PVS-PM 1005 was the earliest to emerge (4.2 days) and Kimbeere was the latest (5.3 days) to emerge (Table 4.18). In general the hybrids which emerged earlier than the farmer variety produced higher yields. Similar results were reported by Wilson *et al.,* 2008.

5.1.4.2 Days to anthesis

Data on number of days to anthesis as influenced by pearl millet variety as presented in Table 5.3 showed that Kimbeere varieties had significantly the longest number of days to anthsis, 45.9 days compared with the rest of the varieties. PVS-PM 1005 took the shortest time of 34.6 days. Generally there was a signifucant variation in the number of days to anthesis and among the varieties and seasons Table 1.9). Season 1 had the longest days of 44.9, Season 2, 39.9 and season 3, 40.4 days. This implies that the amount of rainfall affected days to anthesis among millet varieties. Therefore adjustment of the crop cycle to water supply through genotypic variation in phenology is a vital means of terminal drought escape (Borrell *et al.*, 2001). At the end of season drought stress, early flowering genotypes yield more grain than later flowering ones, because it enables the plant to escape water stress during the critical stage of yield formation. This may have ascribed to the hybrids maturing earlier than the farmer variety .

5.1.4 3 Days to 50% Flowering

The results on days to 50% booting/flowering among the six pearl millet genotypes were significantly different ($p<0.05$). The number of days to 50% booting ranged between 46 and 56 days (Table 5.4). The average days to flowering were 54.2 days. This is an indication that the rainfall distribution affected days to 50% flowering among millet varieties.

Results show that the duration from 50% flowering to harvest period was longer for the hybrids than for local check because the hybids started flowering earlier than the local kimbeere variety. This resulted to higher yields for the hybrids**.** Similar results have been reported by Ntare (1990), who reported that the early ripening millet varieties gave the highest grain yield. Time required to reach 50% flowering influenced pearl millet grain yield with higher grain yield being associated with longer days to attainment of 50% flowering. This could be due to longer periods of utilization of plant growth resources such as nutrients; soil moisture and solar radiation. Begg and Burton(1973), from a study on comparison of five genotypes of bulrush millet, reported that the late maturing inbred and the F_1 hybrids gave higher dry matter indicating there suitability for development as forage types for use in ASAL regions.

5.1.4.4 Days to maturity

The results showed a variable significance ($p<0.05$) on days to 50% to maturity among the pearl millet genotypes in all the three seasons (Table 4.24). The mean for days to 50% maturity for all the genotypes was 75.07 days. PVS-PM 1005 was relatively early and attained 50% maturity at 66.1 days followed by PVS-PM 1006, while Kimbeere attained 50% maturity at 80.33 days. There were no differences in days to 50% Maturity between genotypes and seasons. Similar results have been reported by Muhammed *et al.* (2002).

Days to 50% maturity ranged from 66.1 days for PVS-PM 1005 to 80.33 days for Kimbeere. This is an indication that the hybrids adapted better to the environments than the local check (Table 5.5).

Crop production and subsequent attainment of maximum yields are highly influenced by environmental factors in addition to management practices. Boyer (1982) reported that in agricultural systems, crops are limited to approximately 25% of their potential due to environmental stresses. There were no differences in days to 50% maturity between genotypes and seasons (Table 4.24).

5.1.5 Correlation of selected physiomophological parameters of pearl millet

The summary of the correlation coefficients between grain yield per hectare and other physiological parameters average across the three cropping seasons is presented in Table 4.25. The correlation among the variables showed many significant values. Pearl millet grain yield per hectare was positively correlated with days to emergence (0.5366), days to anthesis (0.641), days to flowering (0.0098), height (0.0685), Spike length (0.0145), tillers per plant (0.385) and 1000 grain weight (0.01533). The significant positive correlation observed between grain yield yield and the selected physiomophological parameters in this study implies that days to anthesis, days to emergence and tillers per plant contribute immensely to high grain yields in pearl millet. Similar patterns of variability also reported by Abuali *et al*. (2012) and Govindaraj *et al*. (2010).

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSION

This study which characterised pearl millet genotypes in order to establish a basis for exploiting the genetic potential of pearl millet for the development of high yielding (hybrid) varieties in Kenya. This revealed significant variability among the genotypes for most of the characters studied pointing to potential for genetic improvement in pearl millet as superior ones can be isolated from the rest. The work confirmed that even under well managed, but rainfed, arid zone environments, current hybrids offer farmers more advantage over their traditional landrace. On the basis of growth and yield of the six pearl millet varieties the, PVS-PM 1005, PVS-PM 1006 and PVS-PM 1002 were identified as superior for semi arid conditons of South Eastern Kenya. On the basis of the number of days to maturity, PVS-PM 1005 was identified as the most superior, followed by PVS-PM-1006, PVS-PM 1002, PVS-PM 1003, PVS-PM 1004. Kimbeere was last to mature. The hybrid varieties are more superior than farmers varieties in terms of grain yield and biomass production thus it is possible to use any accession at any location within the area as breeding material. The study also reavealed that there was direct ralationship between grain yields and other selected physiomophological parameters such as days to emergence, days to flowering, hieght, spike length and tillers per plant.

6.2. RECOMMENDATION

- There is need to develop pearl millet varieties whose growth period and adaptability closely matches the respective environments in arid and semi arid areas.
- There is need to develop pearl millet varieties that satisfy the needs of farmers in terms of adaptability, maturity and yield performance. This can be achieved by improving the undesirable traits such as disease resistance in some of the improved varieties. This can be done through participatory plant breeding (scientists-farmers-seed industry partnership).
- Further evaluation need to be carried out on the core selection to identify trait-specific accessions that can be exploited for hybrid development as well as improvement in the landraces as well as variety development.

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APPENDICES

Appendix 1.1 ANOVA table for 1000 grain mass of Pearl millet

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2.357	1.1785	3.1	
Block.*Units* stratum					
Season	2	98.307	49.1535	129.32	<.001
Treatment	5	137.9037	27.5807	72.56	<.001
Season.Treatment	10	139.0907	13.9091	36.59	<.001
Residual	34	12.923	0.3801		
Total	53	390.5815			

Appendix 1.2 ANOVA table for height of Pearl Millet varieties

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	591.6	295.8	2.21	
Block.*Units* stratum					
Season	2	1351.5	675.8	5.04	0.012
Treatment	5	416.3	83.3	0.62	0.685
Season.Treatment	10	812.1	81.2	0.61	0.798
Residual	34	4560.8	134.1		
Total	53	7732.3			