EVALUATING PRODUCTIVITY OF THREE LEGUME SPECIES AND THEIR RESPONSE TO INORGANIC FERTILIZER IN MAKUENI COUNTY, KENYA

BY

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DECLARATION

DECLARATION BY THE CANDIDATE

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This work is dedicated to my dad, mum and all those who have helped me in my education.

ABSTRACT

Grain legume production in Makueni County is low mainly due to drought and declining soil fertility. Drought tolerant legumes can be used to mitigate the effects of drought as well as improving soil fertility. The objective of the study was to evaluate the productivity of three legume species in different agro-ecological zones in Makueni County and their response to DAP fertilizer application. The study was conducted in Makueni County during the 2014 long rain season in three locations namely Machinery (IL6), Utafiti (LM5) and Mwanzo (LM4). The three legume species were Beans (KAT/B-9), Cowpea (M66), Lablab (KAT/DL-1) and Lablab accession CP1 81364. The experiment was laid out in a Randomised Complete Block Design in a factorial arrangement with five blocks per location. Data was collected on number of days to flowering and physiological maturity, biomass yield at flowering and at physiological maturity and grain yield at harvest. Data was subjected to ANOVA using SAS version 9.3. The results showed that the mean number of days to 50% flowering and physiological maturity for the three legumes were significantly ($P \leq 0.05$) lower in Machinery (IL6) as compared to the other two locations. There was no significant difference ($P \geq 0.05$) in the biomass and grain yields of KAT Bean-9 in the three locations. However, cowpea and lablab yields were significantly ($P \leq 0.05$) different in the three locations. Cowpea M66 biomass and grain yield was significantly higher in Mwanzo as compared to the other locations. The biomass yield was 2840 kg/ha while grain yield was 1823 kg/ha. Lablab biomass and grain yields were significantly higher in Utafiti and Mwanzo locations than Machinery. KAT/DL-1 biomass yields was 3856 kg/ha and 4012 kg/ha in Utafiti and Mwanzo respectively. The grain yields were 1604 and 1823 kg/ha. Overall, lablab variety KAT/DL-1 significantly ($P \leq 0.05$) yielded more biomass and grain than CP1 81364 at the three locations. DAP fertilizer application significantly ($P \leq 0.05$) increased the grain and biomass yield of the legumes. Biomass yield of beans increased up to 100% while grain yield increased up to 204%. Cowpea M66 yield increased by 96% and 127% for biomass and grain yields respectively. Lablab biomass and grain yields increased up to 120% and 116% respectively. The results show that KAT Bean 9 was suitable in all the three agro-ecological zones while cowpea variety M66 was more suited to LM4 agro-ecological zone. Lablab variety KAT/DL-1 and accession CP1 81364 were suitable for LM4 and LM5 agro-ecological zones. DAP fertilizer application significantly increased the grain and biomass yields of the three legumes. Farmers should use DAP fertilizer and the legumes which were found suitable in the various agro-ecological zones to improve yields.

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ABBREVIATIONS AND ACRONYMS

AEZ	Agro-ecological Zone
ASAL	Arid and Semi-arid Lands
BNF	biological nitrogen fixation
CV	coefficient of variation (%)
DAP	Di-ammonium phosphate
DAS	days after planting (sowing)
FAO	Food and Agriculture Organization of the United Nations
IL 6	Inner Lowland Ranching Zone (AEZ)
KALRO	Kenya Agricultural and Livestock Research Organisation
KEPHIS	Kenya Plant Health Inspectorate Service
LM 4	Lower Midland Marginal Cotton Zone (AEZ)
LM 5	Lower Midland Livestock Millet Zone (AEZ)
LR	Long Rains
MOA	Ministry of Agriculture
RoK	Republic of Kenya
SAS	Statistical Analysis Software
TSP	Triple superphosphate

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CHAPTER ONE

INTRODUCTION

1.1 Background information to the research project

The research project on "evaluating productivity of three legume species and their response to inorganic fertilizer in Makueni County, Kenya" was part of a collaborative project "utilizing agro-biodiversity in smallholder farming systems of Eastern Africa to cope with climate variability." The goal of the main project was identification of niches for drought tolerant dual purpose legumes in the agro-ecological environment of complex small-holder farming systems in semi-arid Eastern Kenya. This study was undertaken in the context of the main project.

1.2 Overview of grain legume production in Kenya.

Grain legumes are valued for their multiple uses as food, fodder, green manure and cover crops (Kimiti *et al.,* 2009). They also have the ability to improve the fertility of soil through biological nitrogen fixation (Chianu *et al.*, 2011; Mweetwa *et al.*, 2014). In Kenya, many types of grain legumes are grown in various parts of the country (Table 1). The common legumes cultivated in Makueni County are beans (*Phaseolus vulgaris* L.), pigeon peas (*Cajanus cajan* (L.) Millsp), cowpea (*Vigna unguiculata* (L.) Walp) and green grams (*Vigna radiata* Wilczek) (Wambua *et al.,* 2014).

Table 1: Production (MT) of major legume crops in Kenya.

Crop	2008	2009	2010	2011	2012	Mean
Common bean	261 137	465 363	390 598	577 674	613 902	461 734
Pigeon pea	84 168	46 474	103 233	84 313	89 390	81 515
Cowpea	47 958	60 152	72 274	81 534	113 961	75 175
Green gram	26 713	42 333	61 125	70 225	91 824	58 444

Source: Ministry of Agriculture (MOA, 2013).

Common bean (*Phaseolus vulgaris* L.) is one of the most important grain legumes for human consumption (Beebe, 2012). It is considered one of the most important grains for human consumption and is planted worldwide on approximately 26 million hectares (Emam *et al*., 2010). It plays a big dietary role; supplying proteins, carbohydrates, essential elements and vitamins to both rural and urban households (Manjeru *et al*., 2007). Common bean is an important commercial crop contributing significant incomes to the majority of the small scale farmers in Kenya (Wortman *et al.,* 2004).

Common bean requires deep well drained, sandy loam, sandy clay loam with a soil pH range of 4.6 - 5.0. The minimum organic carbon in the soil should be about 2.4% (Kimani *et al*., 2010; Lunze *et al.,* 2012). It also requires moderate amounts of rainfall ranging from 300 mm to 600 mm. Adequate rainfall amount is required during the critical flowering stage for better yields (Katungi *et al*., 2009). It is a short season crop with most varieties maturing in a range of 65 to 110 days (Buruchara, 2007).

In Kenya, common bean is ranked as the most important legume crop in both production and utilisation (Gicharu *et al.*, 2013). According to MOA (2015), the area under beans production was 1,052,408 ha and production was 6.8 million bags (90 kg) in 2014. Eastern Kenya accounts for 35 % of common bean production in Kenya. The other main bean production areas in Kenya are Central, Western and Nyanza regions at altitudes varying from 1,500 to 2,500 m above sea level (Okwiri *et al.,* 2009; Katungi *et al.,* 2010).

The production has been fluctuating over the years due to several constraints such as erratic rainfall patterns, drought, low soil fertility, insect-pests and diseases (Beebe *et al.,* 2013). Beans have a relatively short maturity period compared to other legumes. This makes it suitable for the drought conditions of Makueni County since they are able to escape drought.

Cowpea (*Vigna unguiculata* (L.) Walp) is an annual or bi-annual legume grown throughout the semiarid tropics, where it is valued as both human and livestock food. It is drought tolerant, can be grown on relatively poor soils, and fixes nitrogen, thereby improving soil fertility (Timko & Singh, 2008). In Kenya, it is the third most important grain legume, after common bean and pigeon peas and covers about 18,000 ha (FAO, 2014). Its production in Kenya was 1,540,813 bags (90kg) in 2014 (MOA, 2015). About 85 % of the total area under cowpea is in arid and semi-arid lands (ASALs) of Eastern Kenya and 15 % is in the Coast, Western, and Central regions of Kenya (Kimiti *et al.,* 2009).

Cowpea can be grown alone or intercropped with various other crops. It normally matures early compared to other cereals and legumes and this is an important characteristic in evading drought. It also enables farmers to have some harvest as they await the other crops during the season (Onduru *et al.,* 2008). Cowpea has a well developed deep root system and has the ability to fix atmospheric Nitrogen. These adaptations enable it to grow well under drought and in soils with low fertility (Singh *et al.,* 2010).

Its drought tolerance, relatively early maturity and nitrogen fixation characteristics makes it a good legume for the Makueni County where drought and low soil fertility are the major limiting factors to crop production and food security (Karanja *et al.,* 2014).

Lablab bean (*Lablab purpureus* L. Sweet) is a dual-purpose legume, which means it can be traditionally grown as a pulse crop for human consumption, used as a fodder for livestock or as green manure (Hassan *et al.,* 2014). The plant can also be used as a cover crop to control soil erosion and is drought tolerant (Maass *et al.,* 2010).

Lablab can be utilized in many ways. The grain can be used for human consumption and is very nutritious compared to other legumes. It has a high biomass yield compared to other legumes and is highly palatable to livestock and can be used as livestock feed. It can also be utilized as green manure to provide on-farm organic nitrogen (Whitbread *et al.,* 2011).

Lablab bean combines a great number of qualities that makes it well adapted to drought and low soil fertility conditions of Makueni County. Lablab is not only drought tolerant but is also able to grow in low soil fertility conditions (Pengelly & Maass, 2001). It stays green at harvest even in the dry season increasing palatability to livestock and can be incorporated to the soil as green manure (Maass *et al.*, 2010). Despite its potential to do well in the eastern Kenya region, it remains underutilised (Sennhenn, 2013).

Grain legume production in Makueni County remains low despite its potential. This is mainly due to drought and low soil fertility (Wambua, 2013). There is therefore need to increase legume grain yields in the region through utilization of drought tolerant, early maturing legume varieties suited to the various agro-ecological zones. There is also need to improve soil fertility through interventions, such as use of inorganic fertilizers (Gachimbi *et al.*, 2002; Katungi *et al.*, 2010).

The three legumes that were used in the study were Bean variety KAT/B-9, Cowpea variety M66, Lablab variety KAT/DL-1 and Lablab accession CP1 81364. These legume varieties had already been tested under controlled on-station conditions and were found to be drought tolerant and well suited to climatic conditions of Makueni County (Karanja *et al.*, 2006; Sennhenn, 2013). The inorganic fertilizer used was DAP fertilizer at two application rates.

The study will contribute to increased grain legume production by encouraging utilization of the most efficient legume variety in a given agro-ecological zone and use of mineral fertilizer to improve soil fertility. This will lead to increased legume yields leading to improved food production and increased income to farmers in Makueni County.

1.3 Statement of the problem

Makueni County is one of the main grain legume producing counties in Kenya. However, legume productivity in the County remains far lower than its potential mainly due to drought and low soil fertility (Kimiti *et al.*, 2009). Drought tolerant legume varieties have been developed to mitigate the yield losses due to drought (Karanja *et al.*, 2006). However, their productivity in the various agro-ecological zones of Makueni County is yet to be determined (Karugia *et al.,* 2012). Fertile soils cover less than 10 % of the area under grain legume production in Makueni County (Kimiti *et al.*, 2009). Soils in the county are commonly nutrient deficient, especially of nitrogen and phosphorus. This is largely due to continuous cropping without external inputs (Wambua, 2013). Use of external inputs especially inorganic fertilizers can help replenish soil nutrients. However, inorganic fertilizer use in Makueni County is low and it’s estimated that only 2 % of the farmers in Makueni County use inorganic fertilizers (Kimiti, 2014).

1.4 Justification of the study

In order to improve grain legume yields and food production in Makueni County, there is need to tackle the problems of drought and low soil fertility that are the major causes of yield losses in the area. The use of drought tolerant legume varieties is very important in combating the problem of drought. Determining their suitability in the various agro-ecological zones will lead to better utilization of the varieties leading to better yields. Continuous cropping without external inputs has led to the soils in the county being nutrient deficient, especially of nitrogen and phosphorus (Kimiti *et al.*, 2009). DAP fertilizer use can help to replenish the soil with these nutrients.

The study was aimed at evaluating the three legume species for their productivity in drought conditions of the County and their response to DAP fertilizer application. This will help determine the potential of the three legumes to mitigate the effects of drought and declining soil fertility experienced in Makueni County.

1.5 Objectives

1.5.1 General objective

To improve the production of legume species under drought and low soil fertility conditions of Makueni County.

1.5.2 Specific Objectives

The specific objectives of the study were:

1. To evaluate productivity of Beans, Cowpea, Lablab (KAT/DL-1) and Lablab accession CP1 81364 at the three agro-ecological zones in Makueni County.
2. To determine the soil fertility status of the area and the response of Beans, Cowpea, Lablab (KAT/DL-1) and Lablab accession CP1 81364 to DAP fertilizer application in Makueni County.

1.6 Research hypotheses

The study tested the following hypotheses:

1. Beans, Cowpea, Lablab (KAT/DL-1) and Lablab accession CP1 81364 have different levels of productivities in each of the three agro-ecological zones in Makueni County.
2. Application of DAP fertilizer increases the productivity of Beans, Cowpea, Lablab (KAT/DL-1) and Lablab accession CP1 81364 in Makueni County.

CHAPTER TWO

LITERATURE REVIEW

2.1 Importance of legumes to Kenyan agriculture

Legumes play an important role in the cropping systems of Kenya. Grain legumes are a key source of food to humans. They are a major source of protein, fibre, minerals and vitamins to most people in most parts of Kenya (Bationo, 2008). Processed grains also provide wide range of products rich in protein. Legumes such as groundnut and soybean are also major sources of edible oil and other industrial by-products (Bourgault & Smith 2010).

Legumes can replenish nutrients to the soil. They biologically fix nitrogen, thus meeting much of their own N requirement while also leaving significant amounts of N in the soil for following crops (Nyambati *et al.*, 2006). They also release nitrogen from decomposing leaf residues, roots and nodules which results to increased amounts of N in the soil (Macharia *et al.*, 2011). Legumes provide a relatively low-cost method of replacing otherwise expensive inorganic nitrogen in the soil (Maass *et al.*, 2010).

Legumes help prevent soil erosion and control weeds. They provide good ground cover, minimizing soil erosion through raindrop impact and runoff (Maass *et al.*, 2010). They also extend the duration of protective land cover vegetation protecting the soil from erosion especially long season legumes. Legume rotations may also play an important role in weed control (Whitbread *et al.*, 2011).

Legumes can be used as green manure. Legume residues can be incorporated into the soil for manure. Legume residues incorporated to the soil can add as much as 140 kg N/ha depending on the legume variety (Macharia *et al.,* 2011). Green manure legumes can increase plant nutrient supply in the soil and improve soil physical properties, thereby improving crop yield (Cherr *et al.,* 2006). In addition, many legumes have the capacity to excrete root compounds that access phosphorus pools that otherwise remain unavailable (Drinkwater & Snapp, 2007). Legumes also have the capacity to grow in low fertility environments.

Legumes can be used as fodder for livestock. Residues of grain legumes as well as herbaceous and fodder legumes provide an excellent source of high quality feed to livestock especially during dry seasons when animal feeds are in short supply (Maass *et al.,* 2010; Whitbread *et al.,* 2011).

The sale of legume seed, leaves and fibre generates income for the marginalized communities especially women. Hence legumes play a critical role in enhancing the livelihoods of the rural communities (Ojiem *et al.* 2007).

Some of the constrains to legume production in Kenya are drought and moisture stress, low and declining soil fertility, diseases pests and weeds, damages, inadequate farm inputs, unavailability of seeds at planting time and climate change. Farmers need to learn how to overcome these constraints in order to increase the grain legume productivity and yields (Kimiti *et al.,* 2009; Katungi *et al,* 2010).

2.2 Beans

2.2.1 Importance of beans

Beans are an important source of protein, calcium, energy, folic acid, dietary fibre and carbohydrates (Buruchara *et al.,* 2011). Beans provide a cheaper alternative source of proteins to low-income earners since animal protein sources are scarce and unaffordable to majority of them (Katungi *et al.,* 2010; Gichangi *et al.,* 2012). Beans are also cholesterol free and have low fat content hence recommended for consumption by health organizations as they reduce the risk of diabetes, coronary heart diseases and cancer (Katungi *et al*., 2009). Young pods and green leaves of certain varieties can be used as green vegetables or canned as baked beans.

Beans are an important source of income to many households. Surplus beans produced by smallholder farmers can be sold to generate income thus contributing to poverty alleviation (Mwang`ombe *et al*., 2007). An economic survey by the East Africa Bean Research Network's (EABRN) shows that approximately 50 % of producers sell part of their harvest, primarily to urban populations (Katungi *et al*., 2010).

2.2.2 Bean production constraints

Common bean production has been in decline over the last few years (Katungi *et al*., 2010). This is mainly due to increasing severity of biotic and abiotic production constraints (Odendo *et al*., 2004; Wagara & Kimani, 2007). Drought is the most crucial constraint to bean production and accounts for over 50 % of the total bean yield losses in Kenya (Katungi *et al*., 2009). This is largely because bean production is mainly conducted in the semi arid areas of Eastern Kenya which accounts for 35 % of the country total bean production (Okwiri *et al*., 2009). These areas are prone to drought due to inadequate rainfall, erratic rainfall distribution, long dry spell, delayed onset of rains or early cessation of rainfall (Katungi *et al.*, 2009).

Low soil fertility and soil nutrient depletion is another major constraint that leads to low yield in beans. Deficiencies of nitrogen, phosphorus and organic matter all reduce bean productivity (Lunze *et al*., 2012). There is limited use of organic manure to help improve the physical and chemical conditions of the soil due to lack of enough manure while use of inorganic fertilizers is limited by high costs (Katungi *et al*., 2010). Use of poor seed for planting has also constrained bean production (Opole *et al*., 2006; Katungi *et al*., 2009). Many smallholder farmers continue to plant farm saved bean seed which lacks the advantages of tolerance to various pests and diseases. This is mainly attributed to the high cost of certified seed and unavailability of the improved variety seeds (Rubyogo *et al*., 2010).

2.3 Cowpea

2.3.1 Importance of Cowpea

Cowpea is a multipurpose crop, providing food for human and feed for livestock. Its leaves, young pods and grain can be used for food. It can also be used as cover crop (Timko & Singh, 2008). Cowpea has the ability to tolerate drought and fix atmospheric N, which allows it to grow and improve poor soils. Cowpea can fix atmospheric nitrogen of up to 240 kg/ha and leaves about 60-70 kg/ha nitrogen for succeeding crops (Aikins & Afuakwa, 2008; Karanja *et al.*, 2014). It has a well-developed deep root system and grows well under drought conditions (Dube & Fanadzo, 2013). In phosphorus deficient soils, the roots of cowpea develop effective mycorrhizal associations, improving the soil's available phosphorus content (Valenzuela & Smith, 2002).

Some of the early maturing cowpea varieties provide the first harvest earlier than most other crops during production period. This shortens the "hunger period" where the small-scale farmers can experience food shortage a few months before the maturity of the new crop (Karanja *et al.*, 2012). Its drought tolerance, relatively early maturity and nitrogen fixation characteristics fit very well to the tropical soils where moisture and low soil fertility is the major limiting factor in crop production (Hallensleben *et al.*, 2009).

2.3.2 Cowpea production Constraints

Cowpea has a potential yield of over 1500 kg/ha. However, cowpea yields are normally 20 to 30 % of the potential (Nzioki *et al.*, 2014). The extremely low cowpea yields, ranging from 150-500 kg/ha, are attributed to damage due to noxious weeds, diseases and insect pests, low soil fertility, inadequate farm inputs, unavailability of seeds during planting time and climate change (Lobell *et al.*, 2008; Karanja *et al.*, 2012). However, low soil fertility is the most limiting factor in cowpea production in Makueni County (Kimiti, 2011).

2.4 Lablab

2.4.1 Importance of lablab

Lablab bean (*Lablab purpureus* L. Sweet) is an important dual purpose legume crop. Lablab is traditionally grown as a pulse crop. Its leaves and immature pods can be consumed as a green vegetable (Maass *et al.,* 2010). It can also be used as fodder for livestock. Its leaves are green at grain harvest hence are more palatable to livestock and has more fodder yield than other legumes (Valenzuela & Smith, 2002; FAO, 2012).

It can be used as green manure to improve soil fertility by providing on-farm organic nitrogen (Cherr *et al.*, 2006). It fixes nitrogen to the soil through biological nitrogen fixation (Cook *et al.,* 2005). It can be used as a cover crop as it produces adequate ground cover and good weed suppression (Sheahan, 2012). It can be grown as a ratoon crop and can play a critical role of reducing soil erosion at the onset of the second rains (Ewansiha & Singh, 2006).

2.4.2 Lablab production constrains

Generally, lablab is drought tolerant and can grow well even in poor soils (Pengelly & Maass, 2001). It is also less susceptible to pests and diseases. However, it can be affected by diseases such as root-knot nematode, bacterial wilt and powdery mildew (Valenzuela & Smith, 2002; Cook *et al.,* 2005). Lablab pests include pod borers which affect seed pods, cutworms and wireworms which damage the plant during establishment and thrips which damage the crop during flowering (Sheahan, 2012).

2.5 Effect of drought on grain legume production in Makueni County

Drought is the inadequacy of water availability, including precipitation and soil moisture storage capacity, in quantity and distribution during the life cycle of the crop, which restricts the expression of the full genetic potential of the cultivar (Beebe *et al.*, 2013). Legumes are highly sensitive to water deficit stress (Labidi *et al*., 2009). Drought stress has been found to reduce the individual yield components of legumes i.e. number of pods per plant, number of seeds per plant, seeds per pod and seed weight, thereby resulting in reduction of grain legume yield. These traits are severely affected when drought occurs during post flowering stage (Polani *et al.,* 2008; Rao *et al.,* 2009). Legumes such as common bean, cowpea and green grams usually need average moisture for farmers to realize harvest. Severe drought has been found to reduce common bean yields by 72 % in Central Kenya while moderate droughts have been found to reduce common bean yields by 44 % (Mburu *et al*., 2010).

Makueni County experiences severe droughts which are increasing in intensity and recurrence (Rao *et al.,* 2009). This often leads to crop failure and declining yields (Kirina *et al.*, 2012). Drought accounts for up to 50 % yield loss of grain legumes in Makueni County and is one of the most significant shocks affecting farmers in the county affecting 98 % and 99 % of the farmers respectively (Okwiri *et al.,* 2009; Muhammad *et al.*, 2010). According to a survey conducted by ACF-USA (2012) during the 2011 long rains, 74.3 % of the households who planted green grams were reported to have had a total crop failure while 44.7 % of farmers who planted beans did not harvest anything. The mean harvest of cowpea was 27.3 kg and 11 kg for green grams per household. The poor harvest was due to drought and low rainfall.

2.6 Strategies for coping with drought in Makueni County

2.6.1 Small-Scale Irrigation

The use of small-scale supplementary irrigation can alleviate the problem of unreliable rainfall. This can be done either through full irrigation or supplementary irrigation (Recha *et al.,* 2012). Irrigation can be used to grow a range of crops, e.g. pigeon pea, cassava, maize, millet, and high value vegetables such as Okra, bitter gourd, brinjals, chillies, French beans grown for export (Bishaw *et al.,* 2013).

Majority of the farmers in the county depend on rain fed agriculture. Only 18.1 % of the farmers in Makueni County do irrigation. This is because irrigation facilities are costly for most small scale farmers and inadequate water resources. Irrigation is therefore carried out only for high value horticultural crops (ACF-USA, 2012).

2.6.2 Use of drought tolerant crops

Drought tolerance is defined as the ability of the crop to withstand water deficit with low tissue water potential (Blum, 2005). Drought tolerant legumes have been used to mitigate the effects of drought in Makueni County (Wambua *et al.,* 2014). Short season legumes which are early maturing have also been used to mitigate the effects of drought. Farmers use faster maturing varieties that avoid drought or heat stress during sensitive stages of plant growth, such as flowering and grain filling. This ensures that there is some yields realised even in drought conditions (Manjeru *et al.,* 2007).

Farmers in Makueni County normally use short season and drought tolerant crops to mitigate the effects of drought in the county. According to a household survey carried out by Kirina *et al.,* (2012), 90 % of the farmers used short maturing crop species to mitigate the effects of drought and 81 % used drought tolerant crop varieties. Use of drought tolerant, early maturing crops and genotypes can be an appealing way of combating drought in the County as farmers would not be required to provide extra inputs (Lobell & Burke, 2010).

2.7 Grain legume species with most potential to combat drought in Makueni County

Generally, drought stress greatly decreases grain legume productivity. However, some legumes such as beans, cowpea and lablab perform better under drought stress as compared to other legumes. Improved seed varieties that are more suitable to arid and semiarid lands (ASALs) have been developed (Karugia *et al.,* 2012). Some of the common bean varieties developed for ASALs include: KAT X56, KAT X69, KAT/Bean 1, KAT/Bean 9 and Wairimu Dwarf (Karugia *et al.*, 2012; KEPHIS 2014). Some of the cowpea varieties developed for ASALs include: MTW 63, MTW 610, KCP 022, KVU-419, KVU 27-1, M66 and K80 (Karugia *et al.*, 2012; KEPHIS 2014). The only lablab varieties developed for ASALs are DL1002 and DL1009 (Karanja *et al.*, 2006; KEPHIS, 2014).

The most suitable variety of beans to the agro ecological conditions of Makueni County is KAT/B-9. It was developed by KARLO (formerly KARI) and released in 1998. It is recommended because it is tolerant to heat and can do well in low altitudes (Karugia *et al.,* 2012). The most suitable variety of cowpea is M66 developed by KARLO in 1998. It is recommended because it is drought tolerant and matures early (Karanja *et al.,* 2006; Karugia *et al.,* 2012). The suitable variety of dolichos is DL1002. It was developed by KARLO and released in 1998 (KEPHIS, 2014). It is high yielding and relatively early maturing hence is recommended for the region

(Karanja *et al.*, 2006). The other lablab variety used in the research is accession CP 81364.

2.7.1 Variety characteristics of bean KAT/B-9 (Katumani Bean 9)

It is a determinate plant with an average height of 35-40 cm. It flowers in 30-40 days and has a uniform flowering period. The flower colour is light pink. It matures within 60-65 days. The grain is brilliant red and gives an Irish brown colour when cooked with maize, a quality preferred by farmers. Its potential yield is 1400-1900 kg/ha. It's more drought tolerant than Katumani Bean 1 and is also tolerant to Common Bean Mosaic Virus (CBMV), rust and several fungal diseases (Karanja *et al.*, 2006; Karugia *et al.*, 2012).

Katumani Bean 9 is suitable for cultivation in lower altitude areas of 1000 m and below where the average rainfall season is more than 200 mm. It is sensitive to water logging and acidic soils. Optimum temperatures range from 15˚ C – 27˚ C (KEPHIS, 2014).

2.7.2 Variety characteristics of cowpea variety M66 (Machakos 66)

Machakos 66 is a bushy semi-spreading plant with an indeterminate growth habit. It is a dual-purpose variety of cowpea grown for both leaves and grain. The leaves and midribs are dark green. It flowers within 55-60 days and the flowers are purple with a white corolla. It matures within 80-90 days. The pods are green when young, turn bright red during grain filling and brown purple when dry. It has smooth creamy brown seeds having a small eye. The yields range from 800-1700 kg/ha. M66 is tolerant to yellow mottle virus and scab moderately tolerant to septoria leaf spot and powdery mildew. It also has been found to have tolerance to aphids and thrips (Karanja *et al.,* 2006; Karugia *et al.,* 2012).

Machakos 66 is recommended for medium and higher altitudes of between 1200 -1500 metres above sea level, receiving an average of 200 mm rainfall per season (KEPHIS, 2014).

2.7.3 General characteristics of the two lablab varieties

Lablab variety DL 1002 and accession CP 81364 are both short season varieties. Short season lablab varieties produce high grain yield and can mature faster compared to long season ones. Furthermore, short season varieties can increase the number of harvests per year, but also their growing cycle fits better into the rainfall pattern, reducing the risk of water deficits (Maass & Tefera 2008). They are also less competitive with the main crop when intercropped. However, they produce less biomass yield and fix less nitrogen compared to long season varieties. Long season lablab varieties normally produce high biomass yields. This is advantageous in green manure and fixing soil nitrogen. However, long season types flower after 5 to 6 months. Late flowering and maturity is major constraint in drought prone areas. They are also too competitive with maize in mixed cropping production system on low fertility soils (Whitbread *et al.,* 2011). This makes short season lablab varieties to be more suitable for Makueni County.

a) Variety characteristics of lablab variety DL1002 (KAT/DL-1)

The plant has a determinate growth habit. It flowers between 65-75 days and has a definite indeterminate flowering period. It has purple flowers. It matures between 80-90 days and the grain is black with a white hilum. The grain potential yield is 3000-4000 kg/ha. The crop can be ratooned giving a second crop that is 80% more grain than the first crop. It is mainly a grain type but can also be used as fodder (Karanja *et al.,* 2006)

DL1002 can be grown between 500 -1800 metres above sea level. It is recommended for cultivation in the lower and more marginal areas of Machakos, Kitui, Makueni, Mwingi, and Tharaka-Nithi and Laikipia district. It can tolerate a wide range of soils including acidic and vertisols (KEPHIS, 2014).

b) Accession CP 81364

i) Background on selection

The accession was provided by the Australian Tropical Crops Genetic Resource Centre, and was part of the germplasm collection characterized and classified by Pengelly and Maass (2001). Deriving from this germplasm collection, 33 relatively early-flowering lablab accessions were selected and evaluated by Whitbread *et al.,* (2011) in South Africa. On the basis of the growing season, six most promising short season lablab accessions were selected and morphological tests done by Kristina in 2014 at KARLO, Katumani Research Station. The most promising accession among those, CP 18364 was selected for the study so as to compare its productivity with lablab variety KAT/DL-1. This accession had superior characteristics of less number of days to flowering and maturity, taste of the grains and yields (Kristina, 2014).

ii) Variety characteristics of lablab accession CP 81364

It has a determinate growth habit. It is a dual purpose legume and can be grown for grain and fodder. It flowers between 59 to 61 days. It has white flowers and matures between 90 to 100 days after planting. The seed colour is tan. It can be grown as a ratoon crop and give more grain in the second season (Kristina, 2014).

2.8 Effect of low soil fertility on grain legume productivity in Makueni County

Soil fertility refers to the ability of the soil to supply essential plant nutrients and soil water in adequate amounts and proportions for plant growth and reproduction in the absence of toxic substances which may inhibit plant growth (FAO, 2015).

Low soil fertility has led to significant decrease in legume productivity at Makueni County. Low soil fertility in the County is caused by continuous cropping with little inputs to replenish soil fertility, nutrient loss through crop harvest, removal of crop residues to feed animals, soil erosion and leaching (Wambua, 2013). Such practices often lead to soil nutrient depletion leading to reduction in land productivity. Inorganic fertilizer use is also low in the County leading to a further decline in soil fertility (Kimiti, 2014).

Low soil fertility contributes to reduction in productivity, thereby reducing actual legume yields. Putting nutrients back into the soil is the only realistic way to maintain the soil fertility necessary for sustained grain legume production in the County.

2.9 Strategies for coping with declining soil fertility in Makueni County

Some of the ways of replenishing nutrients to the soil are application of organic manures, application of inorganic fertilizers, integrated use of organic and inorganic fertilizers and biological nitrogen fixation by legumes.

2.9.1 Organic manure

Application of organic fertilizers can be used to replenish nutrients back to the soil. They are normally preferred because of their lower cost compared to inorganic fertilizers and are readily available since many small scale farmers keep livestock and there are plenty of crop residues (Odundo *et al.*, 2006). However, application of organic manures is limited. This is because organic manures such as crop residues and animal manures are bulky and labour intensive for transportation and application; they are not sufficiently available at the recommended rates of 5000 kg/ha for most crops and their quality is often poor and nutrients are released over a period of time hence may not be readily available for crop use (Odundo *et al.,* 2006; Okalebo *et al.*, 2006).

Organic manure can be applied in various forms such as compost, farmyard manure, use of green manure crops and biomass transfer in the form of crop residues. However, farmyard manure and crop residues are the most common forms of organic manure used in Makueni County (Recha *et al.*, 2012).

2.9.2 Inorganic fertilizers

Inorganic fertilizers can be used to replenish soil nutrients. They contain concentrated nutrients that are readily available and supply them to plants. Fertilizers amend soil fertility and increase the productivity of crops. Low productivity of soils is directly correlated with low inorganic fertilizer use (Marenya & Barett, 2009).

However, mineral fertilizer use in Makueni County remains low. This is mainly due to high costs of inorganic fertilizer. Some farmers also fear using fertilizers so as to shield them against further losses in case of reduced crop production or crop failure due to drought (Mugwe *et al.,* 2007; Chianu *et al.,* 2012). Farmers in Makueni County also believe that use of inorganic fertilizers will harden their farms resulting to a decrease in crop production (Kimiti, 2014).

Examples of commonly used mineral fertilizers are Di-ammonium phosphate (DAP), triple-Super phosphate (TSP), urea, Calcium ammonium nitrate (CAN) and NPK. DAP fertilizer is the most recommended mineral fertilizer for grain legume production and may be used at the rate of 50 kg/ha (Karanja *et al.,* 2006). However, DAP fertilizer increases soil acidity when used over a long period of time. Alternating DAP with less acidifying compound fertilizer like NPK or straight fertilizers like TSP can reduce acidity problems (Kimani *et al*., 2010).

2.9.3 Integrated use of organic manure and inorganic fertilizers

Organic manure and inorganic fertilizers can be combined to replenish nutrients to the soil. The two can complement each other. Organic manure increases the amount of organic matter in the soil. Organic matter improves the soil structure, which in turn increases infiltration and the amount of water the soil can hold. It also increases the nutrient level in the soil and the activity of soil organisms. It has also been found to increase the fertilizer use efficiency of crops (Lindqvist, 2005). However, organic manure contains less nutrient content to meet the crop growth requirements. Most animal manure and plant material contain between 1 and 4 % nitrogen content compared with 20 to 46 % in inorganic fertilizers. The phosphorus content of plant residues and manure is generally not sufficient to meet crop growth requirements

(Morris *et al.,* 2007). Organic manures are also available in limited quantities and cannot sustain crop production when used exclusively. Their nutrients also mineralise more slowly compared to inorganic fertilizers hence not readily available to crops.

Integrated use of organic manures and inorganic fertilizers is essential for sustainable soil fertility management on smallholder farms (Vanlauwe, 2004). Organic and inorganic fertilizers have different functions on soil fertility and crop production and their use in combination can have synergic effects, which lead to greater resource use efficiencies than when used separately (Giller, 2002).

2.9.4 Biological nitrogen fixation by legumes

Legumes have the ability to fix nitrogen to the soil by a process known as biological nitrogen fixation (BNF). BNF is the process that changes atmospheric nitrogen to a biologically useful form (Uchida, 2000). Legumes' ability to fix atmospheric nitrogen is dependent on the appropriate *Rhizobium* bacteria and suitable environmental conditions. Grain legumes contribute more than 20 million tons of fixed N to agriculture each year (Herridge *et al.,* 2008).

The legume species that have the potential to fix nitrogen through BNF are bean (*Phaseolus vulgaris* L.), pigeon pea (*Cajanus cajan* (L.) Millsp), cowpea (*Vigna unguiculata* (L.) Walp), and green grams (*Vigna radiata* Wilczek) (Kimiti *et al.*, 2009).

2.10 Inorganic fertilizer use in Makueni County

Inorganic fertilizer use is considered the obvious way to overcome soil fertility depletion given high levels of nitrogen and phosphorus content. Inorganic fertilizers can also help to enhance soil fertility by sustaining more crop production and also above ground vegetation. This will generate additional biomass to be incorporated into the soil (Chianu *et al.*, 2012).

Nitrogen and phosphorus are the most limiting nutrients in the county. This is caused by continuous cropping without replenishing the nutrients to the soil. Fertilizer trials carried out by KALRO showed that N and P are the two most limiting nutrients in the area (FURP, 1994; Kimiti, 2014).

2.10.1 Nitrogen

a) Importance to plants

Nitrogen is usually the most limiting nutrient in crop production. It is supplied to crops by commercial fertilizers, mineralization of soil organic matter and atmospheric nitrogen fixed by legumes through BNF (Uchida, 2000). It is required in large quantities by plants. Nitrogen is essential to the photosynthesis and healthy cell growth and reproduction. It is a major component of chlorophyll compound. It is also a major component of amino acids, the building blocks of proteins. Nitrogen is a component of energy-transfer compounds, such as adenosine triphosphate (ATP). ATP allows cells to conserve and use the energy released in metabolism. Finally, nitrogen is a significant component of nucleic acids such as DNA, the genetic material that allows cells to grow and reproduce (Tisdale *et al.,* 1990). Nitrogen is useable by plants in two forms, ammonium (NH4+) and nitrate (NO3-). N deficiency results from its continued depletion from the soil pool by processes such as volatilization, leaching and removal by crop harvest from the farms (Amba, *et al.,* 2013).

b) Effect on biomass and grain yield

Nitrogen is an important macronutrient in grain legume production. It promotes shoot and leaf growth and is very important for biomass accumulation. Nitrogen has been found to significantly increase the yield and yield components of legumes such as number of pods per plant, number of seeds per plant, 100-seed weight and seed yield (Bambara & Ndakidemi, 2010).

2.10.2 Phosphorus

a) Importance of phosphorus in plants

Phosphorus is the second most limiting soil nutrient in plant growth after Nitrogen. Plants need phosphorus for growth, utilization of sugar and starch, photosynthesis, nucleus formation and cell division. It is required in large quantities in young cells, such as shoot tips and root tips, where metabolism is high and cell division is rapid. It also aids in flower initiation, seed and fruit development (Ndakidemi & Dakora, 2007). Phosphorus compounds are involved in the transfer and storage of energy within plants. Energy from photosynthesis and the metabolism of carbohydrates is stored in phosphate compounds for later use in growth and reproduction (Tisdale, 1990). Phosphorus deficiency inhibits nodulation, nitrogen fixation and rhizobial growth.

Primary source of P is mineral apatite found in primary rocks. However, organic matter, inorganic fertilizers and secondary and complex compounds in the soil are other sources of P. Therefore soil P can be replenished by addition of inorganic fertilizers, organic matter in form of plant and animal residues or phosphate rocks such as Busumbu and Mijingu phosphate rocks (Chien & Menon, 1995).

b) Effect of phosphorus on biomass and grain yield of legumes

Application of P is essential for increasing both biomass accumulation and grain yield. Phosphorus is essential for the general health and vigour of all plants. Some of the growth factors that have been associated with phosphorus are stimulated root development, increased stalk and stem strength, improved flower formation and seed production, more uniform and earlier crop maturity, increased nitrogen fixing capacity of legumes, improvements in crop quality and increased resistance to plant diseases (Magani & Kuchinda, 2009; Singh *et al.,* 2011; Hussain *et al.,* 2012; Ndor *et al.,* 2012). Phosphorus has been found to enhance nodulation in legumes which results in high nitrogen fixation and hence high grain and biomass yield (Singh *et al.,* 2011; Nyoki, *et al*., 2013).

Phosphorus has been found to have a significant effect on the growth of cowpea. P application increased the number of branches per plant, number of nodules, number of pods, number of seeds per pod, mean pod weight, 100 seed weight and grain yield in cowpea (Mokwunye & Bationo, 2002). Research done by Nyoki *et al.,* (2013) also found out that phosphorus supplementation had a significant effect on the number of branches per plant, number of nodules, number of pods, number of seeds per pod, mean pod weight, 100 seed weight and grain yield of cowpea.

Other studies have found phosphorus to have a significant effect on yield and yield components of beans. Phosphorus increased the number of pods per plant and grain yield following phosphorus supplementation over the control treatment (Ndakidemi *et al.,* 2006; Zafar *et al.,* 2011). Phosphorus has also been found to enhance nodulation, nitrogen fixation and rhizobial growth of legumes (Chianu *et al.*, 2012).

c) Effect of phosphorus on legumes tolerance to drought

Phosphorus application leads to rapid growth and early maturity which are important in drought prone areas. An adequate supply of available phosphorus in soil is associated with increased root growth, which means roots can explore more soil for nutrients and moisture. It also enhances root emergence and increases root hair numbers. This will enable the crop to grow faster and evade drought during critical growth stages such as flowering and grain filling (Pellerin *et al.,* 2000). Deficiency of phosphorus will slow overall plant growth and delay crop maturity.

Drought resistance has been reported in common bean partly caused by availability of phosphorus in the soil. The uptake of phosphorus leads to faster development of roots that facilitates extraction of available soil moisture at the early stage of crop growth well before the commencement of soil moisture deficit is triggered by terminal drought (Chaves *et al.,* 2003).

Studies have indicated that application of phosphoric fertilizers promotes drought tolerance. Garg, *et al.,* (2004); Jones, *et al.,* (2005) and Jin *et al.,* (2006) reported that application of phosphorus at the time dry spells occurred for moth bean (*Vigna aconitifolia*), barley (*Hordeum vulgare*) and soybean (*Glycine max*), respectively, accelerated root development with subsequent access to soil moisture that enhanced early grain maturation before the beginning of terminal drought. Therefore, adequate levels of available phosphorus in the soil leads to early maturity allowing the plant escape the effect of soil moisture deficit.

2.11 Literature review gaps

Potential yields of the three legume species has been determined using national performance trials. However, the actual yield in the various agro-ecological zones in Makueni County is yet to be determined hence need for this study.

Most soils in Makueni County are deficient in nitrogen phosphorus and organic matter. Most studies have been carried on effects of nitrogen and phosphorus on legume production separately. However, no studies have been carried out on the effect of both nitrogen and phosphorus application and their effect on legume production in Makueni County. Also most research has been on single stress factors affecting grain legume production in Makueni Count yet the aggregate effect of low soil fertility and drought on grain legume production has not been determined necessitating this research.

CHAPTER THREE

MATERIALS AND METHODS

3.1 General description

3.1.1 Description of research area

The research was conducted in Makueni County. It is located in South Eastern part of Kenya and borders Kitui County to the East, Kajiado to the West, Machakos to the North and Taita Taveta to the South. It stretches from latitude 1º35´S to 3º01´S from North to South and from longitudes 37º10´E and 38º30´E from West to East. The County is sub-divided into six sub counties namely; Makueni, Kilome, Mbooni, Kaiti, Kibwezi East and Kibwezi West (Makueni County report, 2013). It has an area of 8,009 Km^2, about 70 % being arid and semi arid lands. It has a population of 884,527 as at 2009 (KNBS, 2010). The poverty rate is 64 % based on KIHBS (RoK, 2010; Cheserem, 2011).

Majority of Makueni County lies within agro-ecological zone 5 (AEZ 5) in the semi-arid region of Eastern Kenya (Jaetzold *et al.,* 2010). Highly weathered soils (Ferralsols, Acrisols and Luvisols) dominate the area. In general, the soils have low organic matter and are less fertile (Recha *et al.*, 2012). The area receives mean annual rainfall of 231 mm and 361 mm during long and short rain seasons respectively. Long rains start from March to July while short rains start from October to February. The short rains are evenly distributed, reliable and thus more effective than the long rains (Recha *et al.,* 2012). The mean maximum temperature of the area is 25°C and the mean minimum temperature is 13°C (Jaetzold *et al.*, 2010; Recha *et al.*, 2012).

Most of the farmers are small-holder practicing both livestock and crop production. Farming is mainly rain fed. The major crops grown are maize, green grams, cowpea, pigeon peas, sorghum, beans, dolichos beans, millet, cassava and sweet potatoes (Bishaw *et al.,* 2013). The major livestock kept are cattle, goats, rabbits, pigs, poultry, sheep, donkeys, camels (Makueni County report 2013).

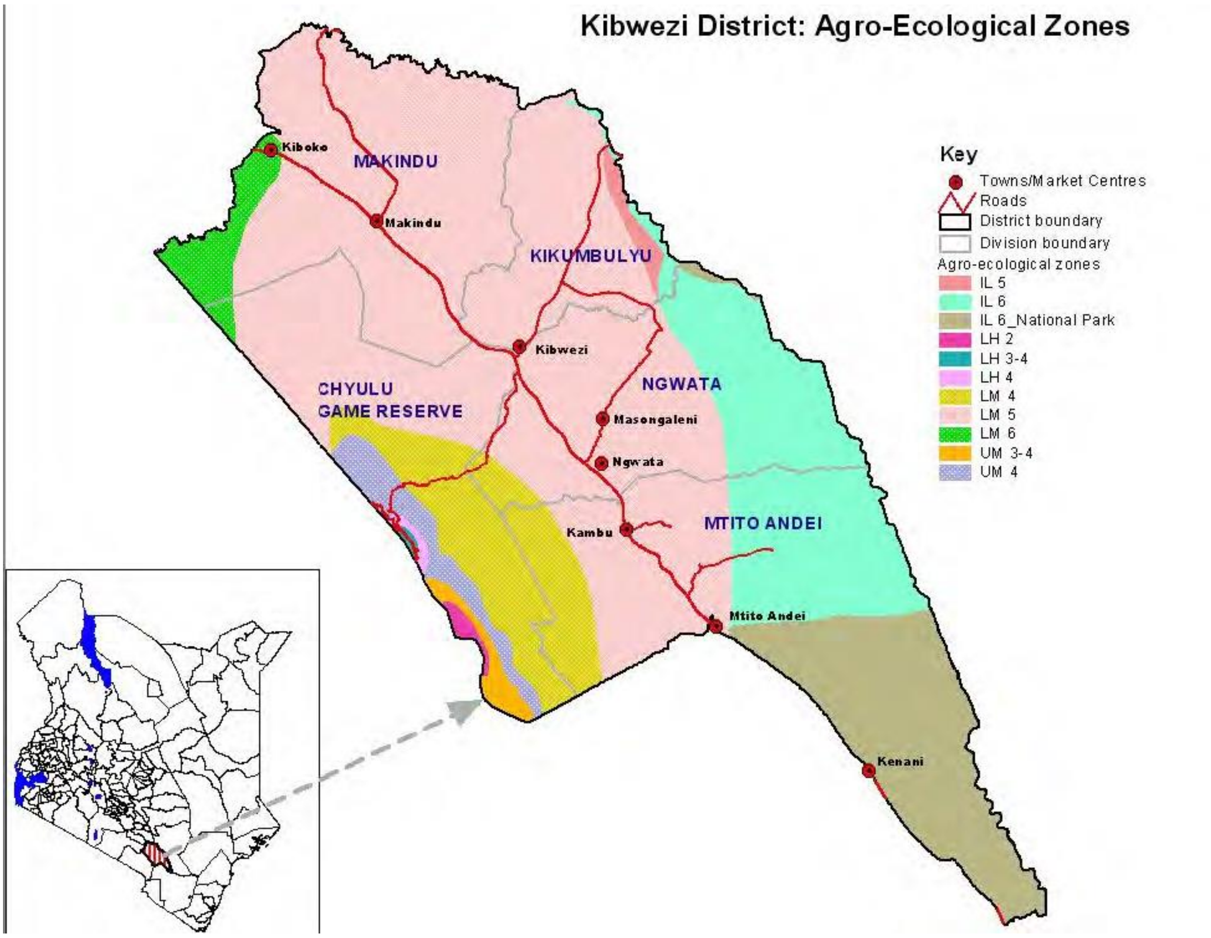

Figure 1: Map of Makueni County, Kenya showing different agro-ecological zones (Source: Bishaw *et al.*, 2013).

3.1.2 Site and farmer selection

The study was conducted in three locations selected across Makueni County. The locations were selected based on the different agro-ecological zones as shown in figure 1 above. The first location was at Machinery which is in the inner lowland ranching zone (IL 6). The other location was at Utafiti which is in the lower midland livestock-millet zone (LM 5). The third location was at Mwanzo which is in the Lower Midland marginal cotton zone (LM 4). From each location, five smallholder farmers that rely on farming activities as their first income source were selected. Utooni Development Organisation helped in identifying the farmers since they work with farmer groups in the area and have a good knowledge of the area. The experiment was carried out from March to July, 2014 during the long rainy season.

3.1.3 Soil sampling and preparation of samples

Surface soil samples at 0-20 cm deep were randomly taken using a soil auger (75 mm in diameter) from 12 points per experimental site and mixed well to get a composite soil sample in each site. The soil samples were then prepared for laboratory analysis. The samples were air-dried, crushed using a mortar and pestle and sieved through 2 mm mesh.

3.2 Experimental details

3.2.1 Treatment details

Each experimental unit contained legume species as one factor and DAP fertilizer level as the other factor. The three legumes were Bean variety KAT/B-9, Cowpea variety M66, Lablab variety KAT/DL-1 and Lablab accession CP1 81364. The two

DAP fertilizer levels were 0 kg of DAP per hectare and 50 kg of DAP per hectare. DAP fertilizer contains 18 % nitrogen and 46 % phosphorus. This equates to 9 kg N per hectare and 10 kg P per hectare. The choice of DAP fertilizer treatments was determined by farmer practice and the recommended practise. Farmers normally don't use mineral fertilizers in legume cultivation while 50 kg of DAP per hectare is the recommended rate. The legume varieties used were the most recommended for the study area (Karanja *et al.*, 2006; Karugia *et al.*, 2012; Kimiti, 2014).

3.2.2 Treatment combinations

B P_0 Beans KAT/B-9 + 0 kg DAP/ha.

B P_1 Beans KAT/B-9 + 50 kg DAP/ha.

C P_0 Cowpea M66 + 0 kg DAP/ha.

C P_1 Cowpea M66 + 50 kg DAP/ha.

L1 P_0 Lablab KAT/DL-1 + 0 kg DAP/ha.

L1 P_1 Lablab KAT/DL-1 + 50 kg DAP/ha.

L2 P_0 Lablab CP1 81364 + 0 kg DAP/ha.

L2 P_1 Lablab CP1 81364 +50 kg DAP/ha.

3.3 Experimental Design and layout

The experiment was a farmer participatory research. The field experiments were laid out in a Randomized Complete Block Design and in a factorial arrangement as shown in Figure 2 below. There were five farmers (blocks) per location. The experimental units measured 5 m by 3 m. The experimental units were separated by 1 metre paths.

Each block measured 25 m by 13 m covering a total area of 325 m^2 (0.0325 Ha). Guard rows of cowpea surrounded each experimental site.

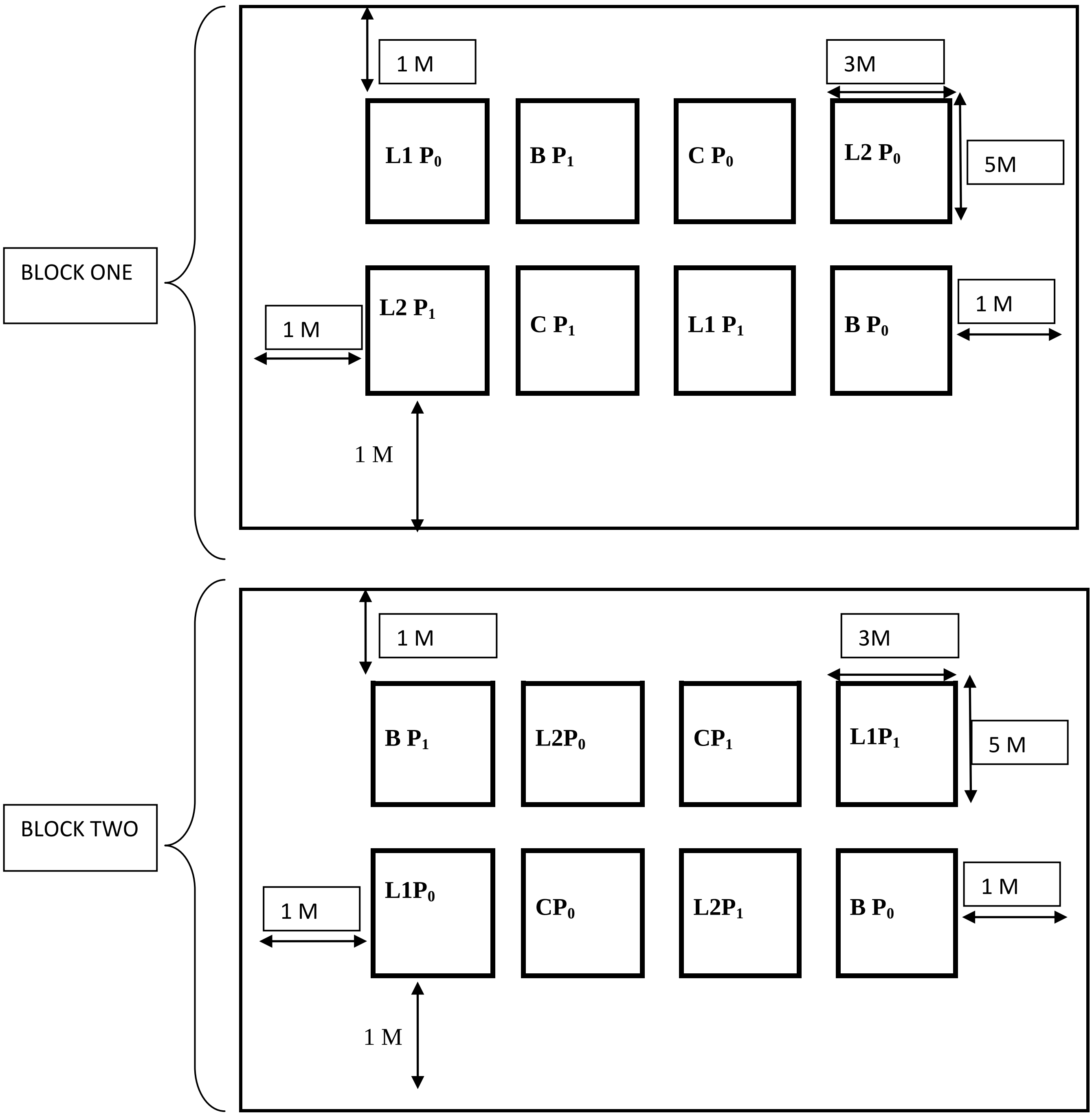

Figure 2: Layout of the experiment

3.4 Cultural operations

3.4.1 Land preparation

The land was cleared and all the ground vegetation and crop debris removed. Ploughing was done using oxen plough and hoes during the month of March. Harrowing was done after first ploughing using hoes. The field was prepared to a fine tilth and big soil clods removed.

3.4.2 Planting

Planting was done during the second week of March after the onset of long rains. Planting was done within three days in all experimental sites and hill planting was done. The spacing was 0.45 m by 0.2 m for beans, 0.5 m by 0.3 m for cowpea and 0.7 m by 0.3 m for lablab (Karanja *et al.,* 2006). Inoculation of seeds was done before sowing. Three seeds were placed in each planting hole and planted at a depth of three to five centimetres. Gapping was done eight days after sowing so as to establish a uniform plant population.

3.4.3 Weeding and thinning

First weeding was done at fourteen days after emergence (DAE). Weeding was done by inter row cultivation between the rows and hand weeding within the rows. Thinning was done simultaneously with first weeding so as to achieve the required plant population. Second weeding was done five weeks after emergence (Karanja *et al.*, 2006).

3.4.4 Pests and disease control

Spraying was done to control pests. Duduthrin Super (Lambdacyhalothrin 50g/l) was used to control caterpillars and aphids (Pest Control Products Register, 2010). It was applied at rates of 1 litre per hectare. Lablab, cowpea and beans have no diseases of economic importance in the area (Karanja *et al.*, 2006).

3.4.5 Harvesting

Harvesting was done at physiological maturity. Beans and cowpea were harvested when all pods had turned brown and hard. Harvesting of lablab was done when 90 % of the pods had turned brown (Karanja *et al.,* 2006). The net plot was harvested. The seeds were dried to 12 % moisture content. After drying, the dry weight of the seeds was recorded.

3.5 Data collected

3.5.1 Physical and chemical characteristics of the soil

Soil samples were taken for laboratory analysis from the various experimental sites before land preparation. Soil samples were analysed for soil pH (Soil H_2O; 1:2.5), soil texture using the hydrometer method, total carbon (%) and total nitrogen (%) using the colorimetric method and available phosphorus using the Olsen method (Okalebo *et al.,* 2002).

3.5.2 Phenological dates

These include:

a) Days to 50 % flowering: Was recorded when at least half the plants in the experimental unit showed exposed petals. Days were recorded in days after planting (DAS).

b) Days to physiological maturity: Was recorded when at least 90 % of the pods had changed colour to brown. Days were recorded in days after planting (DAS).

3.5.3 Biomass yield

Biomass yield was recorded at flowering and at physiological maturity. Biomass samples were taken from all plots by cutting the plants at first node from the soil surface using secateurs. Plant samples were randomly selected within the net plot, cut and packed in a well labelled paper bag. Plant samples from each experimental unit were oven dried at 65°C for 48 hours and weighed using an electronic balance (5 000 g). Biomass yield per experimental unit was worked out and expressed in kilograms per hectare (Amole *et al.*, 2013).

3.5.4 Grain yield

The three legumes were harvested from the net plot at physiological maturity. The pods were harvested, dried, threshed, winnowed and weighed. The dry weight of seeds harvested in the net plot was recorded. This was extrapolated to kilogram per hectare.

3.6 Data analysis

The models used for data analysis were:

a) Model for analyzing beans and cowpea data

$Y_{ijk} = \mu + L_i + B_{j(i)} + F_k + FL_{ik} + E_{ijk}$

μ = the general mean

L_i = effect due to location i

$B_{j(i)}$ = effect due to block j in location i

F_k = effect of the k^{th} fertilizer level

FL_{ik} = interaction between location i and k^{th} fertilizer level

ε_{ijk} = the random error effect

b) Model for analyzing lablab data

$Y_{ijk} = \mu + L_i + B_j + G_k + LG_{ik} + F_l + GF_{kl} + LGF_{ikl} + \varepsilon_{ijklm}$

μ = the general mean

L_i = effect due to i^{th} location

B_j = effect due to j^{th} Block in i^{th} location

G_k = effect due to k^{th} legume species

LG_{ik} = effect due to the interaction of i^{th} location and k^{th} legume species

F_l = effect of the l^{th} fertilizer level.

GF_{kl} = effect due to the interaction between k^{th} legume species and l^{th} fertilizer level.

LGF_{ikl} = effect due to the interaction of i^{th} location, k^{th} legume species and l^{th} fertilizer level

ε_{ijklm} = the random error effect due to j^{th} Block the i^{th} location of the k^{th} legume species in the l^{th} fertilizer level.

Data were analysed using SAS Statistical software version 9.3 (SAS Institute Inc, 2012). Data collected were statistically evaluated by analysis of variance (ANOVA) using the general linear model; PROC GLM procedure (SAS, 2012). Least Significant Difference (LSD) test was used to separate treatment means at 95 % confidence level (Steel & Torrie, 1981)

CHAPTER FOUR

RESULTS

4.1 Initial soil chemical and physical characterization

The results of the physical and chemical properties of the soil sampled from experimental sites at the beginning of the experiment are presented in Table 2 below.

Table 2: Physical and chemical characteristics of top soil (0-20 cm) at the three locations in Makueni County.

	Location means			Critical levels
Soil characteristic	Utafiti	Machinery	Mwanzo	(Thomas *et al.*, 1997)
Chemical composition				
pH	6.53	6.45	6.58	near neutral
N (%)	0.10*	0.07*	0.06*	< 0.2
P (mg/kg)	14.00*	7.00*	13.00*	< 20
C (%)	0.92*	0.69*	0.52*	< 1.0
K (cmolc/kg)	0.52	0.33	0.59	< 0.2
Ca (cmolc/kg)	1.90	1.60	2.00	< 0.2
Mg (cmolc/kg)	1.58	1.74	1.63	< 1.0
Zn mg/kg	2.00*	2.00*	3.38*	< 7.5
Physical composition (%)				
% clay	27.60	22.40	26.60	
% sand	67.60	70.80	66.20	
% silt	4.80	6.80	7.20	
Textural class:	sandy clay loam	sandy loam	sandy clay loam	

* Below critical levels

The average soil pH at the three locations was near neutral. It ranged from 6.45 to 6.58. The soils also had low organic carbon content ranging from 0.52 % to 0.92 %. Total nitrogen was less than 0.10 % at the three locations while available phosphorus ranged from 7 % to 14 % at the three locations.

The soils at the three locations had different textures. Soils in Machinery were sandy loam while those in Utafiti and Mwanzo were sandy clay loam.

4.2 Productivity of KAT Bean-9 in Makueni County

4.2.1 Days to flowering and physiological maturity

a) Days to flowering

The mean number of days to 50 % flowering of KAT Bean-9 at the three locations in Makueni County was 38 days (DAS). The mean number of days to 50 % flowering of KAT Bean-9 was highest in Mwanzo (39.7 DAS) and least in Machinery (36.5 DAS) as shown in Figure 3 below.

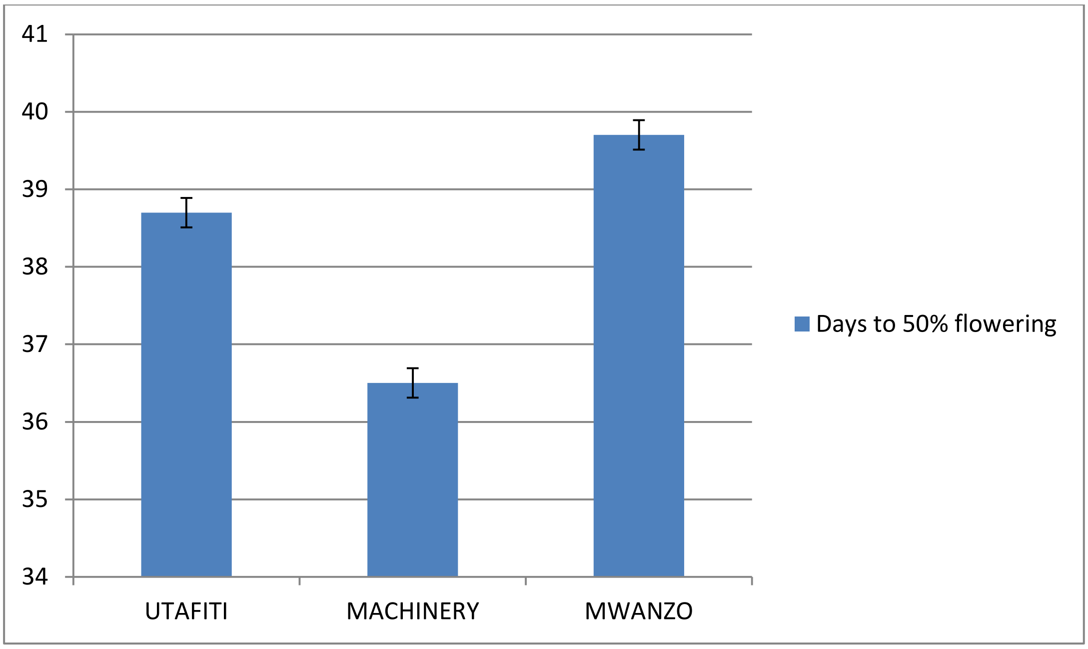

Figure 3: Mean number of days to 50 % flowering (DAS) of KAT Bean-9 at the three locations in Makueni County. Error bars represent standard error of the mean.

b) Days to physiological maturity

The mean number of days to physiological maturity of KAT Bean-9 at the three locations in Makueni County was 67 days (DAS). The mean number of days to physiological maturity of KAT Bean-9 was 63.9 days in Machinery, 68 days in Utafiti and 68.9 days in Mwanzo (Figure 4).

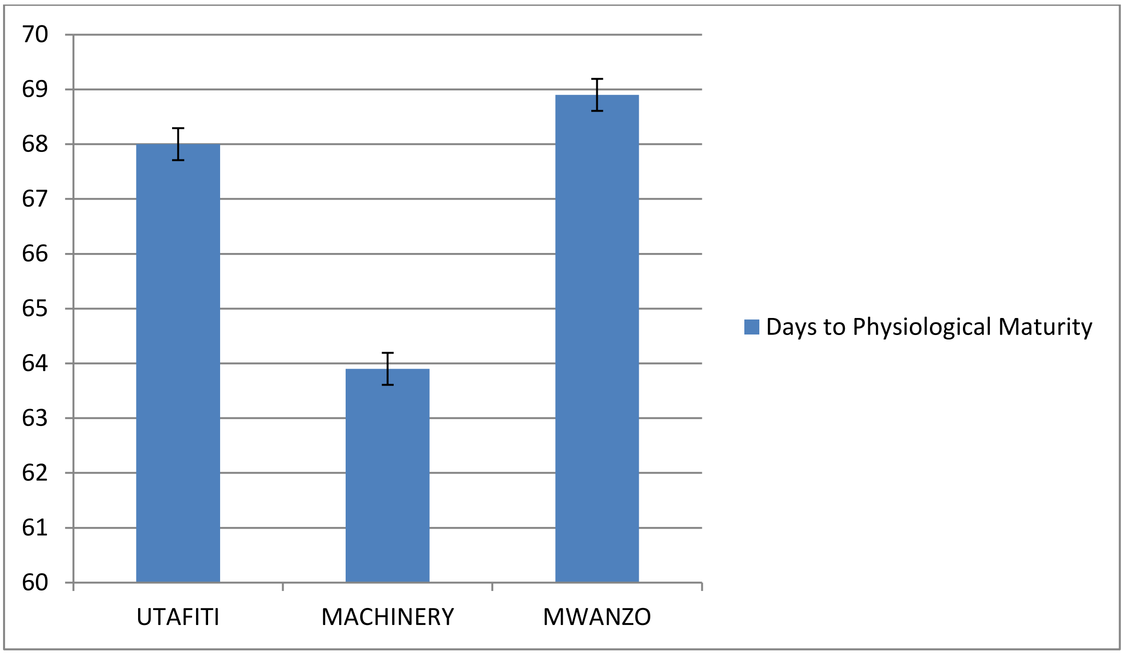

Figure 4: Mean number of days to physiological maturity (DAS) of KAT Bean-9 at the three locations in Makueni County. Error bars represent standard error of the mean.

4.2.2 Biomass yield of KAT Bean-9 at the three locations

The mean biomass yield of KAT Bean-9 at the three locations at flowering and harvest was 706 kg/ha and 1280 kg/ha respectively. There were no significant differences ($P \geq 0.05$) in the bean biomass yield at flowering at the three locations (Table 3).

Table 3: Plant biomass yield of KAT Bean-9 (kg/ha) at flowering and harvest.

Location	Biomass yield at flowering kg/ha	Biomass yield at harvest kg/ha
Utafiti	651a	1171a
Machinery	773a	1157a
Mwanzo	695a	1512b
LSD	208	171
CV%	30	14

Means with different letters in the column are significantly different at $P \leq 0.05$.

However, significant differences were observed in biomass yield at harvest at the three locations (Table 3). Biomass yield of Mwanzo (1512 kg/ha) was significantly higher ($P \leq 0.05$) than that of Machinery (1157 kg/ha) and Utafiti (1171 kg/ha). The biomass yield of Machinery and Utafiti was not significantly different.

4.2.3 Grain yield of KAT Bean-9 at the three locations

There were no significant differences (P≥ 0.05) in the grain yield of KAT Bean-9 at the three locations as shown in Figure 5 below.

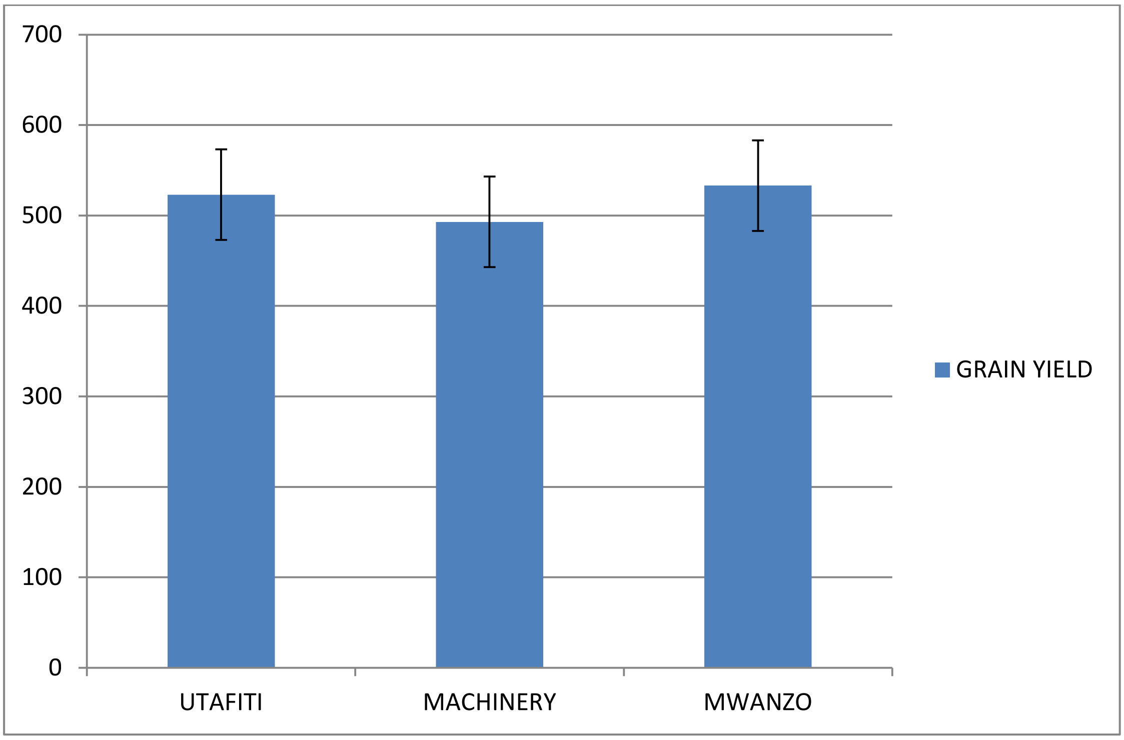

Figure 5: Grain yield of KAT Bean-9 (kg/ha) at the three locations in Makueni County. Error bars represent standard error of the mean.

4.3 Response of KAT Bean-9 to DAP fertilizer application

4.3.1 Effect of DAP fertilizer on biomass yield

DAP fertilizer application significantly ($P \leq 0.05$) increased the biomass yield both at flowering and at harvest (Table 4). DAP fertilizer increased biomass accumulation at flowering in Mwanzo by 79 %. Biomass yield at Utafiti and Machinery was also increased by 69 % and 54 % respectively.

Table 4: Plant biomass yield of KAT Bean-9 at different fertilizer levels.

Location	Fertilizer level	Biomass yield at flowering kg/ha	Biomass yield at harvest kg/ha
Utafiti	0 kg DAP/ha	484a	816a
Utafiti	50 kg DAP/ha	819b	1525c
Machinery	0 kg DAP/ha	608a	927ab
Machinery	50 kg DAP/ha	938b	1388c
Mwanzo	0 kg DAP/ha	497a	1000b
Mwanzo	50 kg DAP/ha	892b	2022d
LSD		208	171
CV%		30	14

Means with different letters in the column are significantly different at *P≤ 0.05*.

DAP fertilizer application also had a significant effect on biomass yield at harvest. Fertilizer application increased biomass accumulation at harvest by 100 % in Mwanzo, 86 % in Utafiti and 49 % in Machinery.

4.3.2 Effect of DAP fertilizer on grain yield

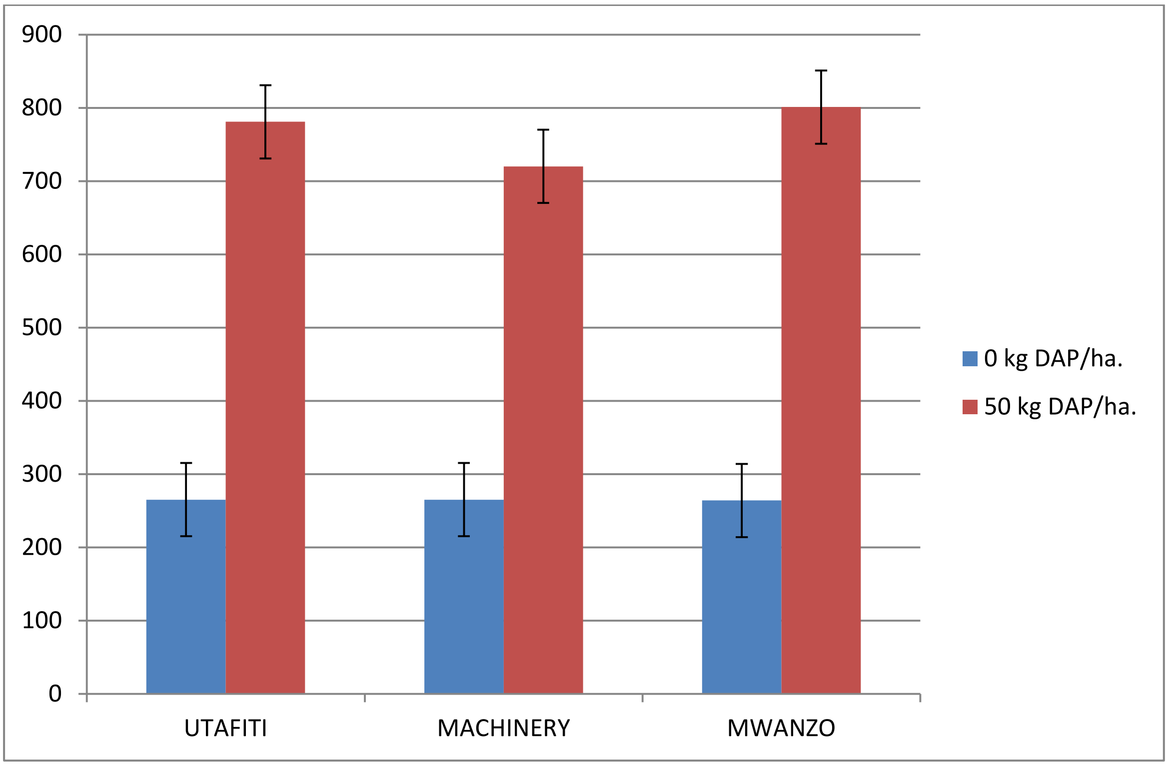

Figure 6: **Grain yield of KAT Bean-9 (kg/ha) under two levels of fertilizer application at the three locations in Makueni County. Error bars represent standard error of the mean.**

DAP fertilizer application significantly (P≤ 0.05) increased the grain yield of bean KAT/B-9 at the three locations as shown in Figure 6 above. DAP fertilizer application increased the grain yield by 204 % in Mwanzo. The grain yield increased by 195 % and 171 % in Utafiti and Machinery respectively.

4.4 Productivity of Cowpea M66 in Makueni County

4.4.1 Number of days to flowering and physiological maturity

a) Number of days to flowering

The mean number of days to 50 % flowering of Cowpea M66 at the three locations in Makueni County was 56 days (DAS). The mean number of days to 50 % flowering of cowpea was highest in Mwanzo (57 DAS) and least in Machinery (55.5 DAS) as shown in Figure 7 below.

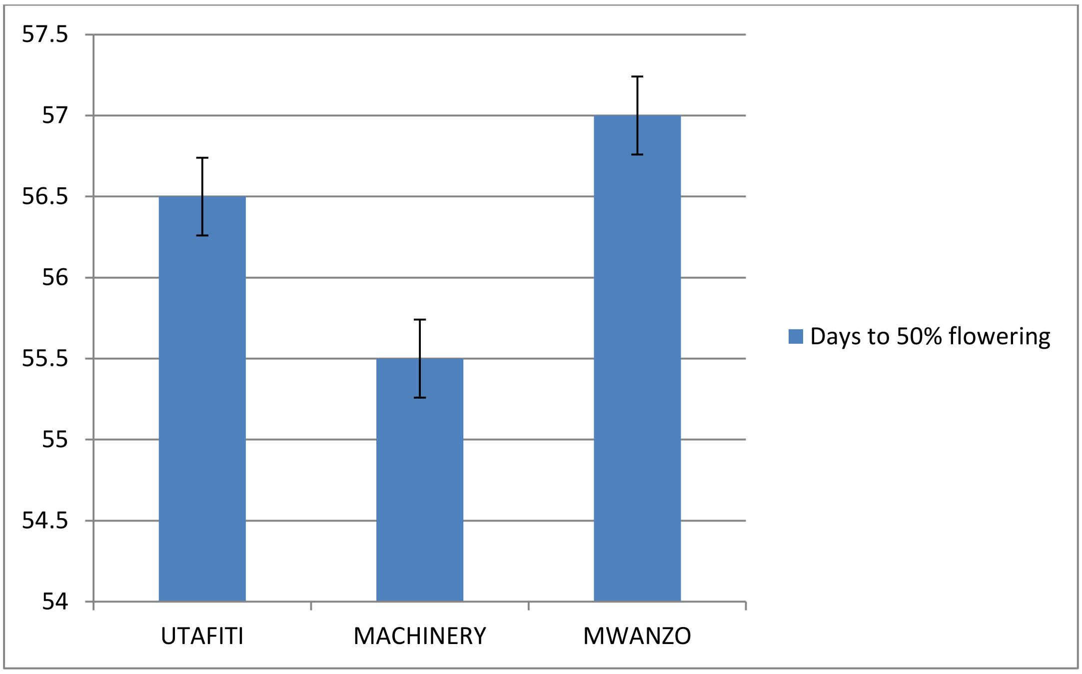

Figure 7: Mean number of days to 50 % flowering (DAS) of Cowpea M66 at the three locations in Makueni County. Error bars represent standard error of the mean.

b) Number of days to physiological maturity

The mean number of days to physiological maturity of Cowpea M66 at the three locations in Makueni County was 85 days (DAS). The mean number of days to physiological maturity of cowpea was 83 days in Machinery, 85.5 days in Utafiti and 86.6 days in Mwanzo (Figure 8).

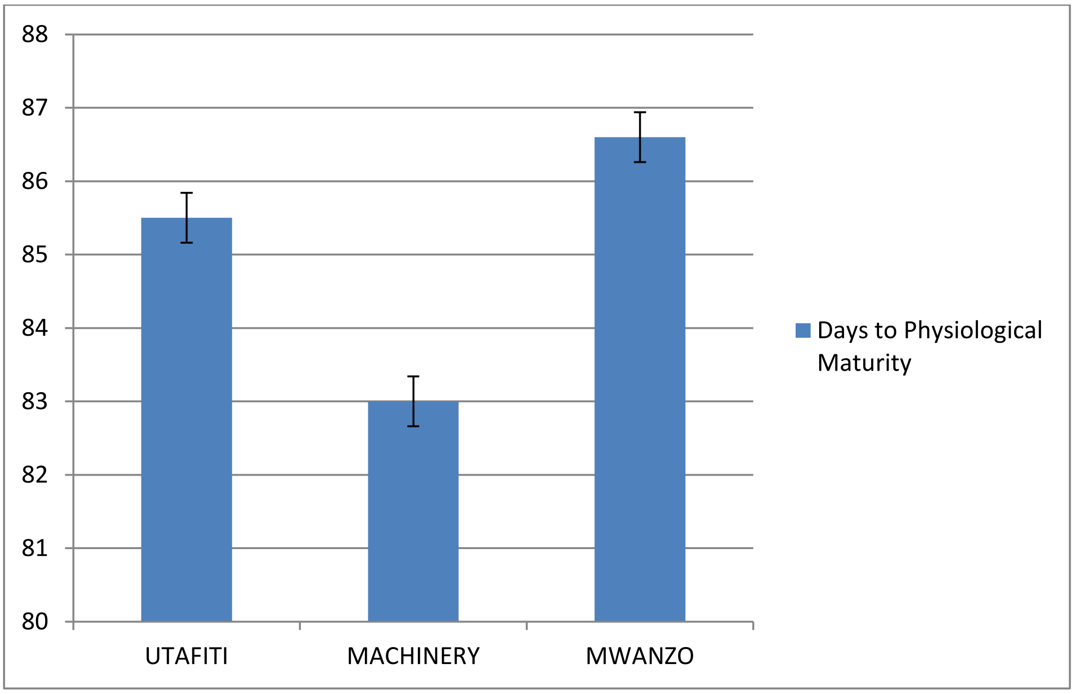

Figure 8: Mean number of days to physiological maturity (DAS) of Cowpea M66 at the three locations in Makueni County. Error bars represent standard error of the mean.

4.4.2 Biomass yield of Cowpea M66 at the three locations

The mean biomass yield of Cowpea M66 in all the three locations at flowering and harvest was 1642 kg/ha and 2372 kg/ha respectively. Significant differences ($P \leq 0.05$) were observed in the mean biomass yield of cowpea between the locations at flowering and at harvest (Table 5). Biomass yield at flowering was highest at Mwanzo (1990 kg/ha) and lowest in Machinery (1145 kg/ha).

Significant differences ($P \leq 0.05$) were also observed in the biomass yield at harvest of Machinery (1505 kg/ha) from the other locations (Table 5). Biomass yields in both Mwanzo and Utafiti were significantly higher than those of Machinery. However, there were no significant differences between their biomass yields of 2770 kg/ha and 2840 kg/ha respectively.

Table 5: Plant biomass yield of Cowpea M66 (kg/ha) at flowering and harvest.

Location	Biomass yield at flowering kg/ha	Biomass yield at harvest kg/ha
Utafiti	1793b	2840b
Machinery	1145a	1505a
Mwanzo	1990c	2770b
LSD	192	294
CV%	12	13

Means with different letters in the column are significantly different at $P \leq 0.05$.

4.4.3 Grain yield of Cowpea M66 at the three locations

The mean grain yield of Cowpea M66 at the three locations was 1570 kg/ha. There were significant differences observed ($P \leq 0.05$) in the grain yield of cowpea at the three locations (Figure 9). Grain yield was highest in Mwanzo (1823 kg/ha) and lowest at Machinery (1282 kg/ha). Utafiti had grain yields of 1604 kg/ha.

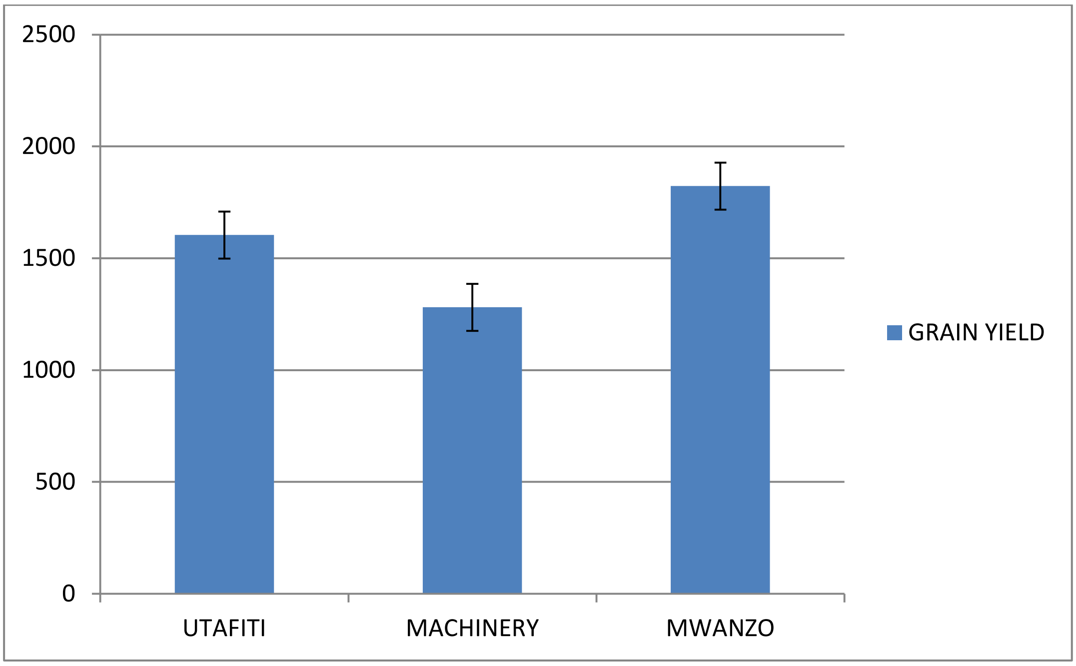

Figure 9: **Grain yield of Cowpea M66 (kg/ha) at the three locations in Makueni County. Error bars represent standard error of the mean.**

4.5 Response of Cowpea M66 to DAP fertilizer application

4.5.1 Effect of DAP fertilizer on biomass yield

DAP fertilizer application significantly ($P \leq 0.05$) increased the biomass yield of Cowpea M66 both at flowering and at harvest (Table 6). DAP fertilizer increased biomass accumulation at flowering in Mwanzo by 91 %. Flowering biomass yields also increased in Utafiti and Machinery by 68 % and 36 % respectively.

Table 6: Plant biomass yield of Cowpea M66 at different fertilizer levels.

Location	Fertilizer level	Biomass yield at Flowering kg/ha	Biomass yield at harvest kg/ha
Utafiti	0 kg DAP/ha	1336b	1958 b
Utafiti	50 kg DAP/ha	2250c	3721c
Machinery	0 kg DAP/ha	968a	1144a
Machinery	50 kg DAP/ha	1320b	1866b
Mwanzo	0 kg DAP/ha	1365b	1866b
Mwanzo	50 kg DAP/ha	2615d	3674c
LSD		156	240
CV%		12	13

Means with different letters in the column are significantly different at *$P \leq 0.05$*.

DAP fertilizer application also significantly increased the biomass yield at harvest. It increased biomass accumulation at harvest by 96 % in Mwanzo, 90 % in Utafiti and 63 % in Machinery.

4.5.2 Effect of DAP fertilizer on grain yield

DAP fertilizer application significantly ($P \leq 0.05$) increased the grain yield of cowpea at the three locations (Figure 10). The grain yield increased by 127 % in Mwanzo, 101 % in Utafiti and 60 % at Machinery.

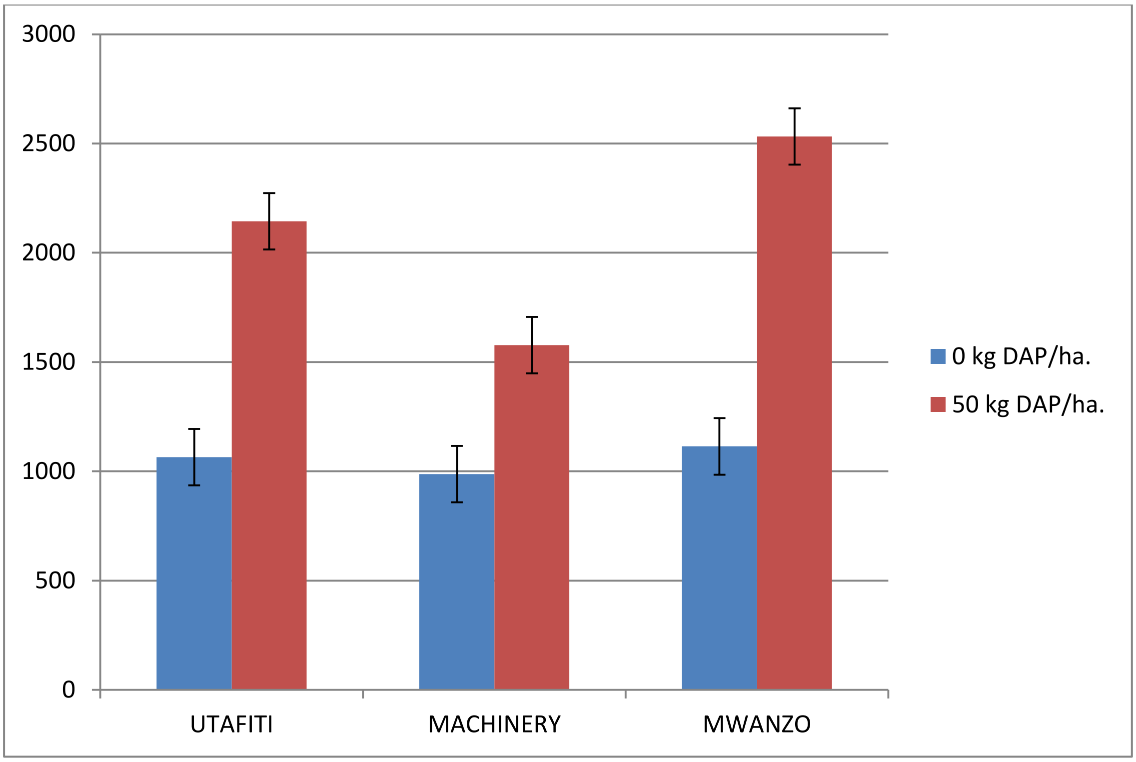

Figure 10: **Grain yield of Cowpea M66 (kg/ha) under two levels of fertilizer at the three locations in Makueni County. Error bars represent standard error of the mean.**

4.6 Productivity of lablab in Makueni County

4.6.1 Number of days to flowering and physiological maturity

a) Number of days to flowering

The mean number of days to 50 % flowering of lablab variety KAT/DL-1 at the three locations in Makueni County was 76 days (DAS) while that of CP1 81364 was 61 days (DAS). The mean number of days to 50 % flowering of KAT/DL-1 was highest in Mwanzo (77 DAS) and least in Machinery (75.5 DAS). The mean number of days to 50 % flowering of CP1 81364 was highest in Mwanzo (62.1 DAS) and least in Machinery (59.6 DAS) as shown in Figure 11 below.

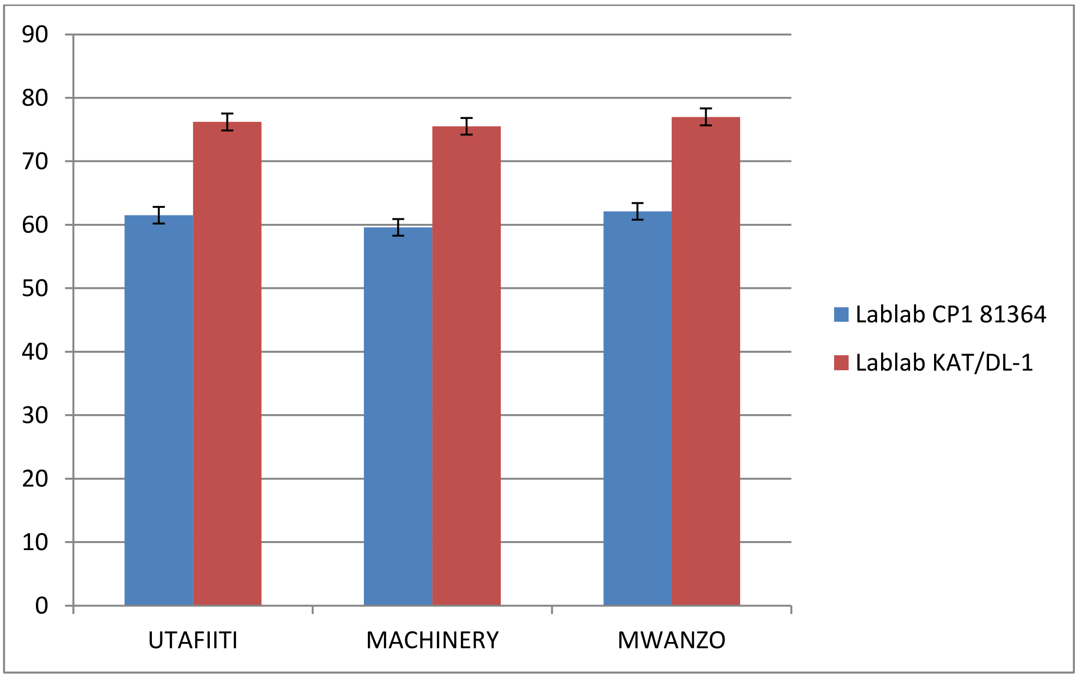

Figure 11: Mean number of days to 50 % flowering (DAS) of lablab at the three locations in Makueni County. Error bars represent standard error of the mean.

b) Number of days to physiological maturity

The mean number of days to physiological maturity of lablab variety KAT/DL-1 at he three locations in Makueni County was 122 days (DAS) while that of CP1 81364 was 113 days (DAS). The mean number of days to physiological maturity of KAT/DL-1 was 120.5 days in Machinery, 122.4 days in Mwanzo and 123.7 days in Utafiti. The number of days to physiological maturity of CP1 81364 was 112.9 days in Machinery, 114 days in Mwanzo and 114.6 days in Utafiti (Figure 12).

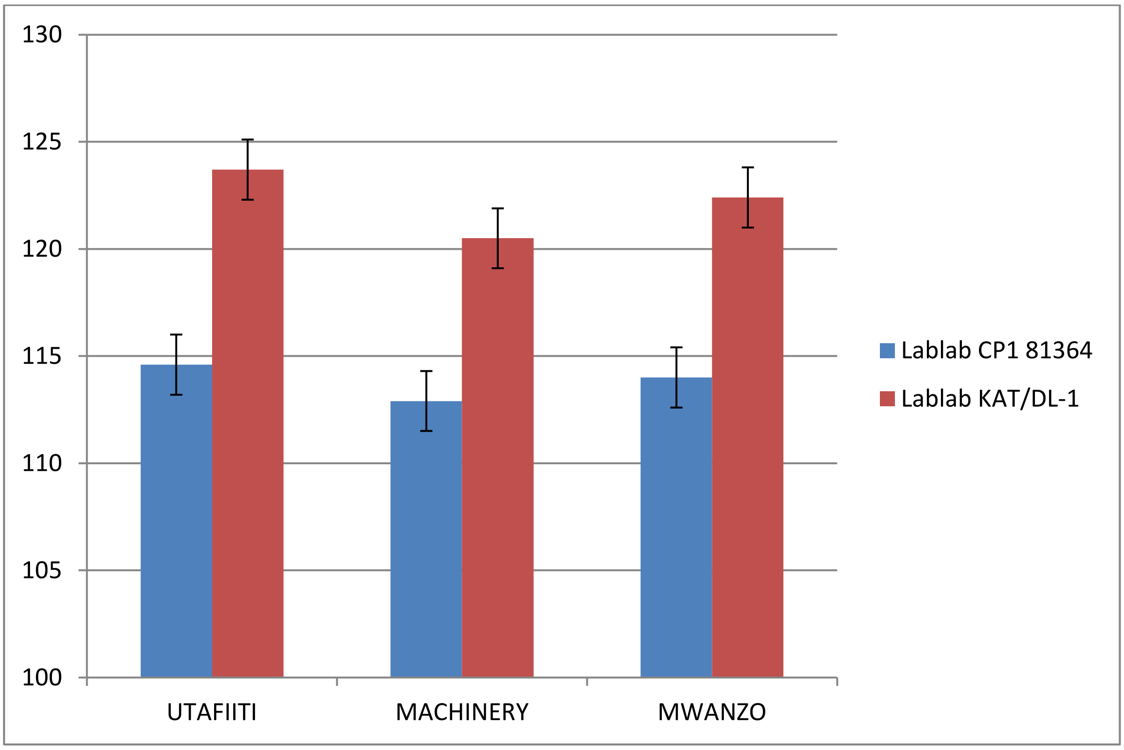

Figure 12: Mean number of days to physiological maturity (DAS) of lablab at the three locations in Makueni County. Error bars represent standard error of the mean.

4.6.2 Biomass yield of lablab at the three locations

There were significant differences (P≤ 0.05) in the mean biomass yield of KAT/DL-1 at the three locations both at flowering and harvest (Table 7). Flowering biomass yield at Machinery (2174 kg/ha) was significantly lower than that of Mwanzo and Utafiti. There was no significant difference between biomass yields at Mwanzo (3144 kg/ha) and Utafiti (2992 kg/ha).

Significant differences (P≤ 0.05) were also observed in the mean biomass yield of CP1 81364 between the locations at flowering and harvest (Table 7). Flowering biomass yield at Machinery (1405 kg/ha) was significantly lower than that of Mwanzo and Utafiti. There was no significant difference between biomass yields of Mwanzo (2236 kg/ha) and Utafiti (2142 kg/ha). Flowering biomass yield of KAT/DL-1 was significantly (P≤ 0.05) higher than that of CP1 81364 at the three locations.

Table 7: Plant biomass yield of lablab (kg/ha) at flowering and harvest.

Location	Lablab variety	Biomass yield at flowering kg/ha	Biomass yield at harvest kg/ha
Utafiti	KAT/DL-1	2992c	3856d
Utafiti	CP1 81364	2142b	3179c
Machinery	KAT/DL-1	2174b	2767b
Machinery	CP1 81364	1405a	1813a
Mwanzo	KAT/DL-1	3144c	4012d
Mwanzo	CP1 81364	2236b	3092c
LSD		169	207
CV%		14	11

Means with different letters in the column are significantly different at *P≤ 0.05*.

There were significant differences (P≤ 0.05) observed in the biomass yield at harvest of KAT/DL-1 at Machinery (2767 kg/ha) from the other locations. Biomass yields in both Mwanzo and Utafiti were significantly higher than those of Machinery. However, there was no significant difference between their yields of 4012 kg/ha and 3856 kg/ha respectively.

There were significant differences (P≤ 0.05) observed in the harvest biomass yield of CP1 81364 at Machinery from the other locations (1813 kg/ha). Biomass yields in both Mwanzo and Utafiti were significantly higher than those of Machinery. However, there was no significant difference between their yields of 3092 kg/ha and 3179 kg/ha respectively. Harvest biomass yield of KAT/DL-1 was significantly (P≤ 0.05) higher than that of CP1 81364 at the three locations.

4.6.3 Grain yield of lablab at the three locations

The mean grain yield of KAT/DL-1 at the three locations in Makueni County was 1050 kg/ha while that of CP1 81364 was 659 kg/ha. The mean grain yield of KAT/DL-1 was significantly (P≤ 0.05) higher than that of CP1 81364 at the three locations in Makueni County as shown in Figure 13 below.

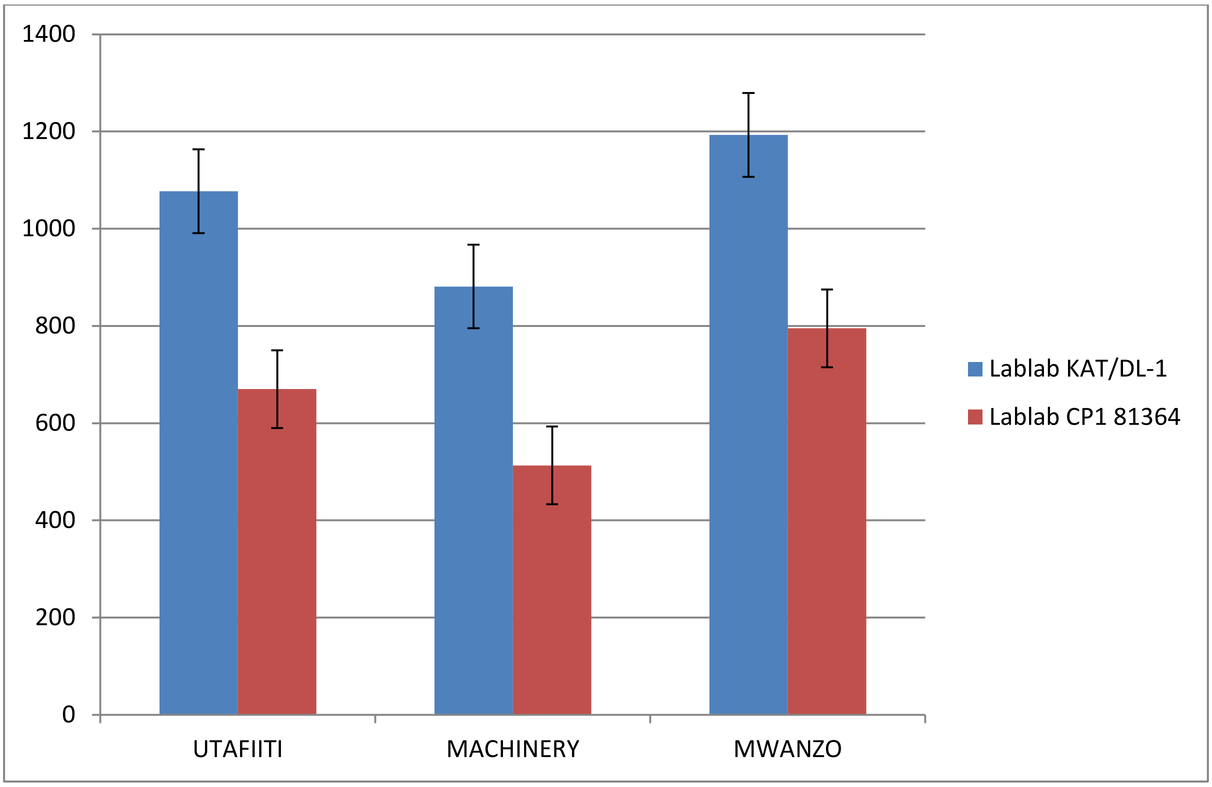

Figure 13: **Grain yield of lablab (kg/ha) at the three locations in Makueni County. Error bars represent standard error of the mean.**

The grain yields of KAT/DL-1 at Machinery were significantly different (P≤ 0.05) from those of the other two locations. Machinery had a grain yield of 1282 kg/ha while Utafiti and Mwanzo had grain yields of 1604 kg/ha and 1823 kg/ha respectively. There were no significant differences between the grain yields of Utafiti and Mwanzo.

Significant differences (P≤ 0.05) were observed in the grain yield of CP1 81364 at Machinery (881 kg/ha) as compared to the other two locations. However, the grain yields at Utafiti (1077 kg/ha) and Mwanzo (1193 kg/ha) were not significantly different.

4.7. Response of lablab to DAP fertilizer application at the three locations

4.7.1 Effect of DAP fertilizer on biomass yield of lablab at Utafiti

DAP fertilizer application significantly ($P \leq 0.05$) increased the biomass yield of the two lablab varieties both at flowering and at harvest (Table 8). DAP fertilizer application increased biomass accumulation of KAT/DL-1 at flowering in Utafiti by 102 %. Flowering biomass yields of CP1 81364 also increased by 81 % in Utafiti.

Table 8: Plant biomass yield of lablab (kg/ha) at flowering and harvest in Utafiti.

Lablab variety	Fertilizer level	Biomass yield at flowering kg/ha	Biomass yield at harvest kg/ha
KAT/DL-1	0 kg DAP/ha	1982b	2526b
CP1 81364	0 kg DAP/ha	1525b	2101a
KAT/DL-1	50 kg DAP/ha	4003d	5186d
CP1 81364	50 kg DAP/ha	2759c	4256c
LSD		169	207
CV%		14	11

Means with different letters in the column are significantly different at $P \leq 0.05$.

DAP fertilizer application also had a significant effect on biomass yield at harvest. It increased biomass accumulation of KAT/DL-1 at harvest in Utafiti by 105 %. Harvest biomass yields of CP1 81364 also increased by 103 %.

4.7.2 Effect of DAP fertilizer on biomass yield of lablab at Machinery

DAP fertilizer application significantly increased the biomass yield of lablab both at flowering and at harvest (Table 9). DAP fertilizer increased biomass accumulation of KAT/DL-1 at flowering in Machinery by 98 %. Flowering biomass yields of CP1 81364 also increased by 72 % in the same location.

Table 9: Plant biomass yield of lablab (kg/ha) at flowering and harvest in Machinery.

Lablab variety	Fertilizer level	Biomass yield at flowering kg/ha	Biomass yield at harvest kg/ha
KAT/DL-1	0 kg DAP/ha	1455b	2046b
CP1 81364	0 kg DAP/ha	1034a	1325a
KAT/DL-1	50 kg DAP/ha	2894d	3488d
CP1 81364	50 kg DAP/ha	1775c	2300c
LSD		169	207
CV%		14	11

Means with different letters in the column are significantly different at $P \leq 0.05$.

DAP fertilizer application also had a significant effect on biomass yield at harvest. It increased biomass accumulation of KAT/DL-1 at harvest by 70 %. Harvest biomass yields of CP1 81364 also increased by 74 %.

4.7.3 Effect of DAP fertilizer on biomass yield of lablab at Mwanzo

DAP fertilizer application significantly increased the biomass yield of lablab both at flowering and at harvest (Table 10). DAP fertilizer increased biomass accumulation of KAT/DL-1 at flowering in Mwanzo by 140 %. Flowering biomass yields of CP1 81364 also increased by 99 % in the same location.

Table 10: Plant biomass yield of lablab (kg/ha) at flowering and harvest in Mwanzo.

Lablab variety	Fertilizer level	Biomass yield at flowering kg/ha	Biomass yield at harvest kg/ha
KAT/DL-1	0 kg DAP/ha	1847b	2506b
CP1 81364	0 kg DAP/ha	1494a	2070a
KAT/DL-1	50 kg DAP/ha	4440d	5518d
CP1 81364	50 kg DAP/ha	2980c	4114c
LSD		169	207
CV%		14	11

Means with different letters in the column are significantly different at $P \leq 0.05$.

DAP fertilizer application also had a significant effect on biomass yield at harvest. It increased biomass accumulation of KAT/DL-1 at harvest by 120 %. Harvest biomass yields of CP1 81364 also increased by 102 %.

4.7.4 Interaction between location, fertilizer and legume

There were significant interactions observed between location, fertilizer and lablab varieties as shown in appendix x and xi.

4.7.5 Effect of DAP fertilizer on grain yield of lablab at Utafiti

DAP fertilizer application significantly increased the grain yield of the two lablab varieties (Figure 14). DAP fertilizer application increased the grain yield of KAT/DL-1 in Utafiti by 114 %. The grain yields of CP1 81364 also increased by 78 %.

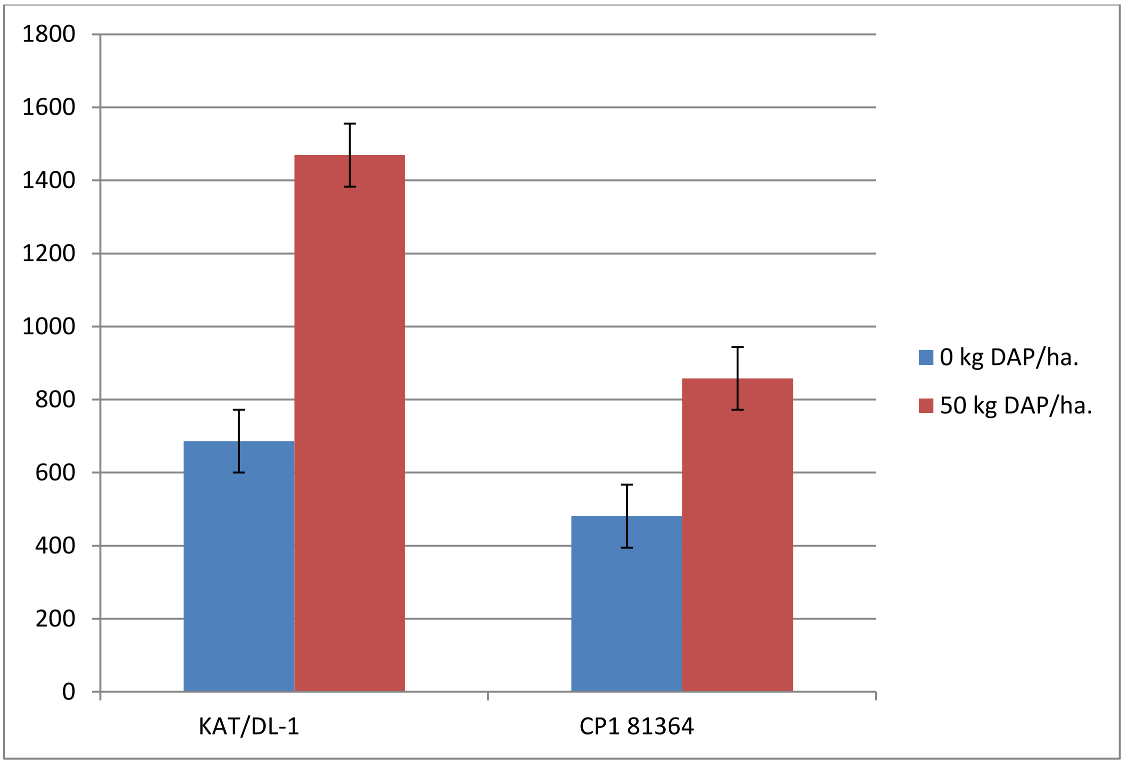

Figure 14: Grain yield (kg/ha) of the two lablab varieties under two DAP fertilizer levels at Utafiti. Error bars represent standard error of the mean.

4.7.6 Effect of DAP fertilizer on grain yield of lablab at Machinery

DAP fertilizer application also had a significant ($P \leq 0.05$) effect on grain yield of both lablab varieties at harvest (Figure 15). DAP fertilizer increased the grain yield of KAT/DL-1 in Machinery by 116 %. Grain yields of CP1 81364 also increased by 101 % in the same location.

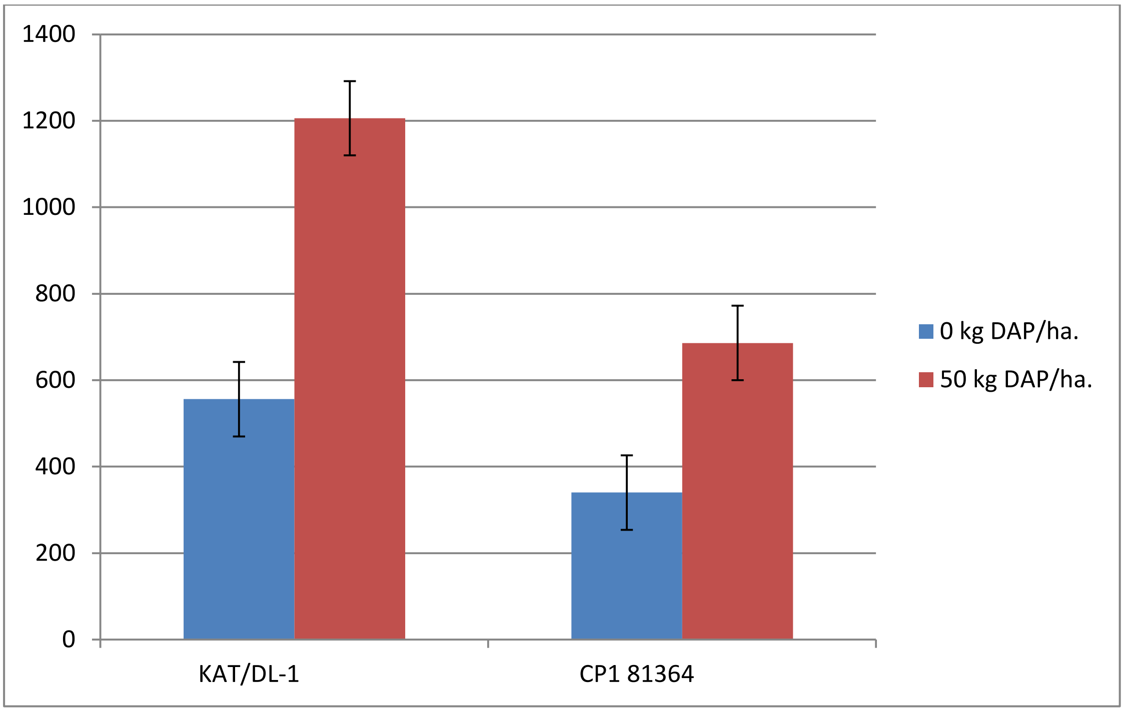

Figure 15: Grain yield (kg/ha) of the two lablab varieties under two DAP fertilizer levels at Machinery. Error bars represent standard error of the mean.

4.7.7 Effect of DAP fertilizer on grain yield of lablab at Mwanzo

DAP fertilizer application significantly increased the grain yield of the two lablab varieties at harvest (Figure 16). DAP fertilizer increased grain yield of KAT/DL-1 in Mwanzo by 103 %. Grain yields of CP1 81364 also increased by 70 % in the same location.

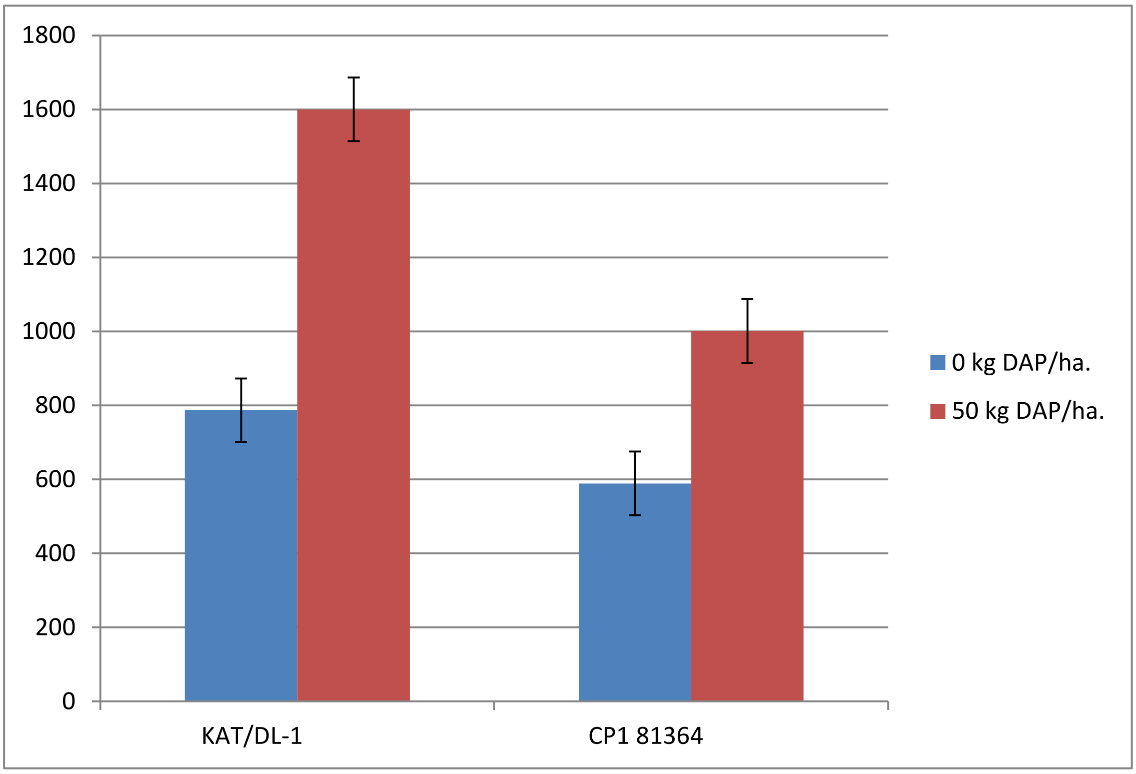

Figure 16: Grain yield (kg/ha) of the two lablab varieties under two DAP fertilizer levels at Mwanzo. Error bars represent standard error of the mean.

4.7.8 Interaction between location, fertilizer and legume

There were no significant interactions observed between location, fertilizer and lablab varieties as shown in appendix xii.

CHAPTER FIVE

DISCUSSION

5.1 Physical and chemical characteristics of top soil (0-20 cm) in Makueni County

Soil analysis results from Table 2 show that the average values for total nitrogen, available phosphorus and organic carbon were below critical levels at the three locations. They are less than half of what is considered to be adequate for grain legume production (Thomas *et al.,* 1997). These soil test results are in conformity with those of Onduru *et al.,* (2001) and Mora-Vallejo *et al.,* (2008) whose study revealed that soils in Makueni County had low fertility and were generally deficient in nitrogen, phosphorus and soil organic carbon.

This combination of N, P and organic C values is typical in situations where there is continuous cropping with little replenishment of nutrients back to the soil (Kimiti, 2014). The low organic carbon at the three locations can be attributed to continuous cropping with low farm inputs to replenish soil fertility, removal of crop residues to feed animals and low returns of crop residues and farmyard manure to the farms (Wambua, 2013). The low nitrogen and phosphorus levels can be attributed to failure to apply farmyard manure and fertiliser, nutrient loss through crop harvest, soil erosion and continuous cultivation in the same piece of land. The same have been identified as the main causes of declining soil fertility in Makueni County (Kimiti *et al.,* 2009; Kimiti, 2014).

5.2 Productivity of KAT Bean-9 in Makueni County

The mean number of days to flowering and physiological maturity differed at the three locations in Makueni County. This is mainly due to the different agro ecological conditions of the three locations (Jaetzold *et al.,* 2010). The three zones receive different amounts of rainfall, temperatures and soil fertility conditions which affect the growth rate of beans. Early flowering and maturity at Machinery may be due to drought induced early maturity due to lower rainfall and soil moisture as compared to the other two locations (Acosta-Díaz *et al.,* 2009; Beebe *et al.,* 2013).

Biomass yield at flowering was not significantly different between the locations. This might be due to availability of adequate rainfall at the three sites in the months of April and May (Appendix iii).

Biomass accumulation at harvest differed significantly ($P \leq 0.05$) at the three locations. Biomass yield at harvest was highest at Mwanzo (1512 kg/ha) and lowest in Machinery (1157 kg/ha). This could be attributed to low rainfall and soil moisture deficit that was highest in Machinery (appendix iii). Soil moisture deficit lowers mobility of nutrients especially phosphorus and nitrogen leading to decreased biomass yields (Farooq *et al.,* 2009; Sun *et al.,* 2014). This could also be attributed to the low phosphorus levels in the soils of Machinery as compared to that of Mwanzo and Utafiti. Soil analysis results showed that the phosphorus levels at Machinery were 7 mg/kg and those of Mwanzo and Utafiti were 13 mg/kg and 14 mg/kg. Soils are considered to be deficient of phosphorus if available P is less than 40 mg/kg (Mourice & Tryphone, 2012).

There was no significant difference ($P \geq 0.05$) in the grain yield of beans at the three locations. This is due to the variety being early maturing (60-65 days) hence escaping the effects of drought especially during flowering and grain filling stages (Karanja *et* *al.,* 2006; Karugia *et al.,* 2012). The grain yields were way below the potential yields of KAT Bean 9 as documented by Kenya Agricultural and Livestock Research Organisation (KALRO) and KEPHIS which are estimated to be between 1400-1900 kg/ha (Karanja *et al.,* 2006; KEPHIS, 2014). This can be attributed to low soil fertility in the County. Soil analysis results showed that soils in the three locations were low on nitrogen, phosphorus and organic carbon (Kimiti, 2014). These are major nutrients and they greatly affected the yields in the three locations.

These results are in conformity with a study carried out by Kimiti *et al.,* 2009 whose findings indicated that the average grain yields of beans in the county was at 250 kg/ha. Beans need minimum organic carbon of 2.4 % in order to grow well and most varieties will not do well in soils depleted of nitrogen and phosphorus (Kimani *et al*., 2010). Other studies have also established that plant available P is one of the most deficient nutrient in common bean cultivation (Beebe *et al.,* 2011; Buruchara *et al.,* 2011; Beebe *et al.,* 2013).

5.3 Response of KAT Bean-9 to DAP fertilizer application

DAP fertilizer application significantly ($P \leq 0.05$) increased the biomass yields both at flowering and at harvest (Table 4). DAP fertilizer increased biomass accumulation at flowering in between 49 % and 100 % at the locations. DAP fertilizer application also increased biomass accumulation at harvest between 54 % and 79 % at the three locations. The increase in biomass yield was attributed to addition of Nitrogen and Phosphorus; two macronutrients that are most limiting the three locations (Kimiti *et al.,* 2009). Nitrogen has been found to promote shoot and leaf growth and is very important for biomass accumulation (Lunze *et al.,* 2012).

DAP fertilizer application significantly improved the grain yield of beans (Figure 6). Grain yield increased between 171 % and 204 % at the three locations. The consistently higher grain yields recorded in treatments where DAP fertilizer was applied was attributed to higher amounts N and P nutrients. The two macro elements were found to be below the critical level at the three locations (Table 2). Other studies have found both nitrogen and phosphorus to have a significant effect on yield and yield components of beans. Farm trials carried out by Mugwe *et al.,* (2009) showed that application of 60 kg N/ha increased yields by more than 100 % above the control. A study carried out by Zafar *et al.,* (2011) showed significant improvements on the grain yield and yield components of common bean such as number of pods per plant following phosphorus supplementation over the control treatment.

5.4 Productivity of Cowpea M66 in Makueni County

The mean number of days to flowering and physiological maturity differed at the three locations in Makueni County. This is mainly due to the different agro-ecological conditions of the three locations (Jaetzold *et al.,* 2010). The three zones receive different amounts of rainfall, temperatures and soil fertility conditions all which affected the growth rate of cowpea. The early flowering and physiological maturity observed at Machinery (IL6) may be due to cowpea escaping drought. The location received the least amount of rainfall of the three locations (appendix 3). Legumes have been found to escape drought through reduced number of days to physiological maturity (Acosta-Diaz *et al.,* 2009).

There were significant differences ($P \leq 0.05$) in the mean biomass yield of cowpea between the locations at flowering and at harvest (Table 5). Biomass yield at flowering was highest at Mwanzo and lowest in Machinery. At harvest, biomass yields in both Mwanzo and Utafiti were significantly higher than those of Machinery. Low biomass yields at Machinery might be due to moisture stress compared to the other locations. Moisture stress has been found to reduce the biomass yields of cowpea (Suriyagoda *et al.,* 2010). Soil fertility also differed at the three locations. The levels of nitrogen and phosphorus differed at the three locations (Table 2) and both have been found to greatly affect the biomass yields of cowpea (Odundo *et al.,* 2010).

There were significant differences ($P \leq 0.05$) observed in the grain yield of cowpea at the three locations. Grain yield was highest in Mwanzo and lowest in Machinery. This could be attributed to the difference in soil moisture at the three locations (Appendix iii). Soil moisture enables plants absorb nutrients from the soil leading to better grain yields in legumes (Sun *et al.,* 2014). The actual grain yields obtained were at par with the potential yields of M66 variety documented by KALRO and KEPHIS which are between 1500 to 1800 kg/ha (Karanja *et al.,* 2006; KEPHIS, 2014). This can be attributed to the ability of cowpea to perform well under poor soil fertility conditions. Cowpea is considered to be more tolerant to nitrogen and phosphorus deficiency as compared to other legumes such as soybean and common bean. It has been found to have a greater P use efficiency (Alkama *et al.,* 2008). The variety is also drought tolerant and well adapted to the area.

5.5 Response of Cowpea M66 to DAP fertilizer application.

DAP fertilizer application significantly ($P \leq 0.05$) increased the biomass yield of cowpea both at flowering and at harvest (Table 6). The increase in biomass yield was attributed to addition of nitrogen and phosphorus nutrients which were deficient in the area. These results were similar to those of Odundo *et al.,* (2010) who found out that application of 30 kg P/ha increased the dry matter yield of cowpea up to 74 % compared to the control. Research done by Gweyi-Onyango *et al.,* (2011) also found that application of 50 kg/ha of TSP fertilizer increased the dry matter production of two cowpea genotypes. This is partly because P enhances plant physiology functions of such processes as photosynthesis, nitrogen fixation, flowering, fruiting and maturation (Pang *et al.,* 2010). DAP fertilizer has been found to improve the biomass yield of soybean due to the supply of N which is important in biomass accumulation (Abuli *et al.,* 2012). Research done by Ndor *et al.,* (2012) showed that biomass and grain yield of cowpea was significantly higher in plots supplied with different levels of phosphorus as compared to the control.

DAP fertilizer application significantly ($P \leq 0.05$) increased the grain yield of cowpea at the three locations. The consistently higher grain yields recorded in treatments where DAP fertilizer was applied was attributed to higher amounts N and P of nutrients. These results concur with those of Abuli *et al.,* (2012) where grain yields of Soybean increased with application of DAP fertilizer. He attributed the increased grain yield of soybean under DAP fertilizer application to the nitrogen available in the fertilizer at a rate of 18 kg/ha which may have been vital in vegetative growth and grain filling at a later stage of crop growth. Phosphorus has been found to improve the grain yield of cowpea. Similar research done by Nyoki *et al.,* (2013) and Ayodele *et al.,* (2014) also found out that phosphorus supplementation increased the grain yield of cowpea and other yield parameters such as the number of branches per plant, number of nodules, number of pods, number of seeds per pod, mean pod weight and 100 seed weight. Onduru *et al.,* (2008) also found out that application of TSP fertilizer improved the grain yields of cowpea to 1.7 tonnes per hectare.

5.6 Productivity of lablab in Makueni County

The mean number of days to flowering and physiological maturity of the two lablab varieties differed significantly at the three locations in Makueni County mainly due to the different agro ecological conditions of the three locations (Jaetzold *et al.*, 2010). However, the two lablab varieties had different flowering and maturity periods.

Lablab accession CP1 81364 had shorter maturity period making it more suitable for the drought conditions of Makueni County as compared to KAT/ DL-1.

There were significant differences ($P \leq 0.05$) observed in the mean biomass yield of the two lablab varieties between the locations at flowering and at harvest (Table 7). The biomass yields of both KAT/DL-1 and CP1 81364 were significantly higher in Mwanzo and Utafiti locations than Machinery. The significantly higher biomass of the two lablab varieties at Utafiti and Mwanzo could be attributed to rainfall and soil moisture deficit that was highest in Machinery (Apendix iii). Soil moisture deficit lowers mobility of nutrients especially phosphorous and nitrogen leading to decreased biomass yields (Farooq *et al.*, 2009; Sun *et al.*, 2014).

Overall, lablab variety KAT/DL-1 had a better biomass yield than accession CP1 81364. This is due to CP1 81364 being an early maturing variety leading to lower biomass accumulation. Early maturing lablab varieties have been found to have less biomass yields and fix less nitrogen (Maass, 2003).

There were significant differences ($P \leq 0.05$) observed in the mean grain yield of the two lablab varieties at the three locations. The grain yields of the two lablab varieties were significantly lower at Machinery than the other two locations.

This can be attributed to drought stress that was highest in Machinery (Appendix iii). Studies have shown that although lablab is drought tolerant, moisture stress during flowering and grain filling stages can greatly decrease the grain yields (Guretzki & Papenbrock, 2014).

Overall, lablab variety KAT/DL-1 had a better grain yield than accession CP1 81364 in Makueni County. The grain yields of KAT/DL-1 were below the potential yields documented by KALRO and KEPHIS of 3000 to 4000 kg/ha (Karanja *et al.,* 2006; KEPHIS, 2014). This is attributed to soils being deficient of major nutrients such as nitrogen, phosphorus and organic carbon which greatly reduced the yields (Kimiti, 2014).

5.7 Response of lablab to DAP fertilizer application at the three locations

DAP fertilizer application significantly increased the biomass yield of the two lablab varieties both at flowering and at harvest (Tables 8, 9 and 10). The increase in biomass yield was attributed to addition of nitrogen and phosphorus nutrients to the soil which are deficient in the three locations. These results are consistent with those of Abuli *et al.,* (2012) whose research concluded that DAP fertilizer improved the biomass yield of soybean due to the supply of N which is important in biomass accumulation. Nitrogen and phosphorus application have been found to increase biomass yields of legumes (Odundo *et al.*, 2010; Gweyi-Onyango *et al.*, 2011).

DAP fertilizer application significantly increased the grain yields of KAT/DL-1 and CP81364 in all the three locations. The consistently higher grain yields recorded in treatments where DAP fertilizer was applied was attributed to higher amounts N and P of nutrients which are deficient at the three locations. These results are in line with research carried out by Mugwe *et al.,* (2009) who found out that on farm trials showed that application of 60 kg N/ha increased yields by more than 100 % above the control.

Phosphorus found in the fertilizer has been found to enhance nodulation in legumes which results in high nitrogen fixation and hence high grain and biomass yield (Singh *et al.*, 2011; Nyoki, *et al*., 2013).

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

6.1.1 KAT Bean-9 was productive in all the three agro-ecological zones; Cowpea M66 was most productive in LM4 agro-ecological zone while lablab variety KAT/DL-1 and accession CP1 81364 were more productive in LM4 and LM5 agro-ecological zones.

6.1.2 The three legumes responded well to DAP fertilizer application in all the three locations.

6.2 Recommendations

6.2.1 KAT Bean-9 should be cultivated in the three agro-ecological zones of Makueni County.

6.2.2 Cowpea variety M66 should be cultivated in LM4 agro-ecological zone of Makueni County.

6.2.3 Lablab variety KAT/DL-1 and accession CP1 81364 should be cultivated in LM4 and LM5 agro-ecological zones of Makueni County.

6.2.4 Farmers to apply DAP fertilizer at rates of 50 kg/ha in beans, cowpea and lablab production so as to improve legume yields.

Further research

1. Further breeding work to be done towards reducing the maturity period of lablab variety KAT/DL-1.
2. Further research to be done on farm management practises that can be applied to increase the actual yields of KAT Bean-9 and Lablab variety KAT/DL-1 at the three agro-ecological zones of Makueni County.

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APPENDICES

Appendix i: Tables showing coordinates and elevations of experimental sites at the three locations in Makueni County

LOCATION ONE: UTAFITI

FARMER	LATITUDE	LONGITUDE	ELEVATION
MARY	2° 17′ 34.92″ S	38° 01′ 44.91″ E	789 m
MONICAH	2° 17′ 30.72″ S	38° 00′ 42.45″ E	826 m
ANGELINE	2° 17′ 44.49″ S	38° 00′ 31.36″ E	836 m
NICHOLAS	2° 17′ 02.58″ S	38° 00′ 36.40″ E	816 m
DAVID	2° 17′ 12.60″ S	37° 59′ 53.59″ E	835 m

LOCATION TWO: MACHINERY

FARMER	LATITUDE	LONGITUDE	ELEVATION
MASILA	2° 29′ 24.39″ S	38° 03′ 21.54″ E	841 m
NGINA	2° 29′ 46.32″ S	38° 03′ 46.51″ E	855 m
ROBERT	2° 30′ 00.01″ S	38° 03′ 23.97″ E	871 m
JUSTINE	2° 29′ 58.11″ S	38° 03′ 28.53″ E	869 m
NGUMA	2° 30′ 13.57″ S	38° 03′ 24.53″ E	872 m

LOCATION THREE: MWANZO

FARMER	LATITUDE	LONGITUDE	ELEVATION
DORCAS	2° 36′ 55.12″ S	38° 07′ 20.68″ E	801 m
KIMEU	2° 36′ 57.31″ S	38° 07′ 33.76″ E	787 m
CHRISTINE	2° 36′ 57.91″ S	38° 07′ 39.37″ E	783 m
AGNES	2° 37′ 03.14″ S	38° 07′ 29.62″ E	790 m
JOSEPH	2° 37′ 11.40″ S	38° 07′ 31.47″ E	786 m

Appendix ii: Table showing physical and chemical characterisation of soils at the three locations in Makueni County

4.1.1 Utafiti site

Farm site	pH	P (mg/kg)	% N	% C	K	Ca	Mg	Fe	Zn	% Sand	% clay	% silt
1	7.29	15	0.15	1.42	0.80	2.5	1.58	16.1	2.3	60	6	34
2	6.78	10	0.07	0.71	0.62	2.0	1.58	17.9	1.9	58	4	38
3	5.65	15	0.08	0.76	0.32	1.4	0.75	16.3	2.1	76	6	18
4	6.38	15	0.08	0.76	0.30	1.4	2.33	13.7	1.6	80	2	18
5	6.57	15	0.10	0.95	0.58	2.2	1.66	13.3	2.3	64	6	30
Means	**6.53**	**14**	**0.10**	**0.92**	**0.52**	**1.9**	**1.58**	**15.4**	**2.0**	**68**	**5**	**28**

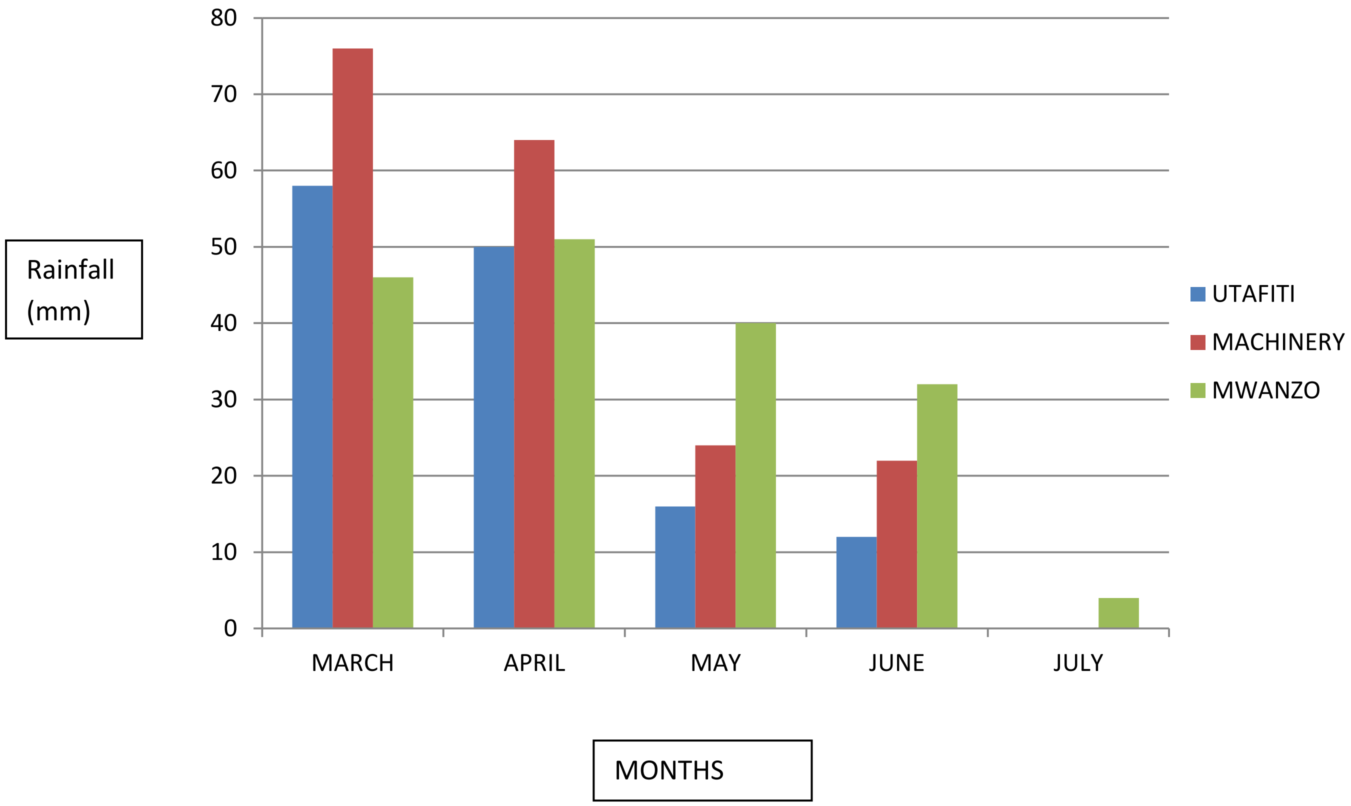
4.1.2 Machinery site

Farm site	pH	P (mg/kg)	% N	% C	K	Ca	Mg	Fe	Zn	% Sand	% clay	% Silt
6	6.77	5	0.06	0.52	0.20	1.6	1.44	16.2	1.6	52	10	38
7	6.21	5	0.07	0.67	0.24	1.2	1.37	15.4	1.6	78	4	18
8	5.73	10	0.08	0.80	0.34	1.0	1.59	12.0	2.1	76	8	16
9	7.04	4	0.07	0.68	0.44	2.2	2.15	21.6	1.9	70	8	22
10	6.53	10	0.08	0.78	0.46	2.0	2.17	18.7	2.9	78	4	18
Means	**6.45**	**7**	**0.07**	**0.69**	**0.33**	**1.6**	**1.74**	**16.8**	**2.0**	**71**	**7**	**22**

4.1.3 Mwanzo site

Farm site	pH	P (mg/kg)	% N	% C	K	Ca	Mg	Fe	Zn	% Sand	% clay	% Silt
11	6.05	25	0.08	0.76	0.30	1.4	1.44	12.1	1.7	52	10	38
12	6.45	25	0.05	0.45	0.60	2.4	1.61	19.6	1.7	74	4	22
13	6.34	5	0.06	0.52	0.60	2.4	2.29	21.5	7.5	70	8	22
14	7.15	2	0.04	0.41	0.82	2.0	1.38	18.3	1.8	57	8	35
15	6.92	10	0.05	0.47	0.64	2.0	1.44	20.2	2.6	78	6	16
Means	**6.58**	**13**	**0.06**	**0.52**	**0.59**	**2.0**	**1.63**	**18.3**	**3.4**	**66**	**7**	**27**

Appendix iii: Rainfall field data from the three locations in Makueni County.



Total monthly rainfall at the three locations during the experimental period.

Appendix iv: ANOVA table of biomass yield of beans at flowering

R-Square	Coeff Var	Root MSE	YIELD Mean
0.952448	13.74692	175.9468	1279.900

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCS	2	805476.200	402738.100	13.01	0.0010
BLOCKS(LOCS)	12	2237719.000	186476.583	6.02	0.0020
FERT	1	4001861.633	4001861.633	129.27	<.0001
LOCS*FERT	2	395658.467	197829.233	6.39	0.0129

Appendix v: ANOVA table of biomass yield of beans at harvest

R-Square	Coeff Var	Root MSE	YIELD Mean
0.854045	30.23109	213.5121	706.2667

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCS	2	75818.067	37909.033	0.83	0.4590
BLOCKS(LOCS)	12	2182312.800	181859.400	3.99	0.0118
FERT	1	936333.333	936333.333	20.54	0.0007
LOCS*FERT	2	6552.467	3276.233	0.07	0.9311

Appendix vi: ANOVA table of beans grain yield.

R-Square	Coeff Var	Root MSE	YIELD Mean
0.916776	19.65380	99.3849	516.2000

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCS	2	8655.200	4327.600	0.13	0.8812
BLOCKS(LOCS)	12	1270763.600	105896.967	3.13	0.0297
FERT	1	1895053.333	1895053.333	55.95	<.0001
LOCS*FERT	2	9032.267	4516.133	0.13	0.8765

Appendix vii: ANOVA table of biomass yields of cowpea at flowering

R-Square	Coeff Var	Root MSE	YIELD Mean
0.969539	11.97288	196.6506	1642.467

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCS	2	3910422.867	1955211.433	50.56	<.0001
BLOCKS(LOCS)	12	4556698.600	379724.883	9.82	0.0002
FERT	1	5275213.333	5275213.333	136.41	<.0001
LOCS*FERT	2	1028053.267	514026.633	13.29	0.0009

Appendix viii: ANOVA table of biomass yields of cowpea at harvest

R-Square	Coeff Var	Root MSE	YIELD Mean
0.970366	12.70156	301.2345	2371.633

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCS	2	11289812.47	5644906.23	62.21	<.0001
BLOCKS(LOCS)	12	7119532.00	593294.33	6.54	0.0014
FERT	1	15361069.63	15361069.63	169.28	<.0001
LOCS*FERT	2	1886122.47	943061.23	10.39	0.0024

Appendix ix: ANOVA table of cowpea grain yield

R-Square	Coeff Var	Root MSE	YIELD Mean
0.958008	16.46944	218.5208	1569.700

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCS	2	1483527.200	741763.600	11.10	0.0019
BLOCKS(LOCS)	12	8003692.600	666974.383	9.98	0.0002
FERT	1	7943365.633	7943365.633	118.85	<.0001
LOCS*FERT	2	866305.067	433152.533	6.48	0.0123

Appendix x: ANOVA table of biomass yields of lablab at flowering

R-Square	Coeff Var	Root MSE	YIELD Mean
0.952723	13.77266	323.5336	2349.100

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCS	2	9544053.10	4772026.55	45.59	<.0001
BLOCKS(LOCS)	12	12808539.30	1067378.27	10.20	<.0001
LEGUME	1	10647936.27	10647936.27	101.72	<.0001
LOCS*LEGUME	2	47936.23	23968.12	0.23	0.7965
FERT	1	37705568.27	37705568.27	360.22	<.0001
FERT*LEGUME	1	2801952.60	2801952.60	26.77	<.0001
LOCS*FERT*LEGUME	4	2382591.33	595647.83	5.69	0.0012

Appendix xi: ANOVA table of biomass yields of lablab at harvest

R-Square	Coeff Var	Root MSE	YIELD Mean
0.970441	10.36672	323.4365	3119.950

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCS	2	20681705.10	10340852.55	98.85	<.0001
BLOCKS(LOCS)	12	21873695.00	1822807.92	17.42	<.0001
LEGUME	1	10855357.35	10855357.35	103.77	<.0001
LOCS*LEGUME	2	228777.10	114388.55	1.09	0.3459
FERT	1	62908416.15	62908416.15	601.35	<.0001
FERT*LEGUME	1	1568490.02	1568490.02	14.99	0.0004
LOCS*FERT*LEGUME	4	5521726.33	1380431.58	13.20	<.0001

Appendix xii: ANOVA table of lablab grain yield

R-Square	Coeff Var	Root MSE	YIELD Mean
0.914188	20.14100	172.2223	855.0833

Source	DF	Type I SS	Mean Square	F Value	Pr > F
LOCS	2	892320.533	446160.267	15.04	<.0001
BLOCKS(LOCS)	12	2858631.300	238219.275	8.03	<.0001
LEGUME	1	2296735.350	2296735.350	77.43	<.0001
LOCS*LEGUME	2	4267.200	2133.600	0.07	0.9307
FERT	1	4766365.350	4766365.350	160.70	<.0001
FERT*LEGUME	1	513930.150	513930.150	17.33	0.0002
LOCS*FERT*LEGUME	4	43241.600	10810.400	0.36	0.8323