Effects of intercropping amaranth with common beans, green grams and cowpeas on the growth and grain yield of Amaranth in Kitui central Sub County

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Declaration and Recommendation

Declaration

This thesis is my original work and has not been submitted for any academic award in any other University

Signature: ………………………………. Date: ……………………

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Recommendation

This thesis has been submitted with our approval as University Supervisors

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Dedication

To my wife Peninah Igoki, my son George Mutuma and my daughter Grace Makena for their prayers and support during my study.

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Abstract

Amaranth is an important crop owing to its highly nutritious grains and leaves. The leaves have high vitamins and calcium levels while grains are rich in proteins. Amaranth flour is used to fortify other flours due to its highly digestible proteins. Some industrial and medicinal properties have also been associated with amaranth leaves and grains. Green grams, common beans, and cowpeas are important sources of proteins from plant. This makes them cheap and valuable substitutes for meat and other animal proteins.In this study, amaranth (*Amaranthus hypochondriacus*), KAM 01 was intercropped with green gram (*Vigna radiata*) N-26, common bean (*Phaseolus vulgaris* L.) KB9, and cowpeas (*Vigna unguiculata)* M66 to compare and establish their effect on the growth and grain yields of amaranth. Pure stands of amaranth and the three legumes were also established for purposes of comparison. The study was carried out during the March-May rainy season of the year 2017. Randomized complete block design (RCBD); replicated four times was used to test treatment combinations. Treatment means were differentiated at 95% confidence ($P<0.05$) upon carrying out of the analysis of variance. Post-hoc tests were carried out using Fishers' Least Significant Difference (LSD). Land Equivalent Ratio (LER) was used to assess the amaranth-legumes intercropping advantages relative to sole cropping. This study found that intercropping amaranth with green grams common beans, and cowpeas had a significant effect ($P<0.05$) on grain yields and the above ground biomass. Amaranth grain yields were least (1,088 kg/ha) when it was intercropped with common beans and highest (1,741 kg/ha) when it was intercropped with green grams. The highest above-ground biomass for amaranth was recorded in amaranth-green grams intercrop (4,159 kg/ha) while common beans intercrop gave the least (2,241 kg/ha) biomass. The highest harvest index in amaranth (0.37) was recorded in amaranth-common bean intercrop followed by green gram intercrop (0.34), while Cowpeas intercrop had the least harvest index of 0.29. Land equivalent ratio (LER) was greater than one unit in all the treatments, indicative of intercropping advantage relative to sole cropping. Amaranth-cowpea intercrop had the highest LER (1.95) followed by green gram intercrop (1.90) while common bean intercrop had the least LER at (1.67), respectively. It was concluded that intercropping amaranth with legumes was better than sole cropping and that green gram was the most suitable legume to intercrop with amaranth in Kitui central sub county. It was therefore the one recommended for use by farmers.

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List of Abbreviationd and Acronyms

AIDs	Acquired Immuno- Deficiency Syndrome
ANOVA	Analysis of Variance
a.s.l	above sea level
ATC	Agricultural Training Centre
EU	European Union
HI	Harvest Index
HIV	Human Immune Virus
KALRO	Kenya Agriculture and Livestock Research Organization
LER	Land Equivalent Ratio
pH	Acidity or alkalinity of a water soluble substance
SPSS	Statistical Package for Social Sciences

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Amaranth (*Amaranthus spp*.) is an herbaceous annual plant in the Amaranthaceae family. It has green or red leaves and branched flower stalks and bears small seeds, variable in colour from pink to shiny black to cream gold and pink. It is a C4 plant with an upright growth habit. Amaranth grows optimally under warm conditions (above 25^0C day temperatures and not less than 15^0C night temperatures), bright light and availability adequate plant nutrients. It reaches a height of 1.5 metres (Rensburg, Averbeke, Slabbert, Fabers, Jaarsveld & Oelofse, 2007).The common name for amaranth is pigweed and other local names include mchicha, lidodo, ododo and w'oa; among other names.

Amaranth is used as a grain with high-protein grain or as a leafy vegetable. The seeds are eaten as cereal grains. The grains can be ground into flour and cooked into porridge. They can also be popped like popcorn. The leaves which are rich in calcium and vitamins A, B and C can be cooked alone or mixed with other vegetables (Ouma, 2004). Amaranth is mentioned to have been recommended for use by diabetics and people suffering with HIV/AIDs (Kunyanga, Imungi, Okoth, Biesalski & Vadivel, 2012). According to Ouma (2004), roughly 60 amaranth species exist, but only a few types are cultivated. Most species on the other hand are considered weedy species and thus rarely preserved. Some of the amaranth species grown for grain production are *Amaranthus* *hypochondriacus, Amaranthus cruentus and Amaranthus caudatus*; while those grown for leaf vegetables are *Amaranthus dubius, Amaranthus blitum Amaranthus tricolor, Amaranthus viridis* and *Amaranthus hybridus*. According to Kaur, Sing and Rana (2010) *A. Hypochondriacus L*. is increasingly being grown in Kenya after introduction from the Americas. Some of its commercial varieties include KAM 105, KAM 106, KAM 114, KAM115, KAM 201, KAM 01 and KAM 02. A study conducted at KALRO katumani and Kiboko KALRO station showed that KAM 01 variety was the best grain yielder under low midland zone five and four (LM5 and LM4) (Mutisya, Ghelle & Njiru, 2015) These varieties though grown mainly for grains also give leaves which are harvested for vegetables.

Yields of grain amaranth are highly variable. Good yields are considered to be 1000 kg/ha or better (Myers, 1996). These have been achieved in a number of states in United States in research plots. Yields of 3000 kg/ha have also been achieved in a few locations in small research test plots. Amaranth requires appreciable amount of nutrients for good performance. According to Skwaryło-Bednarz and Krzepilko (2013), the plant is a heavy feeder of nitrogen. Maximum amaranth yields and grain quality are achieved at 45 kg N ha $^{-I}$ (Olaniyi, Adelasoye & Jegede, 2008). While studying the effect of nitrogen fertilizer rate on amaranth yield and development Myers (1996) reported that 45 to 90 kg N ha^{-1} were needed to achieve maximum yield across cultivars. Optimum phosphorous requirement in grain amaranth is 30 kg P ha^{-1}. A study conducted by Ojo, Akinrinde and Akoroda (2000) at Ibadan, Nigeria to evaluate the effect of Phosphorous (P) in *A.*

Cruentus L. showed that 30 kg P ha^{-1} was necessary for the maximum grain yield and its components.

Intercropping cereals and legumes has been shown to improve both soil fertility and crop yields, particularly for cereal crop (Matusso, Mugwe, & Mucheru-Muna, 2012). Legumes used for provision of grain and green manure have potential to fix between 100 and 300 kg N ha^{-1} from the atmosphere. Some legumes fix nitrogen better than others. For example, common beans are poor fixers and fix less than their nitrogen needs. Other grain legumes, such as cowpeas, peanuts, soybeans, and fava beans, are good nitrogen fixers and will fix all of their nitrogen needs other than that absorbed from the soil. Walley, Tomm, Matus, Slinkard and Kessel (1996) reported that up to 250 lb of nitrogen is fixed per acre by these legumes. Forage legumes, such as sweet clover, alfalfa and vetches can fix between 250 - 500 lb of nitrogen per acre. Similar findings were reported by Flynn and Idowu (2015). Most of the fixed nitrogen goes directly into the plant. Some nitrogen (30 - 50 lb N/acre) however, is "transferred" or "leaked" into the soil for non-leguminous plants grown in association (Flynn & Idowu, 2015). Eventually most of the nitrogen goes back to the soil for neighboring non-legume plants when vegetation of the legume dies and decomposes.

Intercropping amaranth with other crops has been done with varying results in grain yields, leaf yield and pest control. A study on intercropping of soya beans and amaranth carried out in Teso district of western Kenya showed that single and double rows intercrops significantly increased ($P < 0.05$) amaranth grain yield by 32–33% compared to mono-cropping (Ng'ang'a , Ohiokpehai, Muasya & Omami, 2011). High average land use ratios of LER were also achieved in both sites where studies were conducted. A LER of 1.5 and 1.6 in single-row intercrops and LER = 1.8 and 1.9 in double-row intercrops were recorded in sites A and B, respectively, in both seasons. This showed that soya bean was beneficial when intercropped with amaranth.

Myers (1996) also showed that intercropping amaranth with cowpeas had higher land equivalent ratios that than cowpea-pearl millet intercrop. Amaranth has also been found to have no allellopathic effects in an intercropping system. This was shown in a study to evaluate canola and amaranth as alternative crops in rotational combinations with soybeans, maize, and wheat (Myers, 1996). Amaranth has also been successfully intercropped with cowpeas with no adverse effects on cowpea yields (Adgibo, 2009).

Although various studies have been done to establish the potential of amaranth intercropping with other crops, very little has been done to compare the effects of intercropping green grams, common beans and cowpeas on the growth and grain yield of amaranth . This study therefore seeks to compare and establish the effects of intercropping these three legumes on the growth and grain yields of amaranth (KAM 01) in Kitui central sub county in Kitui County, Kenya.

1.2 Statement of the Problem

Reduced soil fertility especially inadequate nitrogen is one of the key contributors to low crop production hence food insecurity in most sub-Saharan countries in Africa. This is mainly due to increased settlements which leads to soil degradation and nitrogen deficiency. This impacts negatively on the national food security. Intercropping legumes in cereals presents one of the options for addressing the land scarcity problem and soil nitrogen deficiency. Grain amaranth crop being an annual crop that withstands dry spells relatively well, can serve to contribute to the country's food security especially in an intercrop with legumes.

1.3 General Objectives

The purpose of this study was to establish the effects of intercropping common beans, green grams and cowpeas on the growth and grain yields of amaranth in Kitui Central Sub County

1.4 Specific Objectives

The specific objectives of the study were:

i) To determine the effects of intercropping common beans, green grams and cowpeas on the grain yields of amaranth in Kitui Central Sub County

ii) To establish the most appropriate legume for intercropping with amaranth in Kitui central sub county

iii) To determine the effects of intercropping on the allometric measurements of amaranth

1.5 Research Hypotheses

i) Intercropping common bean, green gram and cowpeas with amaranth has a significant effect on the grain yields of amaranth

ii) One of the legumes (common beans, green grams or cowpeas) is significantly better in an intercrop with grain amaranth

iii) Intercropping has an effect on allometric measurements of amaranth

1.6 Justification of the Study

This study is important to Kitui farmers by ensuring increased production of amaranth grains, green grams, beans, and cowpeas thus leading to increased incomes and improved livelihoods. Health and nutritional standards for Kitui central community is also expected to improve as a result of consuming more products made from grain amaranth, beans, green grams and cowpeas. Intercropping these crops is one of the options for addressing ever-increasing land scarcity problem. This is through intensifying production thus maximizing land use. It also addresses the challenge of low nitrogen levels in soils through nitrogen fixation by legumes.

1.7 Significance of the Study

Information got from the study may assist Kitui County government policy makers in planning for food security interventions using grain amaranth, green grams, common beans, and cowpeas in intercropping systems. The study also forms critical input in development of training manuals by extension officers and other stakeholders in food security initiatives.

1.8 Operational Definition of Terms

Amaranth - The word *Amaranth* means "everlasting" in Greek. The seed of amaranth has been used for long, as a source of food for old civilizations in Mexico and Southern America. It has lately emerged as a highly nutritious grain which is free of gluten. Amaranth meant the traditional vegetable grown for its grain and leafy vegetable. Other names for amaranth include mchicha, terere, lidodo, ododo, kelichot, w'oa, emboga, kichanya and doodo.

Grain amaranth – in this study grain amaranth means the amaranth grown for production of seeds.

Legumes - a legume is a plant or fruit/seed in the family Fabaceae. Legumes are grown agriculturally, primarily for their grain seed called pulse, for livestock forage and silage. They are known to enrich the soils through Biological Nitrogen Fixation (BNF).

Intercropping – This is growing of two crops or more, at the same time on the same piece of land. Its main reason is to maximize production in terms of yield from a given piece of land by utilizing resources which would not have been achieved by growing a single crop.

Yield- is an amount produced of an agricultural or industrial product. In this study, yield is used in reference to the amount of amaranth grains, beans, green grams and cowpeas grains produced.

Harvest index- in agriculture, HI is used to quantify the yield crop species' yield against its total biomass. The commercial yield can be grain, tuber or fruit. For grain crops, harvest index (HI) is the ratio of harvested grain to total shoot dry matter, and this can be used as a measure of reproductive efficiency

Land equivalent ratio (LER) - This is a ratio used to evaluate efficiency of an intercropping system compared sole cropping. In this study land equivalent ratio is used to compare advantages of intercropping legumes with grain amaranth.

CHAPTER TWO: LITERATURE REVIEW

This chapter reviews important literature on history and economic value of amaranth, growth requirements, production and adoption of grain amaranth in Kitui County, some of the factors that affect leaf and grain yields of amaranth; and challenges encountered in production of the same. Literature review on importance of common beans, green grams and cowpeas is also covered.

2.1 History, Uses, and Growth Requirements of Grain Amaranth

2.1.1 History of amaranth

Amaranth is a pseudo cereal, herbaceous plant belonging to Amaranthaceae family. It has red or green or red s with branched flower stalks and bears small seeds which varies in colour from pink to cream, gold to shiny black. The leaves and stem can be green, red or purple. It is a C_4 plant with an upright growth habit and grows optimally under warm conditions (day temperatures above 25°C and night temperatures not lower than 15°C), bright light and adequate availability of plant nutrients. It can grow up to a height of 1.5 metres. It is monoecious and bears both female and male flowers. Female flowers produce upto 100, 000 seeds per plant, which are roundish and poppy-sized seeds. Amaranth exhibits photoperiodism and starts to flower when the day length is shorter than 12hours (Assad, Reshi, Jan & Rashid, 2017).

According to Ouma (2004), approximately 60 amaranth species have been recorded but most are weedy types and only a few are cultivated. The most species are tolerant to harsh climatic conditions and they tolerate drought, but prolonged dry spells induce flowering and decrease leaf yield (Rensburg et al., 2007).

Sauer (1993) showed that amaranth started being used as a grain about 6000 years ago in Central America. *Amaranthus Cruentus* seeds were the oldest found followed by *A. hypochondriacus*, which was the species used by the Aztecs about 1500 years ago. The other species A. caudatus though not well understood is believed to be have been first grown in Andean Mountains of south America (Myers, 1996). The Aztecs also use amaranth grains for religious reasons besides the use as food. Thus making the grain quite important. From Latin America, amaranth is believed to have spread to Europe 1700s where it was use as herbs as well us for ornamentals purposes. It later spread in East Africa by the 1800s. In Kenya, grain amaranth was gazetted by the Ministry of Agriculture via legal notice No. 287 of 19/7/91 (Waithera, 2012).

2.1.2 Uses of amaranth

Amaranth is used both as leaves and grain. The grain type can also be used as a vegetable if the leaves are eaten when the plants are young. Flour from the grains can also be used to prepare a wide range of recipes, either alone or blended with other flours. Some modern day uses of the grain are; sweet rolls, bread, crackers, dumplings and muffins and baby foods (Uriyapongson & Rayas-duarte, 1994; Gelinas, 2007). Amaranth has also been reported to be used as snuff and as substitute to table salt. (Hart &Vorster, 2006).

Digestibility of grain is improved by heat processing. The processing also removes lectins thus improving protein ratio of grain and flour. (Lara & Ruales, 2002). Human development and general health is improved by consumption of amaranth grain. (Ouma, 2004; Spetters & Thompson, 2007). Other medicinal benefits have been reported by Martirosyan, Mirashinichenko, Kulakova, Pogojeva and Zoloedov (2007) who indicated that amaranth leaves and grains can reduce some nutritional related diseases.

2.1.3 Nutritional value of amaranth

Grain amaranth is reported to have high levels of micronutrients that are essential. These include calcium, vitamin C, carotene, and iron (Pospisil, Varga & Svecnjack, 2006). It is also rich in essential amino acid and lysine that is lacking in diets based on tubers and cereals. It has more protein than other grains such as maize, sorghum, wheat, and rice. The level of minerals like phosphorous, magnesium and iron found in amaranth are higher than in meat and milk. It also has high levels of vitamin B, A, and E. The content of fat in amaranth seed is reported to be up to 8% high; which is double that of other cereals. Its highly protein digestibility and absorption makes it a preferred food for young children (Abel & Twine, 2007). Staple foods with low levels of certain elements are fortified with amaranth grain.

Amaranth has also a special oil (squalene) which is use in pharmaceutical industries as an ingredient of cosmetics and also as lubricants for computers. The chemical content of the oil is comparable to cod liver oil mainly used to boost the immune system in children. (Poverty Eradication commission, 2007). The lipid content of grain amaranth which is found mainly in the germ is higher than that of cereals and is up to 10.0% on dry matter basis. (Becker, Wheeler, Stafford, Grosjean, Betschart & Saunders, 1981; Wekesa, 2010). Grain amaranth has no allergens hence useful as a source of non-allergenic food products (Sa-nguansak, Somsak, Pawelzik &Vearasilp, 2007).

Protein

Gelinas (2007) reported that the protein content in grain amaranth is between 12.4 and 16.8%. It is the high content of protein compared to other cereals that greatly favor cultivation of amaranth. Gelinas (2007) also reported that lysine level of grain amaranth's protein is twice that of wheat protein, three times that of corn and comparable to milk protein.

Carbohydrates

Grain amaranth has starch as the highest content of its total weight. The starch component stands at 62% of the total seed weight (Becker et al., 1981). The physical characteristics of the starch grains have been cited as being of potential value for both industrial and food product uses. Small diameter starches can be used in a wide array of food and non-food applications, such as fat replacement ingredient and the making of biodegradable films (Lindeboom , Chang & Tyler, 2004).

Lipids

Oil contents of grain amaranth vary between varieties. The oil content of *A. cruentus* was found to range between 1.9% and 5.0%, and that of *A. hypochondriacus* between 2.18% and 5.23% . The oil is said to have cholestoral-lowering effect which is associated with squalene found in amaranth (He, Cai, Sun & Corke, 2003). Squalene has traditionally been extracted from shark liver oil, but concerns about the sustainability of the practice have increased interest in finding renewable sources (He et al., 2003). The US demand for squalene is around 200-300 tons per year and it could be extracted from amaranth grain as a co-product of starch, making the enterprise economically feasible (Leon-Camacho, Diego, & Aparicio, 2001)

Anti-nutritional factors

Despite grain amaranth having various nutritional benefits, there are some ant-nutritional factors content that are also reported. Among them are tannin, saponin, and phytic acid reported at different levels in different species (Singhal & Kulkarni, 1988; 1990). Others are trypsin inhibitors which were isolated from amaranth seeds and are considered highly heat stable (Gelinas, 2007). Oxalate levels in *Amaranthus caudatus* was also higher than whole wheat flour or corn meal, which ranges between 67 and 54 mg 100 g-\ respectively (Chai & Liebman, 2005).

Table 2.1.

Proximate composition (%) of grain amarantt compared to common cereals

Analysis	***A. hyphocondriacus***	**Maize**	**Rice**	**Wheat**
Crude protein	17.9	10.3	8.5	14
Fat	7.7	4.5	2.1	2.1
Fibre	2.2	2.3	0.9	2.6
Ash	4.1	1.4	1.4	1.9
Carbohydrate	57	67.7	75.4	66.9

Adapted from: Segura-Nieto, Barba de la rosa & Paredes-lopez (1994)

2.1.4 Growth requirements in amaranth

The Altitude suitable for amaranth growth is between 0 and 2400m a.s.l. It prefers temperatures ranging between 22-30°C. Normally the hotter it is the better. Amaranth is adaptable to adverse conditions, tolerates drought and can thrive in soils with low fertility. The drought tolerance in amaranth is mainly due to its C4 photosynthetic pathway which is efficient in utilization of sunlight and nutrients under dry, high temperature conditions. It also has a deep and extensive root system and ability to go dormant under extreme drought conditions (O'Brien & Price, 1983; Wekesa, 2010). Myers (1996) also observes that part of its drought tolerance may be due to its ability to shut down transpiration through wilting and recovering easily when moisture is available.

Studies conducted to determine the water use pattern found the effective rooting depth (maximum depth at which water is extracted) of amaranth had similarity to that of canola (Johnson & Henderson, 2002).The water use efficiency of amaranth in their study ranged from 2.8 to 11.8 kg ha^{-1} mm^{-1} with an average of 5.9 kg ha^{-1} mm^{-1}. This is relatively low, when compared to C3 crops, like wheat grown which can reach a grain water use efficiency of 20 kg ha^{-1} mm^{-1} (Liu & Stutzel, 2002; Gelinas, 2007). However, Passioura (2004) indicated that photosynthetic efficiency is only one factor affecting grain water use efficiency of a crop and harvest index is equally important.

Germination of seeds requires a temperature of at least 15-17°C. Amaranth is rain fed grown but it can also be grown under irrigation. During dry spell however, frequent application of water may be required, depending on the stage of crop growth and the moisture-retaining capacity of the soil (Infonet Biovision, 2011). It is however known to withstand periods of drought after the plant established. Amaranth can grow in different soil types but it is most suited to loam and silt-loam and medium humidity with good water holding-capacity. The pH suitable for amaranth is between 4.5 and 8. Pruning, particularly removing the growing tip results in plant branching, lateral growth and suppresses early flowering. Short days and water stress may promote flowering (O'Brien &Price, 1983). Propagation in amaranth is by either by direct seeding or through transplanting. About 2 kg ha^{-1} of seeds is required (Myers, 1996). The costs of planting and cultivation are equivalent to that of other grain crops since the same equipment can be used, with some modifications to a planter to handle the small seed size. Germination of seeds usually take 3 to 4 days in warm soil (20°c) (Infonet Biovision, 2011).

2.1.5 Physiological maturity and harvesting of grain amaranth

Grain amaranth matures faster at lower altitudes. Some of the maturity indices in amaranth includes colour of seeds becoming opaque, easy detachment of seeds from the heads and no water oozing out when the seed is crushed (Myers, 1996). The appearance of the seeds change from a glossy or translucent to dull when mature. Some seeds mature earlier than others. Those that form early tend to shatter well before all the seeds on a head are mature, but the compactness of the head is enough to hold most of them, unless strong rain or wind occur. Mechanical harvesting is hampered by shattering and the unusual lodging of the plant. A gram of grain amaranth has about 1100 seeds. Proper drying of seeds is essential to minimize molding and for ease of transport. Approximately 11% moisture content is allowed and this can be achieved through use of ambient or heated air. Rodent proof storage is recommended for grain storage. The storage should also be well ventilation to avoid a build-up of condensation. It is also indicated that grains can be stored for seven years (Kauffman & Weber, 1990; Wekesa, 2010).

Yields of amaranth

3000kgs/Ha of yields have been realized in trial plots but on average amaranth yield is 1000kg/ha (Myers, 1996). Although these yields are small compared to cereals like sorghum and maize, it is nevertheless good for a crop with such high protein contents and minimal production costs. The costs are low due to low fertilizer pesticides requirements (Myers, 1996).

Varieties

Some of the amaranth species grown for grain production are *A. hypochondriacus, A. caudatus* and *A. cruentus*; while those grown for leaf vegetables are *A. blitum, A. dubius, A. tricolor, A. viridis, A. cruentus* and *A.hybridus*. Some major grain amaranth varieties grown in Kenya on commercial basis are KAM 105, KAM 106, KAM 114, KAM 115, KAM 201, KAM 01 and KAM 02. A study conducted at KALRO Katumani and Kiboko KALRO station showed that KAM01 variety was the best grain yielder under low midland zone five and four (LM5 and LM4) (Mutisya et al., 2015). These varieties though grown mainly for grains also give leaves which are harvested for vegetables.

2.1.6 Genetic improvement in amaranth

Grain amaranth is predominantly a self-pollinating crop. However, varying degrees of out crossing have been noted. Weedy grain amaranth has been shown to cross-pollinate with cultivated grain amaranth varieties. Seed harvested from plants contaminated with pollen from weedy amaranth produce crop-weed hybrids which reduce the yield of grain amaranth and complicate the cleaning process (Weber, 1987). Crop improvement programmes have included breeding for shortened generation time, dwarfism, flowering and resistance to seed shattering (Brenner, 2002). Vegetative vigour has been observed in hybrids arising from natural out crossing. Synthetic populations for forage, vegetable, or grain traits have been formed through breeding.

2.2 Adoption and Production of Grain Amaranth in Kitui County

In Kitui County, adoption and use of grain amaranth is still low partly due to inadequate knowhow on the grain utilization, lack of certified seeds and non-structured market among others. This is not only in Kitui but in various other parts of Kenya. For example, Kyambo (2014) cited similar challenges while conducting a survey on determinants of adoption of improved amaranth among small scale farmers in Buuri Sub-County, Meru County, Kenya. Efforts are being done by Kitui County Ministry of agriculture, water and Irrigation, KALRO Katumani and Catholic Diocese of Kitui (Caritas programme) to promote growth and utilization of grain amaranth in various sub counties of Kitui. A project to promote growth and utilization of grain amaranth was being implemented by KALRO katumani in conjunction with European Union (EU) through Catholic Diocese of Kitui (Caritas programme). The project covered four sub counties of Kitui County. These are Mwingi West (Muthale), Mwingi central, Kitui Central and Kitui south (Mutomo) (Catholic Diocese of Kitui, 2016).

The ultimate beneficiaries of this programme are the vulnerable groups in the community. The entry point was through the support groups of people infected and affected by HIV/AIDS. But to counter stigmatization, the programme now targets all other interested groups in the community. The final beneficiaries were all the targeted members, their household members and the community at large. A total of 25,000 persons were expected to be reached in the four implementing areas (Caritas, Kitui, 2016). The project was expected to end on 30th April, 2017.

Overall the production of grain amaranth in Kitui Central Sub County is rather low compared to other grain crops grown in the sub county. It for example doesn't feature in the annual sub county crops reports in the year 2016 as can be seen from Kitui Central sub county Ministry of agriculture annual crops report (table 2.2). The table shows that maize occupies the largest acreage in the sub county, followed by sorghum. No area is recorded under amaranth. This signifies minimal or insignificant acreages compared to other grain crops.

Table 2.2

Grain Crops Production in Kitui Central Sub County

Crop	**Area Achieved (Ha)**			**Production (90kg bags)**		
	LR	**SR**	**Total**	**LR**	**SR**	**Total**
Maize	3,805	4,822	8,627	6,828	7,356	14,184
Sorghum	810	1290	2100	3,010	3816	6,826
Pearl millet	72	102	174	224	0	224
Beans	2004	2220	4224	2,613	2610	5,223
Cowpeas	1380	2108	3488	4,278	4150	8,428
Green grams	1426	1946	3372	3,963	4397	8,360
Pigeon peas	5029	2720	7749	2435	0	2435

Source: Kitui County Ministry of Agriculture report, 2016.

The climatic conditions for Kitui central sub county meet the requirements for amaranth production. The annual rainfall received ranges between 300-800mm p.a with 52% reliability. The temperature ranges between 20^0C to 34^0C and the altitude ranges between 800m and 1800m a.s.l. The climate features fits within the spectrum of amaranth growth requirements. Below is the rainfall data from Kitui meteorological department for the years 2015 and 2016 (table 2.3).The data indicates that year 2015 received more rains (1241.6 mm) than year 2015 (827.6). However, there were more wet days in year 2016 than in 2015, indicating fair distribution in time than in year 2016.

Table 2.3

Kitui central rainfall data for 2015 and 2016 calendar years

Month(s)/ Year	2015		2016	
	2015 Rainfall in mm	No. of wet days	2016 Rainfall in mm	No. of wet days
January	9.4	1	55.2	4
February	7.3	1	29.6	4
March	52.3	4	25.2	5
April	320.1	12	226.2	12
May	73.9	4	6.4	4
June	0.0	0	1.8	1
July	0.6	1	0.0	0
August	0.9	2	1.7	3
September	0.6	1	3.6	4
October	31.3	5	0.0	0
November	578.4	18	438.2	23
December	166.8	9	39.7	10
TOTAL	**1241.6**	**58**	**827.6**	**70**

2.3 Some of the Factors that Affects Amaranth Yields

2.3.1 Fertilizer use

Skwaryło-Bednarz (2012) showed that amaranth is a heavy feeder of nitrogen. According to a research by Myers (1996), maximum amaranth yields of grain was achieved at between 45 to 90 kg N ha^{-1} in different cultivars. Higher application of N resulted to lodging of plants. These level of N fertilizer much lower than that which was required for other crops like maize or sorghum in that had undergone testing (Myers, 1996). The number of leaves, dry matter yield, plant height, and stem of the grain amaranth significantly increased when applied N rates was increased from 0 kg ha^{-1} up to 60 kg ha^{-1} of N (Olaniyi et al., 2008).Maximum grain yields were obtained at 45 kg N ha^{-1} (Olaniyi et al., 2008).

Another study carried out to determine how nitrogen affected development and growth of grain amaranth showed that the least dry weight of 12621 kg ha^{-1} was obtained at 50 kg N ha^{-1} while highest weight 32573 kg ha^{-1} was achieved at 150 kg N ha^{-1}. The grain yield also corresponded with dry matter yields where the highest yields were achieved at 150 kg ha^{-1} of N (Masvanhise, 2015). All vital processes in plants are associated with protein of which nitrogen is an essential constituent; hence nitrogen plays a critical role in plant metabolism (Ali et al., 2011). Application of nitrogen fertilizer also improves most of the plants growth parameters r.

High chlorophyll concentrations combined sunlight and nitrogen enables the plant to synthesis its own food essential for its optimum growth and development. The sugars produced stimulate growth leading to grains with high content of proteins. Yellowing and dying of the plant leaves will start in the oldest leaves, followed by the younger ones when there is deficiency of nitrogen deficiency. Stunting of plants also manifest in the plants and the general protein content is the seeds reduce when there is insufficient nitrogen.

Grain amaranth also require appreciable amount of phosphorous for good production. A study conducted to evaluate the effect of Phosphorous (P) in Amaranthus cruentus L. showed that, grain yield, P use efficiency and its components were highest at 30 kg P ha^{-1} (Ojo, Akinrinde & Akoroda, 2000).Thus Optimum phosphorous requirement in grain amaranth is 30 kg P ha^{-1}.These studies were however conducted in different countries with varying climatic and soil conditions and needed to be verified through related studies elsewhere.

2.3.2 Amaranth intercropping with other crops

Growing of more than one crop simultaneously in the same field has potential to address food security problems in and improve livelihoods in most developing counties (Tsubo, Walker & Ogindo, 2004; Nishanthi, Brintha & Sutharsan 2015). Intercropping, avoids dependence on a single crop in a farm thus minimizing risks of crop and ensuring availability of different products from the same field throughout the year. Key aspects of intercropping includes maximizing utilization of available space of land, competition between system components for nutrients, water and light and the optimum organization of these interactions (Oseni, 2010). Small scale farmers are particularly interested in intercropping owing to various challenges and risks associated with mono-cropping (Prasad & Brook, 2005). Legume growing together with cereals and other crops is the most popular form of intercropping adopted by most small scale farmers at the face of unpredictable climatic limitations.

Studies showing amaranth intercropping with other crops have been carried out with varying results. There is evidence of intercropping amaranth with soya beans (Ng'anga, Ohiokpehai, Muasya, & Omami, 2011) and amaranth intercropped with cowpeas (Myers, 1996). The studies showed that amaranth can effectively be intercropped with legumes for increased food security, nutrition enhancement and high land equivalent ratios.

Ng'ang'a et al., (2011) showed that amaranth intercropped with soya beans had varying results on efficiency of land use, yield of grain and economic returns. Results showed an increase in amaranth yield in intercropping relative to sole cropping. The study presented intercrop between soya beans and amaranth a viable enterprise which could improve farmers production and ultimate income at a reduced cost (Ng'ang'a et al., 2011).

Amaranth has also been found to have no allellopathic effects in an intercropping system. This was shown in a study to evaluate amaranth and canola (*Brassica napus*) as alternative crops in various rotation combinations with maize, soybeans and wheat at Columbia, Missouri, in the fall of 1990. 'Plainsman' amaranth variety was rotated with maize and soybeans, after wheat. Myers (1996) reported that in all of the rotations, no allelopathic effects was noticed on the following crop, and the crop residue from amaranth did not have any adverse effects on the crop that followed.

Research on intercropping of cereals and legume was shown to improve crop yields and soil fertility mainly for the cereal crop for smallholder farmers (Matusso et al., 2012). Fixation of nitrogen (N) from the atmosphere by legumes through Biological Nitrogen Fixation, was shown to play a critical role in the intercropping system especially where soils are depleted or deficient of nitrogen . This is particularly so in sub-Saharan Africa where annual nitrogen depletion are recorded at 22 kg ha^{-1}. Smallholder farmers cannot afford or access mineral-N for their use as fertilizer. Thus legume intercropping would help to bridge the gap. Legumes species commonly used for provision of grain and green manure were seen to have potential to fix between 100 and 300 kg N $ha\text{-}^{1}$ from the atmosphere. It was also found that small holder farmers would prefer to intercrop to benefit from nitrogen fixation, soil and water conservation, reduction in rates of crop failures, minimized costs of production and maximization of available land among other benefits.

2.3.3 Leaf harvesting and plant population in amaranth

Harvesting of leaves and plant spacing has effects on both leaf and grain yields of Amaranth. A field experiments conducted out in Meru, Imenti north district of eastern Kenya to study the effects of density of plants and harvesting of leaves on both weight of grains and leaves of amaranth (A. cruentus) showed that grain yield was indirectly proportional to leaf harvesting intervals (Mwai, 2013). The study revealed that planting amaranth at 3 million plants per ha and harvesting leaf at six days interval regime, yielded more fresh leaves and higher amount of grains. The best combination between harvesting regime was harvesting amaranth after every six days for optimum fresh leaves and grain yield.

2.4 Potential of Legume Intercropping in Amaranth

Mixed cropping as opposed to intercropping is the growing more than one crop in a field at a given time. Intercropping on the other hand involves simultaneous growing of more than one crop in alternating rows in the same piece of land. (Mousavi & Eskandari, 2011; Amanullah, Faisal, Haji, Abbas & Ghaffar, 2016). The main advantage of intercropping is the more efficient utilization of the available resources and the increased productivity compared with each sole crop of the mixture. Intercropped legumes fix most of their N from the atmosphere and do not compete with cereals for N resources (Amanullah et al., 2016). Increased leaf cover in intercropping systems helps to reduce weed populations once the crops are established. Having a variety of root systems in the soil reduces water loss, increases water uptake and increases transpiration. This is important during times of water stress, as intercropped plants use a larger percentage of available water from the field than mono-cropped plants. Research by Mousavi and Eskandari (2011) shows that rows of tall crops in a field with shorter crops will reduce the wind speed above the shorter crops and thus reduce desiccation.

Cereal-grain legume intercropping has potential to address the soil nutrient depletion on small holder farms (Sanginga & Woomer, 2009). The legumes also play an important role in nitrogen fixation and are important source of nutrition for both humans and livestock. Intercropping cereals and legumes also has a potential to reduce erosion and raise general soil fertility levels (Matusso et al., 2012).

Research on cereal-legume intercropping systems in Sub Saharan Africa has shown improvement in both soil fertility and crop yields, particularly for cereal crop which is the staple food crop for smallholder farmers (Matusso et al., 2012). Biological Nitrogen Fixation ,which enables legumes to depend on atmospheric nitrogen (N), is important in legume-based cropping systems when fertilizer-N is limited, particularly in Sub Saharan Africa; where nitrogen annual depletion was recorded at all levels at rates of 22 kg ha^{-1} . It was found out that mineral-N fertilization is neither available nor affordable to smallholder. Legumes species commonly used for provision of grain and green manure have potential to fix between 100 and 300 kg N ha^{-1} from the atmosphere. It was also reported that the main reasons for smallholder farmers to intercrop are flexibility, profit maximization, risk minimization against total crop failure, soil conservation and improvement of soil fertility, weed control and balanced nutrition.

Common Beans

Common bean (dry beans) belongs to the family Fabaceae. Common beans are the second most important staple food to maize for the local people in Kenya. Beans were introduced to Africa from Latin America several centuries ago. To date beans is a vital staple in Africa, providing the main source of protein. The growth habit of common beans varies from determinate dwarf or bush types to indeterminate climbing or pole cultivars. Bush beans are the most predominant types grown in Africa. However, improved climbing beans introduced to Rwanda in the 80's have since spread to other countries in the region. They are particularly grown in areas with limited land and high human population. Common beans grow in areas with temperatures ranging from 17.5 - 27°C and at altitudes between 600 - 1950m a.s.l in many tropical areas. Above 30°C flower buds are likely to fall and seeds are rarely formed at temperatures over 35°C. A moderate well-distributed rainfall is required (300 - 400 mm per crop cycle) but dry weather during harvest is essential. Drought or waterlogging is harmful. Climbing cultivars will give economic yields in areas of high rainfall but the dwarf types appear to be more sensitive to high soil moisture levels Suitable soil types range from light to moderately heavy and to peaty soils with near-neutral pH and good drainage. Common bean is susceptible to salinity. Beans are comparatively light feeders and require about 25 - 35 kg P ha^{-1} (equivalent to 1-2 bags of Mijingu rock phosphate/ha) and 75 - 80 kg K ha^{-1} (Infonet Biovision, 2011). Like all legumes, beans are able to fix nitrogen from the atmosphere, so do not require nitrogen fertilization. However a soil conducive to nitrogen fixing with the natural nitrogen fixing bacteria present is preferable. Hard soils with little organic matter will not give good yields of beans, unless organic matter is provided, preferably in the form of good quality compost or well decomposed farmyard manure. Timely and thorough weeding is essential for beans. The first weeding should be done 2-3 weeks after emergence followed by a second weeding 2-3 weeks later. Shallow tillage is preferred especially in the period before flowering as damage to the roots or the collar of the plant encourages soil borne diseases. Common bean can be rain-fed or irrigated. Irrigation is beneficial in semi-arid regions, with overhead irrigation preferred over flood irrigation. In peasant farming, the crop is seldom manured. Crop rotation is necessary to limit soil borne diseases such as bean rust, powdery mildew, anthracnose and fusarium root rot.

Beans are excellent for intercropping with other food crops, such as maize, potatoes, celery, cucumber etc. and can help supply the other crops with nitrogen to a limited degree. Beans however are less efficient in fixing N than other legumes, but is reported to have fixed up to 125 kg N ha^{-1} (Wortmann, 2006). Common beans can also nodulate with several rhizobia. Longer season varieties of beans can fix higher amounts of nitrogen than short season varieties. Intercropping with chives or garlic helps repel aphids (Infonet Biovision, 2011). Common beans are harvested as soon as a considerable proportion of the pods (roughly 80%) are fully mature and have turned yellow. Some cultivars tend to shatter. Usually entire plants are pulled and further dried till ready for threshing. After threshing the beans are further sun dried to estimated 12 % moisture to avoid storage problems

Some of the common pests that attack beans include bean fly (*Ophiomyia spp*) , aphids (*Aphis fabae*) and cutworms(*Agrotis spp.and Spodoptera spp*). Others are flower thrips (F*rankliniella spp. and Megalurotrhips sjostedti*), African bollworm (Helicoverpa armigera) and the legume pod borer (*Maruca testulalis*). Bruchids such as the dried bean weevil (*Acanthoscelides obtectus*), and the Mexican bean weevil (*Zabrotes subfasciatus*) are storage pests, attacking dried beans in Africa. The most common bean diseases on the other hand include common blight (*Xanthomonas axonopodis pv. phaseoli*), fusarium root rot (*Fusarium solani f. sp. phaseoli*), rust (*Uromyces appendiculatus var. appendiculatus*), anthracnose (*Colletotrichum lindemuthianum*) and bean common mosaic virus (BCMV). Others are Angular leaf spot (*Phaeoisariopsis griseola*), halo blight (*Pseudomonas syringae pv. phaseolicola*) and powdery mildew (*Erysiphe polygoni*).

Green grams

Grams are annual legume crops in the family Fabaceae grown for their seed. Grams could be green, black or yellow in colour. Grams are native crops of India. The green grams are the ones most commonly grown in Kenya. They are grown mainly in Eastern region, Coast, Nyanza and western regions of the country. Green grams or Mung bean are locally known as Pojo (Swahili) or Ndengu. They are annual legume crops grown for their seed. The dried beans are prepared by cooking or milling. They are eaten whole or split. The seeds or the flour may be used in a variety of dishes like soups, porridge, snacks, bread, noodles and even ice cream. Green gram also produces great sprouts, which can be sold in health food shops or eaten at home. Crop residues of V. radiata are a useful fodder. Green gram is sometimes specifically grown for hay, green manure or as a cover crop.

They grow best at an altitude of 0-1600 m above sea level and under warm climatic conditions (28 to 30°C). They are well adapted to red sandy loam soils, but also do reasonably well on not too exhausted sandy soils. Green grams are not tolerant of wet, poorly drained soils. They are drought tolerant and will give reasonable yields with as little as 650 mm of yearly rainfall. Heavy rainfall results in increased vegetative growth with reduced pod setting and development. The dried beans are prepared by cooking or milling. Green gram are eaten whole or split. The seeds or the flour may be used in a variety of dishes like soups, porridge, snacks, bread, noodles and even ice cream. Green gram also produces great sprouts, which can be sold in health food shops or eaten at home. Crop residues of V. radiata are a useful fodder. Green gram is sometimes specifically grown for hay, green manure or as a cover crop (Infonet Biovision, 2011).

Green gram harvesting is generally by two to five hand-pickings at weekly intervals and is the most expensive single operation in growing green gram. Short-duration cultivars, which ripen more uniformly, may be processed as whole plants on small rice threshers (Infonet Biovision, 2011). Harvesting is done when 95% of pods have turned black or brownish depending on the variety. The whole plant can then be uprooted and dried for about 2 days, then threshed and winnowed. Grams must be dry before storage. Like most pulses moisture content at storage should not be above 13%. Green grams are very susceptible to bruchid (bean weevil) attack. They should be treated with the appropriate postharvest storage chemicals. They can also be stored in hermetic bags which are air proof.

Green gram is grown mainly on smallholdings, often as mixed crops or intercrops. Grams planted at the end of the long rains are normally intercropped into other major crop. In Meru, Kenya, green gram is a preferred intercrop for millet, each said to protect the other against diseases and pests. If grams are intercropped with maize, the maize spacing is the same as in pure stand, but the grams are inter planted mid-way between the maize rows (Infonet Biovision, 2011).

An experiment was conducted in 2009 and 2010 by Shyamal and Bikas (2013) on sandy loam soil of West Bengal, India to evaluate the productivity and economic viability of maize and legume intercropping systems in additive as well as in replacement series with different row proportions. Maize cv. “Vijay” (composite), green gram cv.

“Samrat”, black gram cv. “Sarada”, soybean cv. “PK 327” and peanut cv. “JL 24”, were tested in monoculture as well as in intercropping situations with 1:1 (additive series) and 1:2 ratios (replacement series). The result indicated that intercropped legumes improved the yield components of maize and offered some bonus yield. The highest maize grain yield (2,916.28 kg/ha) and maize equivalent yield (4,831.45 kg/ ha) were recorded with maize plus green gram (1:1) and maize plus peanut (1:1), respectively.

Cowpeas

Cowpea is an annual crop grown for its leaves and seed. The growth habit is climbing, spreading or erect and they belong to the bean family or Fabaceae. Cowpea is native to Africa where it was domesticated over 4000 years ago. Cowpeas are mainly important in the marginal rainfall areas because they are well adapted to dry climate and suitable for a variety of intercropping systems. Cowpea can grow in a wide range of soils; it is well adapted to light sandy soils where most other crops produce poorly and does well on acid soils. On heavy fertile soils they show a vigorous vegetative growth, but not necessarily a good grain yield. Most varieties need a minimum rainfall of 200 mm during a growing season. Cowpeas are generally tolerant of drought and low light conditions, but are very susceptible to a variety of insects and diseases and do not do well in poorly drained and cool areas. It is cultivated for the seeds (shelled green or dried), the pods or leaves that are consumed as green vegetables or for pasture, hay, silage and green manure. Tender cowpea leaves and shoots contain 4% protein, 4%

carbohydrates and are rich in calcium, phosphorus and vitamin B. Dried seeds contain 22% protein and 61% carbohydrates.

The optimum temperature to grow and develop is 20 - 35°C. Most cowpea crops are rain-fed, a few are irrigated and others use residual moisture in the soil after harvest of a rice crop. Two to three weeding during the first 1.5 months after planting are recommended. Losses due to weeds can be 30 - 65%. Parasitic weeds, such as *Striga gesnerioides* (Purple witch weed), generally associated with continuous cropping of cowpeas in Africa, may also cause severe damage (Infonet Biovision, 2011).

One benefit of cultivating cowpeas is its ability to fix atmospheric nitrogen in root nodules through symbiosis with rhizobium bacteria that is common in most soils. An effective cowpea-Rhizobium symbiosis fixes more than 150 kg ha^{-1} of N and supplies 80-90% of the total N required. Inoculation may be advantageous, if the crop has not been grown for many years (Infonet Biovision, 2011). In general, no fertilizers are applied. Cowpea is commonly incorporated in crop rotations in semi-arid, humid and sub humid environments. A cowpea crop of the leafy types grown before maize or millet crop and incorporated green into the soil, can produce a good grain crop without any addition of more nitrogen. Intercropped cowpeas also share nitrogen with the other crops e.g. maize, millet, sorghum and cotton). For intercropping, cowpea variety should be chosen carefully since the spreading types may over power other crops by entangling their branches and interfering with fieldwork. Cowpeas do not normally respond to nitrogen or phosphorus fertilizers, so none need adding. However where soils are highly eroded an application of 5 tons/ha of dry compost or manure is beneficial. Weeding should be done during early stages of crop. Later the cowpeas will cover the ground and suppress weeds including purple witch weeds. Two weeding are recommended, one to two weeks after emergence and the second weeding just before flowering.

Harvesting leaves for eating must be done when they are young and tender. Three leaf pickings (starting 2.5 - 3 weeks after planting at weekly intervals have little effect on grain yields of five to six 90 kg bags of seed per acre. Green pods are harvested by hand when they are still immature and tender (12 - 15 days after flowering) (Infonet Biovision, 2011). When grown as a grain, harvesting is complicated by the prolonged and uneven ripening of many cultivars.

Time of harvesting is critical as mature pods easily shatter, so hand-picking can be advantageous. Sometimes plants are pulled when most of the pods are mature. For hay, the crop is cut when most of the pods are well developed. Some of the common pests in cowpeas are legume aphids (*Aphis craccivora*), African bollworm (*Helicoverpa armigera*) and flower beetles (*Coryna spp*). Others include legume pod borer (*Maruca vitrata*) and thrips (*Megalurothrips sjostedti*). These should be controlled by appropriate pestcides like deltamethrine, imidacroprids and lambda-cyhalothrin; among others.

2.5 Pest and Diseases in Amaranth

2.5.1 Pests in amaranth

Amaranth like most crops has its own share of pests and diseases that may greatly compromise both leave and grain yields. It is susceptible to damage by foliar insects such as leaf miners, leaf rollers, cutworms, aphids, flea beetles, and mites. Other major pests reported in amaranth worldwide are the pigweed beetle *(Hypolixus haerens*) and some sucking plant bugs (Grubben & Denton, 2004). Adult weevils feed on leaves, but the larval stage is more damaging because they bore into roots and stems. Weevils can be controlled by uprooting and destroying attacked plants. Stink bugs feed on the flowering head and seeds causing severe damage especially during the critical seed fill stage. They can be controlled by spraying with pyrethrin-based insecticides.

2.5.2 Diseases in amaranth

Some disease pathogens like pythium, rhizoctonia and choenephora can be a problem under some environmental conditions. Damping-off disease (caused by *Pythium aphanidermalum* and *Rhizoctonia solani)* and Choenephora blight caused by *Choenephora cucurbitarium are* some of the diseases affecting amaranth (Wekesa 2010). Damping-off is favored by high soil moisture, low soil temperature and high plant density. Seeds affected by damping-off may rot in the soil before emergence while affected seedlings may exhibit stem canker above the soil line and root necrosis which eventually cause wilting. Damping-off can be controlled by use of disease-free seeds and avoiding over watering and dense planting. Choenephora blight infection is predisposed by injuries. The disease is spread by air currents and infected seeds. Warm, moist conditions favour disease development. The disease is indicated by wet rot of stems and leaves. Affected plant parts have hairy appearance (silk-like threads) consisting of fungal spores and heavy defoliation occurs during the rainy season. It can be controlled by use of resistant varieties where available, planting certified disease-free seeds, avoiding dense planting to allow sufficient aeration and field sanitation. Other disease fungus of Rhizoctonia genus, as well as stem canker, caused by Phorma or Rhizoctonia genus which colonizes leaves and stems and causes dieback has been highlighted in the Americas and Africa (Rensburg et al., 2007).

2.6 Biological Nitrogen Fixation by Legumes in a Non-legume Intercropping

Approximately 80% of Earth's atmosphere is nitrogen gas (N_2). Unfortunately, N_2 is unusable by most living organisms. All organisms use the ammonia (NH_3) form of nitrogen to manufacture amino acids, proteins, nucleic acids, and other nitrogen-containing components necessary for life. Biological nitrogen fixation is the process that changes inert N_2 into biologically useful NH_3. According to Sorensen and Sessitsch (2006) this process is mediated in nature only by N-fixing rhizobia bacteria (*Rhizobiaceae,* α*-Proteobacteria*). Other plants benefit from N-fixing bacteria when the bacteria die and release nitrogen to the environment, or when the bacteria live in close association with the plant. In legumes and a few other plants, the bacteria live in small growths on the roots called nodules. Within these nodules, nitrogen fixation is done by the bacteria, and the NH_3 they produce is absorbed by the plant.

Some legumes are better at fixing nitrogen than others. Common beans are said to be poor fixers of N. Their fixation is less than their nitrogen needs. For example, in Mexico the maximum economic yield for beans required an additional 30 – 50 lb of fertilizer nitrogen per acre. Some legumes like cowpeas. Peanuts, soya beans, soybeans, and fava beans, will fix all of their nitrogen needs other than that absorbed from the soil. Flynn and Idowu, (2015) and Walley et al., (1996) reported that these legumes may fix up to 250 lb of nitrogen per acre. Perennial and forage legumes, such as alfalfa, sweet clover, true clovers, and vetches, may fix 250 – 500 lb of nitrogen per acre. Most of the nitrogen fixed goes to the plant directly. Some nitrogen however can be "transferred" or "leaked" into the soil for neighboring non-legume plants (Walley et al., 1996; Flynn & Idowu, 2015). Eventually, most of the nitrogen returns to the soil for non-legume plants neighboring them, once the vegetation of the legume decomposes after their dead.

A study carried out to determine Nitrogen fixation and N transfer from cowpea, mung bean and groundnut when intercropped with maize showed that intercropped groundnut fixed the highest amount of nitrogen from the atmosphere, getting 85% of its N from the atmosphere. Mung bean and cowpea intercropped were able to fix 197 and 161 mg N plant^{-1}, thus obtaining 78% and 81% of their N content from the atmosphere, respectively (Senaratine, Liyanage & Super, 1995). Maize derived a proportion of N from the associated legume ranging from 11-20% for cowpeas, 7-11% for mung bean, and 12–26% for groundnut which was about 29–45, 19–22, and 33–60 mg N maize plant^{-1}, respectively. The greater N-benefit on the associated crop was therefore due to high nitrogen fixation potential of groundnut relative to to the low harvest index for N.

Another study conducted to establish N relationship in a legume non-legume association grown in an intercropping system showed that Sorghum grown in a mixture with legumes viz. groundnut, mung bean and cowpeas took up more N than sorghum grown as sole crop. In a mixture with mung bean the total N uptake by sorghum was 8.65 g m^{-2}, while with sole sorghum it was 6.79 g m^{-2} (Bandyopadyay,1986).The per cent N derived from fertilizer (% Ndff) was highest with sole sorghum and the lowest when grown in mixture with legumes. It is possible that sorghum derived part of the N from the soil pool enriched by concurrently grown legumes in the mixture. The suggested benefits of a legume and non-legume association are the increased growth of roots and shoots, better root stratification and utilization of soil nutrients, and nitrogen fixation by the legume which allows the legume to become independent of soil nitrogen and making some nitrogen available to the associated non-legume. The main benefit is the increase in soil nitrogen available to the non-legume either through soluble root exudates or through the decay of nodules. However, several workers have reported that the yield advantage of mixed crops in the semi-arid and sub humid tropics results in below-ground interactions, mainly the transfer of nitrogen in the rhizosphere from the legume to the non-legume.

2.6.1 Nitrogen transfer in cereal-legume intercropping systems

Studies have been conducted whose evidence suggests non-legume benefiting from interaction with legumes in in an intercropping system through N-transfer from legumes. This N-transfer is considered to occur through root excretion leached from leaves, leaf fall, and animal excreta if present in the system (Fujita, Godfred & Ogata, 1992). The limited studies carried out within Sub Saharan Africa suggested that N2-fixed by a leguminous component may be available to the associated cereal in the current growing season; known as direct N transfer (Stern, 1993; Eaglesham, Ayanaba, Rao & Eskew, 1981)

A research carried in Muheza district in Tanzania to determine the amount of Nitrogen fixed by cowpea, pigeon pea and green grams in pure stand and in a maize intercrop showed that mono cropped cowpea, pigeon pea and green gram fixed 38, 21, and 49 kg N2, respectively. In the intercrop system cowpea, pigeon pea and green gram fixed 16, 4, and 24 kg N2, respectively (Marandu, Semu, Mrema & Nyaki, 2013).

2.7 Challenges in Amaranth Production

Some of the challenges that affect production and adoption of grain amaranth includes; shattering and lodging, competition for land area with other crops, lack of skills in preparation for consumption, unavailability of planting seeds and lack of appropriate husbandry practices (Cheatle &Nekesa, 1993). Other challenges are lack of market for amaranth and infestation from pests and diseases (Mutisya et al., 2015), Although numerous studies have been done on various aspects of the amaranth; like nutrients demands, pests and diseases, nutritional status, leave palatability, varietal grain yield, leave harvesting and spacing; there is very little information documented on the effect of intercropping common bean, green grams and cowpeas on the grain yield of amaranth. This study was therefore conducted to determine their effects on the growth grain yields of amaranth.

2.8 Land Equivalent Ratios and Harvest Index

2.8.1 Land equivalent ratio

Land Equivalent Ratio (LER) - This is a ratio used to evaluate efficiency of an intercropping system compared sole cropping.

$$\text{Land Equivalent Ratio (LER)} = \frac{\text{Yab}}{\text{Yaa}} + \frac{\text{Yba}}{\text{Ybb}}$$

Where, Yab and Yba are the individual crop yield in intercropping and Yaa and Ybb are their yields as sole crop (Willey & Rao, 1980). Land equivalent ratio is a measure of yield advantages achieved by intercropping on the same area of land. When LER is greater than one unit, it is more beneficial to intercrop than growing the sole crops. If LER is less than one, then growing the crops separately will give better total yields. No significant difference in total yields between intercropping and growing sole crops is indicated if LER is one unit.

2.8.2 Harvest index

Harvest index (HI) is used in agriculture to quantify the yield of a crop species versus the total amount of biomass that has been produced. The commercial yield can be grain, tuber or fruit. For grain crops, harvest index (HI) is the ratio of harvested grain to total shoot dry matter, and this can be used as a measure of reproductive efficiency.

$$\text{Harvest index (HI)} = \frac{\text{Weight of grain per plot}}{\text{Weight of above ground biomass}}$$

Grain yield per plant was positively correlated ($P < 0.001$) with plant height, harvest index, total dry matter biomass per plant, as well as with lodging (Gelinas, 2007). An average harvest index of 0.16 to 0.22 was reported. Amaranth intercropped with maize and beans reported a harvest index of between 0.22 to 0.34 on different amaranth varieties (Sa-nguansak, Thanapornpoonpong, Wiwat, Elke & Suchada , 2007).

CHAPTER THREE: RESEARCH METHODOLOGY

This chapter describes the research design, location of the study and materials and methods used. It also covers data collection methods and data analysis.

3.1 Research Design

The study was an experimental research. A randomized complete block design (RCBD) with four replicates was used. The design was chosen because of its ability to account for the physical, visible variation in one direction; which is typical of most agricultural fields. It was therefore able to reduce variability within treatment conditions; thus making it easier to detect differences in treatment outcomes. Treatments were completely randomized within blocks. The arrangement of treatments was a one-way factorial; with three legumes intercrop and one grain amaranth variety. Pure stand of each crop was also incorporated for comparison purposes.

3.2 Location of the Study

The study was carried out at Kitui Agricultural Training Centre (ATC) which is located within Township ward of Kitui central sub county. Kitui central sub county is one of the eight sub counties in Kitui County. It is Semi-arid with very erratic and unreliable rainfall. The annual rainfall received ranges between 300 - 800mm p.a with 52% reliability. The temperature ranges between 20^0C to 34^0C and the altitude ranges between 800m and 1800m a.s.l. Altitude at Kitui ATC is 1143m a.s.l. The sub county is a mixed farming livelihood zone. It falls under agro-ecological zones (AEZ) LM4, suitable for sorghum, millet, cotton, cowpeas, and green grams. However, farmers grow maize as their most preferred crop alongside beans.

The soils in Kitui County range from sandy loam in surface layers with coarse texture in sub-soils to reddish pink clay on the surface and yellow to yellowish red in the sub-surface. The pH is neutral to slightly acidic. Organic matter content is low to medium. The other variations observed in soil texture include clay loam, loam and sandy loam. Agriculture is the main economic activity of Kitui Central sub county farmers. The sub county however hosts Kitui town which is the main town in the county. The farm structure in the sub county is purely small holder with the family serving as the main source of labour in the production activities. The level of mechanization ranges from low to medium.The study area was chosen because it is one of the key areas where land parcels are very small compared to the other parts of the county. This is where intercropping would be more beneficial and practical for most farmers.

3.3 Plot Establishment

The study was carried out within the 2017 long rains (March – May, 2017). A soil sample from the site of the experiment was taken for analysis at KALRO NARL to establish the nutrient status of the soil, the PH and other key soil parameters that influence crop growth. The plot was tractor- ploughed and harrowed to achieve a fine tilth ideal for crop growth. Seven plots representing three treatment combinations and four pure stands was mapped out per block and replicated four times. A uniform basal application of TSP fertilizer (46%) at a rate of 23 kg P_2O_5 per ha was applied on the rows of amaranth before planting. Each plot measured 4.5m x 3.0m. Farm yard manure was also applied uniformly at a rate of 4 tons per Ha before ploughing. Amaranth ('KAM 01') was sown by drilling in rows spaced 90 cm apart. Fourteen (14) days after emergence, the plants were thinned out to achieve a spacing of 90cm x 30cm. The total amaranth plants per plot was therefore fifty. Rainfall and temperature data during the growing season were collected from Kitui Meteorological weather station and Kitui Agricultural Training Centre station. A total of 493.1mm of rainfall was received in 17days during the season. Temperatures ranged between 22^0C to 30^0C.

3.4 Treatment and treatment combinations

Treatment combinations of the three legumes L_1 - L_3 (Common beans L_1, Green grams L_2 and Cowpeas L_3); and one amaranth variety; V (KAM 01) plus pure stands of each crop was applied in the seven plots within the block. The plots had grain amaranth as the main crop. Common bean (KB1 variety), green grams (N26 Variety) and cowpeas (M66 variety) were planted in single rows between amaranth rows at spacing of 15cm, 20cm and 20cm intra plants, respectively. Thus, one plot of amaranth had one row of common bean as treatment; another plot had one row of green gram, while the third plot had one row of cowpeas as treatment. The other four plots had pure stands of amaranth, pure stand of beans, pure stand of green grams and a pure stand of cowpeas, respectively. Each block therefore had seven plots with different treatments. The spacing in sole crops was 90cm x 30cm for amaranth variety, 30cm x 15cm for common bean, 45cm x 20cm for green gram and 60cm x 20cm for cowpeas. These were replicated four times. Appropriate pesticides were used to control pests. Plots were kept weed-free by shallow weeding.

Table 3.1.

Treatment Combinations

LEGUME INTERCROP (L)	AMARANTH VARIETY (V)
Common beans (L1)	VL1
Green grams (L2)	VL2
Cowpeas (L3)	VL3

Besides the treatment combinations shown in table 3.1, pure stands of each legume variety and that of amaranth formed part of the treatments as shown below:

Pure stand common beans – L1
Pure stand green grams – L2
Pure stand cowpeas – L3
Pure stand amaranth - V

BLOCK1 **1m ↔ between plots**

L2	VL2	VL1	V	L1	VL3	L3

BLOCK2

VL3	L2	VL2	VL1	L1	L3	V

BLOCK3 ↕ **2m path between blocks**

VL2	L1	VL3	L2	L3	V	VL1

BLOCK4

VL3	VL1	L3	VL2	L1	L2	V

***Legend is as shown in table 3.1**

Figure 3.1

Plots layout

3.5 Data Collection

During data collection, one outer row of grain amaranth at each end of all the plots was discarded as border. Thus only 3 middle rows of grain amaranth per plot were harvested. Height of ten randomly selected and pre-tagged amaranth plants per plot were measured in centimeters (cm) on 21st, 35^{th,} 49th and 63rd day after sowing. The size (cm) and weight (g) of 10 heads (inflorescent) per plot were measured when plants were physiologically mature (during harvesting). Harvesting of amaranth was done by cutting off the heads with a sharp knife. The heads were then threshed, winnowed and weight of grains per plot determined using a digital weighing scale. The whole stalks of the harvested amaranth were then cut from the base (above the ground), dried under shade for 30 days and their weights determined per plot.

Harvesting of common bean was carried out per plot by cutting the whole stem from the base when they were physiologically mature and kept to dry fully on a plastic mat then threshed and yield measured per plot. Green grams and cowpeas were harvested by picking individual pods per plot when they were physiologically mature. The pods were fully dried on a mat then threshed, winnowed and their weights measured per plot. Sole crops for all the legumes and the amaranth were also harvested by discarding the outer rows on both sides as border. The grains were measured for comparison purposes.

The five parameters measured were:

i. Plant height (cm) – measured from the soil level to the highest part of the growing tip. Done on 21st, 35th, 49th and 63rd days after sowing. An average of 10 randomly selected plants per plot.

ii. Size of amaranth heads (cm) – average length of 10 randomly selected heads were measured during harvesting.

iii. Weight of amaranth heads (g)- average weight of heads for 10 randomly selected plants per plot were measured after harvesting before threshing

iv. Grain yield (g) – Average grain yield from 30 plants per plot were measured after threshing, winnowing and sun dried to a constant moisture level of 13.5%

v. Above ground biomass (g) - Amaranth shoots were cut above the ground after harvesting, dried under shade for 30 days and their weight measured.

3.6 Data Analysis

Data collected on yields, plant height and other growth parameters was summarized in an excel package and exported for analysis using SPSS Version 22.0 (statistical package for social sciences). Analysis of variance (ANOVA) for amaranth height, head size, weight of head, weight of grains and above the ground biomass was carried out for the three intercropping systems and for the amaranth pure stand. Treatment means were differentiated at 0.05 level of significance ($P<0.05$). Post-hoc test was done using Fishers' Least Significant Difference (LSD). LSD was used since the variables compared were less than five. Land Equivalent Ratio (LER) was used to assess the amaranth-legume intercropping advantages relative to sole cropping.

$$\text{Land Equivalent Ratio (LER)} = \frac{\text{Yab}}{\text{Yaa}} + \frac{\text{Yba}}{\text{Ybb}}$$

Where Yab and Yba are the individual crop yield in intercropping and Yaa and Ybb are their yields as sole crop (Willey & Rao, 1980). Land Equivalent Ratio (LER) is one of the most appropriate indices to evaluate efficiency of intercropping system in producing better yields as compared to yields in sole cropping.

Harvest Index was determined as a ratio of grain yield per plot to above ground biomass.

$$\text{Harvest index (HI)} = \frac{\text{Weight of grain per plot}}{\text{Weight of above ground biomass}}$$

This was in line with Arya, Arya, Arya and Kumar (2015) who expressed Harvest index as a relationship of economic yield (yield of main product) and total biological yield (yield of main product + by products). Higher harvest index means superior plant type.

CHAPTER FOUR: RESULTS AND DISCUSSION

This chapter is presented in eight sections. It highlights the results and discussion of parameters measured in support of objectives one, two and three. It also gives the Harvest Index and the Land Equivalent Ratio (LER).

4.1 Plant Height

Results of effects of intercropping on amaranth plant height are presented in figure 4.1. The height of amaranth was highest in the green grams intercrop on all the days measured after sowing (21^{st}, 35^{th}, 49th and 63^{rd} the day after sowing) (Fig. 4.1). Common bean intercrop on the other hand gave the least plant height on all the days measured after sowing.

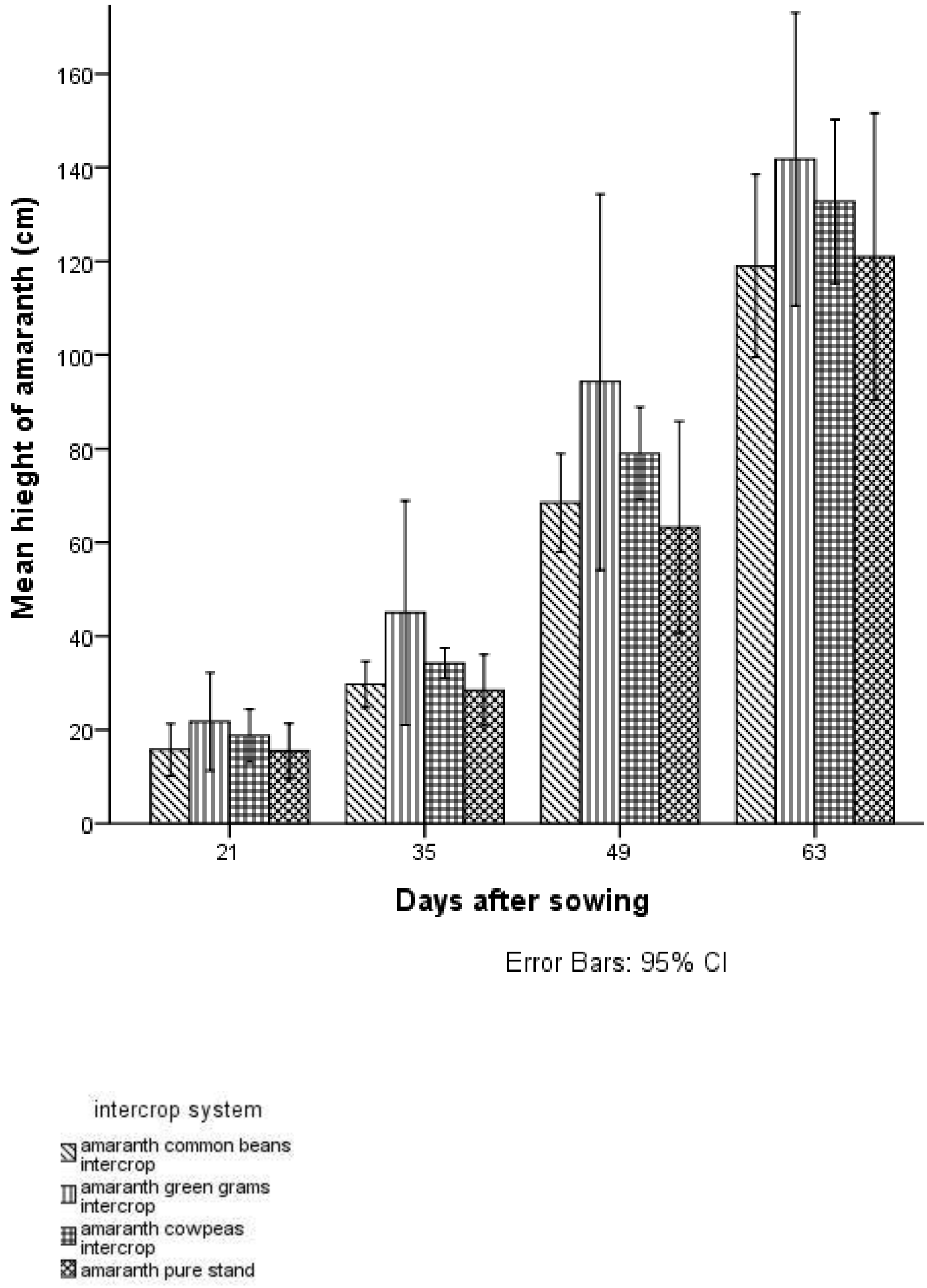

Figure 4.1.

Effects of intercropping on plant height

Analysis of variance was carried out to determine whether there were significant differences on the amaranth heights for the different intercropping system. The results are presented in table 4.1.

Table 4.1.

ANOVA Table for effects of intercropping on amaranth plant height

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Blocks	2510.922	3	836.974	.390	.761
Intercropping systems	3555.547	3	1185.182	.552	.649
Error	122400.891	57	2147.384		
Total	128467.359	63			

a. R Squared = .047 (Adjusted R Squared = -.053)

From the ANOVA table 4.1, there was no significant difference (P>0.05) on the height of amaranth among the three intercropping systems. This shows that legume intercropping did not significantly affect the height of amaranth. This is in contradiction to research by Walley et al., (1996) and Flynn and Idowu (2015) which indicated that common beans was a poor fixer of biological nitrogen compared to greengrams and cowpeas; which fix upto 80% of their nitrogen requirements. It would have been expected therefore, that height of amaranth in common beans intercrop would have been smaller compared to that in greengrams and cowpeas intercrops. This is because greengrams and cowpeas would have met most of their nitrogen requirements through biological nitrogen fixation thus leaving the available soil nitrogen for use by amaranth, as opposed to common beans which would derive most of its nitrogen from the soil. Consequently, amaranth in greengram and cowpeas intercrops would grow with vigor and achieve greater height due to more availability of soil nitrogen compared to that in common beans intercrop. This could perhaps be attributed to inherent genetic survival traits in amaranth that allowed it to achieve its maximum height upon provision of the basic growth requirements; regardless of other factors.

4.2 Head Size

Results of effects of legume intercropping on the amaranth head size are presented in figure 4.2 and tables 4.2 and 4.3.

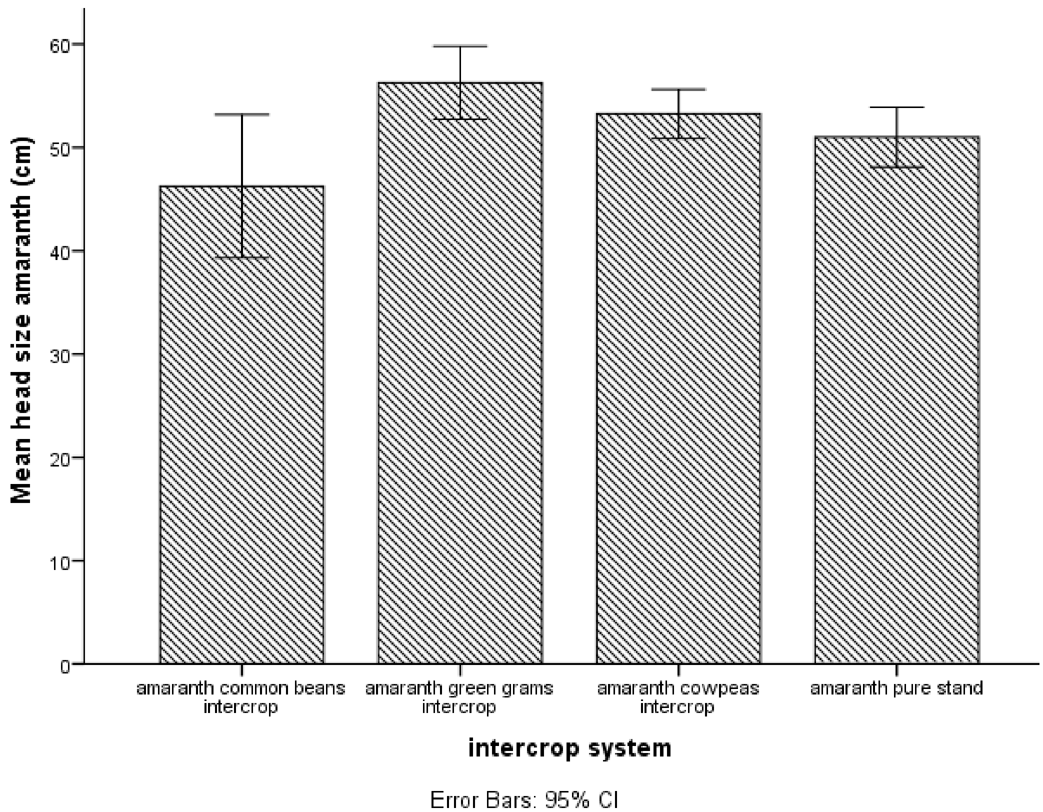

Figure 4.2.

Effects of intercropping on head size of amaranth

From figure 4.2, the amaranth head size was highest in green grams intercrop followed by cowpeas intercrop. Head size was least in common beans intercrop. An Analysis of variance (ANOVA) was carried out to determine if there were significant differences in head size among the various intercropping systems. The results are presented in the table 4.2.

Table 4.2.

ANOVA table for effects of intercropping on amaranth head size

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Blocks	60.187	3	20.062	6.434	.013
Intercropping systems	213.187	3	71.062	22.791	.000
Error	28.063	9	3.118		
Total	301.437	15			

a. R Squared = .907 (Adjusted R Squared = .845)

From table 4.2, analysis of variance revealed that there were significant differences (P<0.05) in amaranth head size among the three intercropping systems. A post-hoc analysis was therefore carried out to determine where the differences lied, as shown in table 4.3:-

Table 4.3.

LSD table for effects of intercropping on the amaranth head size

	amaranth common beans intercrop	amaranth green grams intercrop	amaranth cowpeas intercrop	amaranth pure stand
amaranth common beans intercrop		-10.00*	-7.00*	-4.75*
amaranth green grams intercrop			3.00	5.25*
amaranth cowpeas intercrop				2.25
amaranth pure stand				

*The mean difference is significant at the 0.05 level.

From the post-hoc analysis, table 4.3, it was found that the amaranth head size in common bean intercrop was significantly lower than that of green gram and cowpeas intercrops. The head size was also significantly lower than that of amaranth pure stand. The analysis also found out that there was no significant difference in amaranth head size between green gram and cowpeas intercrops. Head size in green gram intercrop was significantly higher than in amaranth pure stand. The analysis further revealed that there was no significant difference between cowpeas intercrop and amaranth pure stand.

The significantly smaller amaranth head sizes in common bean intercrop was as a result of low nitrogen available to amaranth due to poor biological nitrogen fixation by beans. This is because common bean is a poor fixer of nitrogen (Walley, et al. 1996; Flynn &

Idowu, 2015). This is as opposed to green grams and cowpeas which are good at fixing biological nitrogen. These results are also in conformity with Senaratine et al., (1995) who showed that intercropped cowpea and mung bean can fix and obtain 81% and 78% of their N content from the atmosphere respectively. It is for this reason that the amaranth head sizes were larger in green grams and cowpeas intercrops. The results agree further with Flynn and Idowu (2015) findings, which showed that common bean fixes less than their Nitrogen requirements. High fixation of biological nitrogen by green grams and cowpeas means that the two legumes were able to meet their nitrogen needs leaving the available soil nitrogen for amaranth use. Common bean on the other hand competed for the available soil nitrogen with amaranth. Insufficient nitrogen for the amaranth led to reduced growth vigor hence smaller head sizes.

Amaranth in green gram and cowpea intercrops may also have benefited through 'direct N transfer' (Stern, 1993; Eaglesham et al., 1981). This is a situation where some of the fixed nitrogen leaches from legumes to the non-legume grown in association in the current growing season. This additional nitrogen to the amaranth therefore may have contributed to its larger head sizes in green grams and cowpeas intercrops. The initial nitrogen boost to the amaranth through biological N-fixation and direct N transfer by green grams and cowpeas enabled it to grow with vigor and make better use of its photosynthetic capacity and other growth resources; thus achieving large head sizes and subsequent better yields.

4.3 Weight of Head

Results of effects of legume intercropping on weight of amaranth heads are presented in Figure 4.3 and tables 4.4 and 4.5.

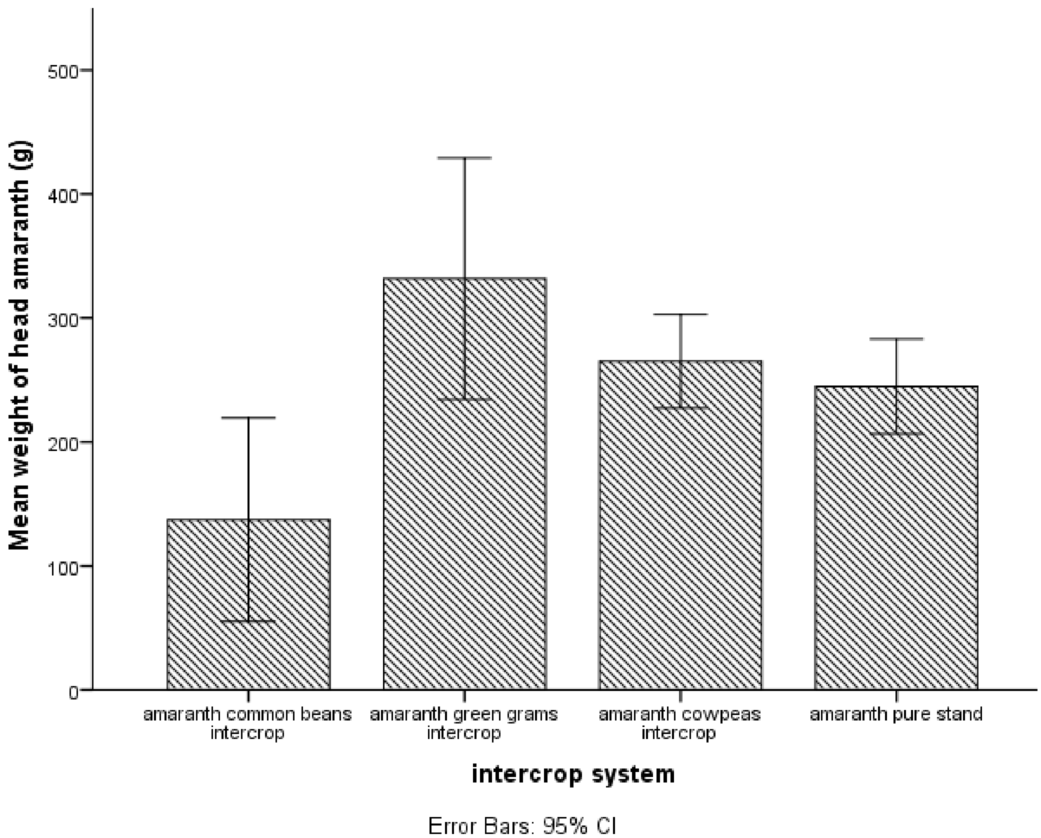

Figure 4.3.

Effects of intercropping on weight of amaranth head

Figure 4.3 shows that the weight of amaranth heads was highest in the green gram intercrop followed by cowpeas intercrop; while common bean intercrop had the least weight. An analysis of variance was carried out to determine if there were significant differences in weight of amaranth. The results are presented in table 4.4.

Table 4.4.

ANOVA table for effects of intercropping on weight of amaranth heads

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Blocks	8898.000	3	2966.000	1.942	.193
Intercropping systems	78182.000	3	26060.667	17.064	.000
Error	13745.000	9	1527.222		
Total	100825.000	15			

a. R Squared = .864 (Adjusted R Squared = .773)

From the ANOVA table 4.4, it was found that there were significant differences ($P<0.05$) in weight of amaranth heads among the three intercropping system. A post-hoc analysis was therefore carried out to determine where the differences lied. This is shown in table 4.5:-

Table 4.5.

LSD table for effects of intercropping on weight of amaranth heads

	amaranth common beans intercrop	amaranth green grams intercrop	amaranth cowpeas intercrop	amaranth pure stand
amaranth common beans intercrop		-194.50*	-128.00*	-107.50*
amaranth green grams intercrop			66.50	87.00*
amaranth cowpeas intercrop				20.50
amaranth pure stand				

*. The mean difference is significant at the 0.05 level.

From the post-hoc analysis, table 4.5, the weight of amaranth head was significantly higher for green gram and cowpeas intercrops compared to that of common bean intercrop. Weight of head for pure stand amaranth was also significantly higher than that of common bean intercrop. There was no significant difference in weight of heads between green grams and cowpeas intercrops. Weight of heads in green gram intercrop was however significantly higher than that of pure stand amaranth. This trend showed similarity to that of amaranth head size (Figure 4.2 and tables 4.2 and 4.3). The weights of amaranth heads were directly proportional to the size of amaranth heads.

The high amaranth head weight in green grams and cowpeas intercrops was due to more nitrogen available to amaranth as result of better biological nitrogen fixation by the two legumes. Cowpeas and green grams are able to fix 81% and 78% of their N requirements from the atmosphere (Senaratine et al., 1995); leaving the available soil nitrogen to the amaranth. This enabled amaranth to grow with vigor and achieve better head development and consequent higher weight of heads. On the contrary, common bean which has very low capacity to fix biological nitrogen (Walley, et al., 1996; Flynn & Idowu, 2015) competed with amaranth for the available nitrogen. This led to reduced growth and development of amaranth heads in the common bean intercrop and consequent reduced weight of heads.

High weight of amaranth heads in green grams and cowpeas intercrop can also be attributed to high more nitrogen available to amaranth through direct N transfer from the two legumes (Stern, 1993; Eaglesham et al., 1981). This enabled amaranth to achieve high growth vigor, better photosynthetic capacity and improved head development resulting higher weight of heads.

4.4 Grain Yields per Plot

Results of Effects of legume intercropping on amaranth grain yields are presented in Figure 4.4 and tables 4.6 and 4.7:-

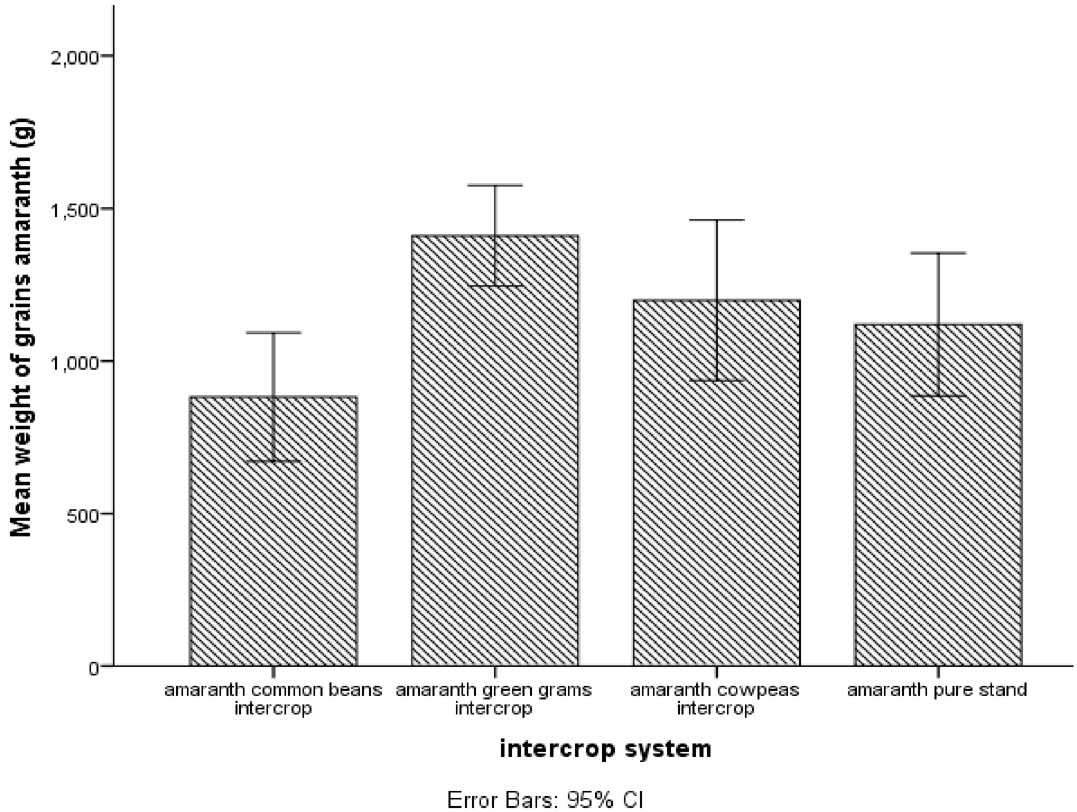

Figure 4.4.

Effects of intercropping on grain yields of amaranth per plot

From figure 4.4 amaranth grain yields per plot were highest in green gram intercrop followed by cowpea intercrop; while common bean intercrop had the least yields. An analysis of variance (ANOVA) was conducted to determine whether there were significant differences in amaranth grain yields among three intercropping systems. Results are shown in table 4.6:-

Table 4.6.

ANOVA table for effects of intercropping on amaranth grain yield

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Blocks	177447.188	3	59149.063	9.771	.003
Intercropping systems	572958.687	3	190986.229	31.549	.000
Error	54482.063	9	6053.563		
Total	804887.937	15			

a. R Squared = .932 (Adjusted R Squared = .887)

From the ANOVA table 4.6, there were significant differences ($P<0.05$) in amaranth yields among the three intercropping systems. A post-hoc analysis was therefore carried out to determine where the differences lied. The results are shown in table 4.7:-

Table 4.7.

LSD table for effects of intercropping on amaranth grain yield per plot

	amaranth common beans intercrop	amaranth green grams intercrop	amaranth cowpeas intercrop	amaranth pure stand
amaranth common beans intercrop		-529.00*	-317.50*	-238.25*
amaranth green grams intercrop			211.50	290.75*
amaranth cowpeas intercrop				79.25
amaranth pure stand				

*. The mean difference is significant at the 0.05 level

From the post-hoc analysis Table 4.7, amaranth yields per plot in the green gram intercrop, cowpeas intercrop and pure stand amaranth were significantly higher than that of common bean intercrop. There was also significant difference in amaranth yields between green gram intercrop and amaranth pure stand. Yields were higher in green gram intercrop than in amaranth pure stand. However, yields in cowpeas intercrop and pure stand amaranth had no significant differences.

Higher amaranth yields in green grams and cowpea intercrops are as a result of more nitrogen available to amaranth due to higher biological nitrogen fixation by green gram and cowpeas. The significantly lower amaranth yields in common bean intercrop on the other hand is as a result of low nitrogen available to amaranth due to poor biological nitrogen fixation by beans. This is because common bean is a poor fixer of nitrogen (Walley, et al., 1996; Flynn & Idowu, 2015).

These results are also in conformity with findings of Senaratine et al., (1995) which showed that intercropped cowpea and mung bean fixed and obtained 81% and 78% of their N content from the atmosphere, respectively. This implies that green grams and cowpeas meet most of their nitrogen needs through N fixation and leave the available soil nitrogen for amaranth use. Amaranth is therefore able to grow with higher vigor and develop larger heads which translates to higher grain yields. This is as opposed to common bean which has very low capacity to fix its nitrogen needs hence has to compete for the available soil nitrogen with amaranth crop; leading to smaller heads and less grain yields. Olaniyi et al., (2008) also reported higher amaranth grain yield and quality through increase in nitrogen. The results are also corroborated by Ng'ang'a et al., (2011) who reported yields increase in amaranth through intercropping with legumes.

The significantly higher amaranth yields in green grams and cowpeas intercrop were also attributed to 'direct N transfer' from green grams and cowpeas to amaranth (Stern, 1993; Eaglesham et al., 1981). This agrees with the findings of Walley et al., (1996) and Flynn and Idowu (2015) which showed that most of the nitrogen fixed by legumes goes directly into the plant, but some nitrogen is "leaked" or "transferred" into the soil for neighboring non-legume plants. This additional nitrogen to the amaranth through direct leakage from green grams and cowpeas therefore, contributed to higher growth vigor in amaranth resulting to larger head sizes and subsequent higher amaranth grain in green grams and cowpeas intercrops.

The initial nitrogen boost to amaranth from green grams and cowpeas is also believed to have improved utilization of other growth resources like nutrients, water and photosynthetic capacity. These in return are believed to have contributed to general better performance of amaranth leading to its higher grain yields when intercropped with the green grams and cowpeas; as opposed to common beans. Most plant processes are associated with proteins whose nitrogen is an essential constituent; thus availability of nitrogen from green grams and cowpeas improved general amaranth growth and grain yield.

4.5 Above Ground Biomass

The results for the effects of intercropping on above ground biomass are presented in figure 4.5 and Tables 4.8 and 4.9.:-

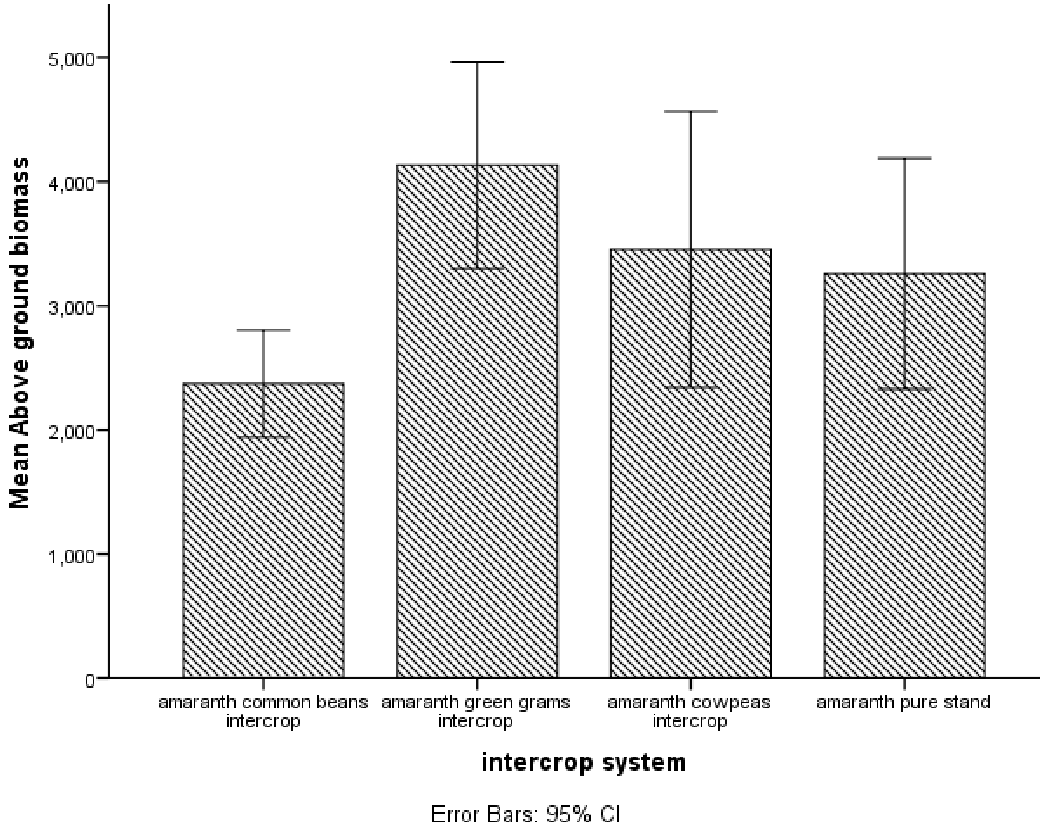

Figure 4.5.

Effects of intercropping on above ground biomass

From figure 4.5, amaranth above ground biomass was highest in the green gram intercrop followed by cowpea intercrop; while common beans intercrop had the least biomass. Analysis of variance was carried out to determine whether there were significant differences among the various intercropping systems. The results are shown in table 4.8.

Table 4.8.

ANOVA table for effecte of intercropping on above ground biomass

Source	Type III Sum of Squares	df	Mean Square	F	Sig.
Blocks	2893515.250	3	964505.083	13.531	.001
Intercropping systems	6324739.250	3	2108246.417	29.577	.000
Error	641529.250	9	71281.028		
Total	9859783.750	15			

a. R Squared = .935 (Adjusted R Squared = .892)

The ANOVA found that on the above ground biomass there were significant differences (P<0.05) between the various intercropping systems. A post-hoc analysis was therefore carried out to determine where the differences were as shown in Table 4.9:-

Table 4.9.

LSD table for effects of intercropping on above ground biomass

	amaranth common beans intercrop	amaranth green grams intercrop	amaranth cowpeas intercrop	amaranth pure stand
amaranth common beans intercrop		-1761.25*	-1083.50*	-887.75*
amaranth green grams intercrop			677.75	873.50*
amaranth cowpeas intercrop				195.75
amaranth pure stand				

*. The mean difference is significant at the 0.05 level.

From the post-hoc analysis Table 4.4, the above ground biomass for amaranth was significantly higher in the green grams and cowpeas intercrops compared to common bean intercrop. There was no significant difference between the above ground biomass for the green grams and cowpeas intercrops. The same was true for the pure stand amaranth which had no significant difference compared to both green grams and cowpeas intercrops.

The significant higher, above ground biomass for amaranth in green grams and cowpea intercrops was as a result of higher availability of soil nitrogen to the amaranth from green grams and cowpeas through nitrogen fixation. This is in comparison to common beans which is a poor fixer of nitrogen. These results are in conformity with the findings of Senaratine et al., (1995) and those of Flynn and Idowu (2015) who showed that intercropped cowpea and mung bean can fix and obtain 81% and 78% of their N content from the atmosphere, respectively; while common bean is a poor fixer of N and fixes less than its N requirements. High fixation of biological nitrogen by green grams and cowpeas means that the two legumes are able to meet their nitrogen needs and leave the available soil nitrogen to amaranth. Common bean on the other hand competes for the available soil nitrogen with amaranth. Insufficient nitrogen for the amaranth leads to reduced growth vigor, fewer branches and less vibrant leaves leading to low above ground biomass in the common beans intercrop.

Higher availability of nitrogen for use by amaranth means in the green grams and cowpeas intercrops on the other hand means better utilization of growth resources like nutrients, light and water. It also improves other plant processes like the photosynthetic capacity by amaranth. This therefore enables amaranth to achieve more vibrant leaves, strong stalks and properly developed branches hence increasing the above ground biomass. Inadequate nitrogen supply to amaranth in the common bean intercrop leads to weaker amaranth plants with thin stalks, fewer branches and smaller leaves; hence less above ground biomass. These findings also agrees with those for Masvanhise (2015) which showed that amaranth dry matter was higher at higher nitrogen levels and least where nitrogen levels were low.

4.6 Harvest Index

Table 4.10.

Effects of intercropping on Harvest Index

Intercropping system	Grain yield (g)	Above ground Biomass (g)	Harvest Index (HI)
Amaranth-common bean intercrop	881	2372	0.37
Amaranth-green grams intercrop	1410	4133	0.34
Amaranth- cowpeas intercrop	1005	3455	0.29
Amaranth pure stand	1120	3259	0.34

From table 4.9, the harvest index (HI) in common bean-amaranth intercrop was highest (0.37), while cowpeas- amaranth intercrop had the least HI (0.29). Overall the harvest indexes for amaranth in the three intercropping system were comparable with studies conducted elsewhere. For instance Sa-nguansak et al., (2007) reported amaranth harvest indexes of between 0.22 and 0.34. Gelinas (2007) on the other hand reported amaranth harvest index of between 0.16 and 0.22. The results on harvest index agrees with another study carried out by Gelinas (2007) which showed that there was a positive correlation between harvest index and grain yield. The high harvest index in common bean intercrop compared to other intercrops was due to low above ground biomass in amaranth as a result of low nitrogen supply to amaranth through N fixation and transfer from common bean. Reduced biomass in amaranth therefore translated to increase in Harvest index ratio. This is due to the fact that common bean is a poor fixer of biological nitrogen compared to green grams and cowpea which fixes most of their N requirement hence reducing competition for soil nitrogen with amaranth (Senaratine et al., 1995; Flynn & Idowu, 2015). Green gram and cowpea intercropped with amaranth ensured higher nitrogen availability to amaranth which boosted the general above ground biomass and consequently led to reduced amaranth harvest index ratio.

4.7. Land Equivalent Ratio (LER)

Land equivalent ratios (LER) for the different intercropping systems were calculated and the results presented in table 4.11.

Table 4.11.

Influence of intercropping on Land Equivalent Ratios (LER)

Treatment	Equivalent Grain yield kgs/ha	LER
Amaranth + common beans	1,088	1.67
Amaranth + Green grams	1,741	1.90
Amaranth + Cowpeas	1,480	1.95
Amaranth purest stand	1,383	
Common bean pure stand	1,286	
Green grams pure stand	1,215	
Cowpeas pure stand	1,368	

From table 4.11 , the land equivalent ratios for all the intercropping systems was more than one; indicating that there were yield advantages in intercropping compared to mono cropping. Amaranth-cowpeas intercrop had the highest (1.95) land equivalent ratio followed by amaranth-green grams intercrop (1.90) while; amaranth-common beans intercrop had the least (1.67) LER. This means that 95%, 90% and 67% more land would be required, respectively, to achieve the same yields in sole cropping compared to intercropping. The Amaranth land equivalent ratios were greater than one unit due to legumes in the intercropping system being able to fix their own nitrogen from the atmosphere. This allows them to achieve their full growth with minimal competition for N with amaranth.

The land equivalent ratios in this study compares with studies carried out elsewhere on amaranth and on other related crops. For example Adigbo (2009) showed that amaranth intercropped with cowpeas gave land equivalent ratios ranging between 1.33 - 1.90 in different amaranth varieties. Kumar and Murthy (2017) reported slightly lower land equivalent ratios on amaranth intercropped with different legumes. Amaranth intercropped with groundnuts had a LER of 1.22, amaranth with pigeon peas, 1.19 while amaranth intercropped with finger millet had a LER of 1.17. The results were also consistent with findings from John and Mini (2005) as cited by Awe and Abegunrin (2009) who reported a LER>1 when okra was intercropped with amaranth, cowpea and cucumber. Ssekabembe (2008) and Ojiewo, Tenkouno, Hughes and Keatinge (2013) also reported amaranth yield advantage of between 39% and 47% in an intercrop between amaranth and garden peas. Ng'ang'a, et al., (2011) found that intercropping amaranth with soya beans gave a land equivalent ratio of between 1.5 and 1.90.

The various studied cited show that there is a general yield advantage in intercropping compared to sole cropping. The yield advantages would serve to compensate for difficult cultural practices occasioned by intercropping. In the case of the current study, the yield advantage portrayed by the high LERs serves as an encouragement to farmers who would otherwise ignore growing of amaranth at the expense of other crops owing to land scarcity. This is particularly so in urban and peri - urban areas where land is scarce.

CHAPTER FIVE: SUMMARY, CONCLUSION AND RECOMMENDATION

5.1 Summary

Results on effect of intercropping on plant height showed that there was no significant difference in amaranth height in the three intercropping systems at 95% level of confidence. Significant differences were however found in amaranth head size, weight of amaranth heads; amaranth yield per plot and above ground biomass; at 95% confidence level. After carrying out the post-hoc analysis, it was found that amaranth in green gram intercrop performed consistently better, followed by cowpeas intercrop, in almost all the parameters measured. Amaranth in common beans intercrop on the other hand, performed poorest in most of the parameters measured.

Harvest index (HI) was highest in amaranth–common bean intercrop (0.37), followed by green gram intercrop (0.34). Cowpea – amaranth intercrop was third with a Harvest index of 0.29. Land equivalent ratio (LER) on the other hand was highest (1.95) in amaranth – cowpea intercrop, followed by amaranth – green gram intercrop (1.90). Amaranth - common bean intercrop had the least (1.67) Land equivalent ratio. The LERs for all the intercropping systems were however greater than one unit, indicating that there were yield advantages in intercropping compared to sole cropping.

The difference in performance on most of the crop parameters measured was attributed to the ability of the different legumes in fixing biological nitrogen. Different abilities of legumes in fixing their own nitrogen needs minimized competition for the available soil nitrogen making it available for use by the amaranth. Ability of the three legumes to transfer some of the fixed nitrogen through ‘direct transfer’ was also found to benefit the amaranth crop grown in association. Nitrogen availability to amaranth intercropped with green grams and cowpeas allowed it to develop with greater vigor, attaining large head dimensions, greater grain returns and greater above surface biomass

5.2 Conclusion

From this study, it was found that intercropping common beans, green grams and cowpeas had significant effect on growth and grain yields of amaranth. Amaranth-green gram intercrop performed better followed by cowpeas intercrop while common bean intercrop had the least yields.

The study also found out that green gram was the best legume for intercropping with amaranth in Kitui central sub County. This was based on the good performance the amaranth showed when intercropped with green gram. Cowpea was the second best legume to intercrop with amaranth; while common bean is the least appropriate legume to intercrop with amaranth in Kitui central sub county.

Intercropping legumes with amaranth had a significant effect on allometric measurement of amaranth. This was shown by the significant differences found in above ground biomass and the resultant harvest index in different intercropping systems. The study found out that the above ground biomass was least when amaranth was intercropped with common beans; and highest when amaranth was intercropped with green grams.

The study also showed that intercropping amaranth with legumes had comparative yield advantage relative to sole cropping. This was based on the relatively high land equivalent ratios in all the intercropping systems.

5.3 Recommendations

i) Based on the findings of this study it is recommended that farmers in Kitui central sub county be encouraged to intercrop amaranth with green grams to increase amaranth grain yield and to improve the general soil fertility.

ii) It is also recommended that green gram be intercropped with amaranth for better leaf and stalks yields for use as vegetables, fuel wood and livestock feed where applicable.

Suggestions for further research

Further research is recommended to determine the effect of legume intercropping on different amaranth varieties and the effects of intercropping as a ground cover alteration of microclimate.

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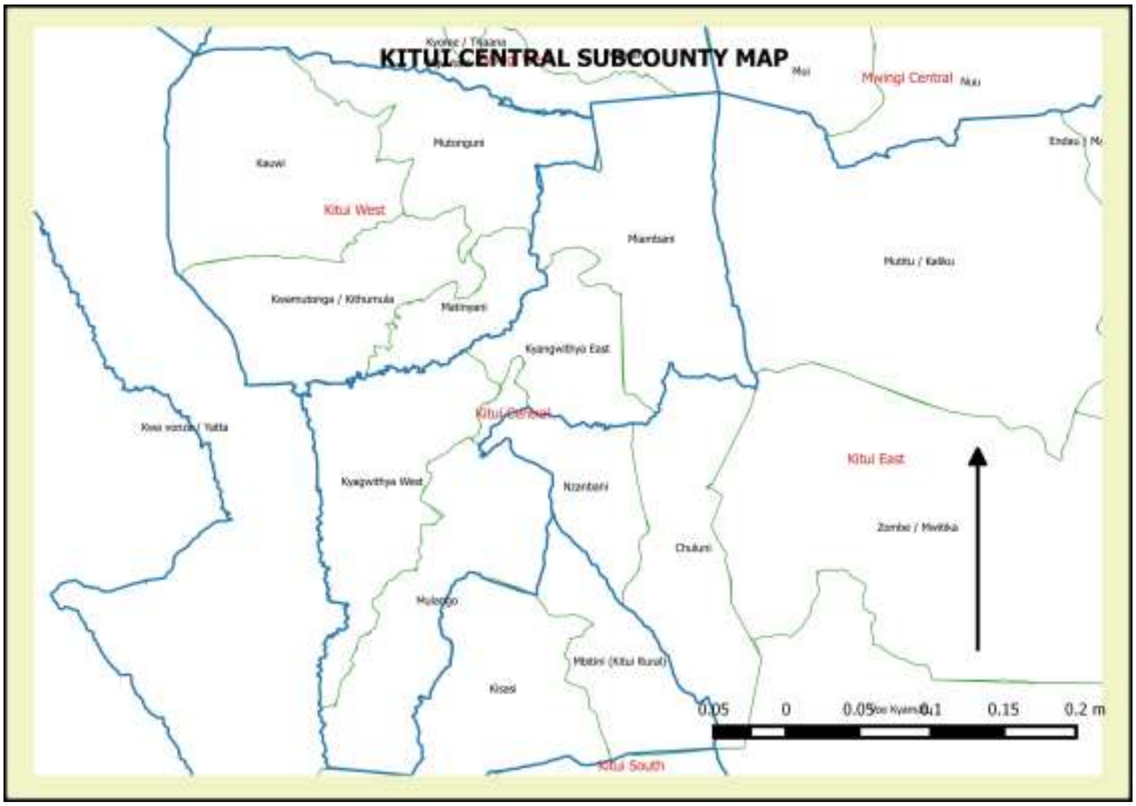
APPENDICES

APPENDIX 1: MAP OF KITUI CENTRAL SUBCOUNTY



Map of Kitui Central sub County

APPENDIX II: SOIL ANALYSIS REPORT

Kenya Agricultural & Livestock Research Organization
National Agricultural Research Laboratories
P. O. Box 14733, 00800 NAIROBI
Tel: 0202464435
Email: soilabs@yahoo.co.uk

SOIL TEST REPORT

Name	James Kiambi Gitonga
Address	P. O. Box 16 - 90200, Kitui
Location of farm	Township, Kitui Central, Kitui
Crop(s) to be grown	Amaranth, beans, green gram
Date sample received	26-10-16
Date sample reported	15-11-16
Reporting officer (through Director NARL)	A. Chek

	Soil Analytical Data							
Lab. No/2016	8906							
Soil depth cm	top							
Fertility results	value	class	value	class	value	class	value	class
* Soil pH	6.12	slight acid						
* Total Nitrogen %	0.14	low						
* Total Org. Carbon %	1.25	low						
Phosphorus ppm	20	low						
Potassium me%	0.84	adequate						
Calcium me%	6.8	adequate						
Magnesium me%	3.52	high						

*** ISO/IEC 17025 accredited**

Interpretation and Fertilizer Recommendation

The soil reaction (pH) is satisfactory for crops' growth. Nitrogen and phosphorus are deficient. Soil organic matter content is low. At land preparation apply through broadcasting 4 tons/acre of well decomposed manure or compost. Mix well with the soil. **Amaranth:** Prior to sowing apply 100 kg/acre of N:P:K 23:23:0. Mix well with the soil. Top dress with 80 kg/acre of calcium ammonium nitrate (CAN) when plants have started growing well. **Beans/ Green gram:** Before planting apply by incorporation into the soil along the ridges 100 kg/acre of N:P:K 23:23:0.

NOTE: Test results are based on customer sampled sample(s).
Methods used: Information is given out on client's request.

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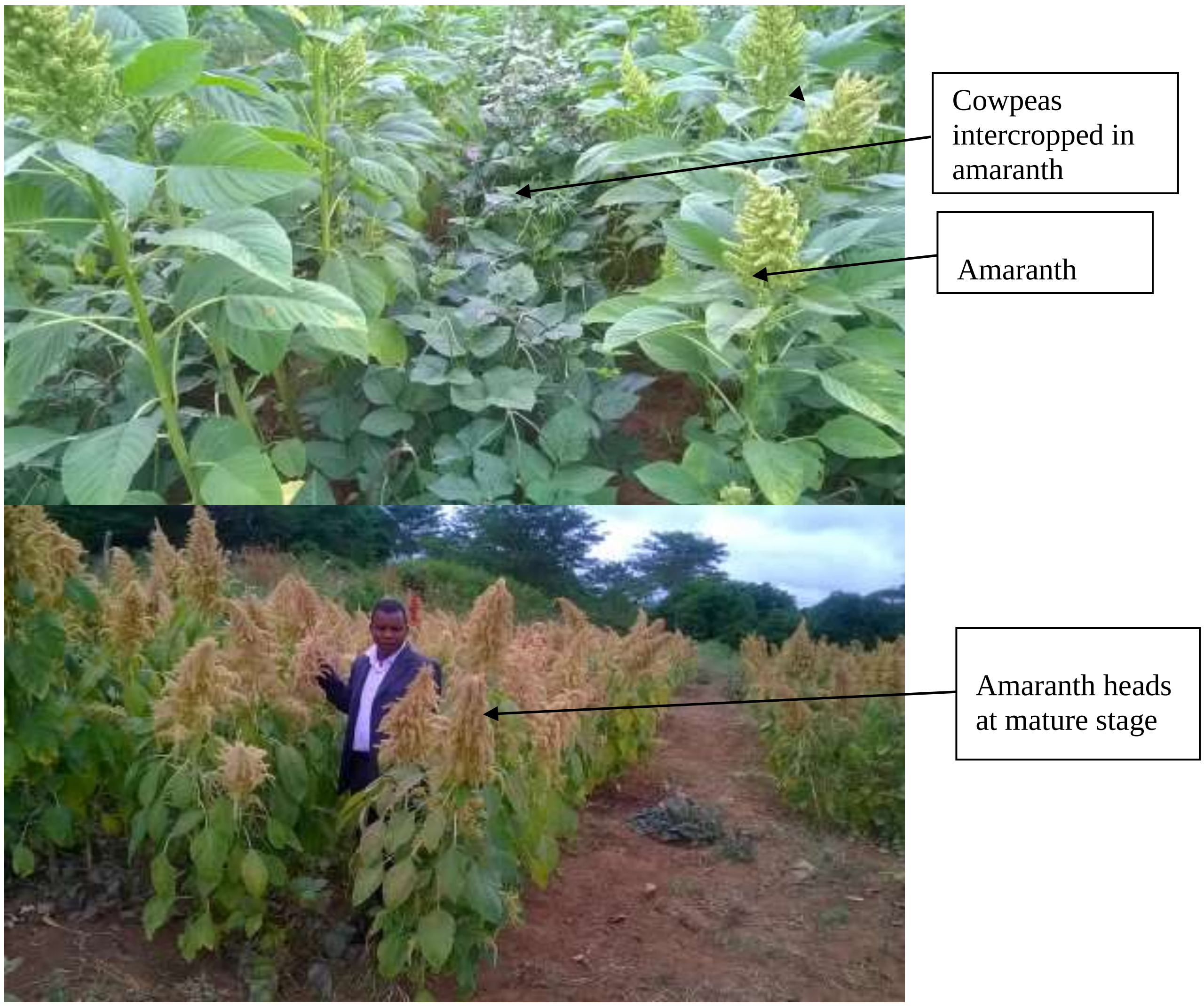
APPENDIX III: PHOTOS SHOWING AMARANTH INTERCROPPING



Photos showing cowpeas and green grams intercropped in grain amaranth at the experimental plots