SOCIO-ECONOMIC ANALYSIS OF PRODUCTION AND RESPONSE OF GRAIN AMARANTH (*Amaranthus caudatus L.) TO* FERTILIZER APPLICATION AND INTERCROPPING WITH MAIZE OR BEANS IN KISUMU WEST DISTRICT, KENYA

FRANCIS SIMIYU WEKESA

A THESIS SUBMITTED IN PARTIAL FULFILLMENT FOR THE DEGREE OF MASTER OF SCIENCE IN AGRICULTURAL RESOURCE MANAGEMENT IN THE DEPARTMENT OF PLANT SCIENCE AND CROP PROTECTION, UNIVERSITY OF NAIROBI

2010

Declaration

I hereby declare that this thesis is my original work and has not been submitted for a degree in any other University.

Candidate

Signature.......................................Date. 25-3-2010 ....

Francis Simiyu Wekesa

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

Signature.......................................Date. 25/3/2010 ....

Dr. Richard O. Nyankanga

Department of Plant Science and Crop Protection

University of Nairobi

Signature.......................................Date. 29/03/2010 ....

Dr. Richard N. Onwonga

Department of Land Resource Management and Agricultural Technology

University of Nairobi

Dedication

This work is dedicated to my wife Margaret and children, Effie, Mercy, Allan and Linet for their patience, support and understanding during the course.

Acknowledgement

I wish to acknowledge the Ministry of Agriculture for granting me paid stu leave and Lake Victoria Research Initiative (*VicRes)* for supporting resear work. Special thanks go to Mr. John K. Mungai, Director, Department of Poli and Agricultural Development and colleagues at the Ministry headquarters f their encouragement. The support of Messrs. Richard Ogira, Solomon Ombew Michael Omondi and Jonathan Atswong'o of Maseno University during fie survey and experiments is also highly appreciated.

I am equally grateful to my supervisors; Dr. Richard O. Nyankanga and D Richard N. Onwonga both of the University of Nairobi for their guidanc counseling and working tirelessly to ensure that I complete the thesis write up the stipulated time.

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List of Acronyms and Abbreviations

AIDS-Acquired immune deficiency syndrome

CAN- Calcium Ammonium Nitrate

DAP-Diammonium Phosphate

HIV-Human immunodeficiency virus

K- Potassium

KAPs- Knowledge, attitudes and practices

LER-Land equivalent ratio

N-Nitrogen

P-Phosphorus

PLWA-People living with HIV/AIDS

ABSTRACT

Protein malnutrition is widespread in developing countries due to prohibitive cost and low availability of animal protein foods and limited purchasing power of vulnerable groups. To ensure sufficient proteins for these vulnerable groups, alternative sources of cheap non-animal proteins must be sought. Grain amaranth is a promising option for meeting the protein requirements of the vulnerable groups in developing countries. It is a readily available and cheap plant food with protein quality and quantity comparable to those of animal foods. However, the crop is relatively new in Kenya. Its adoption and grain yields are low. In Kisumu West District, only 200 ha of the crop are grown annually against a cropped up area of 5800ha. The average grain yield is 1 t/ha compared to 2.5 t/ha achieved in other parts of the country. Determination of optimal fertilizer application rates and suitable intercropping patterns with staple crops could increase adoption and production. A strategy to boost production can be developed if current farmers' knowledge levels, utilization and perceptions of the crop together with agronomic, cultural and environmental factors that limit crop production and consumption are determined. Against this background, a survey was conducted in 2008 to document current knowledge, attitudes and practices (KAPs) regarding grain amaranth production and utilization in Kisumu West District, Kenya. Information was obtained from secondary sources and further investigated through Focus Group Discussions, key informant interviews and questionnaires administered to 84 farmers selected using stratified sampling techniques. Field experiments were conducted at the Maseno University Farm in the short rain season of 2008 and the long rain season of 2009 to determine the effect of intercropping grain amaranth with maize or beans and response of grain amaranth to nitrogen fertilizer and cattle manure. The rates of inorganic fertilizer tested were 0, 30, 60 and 100 kg N/ha. Cattle manure was applied at 0, 0.5, 1.0, 2.0 and 3.0 t/ha. The experiments were laid out in randomized complete block design and replicated three times. Single and double row intercrop arrangements were tested. Land equivalent ratios, aggressivity, relative crowding coefficients, competition ratios and gross margins for the intercrops were measured.

Farmers' knowledge on grain amaranth processing (34.6%), utilization (34.6%) and medicinal value (13.2%) was low. Farmers identified and ranked seven constraints to grain amaranth production as; unreliable rainfall (60.7%); lack of awareness on crop husbandry and utilization (53.6%); lack of seed (38.1%); lack of market (33.3 %); competition with other cereals (23.8%); inadequate capital (3.6%) and pests and diseases (2.4%). Double row intercrops had higher land equivalent ratios (1.44 –1.51) compared to single row (1.11-1.15) grain amaranth intercropping arrangements. In all intercropping arrangements, bean and maize intercrops showed variable LERs. In single row plant arrangements, maize and beans were dominant over grain amaranth but in double row intercrop arrangements, grain amaranth proved to be a better competitor. Maize showed the highest values of aggressivity (0.37), relative crowding coefficient (2.96) and

competitive ratio (1.39) in single row arrangement. In double row intercrop arrangement, grain amaranth had the highest values of 0.38, 15.49 and 1.81 for aggressivity, relative crowding coefficient and competitive ratio, respectively. The highest grain yields, 2.1 and 1.94 t/ha, were achieved at the N rate of 100 kg/ha in 2008 and 2009 respectively. When manure was applied, the highest grain yields of 0.67 and 0.79 t/ha were obtained at the manure rate of 3 t/ha.

Over the two years, bean/grain amaranth intercrop had 64% more returns compared to maize/grain amaranth intercrop. The optimum fertilizer rates based on regression analysis were 87.5 kg N/ha of inorganic fertilizer and 9.0 t/ha of cattle manure.

The current results show that intercropping maize with grain amaranth is more compatible compared to bean/grain amaranth intercrop. Grain amaranth can be intercropped with maize or beans in either single or double rows but preferably in double rows for greater yield advantages. It is recommended that grain amaranth production in the district be done using inorganic fertilizer at the rate of 87.5 kg N/ha or cattle manure at the rate of 9.0 t/ha. Concerted efforts by all stakeholders would be required to address farmers' constraints in a holistic way to ensure sustainable production of grain amaranth. Further work should be done to determine the performance of the crop with application of a combination of organic and inorganic fertilizers. This is in addition to the socio-economic implications for introducing grain amaranth in the district.

CHAPTER 1: GENERAL INTRODUCTION

1.1. Background Information

Protein malnutrition is widespread in developing countries due to the prohibitive cost and low availability of animal protein foods. This is in addition to limited purchasing power of the population (WHO, 2004). In Kenya, the most affected, and yet critically in need of protein energy, are infants, children, women of reproductive age and people living with HIV/AIDS. To ensure sufficient proteins for these vulnerable groups, alternative and sustainable sources of non-animal proteins must be sought.

Grain amaranth (*Amaranthus caudatus*) has the potential to substitute expensive animal protein because of its superior protein quality and quantity. It also grows fast and is high yielding under a wide range of agro-climatic conditions. The grain is easily digestible even by convalescents (Dehiya and Kapoor, 1994; Piha, 1995). Nutritionally, grain amaranth has high protein (15 to 18%), lysine, and calcium concentrations and lacks gluten (Petr et al., 2003). It contains reasonable amounts of lysine and methionine, two essential amino acids that are not frequently found in grains (Railey, 1993; Petr et al., 2003). It contains two times more calcium than milk. Using grain amaranth in combination with wheat, maize or brown rice results in a complete protein as high in food value as fish, red meat or poultry (Railey, 1993). The amino acid composition of grain amaranth protein compares well with the FAO/WHO protein standard (FAO, 1973; Teutonico and Knorr, 1985).

Kisumu West District is characterized by high levels of poverty, high population density, land fragmentation and protein deficiency. Grain amaranth with its potential to substitute expensive animal protein, needs to be promoted for adoption among the small scale resource poor farmers. Grain amaranth was introduced in the district in 2004 as a food security crop but its production and consumption has still remained low. Maize and beans are staple food crops in the district. Intercropping grain amaranth with maize or beans with application of fertilizers could enhance adoption of the crop and increase production.

1.2. Problem Statement and Justification

In Kenya, until recently, amaranth leaves were more commonly consumed than the grains (Alemu, 2005). Production and consumption of grain amaranth varieties is a more recent phenomenon and is still limited to a few areas such as Homabay, Bondo and Kisumu West districts of Nyanza Province (Yongo, 2009). In Kisumu West District, only 200 ha of the crop are grown annually against a cropped up area of 5800ha. Only 25% of the farmers use either inorganic or organic fertilizer in production of the crop. Moreover, the rates of fertilizer used are low. Nitrogen is applied at the rate of 28 kg N/ha compared to other areas where rates of up to 90 kg N/ha have been used. Manure is applied at the rate of 2 t/ha whereas the commonly advised manure rate is 5-10 t/ha. The average grain yield is 1 t/ha compared to 2.5 t/ha and 3 t/ha achieved with optimal use of fertilizers in Kenya and other countries respectively. Moreover, its response to fertilizer application and intercropping is not well known. Information on current knowledge levels, utilization and farmers' perceptions of the crop in the district is scarce. Little is known about agronomic, cultural and environmental factors that limit crop production and consumption. About 30% of increases in harvests by small scale farmers in the third world in the last three decades is attributable to the use of chemical fertilizers (Bunch, 1996). Of recent, there has also been widespread use of green manure crops, compost and boma manure for enhancing soil fertility and reducing dependency on outside sources of fertilizer (Bunch, 1996; Bernick, 2008). Studies show that nitrogen is the most limiting nutrient under most environments and the addition of nitrogen either as chemical fertilizer or manure significantly improves the growth and yields of grain amaranth (Jefferson Institute, 1999; Materechera and Medupe, 2006; Ojo et al., 2007).

Emerging crops like grain amaranth have the potential for improving food and nutritional security, providing diversity in food and agriculture, broadening the food base, enhancing utilization of underdeveloped food materials, and improving profitability of cropping systems (Kauffman and Weber, 1990).

Integration of grain amaranth into existing farming systems and use of fertilizers may increase adoption and yield of the crop by farmers. Intercropping is a common practice used by farmers to improve resource use efficiency, increase productivity or yield per unit area, diversify risks and reduce insect and disease damages (Fisher, 1996). Legume-grain amaranth intercrop systems may help boost small scale farmers' food security, enhance protein content of the diet, raise income levels, replenish soil fertility and increase adoption of grain amaranth by integrating it into the existing farming systems.

Knowledge of the response of grain amaranth to fertilizer application will lead to judicial use of fertilizer for optimum yields due to rising import and transportation costs plus health and environmental concerns.

1.3. Objectives

1.3.1. Overall objective

To increase grain amaranth production and utilization in Kisumu West District, Kenya.

1.3.2. Specific objectives

(i) Document current knowledge, attitudes and practices (KAPs) related to grain amaranth production and utilization in western Kenya.

(ii) Determine the effects of intercropping grain amaranth with maize or beans on growth, yield and profitability of grain amaranth.

(iii) Determine the effects of organic and inorganic fertilizers on growth, yield and profitability of grain amaranth.

CHAPTER 2: LITERATURE REVIEW

2.1 Origin, species and production of grain amaranth

Amaranth is an annual herb, not a "true" grain native to South and Central America (O'Brien and Price, 1983). It occurs mostly in temperate and tropical regions and can produce 40,000 to 60,000 tiny (1/32"), lens shaped seeds per plant (Railey, 1993). About 60 amaranth species are cultivated as leaf vegetables, cereals and ornamental plants while others occur naturally as weeds (Railey, 1993). Vegetable species are *A. tricolor, A. dubius, A. lividus, A. palmeri and A. hybridus*. Grain species are *A. hypochondriacus, A. cruentus* and *A. caudatus*. Grain colour may be white, yellow, or pink (Railey, 1993).

Amaranthus is one of the few genera whose species were domesticated in both the Old and New World. At least fifty tropical countries grow amaranthus. In Africa, Asia and the Americas, these are arguably the most widely eaten boiled greens. The U.S. has been the leading commercial producer of grain amaranth used in retail food products while the largest production area is believed to be in China where its forage is fed to hogs, rather than harvesting the grain (Myers, 1996; National Academy of Sciences, 2006).

In Kenya's rural areas, grain amaranth often grows naturally in open fields. At least every ethnic group has a name for grain amaranth, for instance, Kikuyu call it *Terere*, Waswahili's *Mchicha*, Luhya's *Omboga*, Luo's *Ododo*, Pokot's *Sikukuu* or *Chepkuratian*, Turkana *Lookwa* or *Epespes* and Teso *Ekwala* (Alemu, 2005).

Grains yields of up to 3 t/ha have been obtained in other countries when grain amaranth is grown in monoculture. However, average yields in farmers' fields have ranged from 0.25 to 1 t/ha depending on weather patterns and cultural practices (Grubben and van Sloten, 1981; O'Brien and Price, 1983).

There are two main grain amaranth varieties grown in Kenya, the short and tall varieties. The short varieties are suited for low rainfall areas while the tall varieties are for high rainfall regions. The crop is mainly grown in Central, Western and Nyanza provinces. A number of companies are involved in grain promotion and marketing. Most of these companies process and sell grain amaranth products. Amaranth International Ltd offers both local and export market (Yongo, 2009).

2.2 Grain amaranth production requirements

Grain amaranth grows best under humid conditions and can withstand hot climates. It thrives well in temperature range of 30-35° C. In the tropics, it grows at altitudes of 1000 m to 3500 m. Although it is extremely adaptable to adverse growing conditions and tolerates drought and low fertility, it does well under conditions ideal for maize (O'Brien and Price, 1983). Grain amaranth drought tolerance is due to; its C4 photosynthetic pathway which is efficient in utilization of sunlight and nutrients under dry, high temperature conditions; a deep and extensive root system and ability to go dormant under extreme drought conditions (O'Brien and Price, 1983). Observations indicate that grain amaranth may owe part of its drought tolerance to an ability to shut down transpiration through wilting, then recovering easily when moisture is available (Myers, 1996).

Adequate soil moisture is critical during germination and about three weeks after emergence. Grain amaranth water requirement is 42-47%, 51-62% and 79% that of wheat, maize and cotton respectively (Mwangi, 2003). Since grain amaranth plants grow rapidly and have high leaf surface areas that favour evapo-transpiration, watering the crop improves production (Mwangi, 2003). Warm temperatures of 15-18°C have been shown to be most favourable for biomass accumulation and seed production. Hot temperatures above 35°C cause a decline in seed yield. Seed production under cool and hot temperatures significantly decreases seed germination (Modi, 2006). 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 and Price, 1983).

2.3 Agronomic practices in grain amaranth production

2.3.1. Seed sources and planting of grain amaranth

Available seed material consists of selected lines that vary in, grain characteristics. Seeds are planted shallowly (1-2.5cm deep depending on soil moisture) in finely prepared soil to ensure good seed-to-soil contact. Deep planting may delay and decrease emergence. Seed germinates quickly when soil temperatures are 15°C to 18°C. Because of the shallow planting depth, drying out of the soil should be prevented until plants are established. Grain amaranths grow slowly during the first several weeks when weed control is critical. Once the plant is about a metre tall. it begins to grow rapidly and is competitive with weeds (O'Brien and Price, 1983; Webb et al, 1987; Myers and Putnam, 1988).

2.3.2. Spacing and field emergence

Narrow row spacing provides good early season weed control, but excessive self competition leads to reduced plant height, earlier flowering and maturity, and reduced yield. The typical field emergence of grain amaranth is 3-4 days. Grain amaranth seeds have been noted to imbibe moisture and start germinating under limited moisture conditions leading to ragged stands, where some plants emerge quickly, and others emerge later after rainfall, or not at all. Grain amaranth has been found to have no noticeable allelopathic effects on the following crop. Continuous planting of grain amaranth does not result in disease or insect accumulation although volunteer plants are common (Myers, 1996; Weber, 1987). Although grain amaranth tolerates a wide range of substrates, a light, sandy, well-drained, and fertile loam is desirable. Grain amaranth prefers soils with pH above 6 for establishment. Seeding rates of 1.2 to 3.5 kg seed/ha is recommended. Plant population density has a significant effect on grain yield, with the highest yields achieved at the lowest populations (Mposi, 1999; National Academy of Sciences, 2006).

Grain amaranth can be intercropped with a number of crops in various patterns. It can be sown around a field to protect the main crop against wind and animals. It can also be planted with the main crop in alternate rows or alternating in the same row. Grain amaranth may also be broadcast over the field after the main crop is sown in rows. It can also be cultivated as a volunteer or transplanted to spots where the main crop did not germinate. Grain amaranth has been intercropped with other cereals, legumes and various vegetables (Early, 1990; Harun-ur-Rashid et al., 2003; Ng'ang'a, 2008).

2.3.3. Response of grain amaranth to fertilizer application

There is little data available on the response of grain amaranth to fertilizer application. The most commonly advised fertility guide for grain amaranth has been 112 to 135 kg/ha of total available N, with a soil test of 15 to 30 ppm P and 80 to 120 ppm K (Mposi,1999). Fertility needs vary significantly in higher rainfall areas. Lower N rates can be used following legumes. Studies show that nitrogen is the most limiting nutrient under most environments. Phosphorous and potassium are only applied in soils that are especially deficient in these nutrients. Phosphorus at the rate of 50 kg P/ha is considered optimum (Myers and Putnam, 1988; Jefferson Institute, 1999; Ojo et al., 2007). Nitrogen application increases seed protein and linoleic acid content while maintaining essential amino acids and dietary fiber content. Very high nitrogen rates have been shown to reduce yields and promote excessive vegetative growth making the plants more susceptible to lodging (Thanapornpoonpong, 2004).

Uptake of N and P in the leaves of grain amaranth increases with increase in manure application rate. N uptake reaches a maximum at the manure rate which corresponds with the maximum dry matter yield. Manure rate has been shown to have no effect on residual soil N and Ca, but increases P, K, Mg and Zn. Manure application increases plant iron and crude protein content and raises the soil pH (Mhlontlo et al., 2006).

2.3.4. Grain amaranth susceptibility to pests and diseases

Pests: Grain amaranth is susceptible to the following pests; weevils, stink bugs, leaf rollers, cutworms, aphids, flea beetles, and mites (Yongo, 2009). The most common weevil is the pigweed weevil (*Hypoluxos hearkens*). 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.

Diseases: Grain amaranth has no major disease problems (Railey, 1993). However, some of the diseases that attack the crop are fungal and include damping-off (caused by *Pythium aphanidermatum* and *Rhizoctonia solani)* and Choenephora blight caused by *Choenephora cucurbitarium* (Yongo, 2009). Damping-off is favoured 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.

2.3.5. Physiological maturity, harvest and storage of grain amaranth

Grain amaranth matures faster at lower altitudes. The seeds are mature when they are opaque, easily separated from the heads and no water oozes out when crushed (Myers, 1996; Poverty Eradication Commission, 2007).

Lodging and the loss of seeds by shattering hamper mechanical harvesting. There are approximately 1100 seeds per gram of grain amaranth. Grain should be dried to about 11% moisture using ambient or heated air and foreign material removed to minimize the cost of transport and avoid molding in storage. A gravity table can be used to separate out foreign particles of the same size but of different weight. The grain should be placed in rodent proof storage with adequate ventilation to prevent a build-up of condensation. Grain can be stored for about seven years (Weber, 1987; Myers and Putnam, 1988).

2.4. Genetics and crop improvement

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 (Kulakow, 1990). 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.

2.5. Nutritional value of grain amaranth

The nutritional composition of the grain has been extensively studied (Bressani, 1990; Petr et al., 2003). Grain amaranth has a unique composition of protein, carbohydrates and lipids. It contains 15 to 18% protein, which is higher than most grains except soybeans (Petr et al., 2003). It also contains reasonable amounts of lysine and methionine, two essential amino acids that are not frequently found in grains (Railey, 1993; Petr et al., 2003). It is high in fiber and contains calcium, iron, potassium, phosphorus, and vitamins A and C. The fiber content is three times that of wheat and its iron content, five times more than wheat. It contains two times more calcium than milk. It also contains tocotrienols (a form of vitamin E) which have cholesterol-lowering activity in humans (Railey, 1993).

The amino acid composition of grain amaranth protein compares well with the FAO/WHO protein standard (FAO, 1973). It has a protein score of 67 to 87. By comparison, wheat (14% protein) scores 47, soybeans (37%) score 68-89, rice (7%) scores 69, maize (9%) scores 35. The grain therefore, has the potential to substitute expensive animal protein by complementing cereals (Bressani, 1990).

Grain amaranth seed protein differs from cereal grains by the fact that 65% is found in the germ and 35% in the endosperm; as compared to an average of 15% in the germ and 85% in the endosperm for cereals (Stallknecht and Schulz-Schaeffer, 1993). The carbohydrates in grain amaranth consist primarily of starch made up of both glutinous and non-glutinous fractions. Grain amaranth starch granules are much smaller (1 to 3 μm) than those found in other cereal grains. Due to the unique size and composition of grain amaranth starch, the starch may exhibit unique gelatinization and freeze/thaw characteristics which could be of benefit to the food industry. Considerations for the use of grain amaranth starch in food preparation of custards, pastes, and salad dressing have been studied (Singhal and Kulkarni, 1990a; Singhal and Kulkarni, 1990b).

Grain amaranth has other beneficial characteristics. Its oil contains a special component called squalene which is an important ingredient in pharmaceutical industries including skin cosmetics preparation. It is also used as a lubricant in servicing computers (Poverty Eradication Commission, 2007).

The lipid content of grain amaranth is generally higher than that for cereals and ranges from 5.4 to 10.0% on dry matter basis. The lipid is found mostly within the germ and has a high level of un-saturation (about 75%) and almost 50% linoleic acid, which is important in human nutrition (Becker et al, 1981). Allergens are not observed in grain amaranth and its grains may be used as an alternative source for non allergenic food products (Thanapornpoonpong, 2004).

2.6. Utilization of grain amaranth

Grain amaranth is used as a nutrition security crop and as one of the strategies for reducing poverty. It is eaten along with staple foods to compliment their nutrient density, improve the taste and to promote health. It is used for making porridge, roasted to create traditional beer or milled into flour and mixed with maize and wheat flour to make ugali, chapatti (flat bread) and mandazi (doughnuts). It is also used in multigrain products like breads, noodles, pancakes, cookies and breakfast cereals (Hackman and Myers, 2003; Muyonga et al., 2008). It can be popped and mixed with sugar solution to make confections. The grain is also used in fortifying food where the staple food is low in certain elements (Mnkeni et al., 2006).

Grain amaranth has been found to have medicinal values. It has been used in the management of diabetes, migraines, hypertension, liver disease, haemorrhage, TB, HIV/AIDS, wounds, kwashiorkor, marasmus, stunting, diarrhoea and skin diseases. It also contains dietary fibers important in prevention of coronary heart disease and cancer of the colon. Consumption of the grain has been known to enhance human growth and development, improve general health and strengthen body immunity (Legacy, 2003; Alemu, 2005; Spetter and Thompson, 2007).

2.7. Processing and value addition of grain amaranth

Grain amaranth can be processed in various ways. The toasted grain flour, which lacks functional gluten, is blended with wheat flour to produce more nutritious industrial products such as bread, pastry, biscuits, flakes, crackers, ice-cream, and highly digestible and absorbable lysine rich baby foods. The grains can also be poached, milled and used in gluten-free bread and pan cake-like chapatti (flat bread). The seeds can be cooked with other whole grains or added to soups and stews as a nutrient dense thickening agent. Sprouting the seeds will increase the level of some of the nutrients and the sprouts can be used on sandwiches and in salads, or just to munch on. Because grain amaranth has high protein and fat content, it can be processed into high energy foods (Morales et al., 1988; Railey, 1993).

The balance of carbohydrates, fats, and protein in grain amaranth products allow a balanced nutrient uptake with lower amounts of consumption than with other cereals. Heat processing removes lectins and improves digestibility and protein efficiency ratio of the grain and flour. However, excessive thermal processing reduces the quality of the grain. Temperature, load, and moisture affect the popping capacity, functional properties, nutritional quality, crude protein content, lysine content and sensory texture of the popped grain (Kauffman and Weber, 1990; Lara and Ruales, 2002).

CHAPTER 3: FARMERS' KNOWLEDGE, ATTITUDES AND PRACTICES (KAPS) RELATED TO GRAIN AMARANTH PRODUCTION AND CONSUMPTION IN WESTERN KENYA

Abstract

In Kenya, until recently, amaranth leaves were more commonly consumed than the grains. Production and consumption of grain amaranth varieties is a more recent phenomenon and is still limited to a few areas such as Homabay, Bondo and Kisumu West districts of Nyanza Province. A survey was conducted in 2008 to document current knowledge, attitudes and practices (KAPs) regarding grain amaranth production and utilization in Kisumu West District, Kenya. The study was undertaken to identify potential points for intervention in the development of strategy to increase production and utilization appropriate to the needs and circumstances of low-income, small-scale farmers. Information was obtained from secondary sources and further investigated using Focus Group Discussions and key informant interviews. Semi-structured questionnaires were administered to 84 farmers selected using stratified random sampling techniques to collect data on grain amaranth production, utilization and economic viability.

Farmers' knowledge was relatively low regarding processing (34.6%); utilization (34.6%) and medicinal value of grain amaranth (13.2%). Farmers identified and ranked seven constraints to grain amaranth production as; unreliable rainfall (60.7%); lack of awareness (53.6%); lack of seed (38.1%); lack of market (33.3

%); competition with other cereals (23.8%); inadequate capital (3.6%) and pests and diseases (2.4%).

The study concluded that concerted efforts by all stakeholders would be required to address production, processing, value addition and marketing challenges in a holistic manner to ensure sustainable production of grain amaranth in the region.

3.1. Introduction

Grain Amaranth has been identified as having the potential to improve world food situation as an alternative source of protein (National Academy of sciences, 2006). Yields of grain amaranth are however highly variable and depend on many factors. Weather patterns and cultural practices play a particularly important role. Yields in farmers' fields have been found to range from 0.25 - 1 t/ha (O'Brien and Price, 1983). In East Africa, until recently, amaranth leaves were more commonly consumed than the grains. Production and consumption of grain amaranth varieties is a more recent phenomenon in Kenya (Yongo, 2009).

Although the superior nutrition quality of grain amaranth has long been known, its production and consumption in Kenya is still limited. Western, Nyanza and Central provinces are the major growing areas (Yongo, 2009). In Nyanza province, Maseno and Kombewa divisions of Kisumu West District are some of the main regions growing the crop. Bondo district is the leading producer in Nyanza province.

Plenty of new agricultural technology has been developed, but rates of adoption are low. Too often, small scale farmers find that the new technology is unsuited to their conditions, or they lack the means and incentives to adopt it (Chambers et al., 1989; Macharia, 2005; Okoba and De Graaff, 2005; CIAT, 2006).

Van der Ploeg (1990) underscores the need to bring rural people and local knowledge into research because it is still impossible to understand agrarian development as a mere derivative of scientific progress. According to Gallagher (1999), farmer education should be provided in a participatory manner because farmers already have a wealth of experience and knowledge. It has also been found that when farmers learn about basics, combined with their own experiences and needs, they make decisions that are effective.

An understanding of farmers' perceptions and knowledge could therefore significantly strengthen the practical basis for exploring the potential approaches of intervention to increase grain amaranth adoption and increase yield and utilization. Since grain amaranth is a relatively new crop in Kenya, there are very few detailed studies of crop management and utilization by small-scale farmers. The present study was undertaken to identify potential points for intervention in the development of grain amaranth production strategy and utilization appropriate to the needs and circumstances of low-income, small-scale farmers. The study had two objectives: (1) to examine and record farmers' current practices and perception of grain amaranth production and utilization (2) to determine agronomic and cultural practices that may be limiting production and utilization

3.2. Materials and Methods

3.2.1 Site description

The study was conducted in Kombewa and Maseno divisions, Kisumu West District of Nyanza province (Figure 1) in the short rain season of 2008 and the long rain season of 2009.

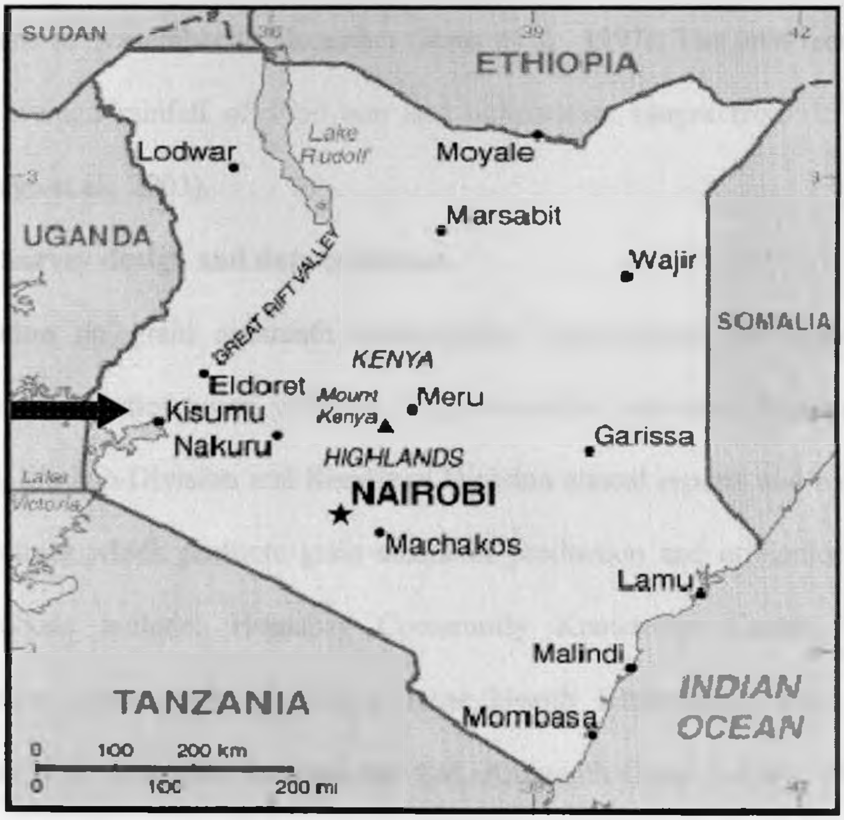

Figure 1: Map of Kenya showing the location of the study area

The agro-ecological zones for the two divisions are classified as lower midlands, semi humid and transitional (LM3 and LM4) while the upper areas are lower midlands subhumid (LM2) with pockets of lower midlands humid (LM1) and upper midlands sub-humid (UM3). The area lies within latitude N 0^0 1'-S 0^0 12' and latitude E 34^0 24'- E34^0 47'. The average altitude of the area ranges between 900-1470 metres above sea level. The major soil types in the two divisions are Nitosols, Acrisols, Vertisols, Regosols and Ferralsols (FAO, 2003).The rainfall distribution is bimodal in nature with the long rains received in March to July and short rains in September to December (Jama et al., 1997). The area receives an annual average rainfall of 1750 mm and temperature ranges from 15°C-31°C (Abednego et al., 2003).

3.2.2 Survey design and data collection

Information on grain amaranth consumption, geographical distribution and production statistics were obtained from secondary sources; Kisumu West District, Maseno Division and Kombewa Division annual reports and records of organizations which promote grain amaranth production and utilization. These organizations include: Homabay Community Knowledge Centre, Poverty Eradication Commission of Kenya, Incas Health International Ltd, African Amaranth Ltd, Amaranth International Ltd, Amaranth Grain Ltd and All Grain Company Kenya Ltd. The secondary data was reviewed to obtain information on current practices, extend of production and utilization of the crop. Important issues identified in the secondary data were then further investigated through Focus Groups Discussion (FGDs) and key informant interviews. All individual interviews were conducted in the local languages and only in a few cases was Kiswahili or English used.

The Focus Group Discussions (FGDs) were held with extension agents, local leaders, community nutrition and health personnel and farmer group representatives to pursue in greater depth issues that had not been sufficiently addressed in the secondary data. A FGD guide was developed and used to direct discussions. Key informants were further interviewed to provide information on current practices concerning grain amaranth production and utilization.

Semi-structured questionnaires were developed, pre-tested and administered to a total of 84 farmers selected using stratified sampling techniques (34 farmers from Maseno division and 50 farmers from Kombewa division). The grain amaranth-growing divisions in the district were chosen and within each division, farmers were selected at random across all the locations and sub-locations.

The questionnaire was used to collect the following data on production; in-field management, harvesting methods, post harvest handling, processing, utilization/ consumption patterns, marketing and economic viability of grain amaranth production in comparison to other crops. Other issues investigated were;

seasonality calendars, key players working on grain amaranth, education level, gender analysis to determine roles and responsibilities, community members' perception of grain amaranth products, interest in production and consumption, challenges faced and coping strategies.

3.2.3 Statistical analysis

Data collected during the survey was analyzed using the statistical package for social sciences (SPSS) to generate descriptive statistics such as percentages and means.

3.3. Results and Discussion

3.3.1 General characteristics of the households surveyed

Most of the farmers interviewed were male and were also the household heads. Only a small percentage of farmers belonged to common interest groups. Most farmers in the two divisions had either primary or secondary education and depended on crop production for income. The average acreage planted with grain amaranth by farmers in Maseno division was significantly higher than that in Kombewa division (Table 1).

Table 1: Demographic and socio-economic characteristics (%) of grain amaranth farmers interviewed in Kisumu West district

	Maseno Division (n=34)	Kombewa Division (n=50)	Weighted Mean (n=84)
Sex			
Male	70.6	64.0	67.9
Female	29.4	36.0	32.1
Status of farmer			
Household head	79.4	64.0	70.2
Not household head	20.6	36.0	29.8
Group association			
Belongs to a group	23.5	4.0	11.9
Does not belong to a group	70.6	90.0	82.1
Role in group			
Official	8.8	6.0	7.1
Member	91.2	94.0	92.9
Education level			
Primary (8 years)	47.1	48.0	47.6
Secondary (12 years)	44.1	42.0	42.9
Tertiary (15 years)	5.9	8.0	7.1
Source of income			
Crop sales	85.3	78.0	81.0
Livestock sales	32.4	46.0	40.5
Fishing	14.0	26.5	19.0
Off-farm employment	17.6	10.0	13.1

3.3.2 Reasons of growing and sources of information on grain amaranth

Most of the farmers interviewed indicated that the crop was being grown in a few homes following its introduction in 2004. Most farmers from both divisions were introduced to the crop by government officers working with the Ministry of Agriculture and the Poverty Eradication Commission. The average acreage planted was 0.91 and 0.38 acres in Maseno and Kombewa divisions respectively. The average acreage in the district was 0.59 acres. Information for the rest of the farmers was obtained from Christian Children's Fund, Kenya Agricultural Productivity Programme (KAPP). Anglican Church of Kenya, welfare groups and fellow farmers (Table 2).

Table 2: Farmers' (%) sources of information on grain amaranth as given in a survey in Kisumu West district

Source of information	Maseno Division (n=34)	Kombewa Division (n=50)	Weighted Mean (n=84)
Government officers	91.2	78.0	83.3
Christian Children's Fund	0.0	4.0	2.4
Kenya Agricultural Productivity Programme (KAPP)	2.9	4.0	3.6
Anglican Church of Kenya	0.0	2.0	1.2
Welfare groups	2.9	0.0	1.2
Other farmers	8.8	12.0	10.7

Farmers generally grew the crop for food or income. Some planted the crop because it was easy to grow, matured fast, as a source of employment or for its medicinal value (Figure 2).

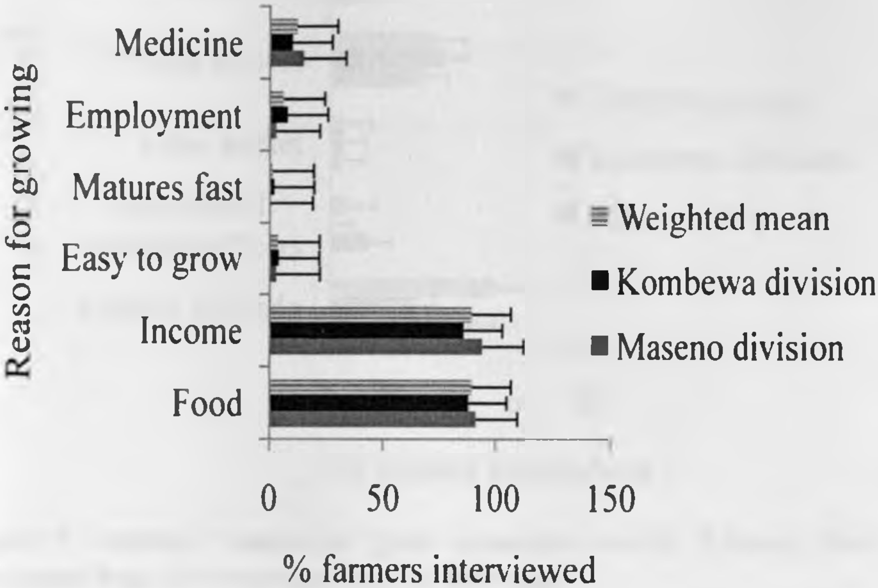

Figure 2: Reasons for growing grain amaranth as given by farmers in Kisumu West district. Horizontal bars show standard error of the mean

3.3.3 Grain amaranth varieties and seed selection

Farmers cultivated two main grain amaranth varieties, the short and tall varieties. The tall variety was planted by 86.5% of the farmers while 13.5% of the farmers planted the short variety. Farmers generally grew the variety that was readily available or was introduced first. Farmers who used certified seed got it from a stockist in Bondo town or through agricultural extension agents. The other farmers planted recycled seed from their previous harvest or acquired from other farmers and local markets (Figure 3).

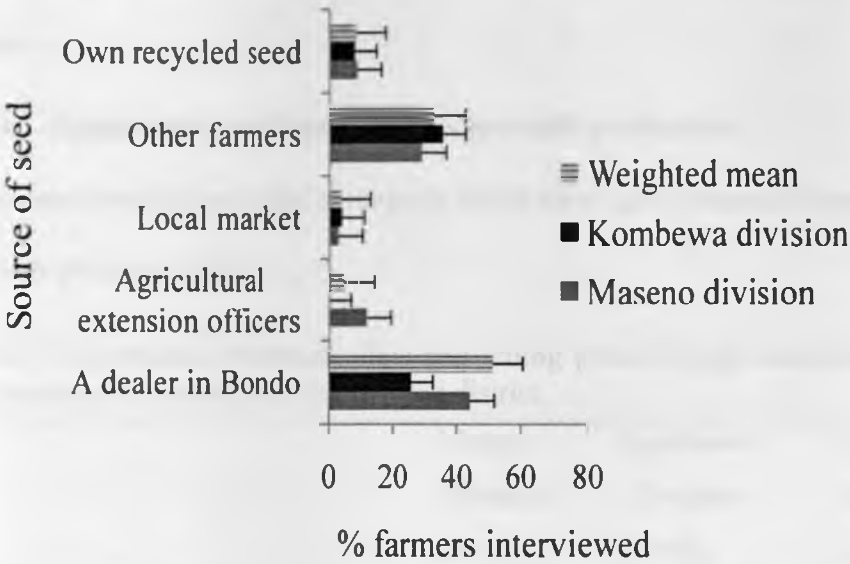

Figure 3: Farmers' sources of grain amaranth seed in Kisumu West district. Horizontal bars show standard error of the mean

The majority of farmers interviewed did not select seed before planting whereas others selected seeds which were properly dried; clean, shiny and well formed; mature; pest and disease free and one that had not been recycled many times.

Use of certified seed was limited. This can be explained by lack of improved varieties, high cost of seed, lack of local seed dealers and inadequate knowledge on husbandry occasioned by limited technical support and the fact that grain amaranth is a relatively new crop. Lack of seed dealers has been found to complicate the process of development of a new crop and to raise the cost of certified seed (Myers, 1996; CIAT, 2006). According to Muendo and Tschirley

(2004), the seed system may be strengthened by supporting the development of small scale seed production enterprises. This can be a cost effective way of making high quality certified seed available to small scale farmers at affordable prices.

3.3.4 Agronomic practices in grain amaranth production

There were variations in the agronomic practices of grain amaranth production for the two divisions (Table 3).

Table 3: Agronomic practices, yield and selling price of grain amaranth as given by farmers in a survey in Kisumu West district

	Maseno Division (n=34)	Kombewa Division (n=50)	Weighted Mean (n=84)
% farmers using DAP	8.80	10.00	9.50
% farmers using manure	17.60	14.00	15.50
Rate of DAP application in kg/ha	125.00	176.67	156.00
Rate of manure application in t/ha	2.14	2.40	2.29
Days to maturity of amaranth	80.14	79.80	79.94
Grain yield in kg/ha	941.59	1036.10	997.85
Selling price of grain in Ksh/kg	66.96	66.91	66.93
% farmers who sell grain amaranth	100.00	94.00	89.30

The percentages of farmers using DAP and manure at planting were very low in both divisions. There was no significant difference in the percentage of farmers using DAP at planting in the two divisions based on chi-square test with χ^2= 1.32, d.f.=1, p=0.25. Farmers in Kombewa division used significantly higher DAP rates at planting than those in Maseno division based on χ^2-test with d.f. =1, $p < 0.001$. No significant difference in the percentage of farmers using manure at planting was noted in the two divisions based on chi-square test with χ^2=3.5, d.f. =1, p=0.06. There was no significant difference in the rate of manure used at planting in the two divisions based on chi-square test with χ^2= 0.27, d.f.=1, p=0.6. Fertilizer use was minimal and the rates low. This could have negatively affected grain amaranth production in the district. A greater percentage of farmers used manure than chemical fertilizer. Apart from economic reasons, this could have been due to limited support from extension agents and the ready availability and relatively low cost of manure.

Significantly ($p < 0.001$) higher yields were obtained in Kombewa division than Maseno division based on χ^2-test with d.f. =1, $p < 0.001$. There was no significant difference in the selling price of grain in the two divisions. Most farmers either sold their produce or used it for domestic consumption. Only a small proportion shared their produce with common interest group members or other farmers as seed. Significantly higher yields were obtained in Kombewa division than Maseno division because of the higher rates of fertilizer used in Kombewa division and more technical support. This might have been due to the influence that the grain amaranth input and produce dealer in nearby Bondo town had on agronomic practices in Kombewa division. There was no significant difference in the market price of the grain in the two divisions probably because farmers relied on the same buyers.

Production process: The production process of grain amaranth followed the following steps; ploughing, manuring, harrowing, furrowing, planting, weeding, thinning, gapping, earthing up, removing off-types, spraying and harvesting. Farmers chose well drained soils (78.6 %) or fertile soils (51.2%) to grow grain amaranth. Some farmers (2.4%) chose land near the homestead for ease of bird scaring and security of the crop. It was also planted by 3.6% of the farmers as a rotation crop on striga infested land to control striga.

Land preparation was done shortly before rains or at the onset of rains. Some farmers only grew the crop during the long rains while others planted in both long and short rain seasons. Some farmers prepared land for grain amaranth after harvesting a major crop or when other farmers were preparing for the major cropping season (Figure 4). Responsibility for ploughing was for the household head (53.6%) or all family members (33.3%). In some instances, it was for hired labour, group members or the wife. Harrowing was done by 67.9% of the farmers. Responsibility for harrowing was for the household head (38.1%), all family members (22.6%) or hired labour (15.5%). In some instances, it was for group members or the wife.

Farmers grew the crop in one or both seasons. This could have been influenced by availability of land and other resources.

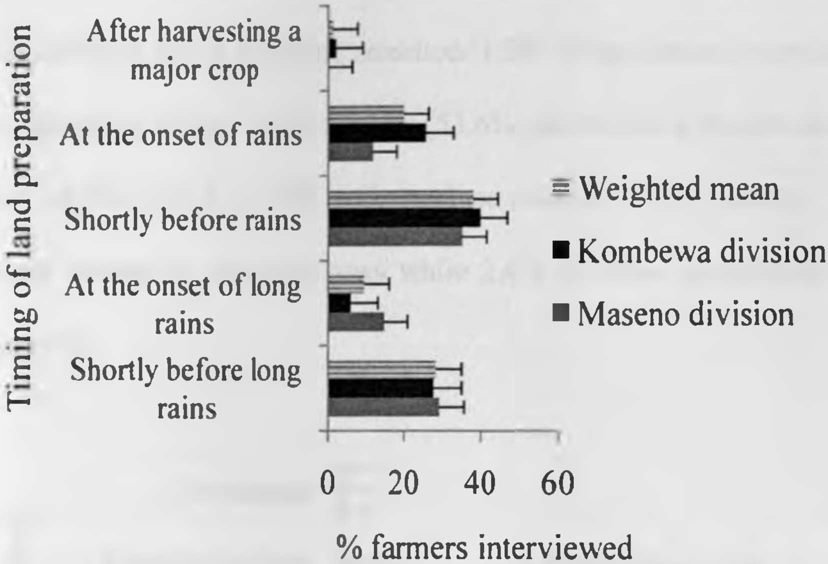

Figure 4: Timing of land preparation for growing grain amaranth in Kisumu West district. Horizontal bars show standard error of the mean

Land near the homestead was preferred. This was probably for security reasons and ease of pest control. Farmers who chose well drained soils and grew the crop in only one season could have been avoiding weather conditions in the other season which encourage disease development and favour emergence of certain weeds. Other studies have shown that well-drained and fertile loam soils free from weeds which germinate under conditions similar to those of grain amaranth are desirable to minimize soil-borne diseases and limit problems with weed control (Weber, 1987; National Academy of Sciences, 2006).

Planting: The majority (94%) of farmers believed land was ideal for planting when ploughed or harrowed to fine tilth. Members of common interest groups chose land with proof of ownership. 2.4% of the farmers considered soil type while 2.4% looked at moisture retention. 1.2% of the farmers interviewed planted after minimum tillage. Most farmers (53.6%) interviewed planted seed by drilling while 34.5% mixed it with soil, sand or manure before drilling. 9.5% of the farmers planted in holes in rows while 2.4% of those interviewed broadcasted (Figure 5).

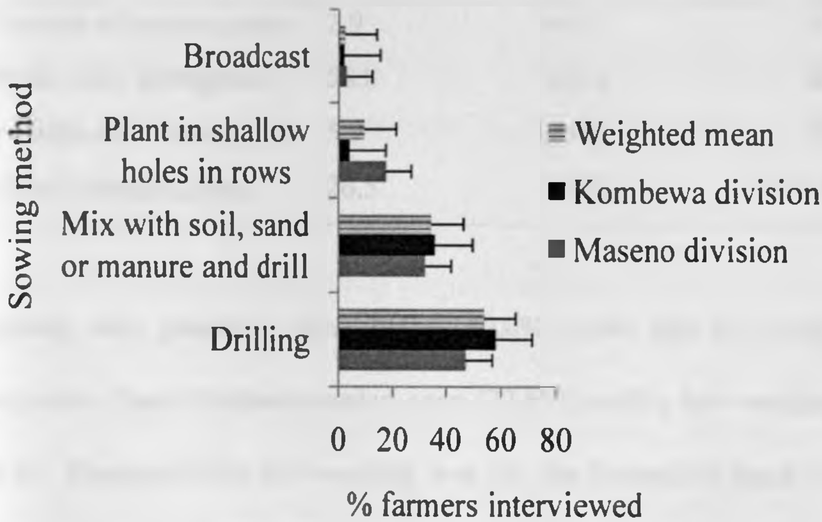

Figure 5: Methods used by farmers in sowing grain amaranth in Kisumu West district. Horizontal bars show standard error of the mean

About 11.9% of the farmers made shallow furrows about 1 inch deep using sticks or jembes before drilling seed. Many farmers mixed the seed with soil, sand or manure before sowing probably for spacing out the plants and attaining uniform seed dispersal since the seed is very small. Myers (1996) also found the tiny nature of grain amaranth seed to hamper uniform seed placement during sowing.

3.3.5 Timing of agronomic practices

Weeding: Most farmers (60.7%) carried out first weeding two weeks after crop emergence while others had no fixed weeding time (22.6%) (Table 4).

Table 4: Time of first weeding of grain amaranth as given by farmers in a survey in Kisumu West district

	Maseno Division(n=34)	Kombewa Division (n=50)	Weighted Mean (n=84)
Time of first weeding	% farmers	% farmers	% farmers
1-2 weeks after emergence	2.9	6.0	4.8
2 weeks after emergence	58.8	62.0	60.7
2-3 weeks after emergence	5.9	14.0	10.7
No fixed weeding time	26.5	20.0	22.6

Weeding was generally done twice (69.0%), two and six weeks after crop emergence. Some farmers weeded once (22.6%) with a few weeding three times (2.4%). Responsibility for weeding was for the household head (53.6%) or all family members (32.1%). In some instances (14.3%), it was for hired labour or group members. Weeding was done soon after crop emergence and repeated whenever weeds emerged. This could have been done to limit crop competition with weeds for nutrients, water and solar energy. Weber (1987) also reported the need to keep grain amaranth fields weed free and avoid competition at least early in the season when the crop is vulnerable to weed competition. Also, weedy amaranth could cross-pollinate with cultivated grain amaranth varieties resulting in loss of grain uniformity and complications in the cleaning process.

Thinning and gapping: Thinning and gapping were practiced by all farmers. These practices were done to attain the desired plant population during; first weeding (51.2%), 2 weeks after crop emergence (34.5%), 2-3 weeks after emergence (6.0%), when necessary (6.0%), at knee high (2.4%) and at flowering (1.2%). Responsibility for thinning and gapping was for all family members (9.5%), the household head (6.0%), children (2.4%) or the wife (2.4%). Thinning and gapping were probably done to take care of uneven seed placement and poor germination. Thinning and gapping have also been reported as intended to reduce inter-plant competition and attain optimum plant population respectively (O'Brien and Price, 1983; Weber, 1987; Myers and Putnam, 1988).

Earthing up, pruning and crop protection: Earthing up was done by heaping soil around the plant to encourage root development. This was only done by 20.3% of the farmers at flowering (11.9%), during weeding (3.6%), when necessary (3.6%) or at knee high (1.2%). Pruning was done to remove excessive branching. It was done by 20.3% of the farmers at flowering (11.9%), during weeding (3.6%) or when necessary (3.6%). Removal of off-types was done by uprooting grain amaranth plants which could be identified as being of another variety or line. Off-types were identified by observing their growth habit and plant or flower characteristics. Removal of these off-types was done by only 6.0% of the farmers interviewed at flowering (1.2%) or when necessary (4.8%). Spraying to control pests and diseases was done by 3.6% of the farmers when necessary. Farmers could have been heaping soil around the plants to counter effects of soil erosion and prevent the plants from being washed away by rain storms. Removal of excessive branching could have been done to encourage apical development and achieve a single well formed inflorescent. Off-types were probably removed to attain uniformity in the grain produced. Farmers sprayed the crop whenever necessary possibly to reduce losses brought about by pests and diseases. Spraying to reduce grain losses brought about by pests and diseases was done by 3.6% of the farmers when necessary. This low usage of crop protection chemicals could be contributing to low crop yields and grain quality. These findings are in agreement with those of other researchers who found that earthing up promoted root development; pruning maintained plant vigour; removal of off-types achieved uniformity and spraying reduced incidences of pests and diseases (O'Brien and Price, 1983; Weber, 1987; Myers and Putnam, 1988).

3.3.6 Harvesting

The farmers interviewed gave various signs of crop maturity. Most of them (48.8%) said the crop was ready for harvest when heads turned yellow then brown. About 40.5% of those interviewed knew the crop was mature when leaves turned yellow and heads turned yellow then brown, 15.5% of the farmers reported leaves to turn yellow, 7.1% expected seeds to start dropping while 2.4% experienced birds starting to feed on the grains. Some farmers (1.2%) knew the crop was ready for harvest after the expected period to maturity (Table 5).

Farmers in the two divisions harvested the crop by cutting the whole head using knives or by hand. Responsibility for harvesting was for the household head (54.8%) or all family members (33.3%). In some instances, it was for hired labour (16.7%) or group members (3.6%).

Myers (1996) and Poverty Eradication Commission (2007) found that grain amaranth seeds were also mature when they were opaque, easily separated from the heads and no water oozed out when crushed.

Harvesting was done manually by cutting the head despite grain losses that were occasioned through seed shattering and dropping on the ground. The tiny nature of the grains makes seed recovery from the soil difficult. This was probably due to the low scale of production, ready availability of relatively cheap labour and lack of appropriate mechanized harvesting, threshing and cleaning equipment.

Table 5: Indicators of grain amaranth maturity as given by int

	Masen Divisio
Indicators of grain amaranth maturity	% farm
Heads turn yellow then brown	50.0
Leaves turn yellow	17.6
Seeds start dropping	8.8
Leaves turn yellow, heads yellow then brown	38.2
Birds start feeding on them	5.9
Expected period to maturity	2.9

Farmers had a number of ways of knowing when the crop was ready for harvesting. Timely harvesting of the crop could then be done to reduce grain losses in the field. These pre-harvest grain losses may be due to damage caused by pests such as weevils, birds and monkeys; grains dropping due to the effect of wind or seed shattering and seed germination as a result of lodging or heavy rains. Studies have shown that waiting for the crop to dry in the field must be balanced against getting it harvested before pre-harvest losses from lodging or seed shatter due to the tiny nature of the seed (Weber. 1987; Myers, 1996; Jefferson Institute, 1999; Spetter and Thompson, 2007).

3.3.7 Grain handling

Different methods were used in grain handling after harvesting. Threshing was done manually by rubbing dry heads between palms before winnowing using trays to separate grain from the chaff. Drying of the grain was mostly done by spreading it in the sun on polythene sheets, canvass, cemented floor or any plain material. In most cases (36.9%), drying took 4 days but the drying period ranged from 3-7 days depending on the weather. Indications of proper drying of the grain as given by the interviewed farmers were; seeds dropping easily (85.7%), heads turning brown or dark brown (33.3%), heads becoming brittle (17.9%) or heads producing a crack sound when touched (4.8%). A few farmers (1.2%) expected properly dried grain to have low moisture content (Figure 6).

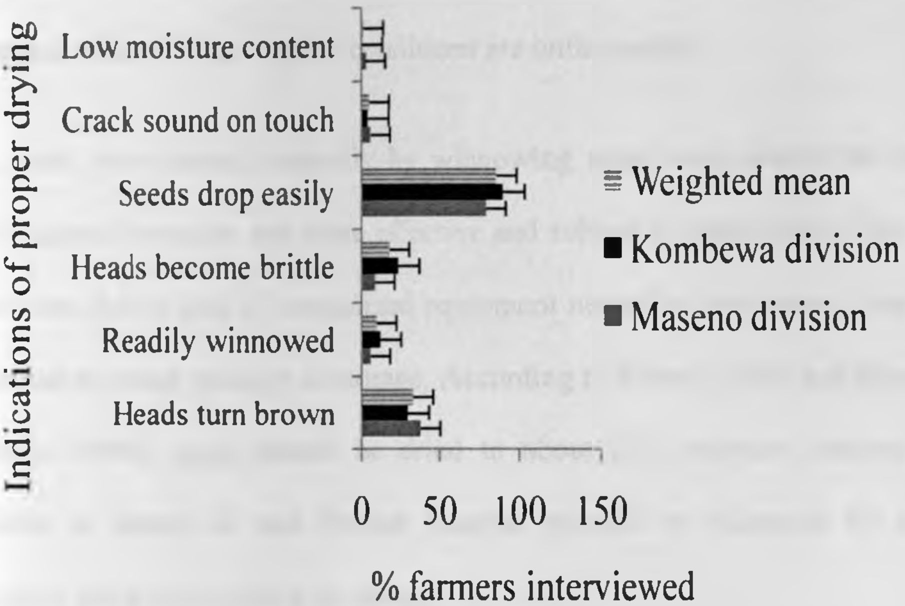

Figure 6: Indications of proper drying of grain amaranth in Kisumu West district. Horizontal bars show standard error of the mean

Grain was mostly dried by spreading it in the sun to reduce moisture content to 11-12% which is recommended for storage. Farmers could tell that this moisture content had been achieved after spreading the grain in the sun for 3-7 days depending on weather conditions until the whole grain looked bright and shiny and there was no further reduction in the volume of produce. This could be due to the small quantities of grain that farmers handle, adequate solar energy, lack of appropriate solar energy devices or lack of improved technology. This agrees with Weber (1987) and Myers and Putnam (1988) who reported that grain can be dried by moving ambient air or heated air over a pile of grain to enhance drying and that grain can also be dried by forcing air through perforated pipe under the pile, an option when drying weather conditions are unfavourable.

The grain was cleaned manually by winnowing using trays despite the process being labour intensive, not quite effective and subject to grain losses. This could have been due to lack of specialized equipment needed to adequately clean grain amaranth to avoid spoilage in storage. According to Weber (1987) and Myers and Putnam (1988), grain should be dried to about 11% moisture content using ambient or heated air and foreign material removed to minimize the cost of transport and avoid molding in storage.

3.3.8 Main constraints to grain amaranth production and processing

The farmers interviewed ranked the main constraints to grain amaranth production in order of priority as; unreliable rainfall with long dry spells within the growing period; lack of awareness about the crop; lack of seed; lack of market; competition for resources with other cereals; inadequate capital and pests and diseases (Figure 7). The growing and harvesting challenges of grain amaranth mentioned by the interviewed farmers include; long dry spells within the growing period; inadequate knowledge on crop husbandry; grain losses during harvesting; bird damage; inadequate capital; lack of seed and lodging.

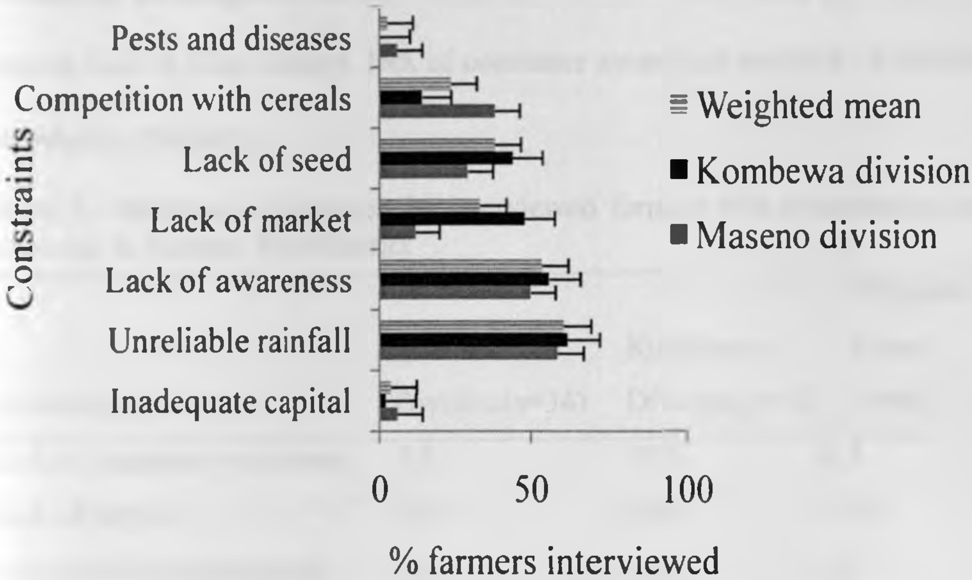

Figure 7: Main constraints to grain amaranth production in Kisumu West district. Horizontal bars show standard error of the mean

Bird damage was controlled by scaring through stone throwing and use of scare crows; planting the crop near homesteads for ease of surveillance; timing crop maturity to coincide with that of other cereals to spread birds and timely harvesting to reduce exposure and attack in the field. Farmers coped with lack of certified seed by use of clean, mature and what appeared disease free grain from the previous harvest, other farmers or local markets. Due to inadequate capital, farmers planted small acreages of the crop near cattle sheds with or without application of farmyard manure to minimize the cost of production. This could negatively affect prospects of commercialization of the crop. The main processing challenges were; grain losses during winnowing and drying, lack of small grain milling machines, labour scarcity and lack of value addition equipment.

Marketing challenges were identified as; low and fluctuating prices, lack of buyers, lack of local dealers, lack of consumer awareness and lack of packaging knowledge (Table 6).

Table 6: Problems experienced by interviewed farmers (%) in marketing grain amaranth in Kisumu West district

Marketing problems	Maseno Division(n=34)	Kombewa Division(n=50)	Weighted Mean (n=84)
Lack of consumer awareness	5.9	10.0	8.3
Lack of buyers	23.5	36.0	31.0
Low and fluctuating prices	32.4	44.0	39.3
Lack of packaging knowledge	2.9	0.0	1.2
Lack of local dealers	20.6	28.0	25.0

Marketing challenges were addressed through selling the grain in small packages to neighbours as seed or as part of diet, encouraging other farmers to venture into production to increase supply and attract dealers, bargaining and selling to any customer that came calling and encouraging middlemen to collect produce and pay after selling it to a dealer in Bondo. The interviewed farmers faced several constraints and challenges in producing grain amaranth. Farmers perceived different constraints to grain amaranth production depending on their socio-economic and infrastructural circumstances. Unless addressed, expanding crop production in the future could be hampered. According to Resource (2008), there is need for scientists to collaborate with farmers in addressing drought and soil degradation because rainfall has become more variable and less reliable over recent years. Cost effective structures and organizations should be established to provide services to the farmers. There should be elaborate programs to ensure farmers get reliable sources of certified seed, credible marketing channels, technical and financial support and control of pests and diseases.

Myers and Putnam (1988) also noted that perhaps the greatest problem facing the development of grain amaranth as a crop is finding sustainable markets for the grain and recommended that the crop should be grown after identifying a market and preferably after arranging a contract with a buyer. In Kenya, this could be done by establishing farmers' cooperative societies to provide inputs on credit with agreement that repayment is made on delivery of produce to the organization for marketing to identified local or export markets. This will require increased commitment to lending to the agricultural sector by the government, banks and other financial institutions. Private companies, non-governmental organizations, hospitals, hotels, supermarkets and food processors can also contract farmers to produce and deliver agreed quantities throughout the year.

3.3.9 Pests and diseases

Many farmers had not experienced any pest and disease problem. However, some farmers reported grain amaranth being attacked by the following pests; birds, aphids, stalk borers and armyworms. Weevils attacked the crop in the field and in storage. The crop has been reported to be susceptible to attack by; leaf-chewing insects like armyworms, amaranth weevils, flea beetles, leafhoppers, leaf miners and grasshoppers; larvae of moths and butterflies, caterpillars,and stem borers; birds; slugs and snails (O'Brien and Price, 1983; Myers and Putnam, 1988; Myers, 1996; National Academy of Sciences, 2006). Control of pests was done by stone throwing and use of scare crows (8.3%), using pesticides (4.8 %) and timely harvesting to escape attack in the field (1.2%).

Use of pesticides was not widespread among the farmers in the two divisions. Its production was done with minimal or no chemical crop protection measures. This could have been due to the relatively low incidence and severity of pests and diseases that attack grain amaranth, inadequate technical support, high cost of pesticides or use of alternative pest control methods. According to Eugene et al. (2009) and Aijaz et al. (2006), limited use of pesticides in crop protection could be due to farmers' lack of knowledge or economic constraints.

3.3.10 Grain amaranth storage

About 76.2% of the interviewed farmers stored the grain in grain stores. The other farmers (23.8%) stored the grain in the main house, on raised boards, in the store house, in the kitchen store or any damp proof place (Table 7).

Table 7: Places of storage (%) of grain amaranth according to farmers interviewed in a survey in Kisumu West district

Place of grain storage	Maseno Division(n=34)	Kombewa Division (n=50)	Weighted Mean (n=84)
Grain store	73.5	78.0	76.2
Main house	8.8	8.0	8.3
On raised boards	2.9	4.0	3.6
Store house	2.9	2.0	2.4
Kitchen store	0.0	2.0	1.2
Damp proof place	2.9	2.0	2.4

The types of containers used to store the grain were gunny bags (63.1%), plastic containers (50.0%) or polythene bags (4.8%). Many farmers (17.9%) said the grain could be stored for one year (10.7%). Others believed the grain could be stored for a long time when properly kept (10.7%) or properly dried (1.2 %). Some farmers had experiences of storing the grain for 1½ years (2.4%), 8 months (2.4%), 6 months (2.4%) and 3 months (2.4%). A number of farmers had not stored the grain before.

Farmers might have been storing grain in such containers to protect the grain from deterioration due to storage pest and disease attack and the vagaries of weather. This could prolong the storage period. Weber (1987) and Myers and Putnam (1988) found that when the grain was placed in rodent proof storage with adequate ventilation to prevent build-up of condensation, the grain could be stored for about seven years.

3.3.11 Stored grain amaranth spoilage

Causes of grain damage in store were identified as moisture, weevils, rats and pests and diseases (Figure 8).

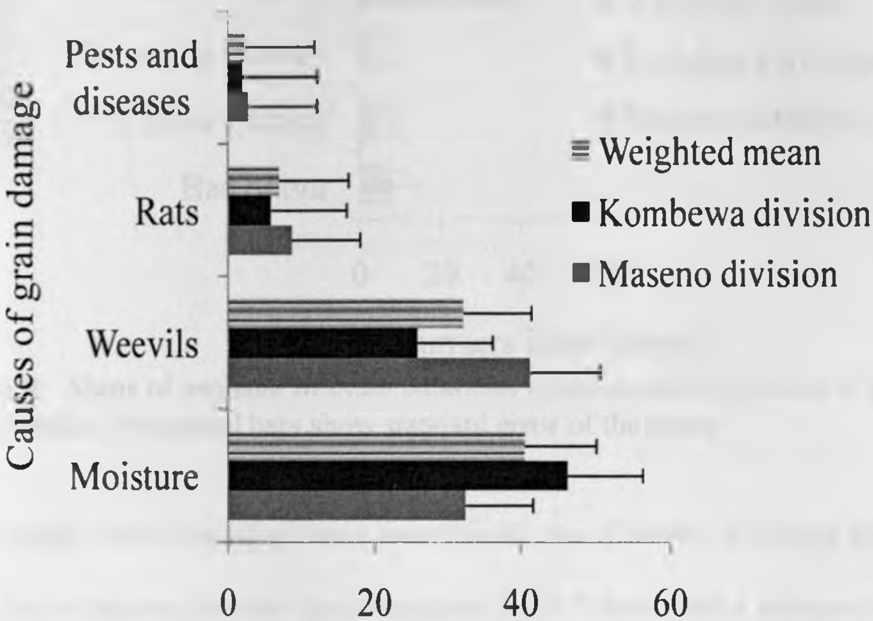

Figure 8: Causes of grain amaranth damage in store according to farmers in Kisumu West district. Horizontal bars show standard error of the mean

Farmers had experienced the following signs of grain spoilage; mouldy growth, presence of weevils, bad odour, colour change, dampness and grains becoming crumby (Figure 9).

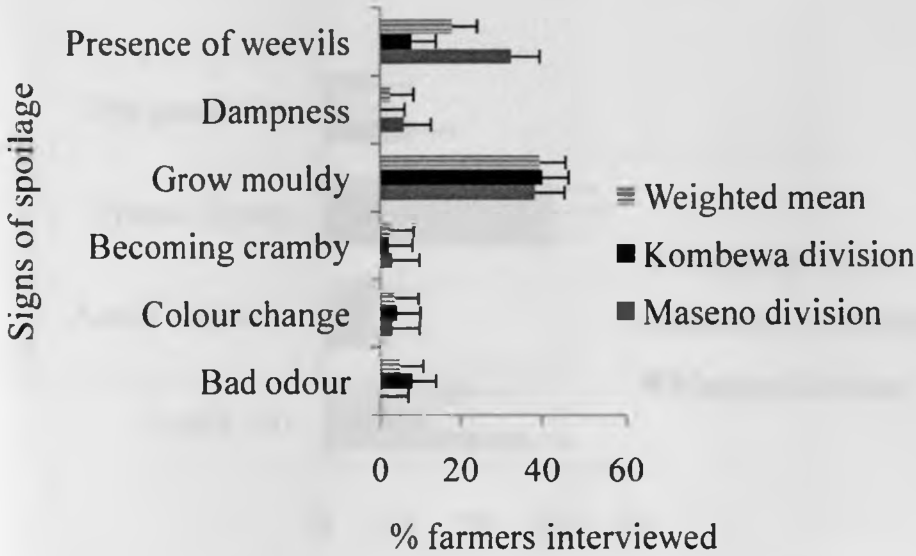

Figure 9: Signs of spoilage of grain amaranth experienced by farmers in Kisumu West district. Horizontal bars show standard error of the mean

The storage pests mentioned were weevils and rats. Control of storage pests was done by drying the grain in direct sunshine for 3-7 days until a moisture content of 11-12% was attained, applying ash, avoiding moisture and using pesticides (Figure 10). Other storage problems included dampness due to inadequate elevation of the store above the ground, type of container and moisture content (13.1%); rats (13.1%); rotting (3.6%) and theft (2.4%). Farmers used both modern and traditional insect pest control methods during grain storage. This was probably due to the indigenous technical knowledge acquired overtime, past experiences in grain storage, cost implications and the influence of extension agents.

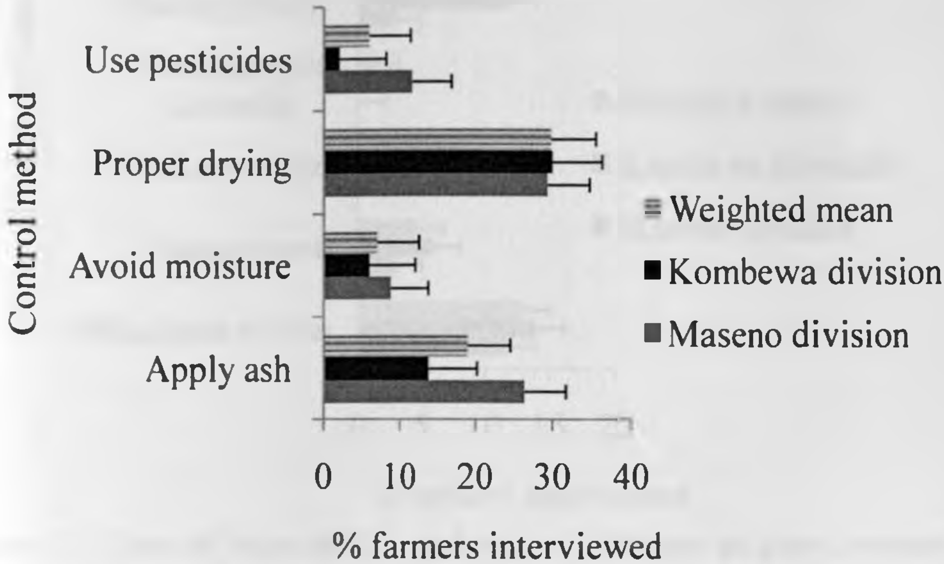

Figure 10: Methods used in control of storage grain amaranth pests in Kisumu West district. Horizontal bars show standard error of the mean

However, improper use of some traditional insect pest control measures may cause grain spoilage. Proper use of traditional measures like application of ash in grain storage has been found to be cost effective and to help reduce environmental and health hazards (Weber, 1987; Teshome et al., 1999; Odeyemi et al., 2006; Peter and Khamouane, 2007).

3.3.12 Farmers' utilization and processing of grain amaranth

About 34.6 % of the farmers interviewed carried out some form of processing of the grain. The main value addition process was milling the grain to flour. Other processes were making porridge, baking mandazi (doughnuts) and chapatti (flat bread) and popping grain amaranth (Figure 11).

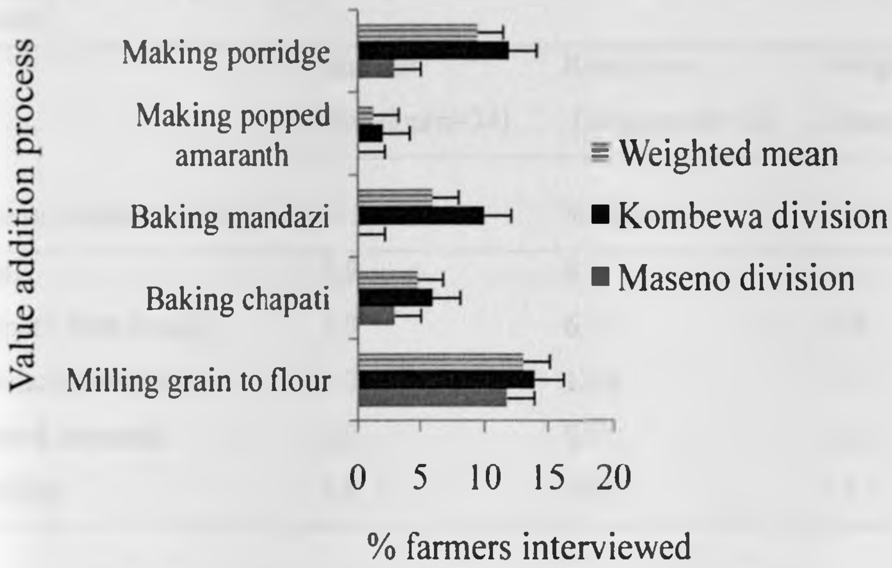

Figure 11: Types of value addition undertaken by farmers on grain amaranth in Kisumu West district. Horizontal bars show standard error of the mean

Processing of the grain could have been limited to these products because they are the ones commonly made from cereals in the region. The cost and availability of other ingredients and equipment required to exploit other uses of the grain could have been prohibitive. Knowledge on value addition and consumer preferences could also have been limiting.

The farmers interviewed consumed grain amaranth in different forms in this order of frequency: Porridge. Mandazi (doughnuts), ugali, chapatti (flat bread) and popped amaranth (Table 8).

Table 8: Forms of grain amaranth products consumed by farmers in Kisumu West district

	Maseno Division(n=34)	Kombewa Division (n=50)	Weighted Mean (n=84)
Type of product consumed	% farmers	% farmers	% farmers
Ugali	2.9	8.0	6
Chapatti (flat bread)	2.9	6.0	4.8
Mandazi (doughnuts)	0.0	12.0	7.1
Popped amaranth	0.0	6.0	3.6
Porridge	8.8	16.0	13.1

These products were consumed by babies, children, adults and patients. Current consumption patterns showed that 9.5% of the farmers only consumed grain amaranth products when available, 4.8% consumed once a day while 1.2% consumed once a week. Their desire was to consume these products regularly (9.5%) or daily (6.0%). Farmers interviewed did not consume grain amaranth products as often as they would have liked. This could have been due to low production of the crop, lack of suitable grain milling facilities, inadequate knowledge on utilization and the high cost of products. This is in agreement with the findings of Weber (1987) and Myers (1996) who found that when production of grain amaranth is low, the cost of grain amaranth products will be high and this limits consumption of the grain.

3.3.13 Farmers' perception of the medicinal value of grain amaranth

About 13.2% of the farmers interviewed were aware of the medicinal value of grain amaranth. Its consumption could help boost body immunity and treat dental diseases. It had also been used in the management of kwashiorkor, gout, high blood pressure, marasmus and diabetes (Table 9).

Table 9: Diseases managed/treated by consumption of grain amaranth products as perceived by farmers in a survey in Kisumu West district

	Maseno Division(n=34)	Kombewa Division (n=50)	Weighted Mean (n=84)
Disease treated	% farmers	% farmers	% farmers
Low immunity	0.0	6.0	3.6
Gum disease	2.9	0.0	1.2
Tooth ache	0.0	4.0	2.4
Kwashiorkor	2.9	0.0	1.2
Gout	0.0	2.0	1.2
High blood pressure	0.0	2.0	1.2
Marasmus	0.0	2.0	1.2
Diabetes	0.0	2.0	1.2

Among the interviewed farmers, consumption of grain amaranth had mostly been found to boost body immunity. Use of the crop for its medicinal value could be more prevalent among general consumers. Alemu (2005) also reported consumption of grain amaranth for its medicinal values in the private wings of Kenyatta National Hospital and in HIV/AIDS orphaned children's homes, where it is recommended for managing common diseases such as diabetes, hypertension, liver disease, hemorrhage, TB, HIV/AIDS, wound healing, kwashiorkor, marasmus and skin diseases.

3.3.14 Marketing of grain amaranth

The proportion of grain amaranth produce sold varied widely among the interviewed farmers and divisions. Most of them (48.8%) sold everything. About 39.3% sold three quarters of the produce, half the produce or a little as seed to neighbouring farmers. A few farmers (2.4%) did not sell any produce. Most of the produce (92.9%) was sold in the form of grain. Other farmers (9.5%) sold vegetables, flour and processed flour products. Most farmers (52.4%) sold their produce after some storage period. Some (25.0%) sold shortly after harvest while others (19.0%) sold any time a customer came calling.

The majority of farmers sold their produce at farm gate. Some sold at their local markets while a few sold in the nearby Bondo town (Table 10).

Table 10: Points of sale of grain amaranth according to farmers interviewed in Kisumu West district

	Maseno Division(n=34)	Kombewa Division (n=50)	Weighted Mean (n=84)
Point of sale	% farmers	% farmers	% farmers
At farm gate	85.3	78.0	81
Local market	14.7	20.0	17.9
Bondo town	0.0	6.0	3.6

Farmers generally sold produce to any willing buyer (60.7%). Others sold to aspiring farmers (28.6%), middlemen (13.1%) and those with young children (7.1%). Only 6.0% of the farmers sold their produce to a dealer in Bondo; 8.8% for Maseno division and 4.0% for Kombewa division. Grain was generally weighed and sold in kilograms or 90 kg bags. Some farmers sold in small quantities depending on demand.

Other products sold were vegetables and flour, which were sold at Ksh. 10 per bundle and Ksh. 125 per kg respectively. These prices were arrived at after bargaining between the parties concerned. Decisions regarding sale of produce and control of the resultant revenues were to a large extent taken by the household head (75.0%). The whole family, group members or the wife were responsible in a few cases.

Grain amaranth value addition: The following ways of increasing income from grain amaranth were advanced; processing grain into other products; packaging; producing more; identifying a reputable buyer; getting market for vegetables; better prices; seeking assistance from Government and NGOs; making it core business and improving quality (Table 11). Packaging entails getting the grain amaranth products standardized and certified by a recognized standards body. The products can be preserved and packed in suitable containers to increase shelf life and thereby increase farmers' bargaining power and hence improve incomes.

Table 11: Proposed ways of increasing income from grain am

	Maseno Division(n=
Ways of increasing income	% farmers
Packaging	2.9
Identify reputable buyer	5.9
Produce more	5.3
Process grain into other products	8.8
Sell more	2.4
Get market for leaf vegetables	5.9
Better prices	2.9
Seek aid from Government and NGOs	2.9
Make it core business	11.8
Improve quality	0.0

With appropriate labeling and bar coding, the products can be marketed more widely. There were very few traders and organizations involved in promotion and marketing of grain amaranth in the region. This could be attributed to lack of the spirit of entrepreneurship among the local people, poor farmer organization, lack of investment capital or traders and financiers being skeptical about the future of a relatively new crop. It could also have been due to lack of established marketing channels and consumer appeal.

3.3.15 Farmers' vision for the grain amaranth industry

Farmers advanced the following as their future plans on increasing production of grain amaranth; increasing production (44.0%), increasing crop area (8.3%), improving crop husbandry (7.1%) and increasing yields (6.0%) (Figure 12).

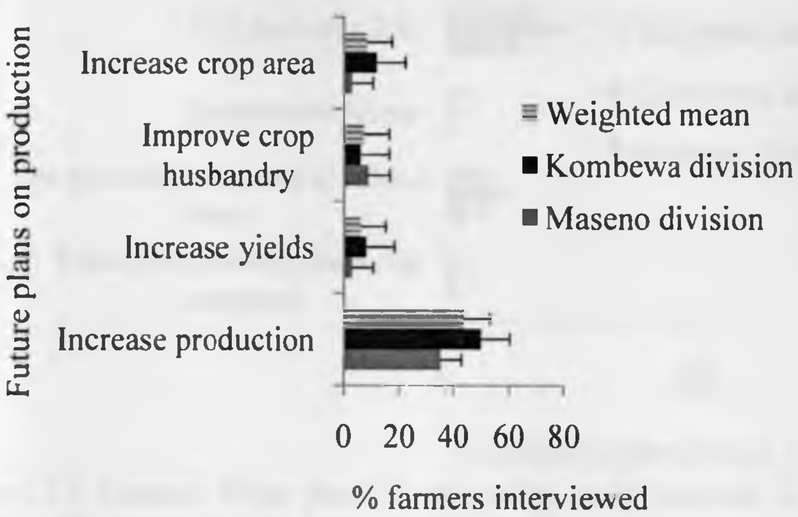

Figure 12: Farmers' future plans on increasing production of grain amaranth in Kisumu West district. Horizontal bars show standard error of the mean

Farmers' plans on household consumption of grain amaranth included; increasing household consumption (32.1%), introducing it as part of diet (15.5%), consuming more processed products (9.5%) and creating awareness on utilization (7.1 %).

Farmers had the following plans on value addition; mill grain into flour (36.9%); process flour into other products like bread, pastries, doughnuts and popped amaranth (17.9%); use appropriate processing machines to reduce losses (14.3%); form groups to buy processing equipment and; employ more labour to improve winnowing and threshing efficiency (1.2%) (Figure 13).

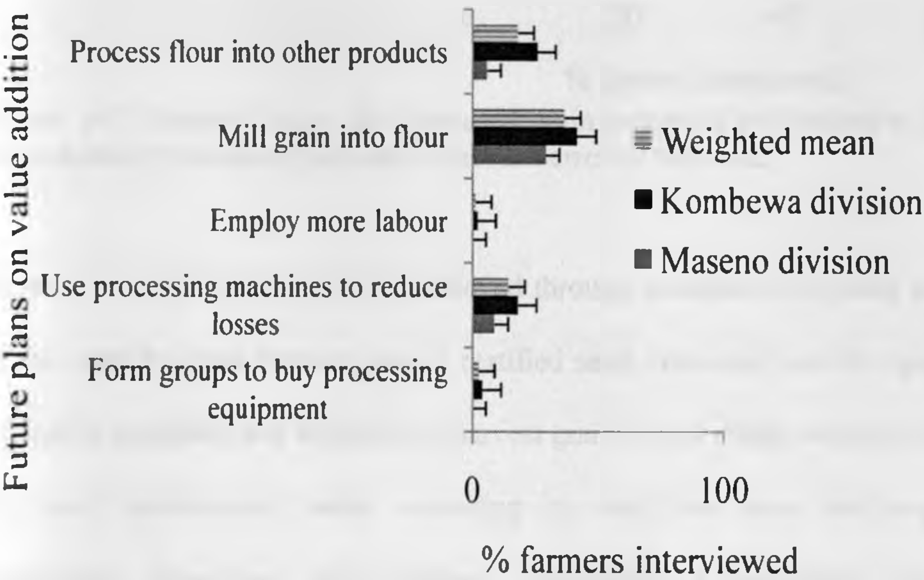

Figure 13: Farmers' future plans on processing grain amaranth in Kisumu West district. Horizontal bars show standard error of the mean

Generally, farmers had a positive perception of the crop and their vision was to; expand area under crop; expand production; increase productivity; use inorganic fertilizers; expand knowledge on the crop; form common interest groups and network linkages (Figure 14).

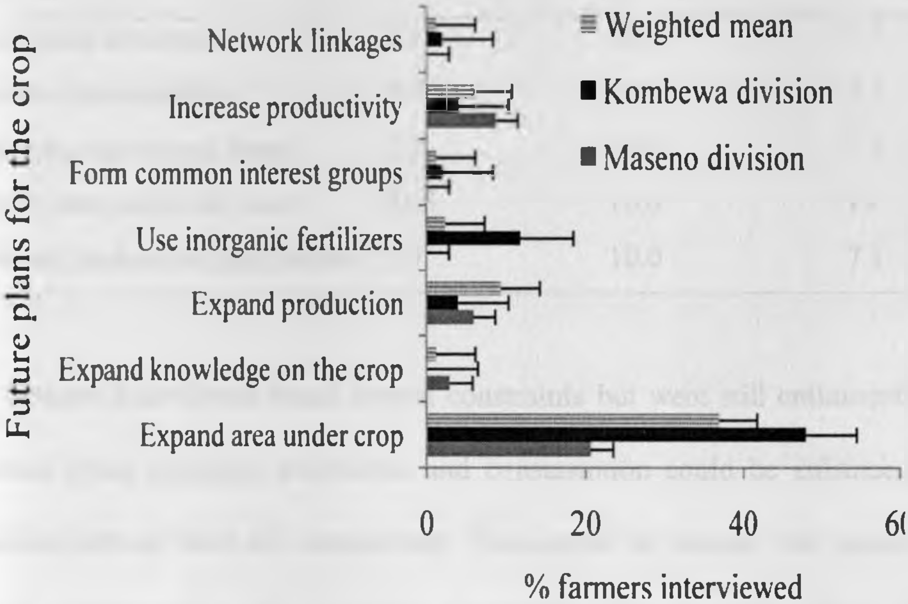

Figure 14: Farmers' vision for increased grain amaranth production in Kisumu West district. Horizontal bars show standard error of the mean

Increase in production would be achieved through increased crop area, adoption of the crop by more farmers, use of certified seed, increased use of organic and inorganic fertilizers and reduced pre-harvest grain losses. Other recommendations for crop development were; exploiting its medicinal uses; reaching more consumers; promoting value-addition; establishing a marketing board and establishing producer organizations (Table 12).

Table 12: Approaches to expanding grain amaranth production according to farmers interviewed in Kisumu West district

Approaches	Maseno Division(n=34) % farmers	Kombewa Division (n=50) % farmers	Weighted Mean (n=84) % farmers
Reach more consumers	2.9	10.0	7.1
Promote value-addition	5.9	8.0	7.1
Establish a marketing board	2.9	10.0	7.1
Venture into medicinal uses	23.5	16.0	19
Establish producer organizations	2.9	10.0	7.1

The farmers interviewed faced several constraints but were still enthusiastic and believed grain amaranth production and consumption could be enhanced with concerted efforts from all stakeholders. This could be because the farmers had limited opportunities for income generation and meeting their dietary requirements.

3.4. Conclusion and recommendations

Farmers' knowledge levels, attitudes and practices related to grain amaranth processing (34.6%), utilization (34.6%) and medicinal value (13.2%) were found to be relatively low due to inadequate technical support as the crop is fairly new. Production of the crop was limited by various agronomic, cultural and environmental constraints. The crop competed for allocation of land, labour and other resources with crops like maize, beans, cassava, sweet potatoes, groundnuts and vegetables. These crops had been grown for long and their husbandry practices were well understood and marketing channels established. The nutritional and socio-economic aspects of these crops were also better known. However, farmers expressed willingness to continue growing the crop and even increase production.

To enhance marketing, farmers need to establish producer organizations, create awareness about the crop and its utilization, try direct marketing and increase production for reduced consumer prices. Studies have shown that groups of persons with common interests can support each other, both with their individual experience and strengths, and to create a critical mass necessary for reducing production costs and responding to commercial opportunities (Gallagher, 1999; Muendo and Tschirley, 2004; CIAT, 2006).

There is need to collect and organize the information disseminated among different agencies on production, markets and value-addition so that it is useful for making decisions about the crop. According to Weber (1987); Myers (1996); CIAT (2006) and Spetter and Thompson (2007), private companies and non-profit organizations composed of scientists, growers and agribusiness can be formed to support development of the crop through information exchange and promotional activities.

Research has shown the benefits of educating customers about the benefits, uses and special qualities of a new crop. Merchandising may be useful in selling amaranth to new buyers. It could also be sold to local health food stores and bakeries or mailed to individuals in small quantities for their own food use. Growers could also specialize in organically grown grain for export (Weber, 1987; Jefferson Institute, 1999). In Kenya, organically grown food products can be exported by Amaranth International Ltd and Farmers Own. Amaranth International Ltd is a company promoting production and marketing of grain amaranth in Central Kenya and Nyanza province. Farmers Own is an association promoting better land husbandry with headquarters in the United Kingdom and involved in organic farming in western and central Kenya.

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CHAPTER 4: EFFECT OF INTERCROPPING GRAIN AMARANTH WITH MAIZE OR BEANS ON THE PERFORMANCE OF GRAIN AMARANTH (*Amaranthus caudatus L.)* IN KISUMU WEST DISTRICT, KENYA

Abstract

Production of grain amaranth in Kisumu West District is affected by low adoption and yields. Land fragmentation due to population pressure calls for judicial allocation of land to competing enterprises. Intercropping grain amaranth with suitable staple crops in appropriate patterns could increase adoption and production of the crop. Field experiments were thus conducted at the Maseno University Farm over two years to determine the effect of intercropping grain amaranth with maize or beans on the performance of grain amaranth. Single and double row intercrop arrangements were tested in a randomized complete block design. The experiment was replicated thrice. Land equivalent ratios, aggressivity, relative crowding coefficients, competition ratios and gross margins for the intercrops were computed.

Double row intercrops had higher land equivalent ratios (1.44 –1.51) compared to single row intercrops (1.11-1.15). In all arrangements, bean and maize intercrops showed variable LERs. In single row plant arrangements, maize and beans were dominant over grain amaranth but in double row intercrop arrangement, grain amaranth proved to be a better competitor. Maize showed the highest values of aggressivity (0.37), relative crowding coefficient (2.96) and competitive ratio

(1.39) in single row arrangement. In double row intercrop arrangement, grain amaranth had the highest values of 0.38, 15.49 and 1.81 for aggressivity, relative crowding coefficient and competitive ratio, respectively. Over the two years, bean/amaranth intercrops had 64% more returns compared to maize/amaranth intercrops. These results suggest that intercropping maize with grain amaranth is more compatible compared to bean/grain amaranth intercrop. Bean/grain amaranth intercrop was however more profitable. Grain amaranth can therefore be intercropped with maize or beans in either single or double rows but preferably in double rows for greater yield advantages.

4.1. Introduction

Intercropping has long been a common practice in developing countries because of potential advantages it offers in respect of improved utilization of growth resources by the crops and sustaining productivity from season to season. Farmers are motivated to adopt intercropping primarily due to its economic gains (McCrown et al., 1988; Nazir et al., 2002; Bhatti et al., 2006). In intercropping systems, when a legume is grown in association with another crop especially a cereal, the nitrogen of the associated crop may be improved by direct nitrogen transfer from legume to cereal (Giller and Wilson, 1991). Legumes with their adaptability to different cropping patterns and their ability to fix nitrogen, may offer opportunities to sustain increased productivity (Jeyabel and Kuppuswamy, 2001; Maingi et al., 2001). Legumes, grown both alone and as intercrops with cereals, have been advocated not only for yield augmentation but also for maintenance of soil health, particularly in degraded soil (Banik and Bagchi, 1994). Provided the morphology, growth habit, duration and spacing of the main crop is amenable to growing additional crops in the interspaces, intercrops may also improve the physical texture and fertility of the soil (Susan and Mini, 2005).

Grain amaranth production has the potential to improve the income of farmers in Kenya. In Kenya, maize and beans are staple food crops. Despite the nutritional qualities of grain amaranth, its production and consumption in Kenya is still limited and remain largely unexplored.

Incorporation of grain amaranth into existing farming systems may increase adoption of the crop by farmers. Intercropping grain amaranth may also help small-scale farmers to boost their food security and replenish soil fertility while raising income levels as well as improving their health. The objective of the current study was therefore to determine the compatibility of grain amaranth/maize and grain amaranth/bean intercrops in relation to growth, yield and profitability.

4.2. Materials and Methods

4.2.1. Site description

Field experiments to determine the effect of intercropping grain amaranth with maize or beans on the performance of grain amaranth were conducted during the short rain season of 2008 and the long rain season of 2009 at the Maseno University Research Farm, Maseno division, Kisumu West District and Nyanza province. The rainfall distribution is bimodal in nature with the long rains received in March to July and short rains in September to December (Jama et al., 1997). The area receives an annual average rainfall of 1750 mm and temperature ranges from 15°C-31°C (Abednego et al., 2003). During the experimental period, 1672 mm of rainfall was recorded in 2008 and 710.5 mm during the months of January-July, 2009. The mean temperatures during the experimental period were 20^0 C and the average maximum and minimum daily temperatures were 32^0 C and 17^0 C respectively. The major soil type in the farm is Acrisols (FAO, 2003). The initial soil characteristics were: Moderate total nitrogen (0.13%), low Mehlich phosphorus (3.95 ppm), high potassium (2.97 Cmol/kg), moderate organic carbon (1.37%) and moderately acid (pH water 5.03, pH $Cacl_2$ 5.8).

4.2.2. Treatments and experimental design

Prior to the commencement of the field experiments, the experimental farm had been under a weed fallow for 1year. Two crops; maize and beans were used to investigate the effect of intercropping on growth, yield and profitability of grain amaranth. Hybrid 513 maize and GLP 2 (Rosecoco) beans were used. Double and single row intercrop arrangements were tested. In double row intercropping, two rows of grain amaranth were alternated with one row of maize or beans. Under single row intercropping, a single row of grain amaranth alternated with one row of maize or beans. Control plots of sole grain amaranth, maize and beans were also set up. The experimental layout was a stratified randomized complete block design in which separate experiments were set up for maize and beans intercropping with three replications conducted over two seasons. The plot sizes were 5x4 m. The plots were 1 m apart with 1 m distance between the replicates.

4.2.3. Agronomic practices

Land preparation was done using a tractor powered disc plough and harrow. In double row intercropping experiments, rows of maize and beans were planted in separate plots at a spacing of 130cm and two grain amaranth rows spaced at 60 cm planted between rows of the main crop. In single row intercrops, planting was done at 60 cm between grain amaranth and maize or beans rows. For sole stands, grain amaranth was spaced at 30 x 60cm; maize at 25 x 75cm and beans at 5 x 45cm. The maize plant population was 53,333, 33,333 and 30,769 in sole crop; single row and double row intercrop arrangements respectively. The plant population of beans was 444,444, 166,667 and 153,846 in sole crop; single row and double row intercrop arrangements. The grain amaranth plant population was

55,555 as a sole crop; 27,777 as a single row intercrop and 51,282 as a double row intercrop. Nitrogen was applied to each plot at the rate of 48.5 kg/ha. Half of the nitrogen was applied at planting in the form of Diammonium Phosphate (DAP 18:46:0) and the balance top dressed as Calcium Ammonium Nitrate (CAN 26% N) six weeks after sowing. Split application of nitrogen was intended to minimize leaching and other losses by supplying the nutrient to meet the physiological demand and uptake ability of the crop. Weed control was through row cultivation using hoes. Weeding was done three times in the season; 3, 6 and 9 weeks after sowing. Aphids were controlled by the use of duduthrin insecticide. The bean fly was controlled by use of dimethoate systemic pesticide.

4.2.4. Data collection

Grain amaranth plant height and inflorescent length were measured on a weekly basis starting from 5 weeks after planting up to harvesting. Plant height and inflorescent length for each treatment were determined by getting the average of each parameter measured on five grain amaranth plants randomly sampled from the inner rows of each plot and tagged. Days to 50% flowering for each treatment were determined by getting the average of the period it took for half of the grain amaranth plants in each plot to flower. Days to harvest for each treatment were determined by the average period to physiological maturity. Grain yield for each crop was measured by getting the average grain weight at 12% moisture of all the plants harvested from the inner rows of each plot. Grain yields and gross margins were assessed by comparing results on different treatment plots. Financial analyses were based on the input costs and output income. Information on labour use was based on farmers' and work rates used at the University farm. Prices were collected from farmers and from local markets.

4.2.5. Soil sampling and analysis

Soil nitrogen, phosphorus and potassium were determined by sampling the top soil (0-20 cm). Soil analysis for N, P and K was done using standard methods of analysis as described by Okalebo et al. (2002). Analysis was done at the Soil Science Laboratory, Kabete Campus, University of Nairobi.

4.2.6. Competition factors

The following factors were used to determine competition among the intercrops.

1. Land equivalent ratio, $LER = \frac{Y_{ab}}{Y_{aa}} + \frac{Y_{ba}}{Y_{bb}}$

Where, Y_{ab} and Y_{ba} are the individual crop yield in intercropping and Y_{aa} and Y_{bb} are their yields as sole crop (Willey and 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 unity, 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 unity.

2. Competitive ratio (CR) was calculated by the formula proposed by Willey and Rao (1980) as

$CRa= (Y_{ab}/Y_{aa} \times Z_{ab}) \div (Y_{ba}/Y_{bb} \times Z_{ba})$,

where CR_a is competitive ratio for the component crop "a", Y_{aa} pure stand yield of crop "a", Y_{ab} intercrop yield of crop "a", Y_{bb} pure stand yield of crop "b", Y_{ba} intercrop yield of crop "b". Z_{ab} and Z_{ba} are sown proportions of crop "a" and "b" in an intercropping system. Competitive ratio is a measure of the ability of component crops in an intercrop system to resist suppression.

3. Aggressivity, $A_{ab} = \left[\frac{Y_{ab}}{Y_{aa} \times Z_{ab}} - \frac{Y_{ba}}{Y_{bb} \times Z_{ba}} \right]$

Where, Y_{ab} and Y_{ba} are the individual crop yields in intercropping and Y_{aa} and Y_{bb} are their yields as sole crop. Z_{ab} and Z_{ba} are proportion of land area occupied on intercropping when compared to sole crop for species 'a' and 'b' respectively (Mc Gilchrist, 1965). Aggressivity is a measure of the ability of component crops to utilize resources in an intercropping system.

4. Relative crowding coefficient, $RCC = K_{ab} \times K_{ba}$

Where, $K_{ab} = \frac{Y_{ab}}{Y_{aa}-Y_{ab}}$ and $K_{ba} = \frac{Y_{ba}}{Y_{bb}-Y_{ba}}$

K_{ab} and K_{ba} are the RCC for species 'a' and 'b' respectively (de Wit, 1960). Relative crowding coefficient is a measure of the ability of component crops in an intercrop system to dominate the other.

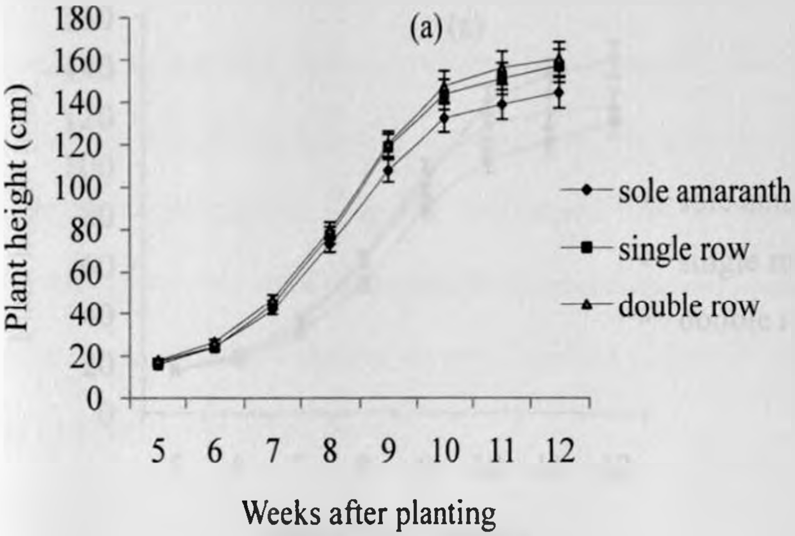
4.2.7. Statistical analysis

Data was subjected to Analysis of Variance using Genstat software and the differences in means compared by least significant difference at the 5% probability level. Data was analyzed using one way ANOVA. Differences between means for each treatment, gross margins and competition factors for the intercrops were computed to determine the effect of intercropping on the measured parameters of grain amaranth.

4.3. Results and Discussion

4.3.1. Effect of intercropping on plant height of amaranth

There were differences in the plant height of grain amaranth at harvest when grown as a sole crop and when intercropped. However, insignificant differences in plant growth occurred in the first 5 weeks after sowing. For all intercrop options with maize or beans, grain amaranth height increased slowly from planting up to six weeks after planting. The most rapid increase in height occurred at 7-10 weeks after planting before increasing slowly until it reached its maximum height in week 12 (Figures 15-16).



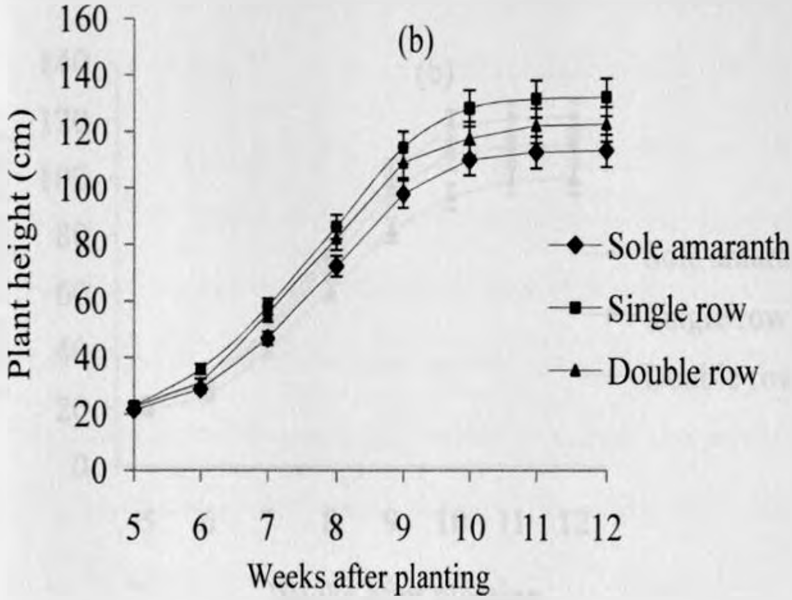


Figure 15: Effect of intercropping grain amaranth with maize on the height of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b). Vertical bars show LSD $_{0.05}$

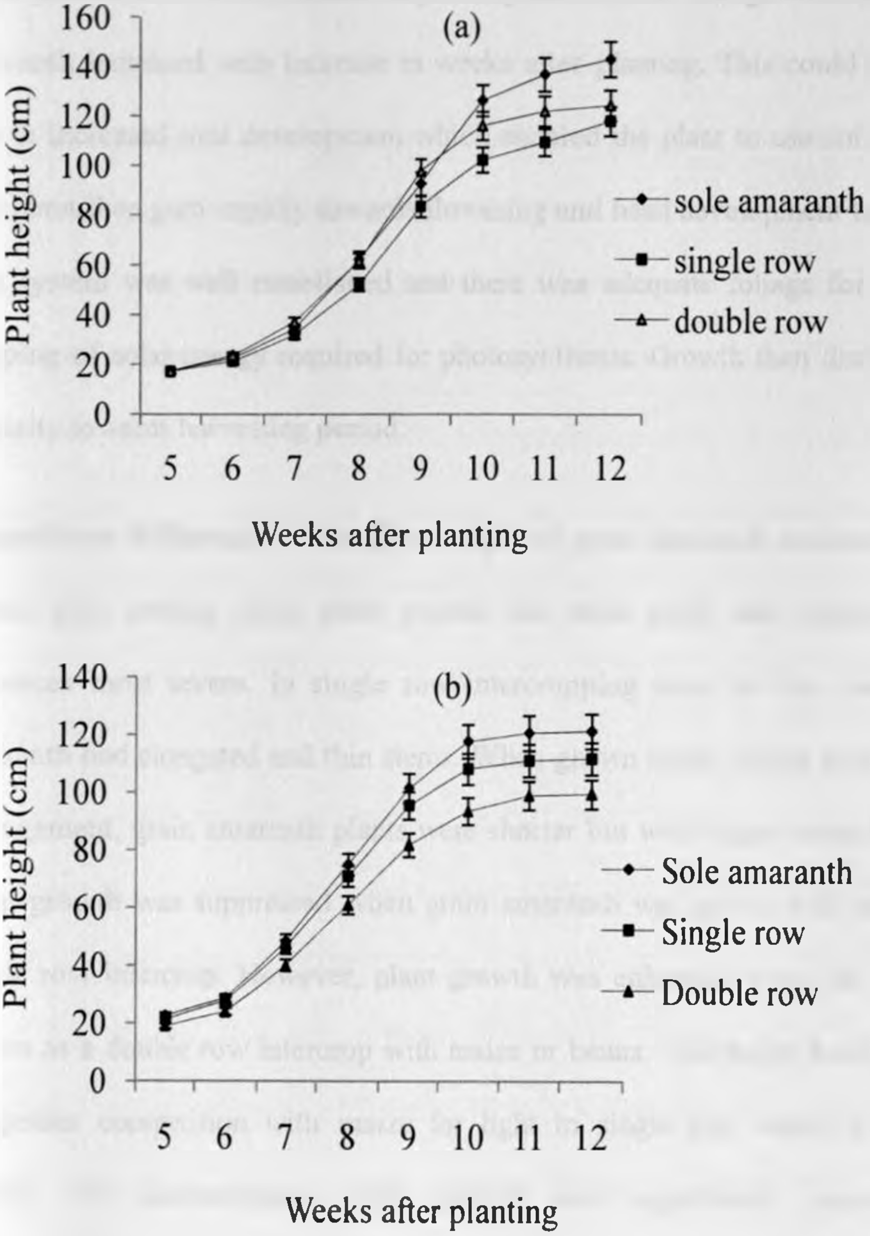


Figure 16: Effect of intercropping grain amaranth with beans on the height of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b). Vertical bars show $LSD_{0.05}$

Plant growth followed the normal sigmoid growth curve. The growth rate of grain amaranth increased with increase in weeks after planting. This could have been due to increased root development which enabled the plant to use soil nutrients. The plant then grew rapidly towards flowering and head development because the root system was well established and there was adequate foliage for increased trapping of solar energy required for photosynthesis. Growth then declined after maturity towards harvesting period.

Insignificant differences in the plant height of grain amaranth occurred at 7-10 weeks after sowing when plant growth was most rapid and competition for resources most severe. In single row intercropping over the two years, grain amaranth had elongated and thin stems. When grown under double row intercrop arrangement, grain amaranth plants were shorter but with bigger stem diameters. Plant growth was suppressed when grain amaranth was grown with maize as a single row intercrop. However, plant growth was enhanced when the crop was grown as a double row intercrop with maize or beans. This might have been due to greater competition with maize for light in single row intercropping than double row intercropping. Plant growth was significantly improved by intercropping grain amaranth with beans. This could have been due to beneficial interaction with the nitrogen fixing legume. More vigorous plant growth was achieved in 2008 than 2009. Crop development could have been depressed by moisture stress due to the low rainfall received during the growing period in 2009.

4.3.2. Effect of intercropping on flowering and maturity

There were differences in the inflorescent length of grain amaranth at harvest in the various plant arrangements. For all intercrop options with maize or beans, grain amaranth plants started flowering about five weeks after planting. Inflorescent length increased slowly from 5th-8th week before increasing rapidly in weeks 8-10 and then increasing slowly in the 10-12 week period (Figures 17-18).

In the two years of field experiments, about 50% of grain amaranth plants had flowered by the 7th week after planting in all intercropping arrangements with maize or beans. Grain amaranth showed no significant differences in the period to flowering and physiological maturity when grown as a sole crop or intercropped (Table 13).

Significant differences in flowering of grain amaranth occurred at 7-10 weeks after planting. When intercropped in single rows, grain amaranth had longer and smaller flowers when compared to the short but bigger heads that developed under double row intercrop systems. Flowering was enhanced when grain amaranth was intercropped with maize or beans in double rows. This could be because grain amaranth was more competitive and used nutrients more efficiently when grown as a double row intercrop.

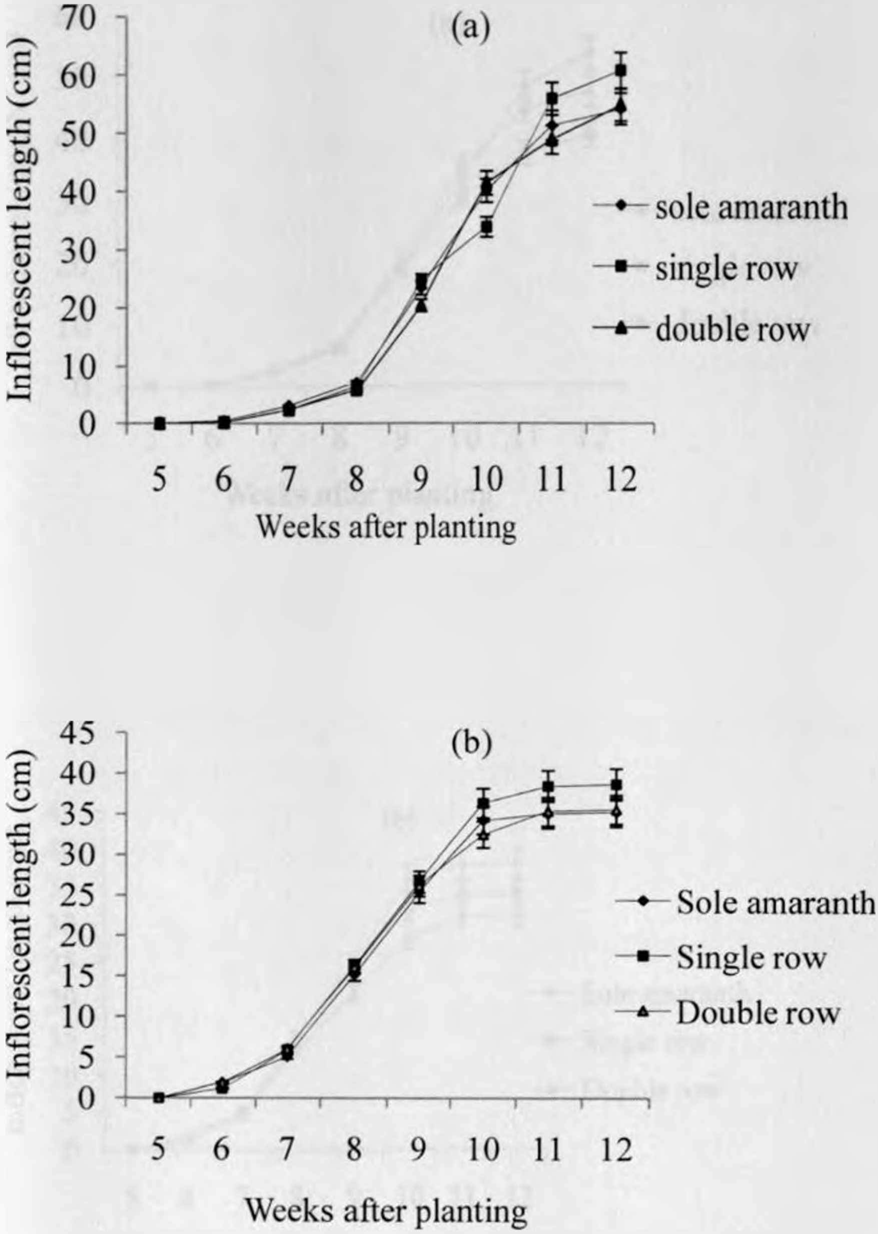


Figure 17: Effect of intercropping grain amaranth with maize on inflorescent length of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b). Vertical bars show LSD $_{0.05}$

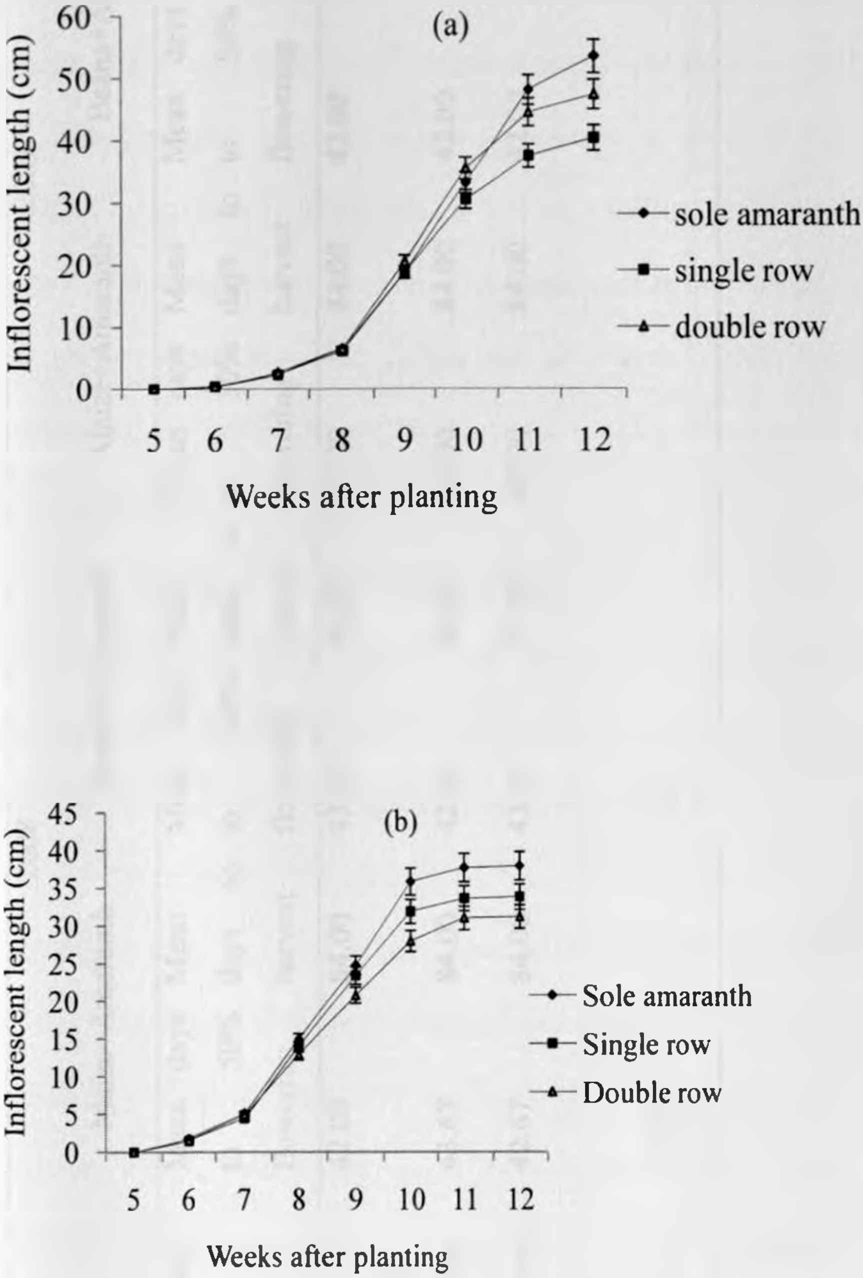


Figure 18: Effect of intercropping grain amaranth with beans on inflorescent length of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b). Vertical bars show $LSD_{0.05}$

Table 13: Effect of intercropping on duration to flowering and harvesting of grain amaranth in Kisumu West district

	2008				2009			
	Maize+Amaranth		Beans+Amaranth		Maize+Amaranth		Beans+Amaranth	
Treatments	Mean days to 50% flowering	Mean days to harvest	Mean days to 50% flowering	Mean days to harvest	Mean days to 50% flowering	Mean days to harvest	Mean days to 50% flowering	Mean days to harvest
Sole amaranth	42.00	84.00	43.33	84.00	42.00	84.00	42.00	84.00
Single row	43.67	84.00	42.00	84.00	42.00	84.00	42.00	84.00
Double row	42.67	84.00	43.33	84.00	42.00	84.00	42.00	84.00
LSD 5%	2.927		1.537					

More robust heads developed when grain amaranth was intercropped with beans than maize. This could have been because of beneficial effects of beans probably due to direct transfer of nitrogen fixed by beans to grain amaranth. Flower development was better in 2008 than 2009. This could be because flowering was enhanced by the higher rainfall received during the experimental period in 2008. These results suggest that plant height and inflorescent length combined with stem diameter and head size are necessary in determining plant competition in grain amaranth intercrops.

4.3.3. Effect of intercropping on competition factors

Land equivalent ratios (LER) showed yield advantages of intercropping over sole crops (Table 14). LER was greater than unity in all treatments. Competition ratios (Table 15), relative crowding coefficients (Table 16) and aggressivity values (Table 17) for the main crops were higher than those for grain amaranth in single row intercrop arrangements. Grain amaranth was more competitive than the intercrops in double row intercrop arrangements (Tables 14-17). Although double row intercropping is not commonly practiced by farmers in the district, double row intercropping of beans with maize has been done. Farmers should therefore find no problem adopting double row intercropping of grain amaranth with maize or beans. Land equivalent ratios represent yield benefits that are achieved in intercropping systems.

Table 14: Land equivalent ratios as influenced by grain amaranth intercropping arrangements in Kisumu West district

Treatments		Land equivalent ratio (LER)	
		2008	2009
Maize+Amaranth	Single row	1.15	1.13
	Double row	1.44	1.51
Beans+Amaranth	Single row	1.14	1.11
	Double row	1.48	1.51

In this study, land equivalent ratios were consistently more than one indicating that intercropping gave yield advantages over the sole crops. This means that more land would be required as sole crops to produce the yield obtained under single and double row intercropping situations. This yield advantage could compensate for difficulties in cultural operations when crops are intercropped. Land equivalent ratios were higher in double row than single row intercropping in all cases showing that double row intercropping could give better yield benefits that single row intercropping. Ssekabembe (2008) also found intercropping of garden egg (*Solanum aethiopicum*) with two rows of grain amaranth to give higher yield advantages (47%) than single row intercropping (39%).

Competition ratio is a measure of the extent to which one crop competes with the other in an intercrop arrangement. Competition ratios for the main crops were greater than those for grain amaranth in single row intercrop arrangements (Table 15). Between the main crops, maize had higher competition ratios indicating that it was more competitive than beans. This could be because maize utilized the resources more aggressively than beans and was able to recover from the effects of competition after grain amaranth was harvested. However, grain amaranth had greater competitive ratios in all double row intercrop arrangements. This means the main crops were more competitive for resources than grain amaranth in single row intercrop arrangements.

Grain amaranth, nevertheless, utilized growth resources more efficiently and dominated maize and beans when grown as a double row intercrop. This implies that maize and beans can be intercropped with grain amaranth in single rows without significantly reducing the yield of the main crop. These findings are in agreement with those of Wahla et al (2009) who noted that intercropping was desirable if the full yield of the main crop and additional yield from the intercrop could be achieved. These results suggest that although grain amaranth is a suitable intercrop for maize and beans when grown in single row intercrop arrangements, the crop is more compatible with maize.

Table 15: Competition ratio as influenced by grain amaranth intercropping arrangements in Kisumu West district

	2008				2009				Mean		
	Maize+Amaranth		Beans+Amaranth		Maize+Amaranth		Beans+Amaranth				
Treatments	Maize	Amaranth	Beans	Amaranth	Maize	Amaranth	Beans	Amaranth	Maize	Beans	Amaranth
Single row	1.31	0.76	1.24	0.81	1.47	0.68	1.16	0.86	1.39	1.25	0.78
Double row	0.66	1.52	0.46	2.17	0.67	1.49	0.48	2.07	0.67	0.47	1.81

The relative crowding coefficients of maize and beans were greater than those for grain amaranth in all single row intercrop arrangements (Table 16). In double row intercrop arrangements, grain amaranth had higher relative crowding coefficients. The greatest relative crowding coefficient was obtained when grain amaranth was intercropped with beans in double rows. This indicates that greatest yield advantages were achieved in this plant arrangement. Relative crowding coefficients for all intercropping systems were greater than the relative crowding coefficients of component crops indicating that yield advantages were achieved in all intercrop arrangements. Values of relative crowding coefficients for the intercropping systems suggest that in all single row intercrop arrangements, greater yield advantages were achieved with maize as the main crop. However, better yield advantages were obtained with beans as the main crop in double row intercrop arrangements.

Aggressivity values show the ability of component species in crop mixtures to utilize available resources. The main crops had positive aggressivity values in all single row intercrop arrangements while grain amaranth values were negative (Table 17). Maize had greater aggressivity values than beans. However, under double row intercrop arrangement, grain amaranth aggressivity values were positive and those of the main crops negative.

Table 16: Relative crowding coefficient as influenced by grain amaranth intercropping arrangements in Kisumu West district

	2008						2009					
	Maize+Amaranth			Beans+Amaranth			Maize+Amaranth			Beans+Amaranth		
Treatments	Maize	Amaranth	system	Beans	Amaranth	system	Maize	Amaranth	system	Beans	Amaranth	System
Single row	2.86	1.99	5.69	2.69	2.03	5.46	3.05	1.85	5.64	2.48	2.05	5.08
Double row	2.69	5.42	14.58	2.09	25.60	53.50	2.98	6.32	18.83	2.19	24.6	53.87

Table 17: Aggressivity as influenced by grain amaranth intercropping arrangements in Kisumu West district

	2008				2009				Mean		
	Maize+Amaranth		Beans+Amaranth		Maize+Amaranth		Beans+Amaranth				
Treatments	Maize	Amaranth	Beans	Amaranth	Maize	Amaranth	Beans	Amaranth	Maize	Beans	Amaranth
Single row	0.31	-0.31	0.24	-0.24	0.43	-0.43	0.17	-0.17	0.37	0.21	-0.29
Double row	-0.14	0.14	-0.65	0.65	-0.12	0.12	-0.59	0.59	-0.13	-0.62	0.38

The positive aggressivity values for the main crops show that they dominated grain amaranth which had negative values in single row intercrop systems. Grain amaranth was however more competitive and dominated the main crops in double row intercrop arrangements.

All the competition factors showed that maize was more compatible with grain amaranth as a single row intercrop than beans and that grain amaranth would exploit the resources more aggressively and suppress the main crops in double row intercrop systems.

4.3.4. Effect of intercropping on grain yield

There were significant differences in the grain yield of grain amaranth when grown as a sole crop and as an intercrop (Tables 18-19). Differences in grain yield of grain amaranth in various plant arrangements could have resulted from differences in plant height, inflorescent length, stem diameter and head size. The grain yields of both maize and beans were significantly increased by intercropping with grain amaranth in the two years. The grain yields of the main crops could have increased when intercropped with grain amaranth due to increased plant spacing under intercropping and better utilization of growth resources by the main crops resulting in better plant growth and flowering.

Table 18: Effect of intercropping on grain yield of grain amaranth in Kisumu West district

		2008				2009			
		Maize+Amaranth		Beans+Amaranth		Maize+Amaranth		Beans+Amaranth	
Treatments	Amaranth Plant population	Grain yield (t/ha)	Grain yield (g/plant)	Grain yield (t/ha)	Grain yield (g/plant)	Grain yield (t/ha)	Grain yield (g/plant)	Grain yield (t/ha)	Grain yield (g/plant)
Sole amaranth	55,555	1.41	25.38	1.28	23.04	1.2	21.6	1.23	22.14
Single row	27,777	0.7	25.2	0.65	23.4	0.55	19.8	0.63	22.68
Double row	51,282	1.15	22.43	1.23	23.99	1.01	19.7	1.18	23.01
LSD 5%		0.154	3.220	0.43	8.790	0.211	6.740	0.281	5.469

Table 19: Effect of intercropping on grain yield of maize and beans in Kisumu West district

			2008				2009			
			Maize+Amaranth		Beans+Amaranth		Maize+Amaranth		Beans+Amaranth	
Treatments	Maize plant population	Beans plant population	Grain yield (t/ha)	Grain yield (g/plant)	Grain yield (t/ha)	Grain yield (g/plant)	Grain yield (t/ha)	Grain yield (g/plant)	Grain yield (t/ha)	Grain yield (g/plant)
Sole crop	53,333	444,444	3.69	69.19	6.09	13.70	3.75	70.31	6.27	14.11
Single row	33,333	166,667	2.4	72.00	3.83	22.98	2.52	75.60	3.74	22.44
Double row	30,769	153,846	2.32	75.40	3.17	20.61	2.49	80.93	3.41	22.17
LSD $_{0.05}$			0.205	5.615	1.101	2.7110	0.581	13.870	0.422	2.085

When beans were intercropped with grain amaranth in double rows, the grain yield was less than that achieved in single row intercropping. This might be due to greater competition for light, soil nutrients and water offered by the two rows of grain amaranth. However, when maize was intercropped with grain amaranth in double rows, the grain yield achieved was higher than that attained under single row intercrop arrangement. This could be explained by differences in the growth habits of maize and beans which makes beans more susceptible to the effects of shading. Also, whereas beans and grain amaranth had similar periods to physiological maturity, maize matured much later. Therefore, the maize crop could have recovered from the effects of competition after the shorter maturing grain amaranth was harvested. These results are in agreement with the findings of Ssekabembe (2008) who reported that main crops faced greater competition when intercropped with grain amaranth in double rows than in single rows. Cenpukdee and Fukai (1991) had also reported more intercropping benefits when there was a greater difference in the duration of the crops.

Grain amaranth yields were significantly reduced by intercropping with maize. This could be because maize was suppressing grain amaranth growth by limiting its access to light, water and soil nutrients. When grain amaranth was grown as an intercrop with beans, yield increases were noted under both single row and double row intercrop arrangements. This could be because grain amaranth may have benefited from transfer of nitrogen from the nitrogen fixing beans. This is in agreement with Giller and Wilson (1991) who found that when a legume is grown in association with a cereal, the nitrogen requirements of the cereal may be improved by direct nitrogen transfer from legume to cereal. Ofori and Stern (1987) also reported that yield advantages from intercropping resulted from better growth resources in cereal/legume intercropping systems.

The grain amaranth yield reduction could be due to increased competition for nutrients, water, space and light for photosynthesis when grain amaranth was grown with maize in alternate rows. Maize plants could also be shading grain amaranth plants and limiting their photosynthetic ability leading to reduced foliage and grain yield. It has been reported by Anitha et al. (2001) that better branching coupled with high leaf area helps in tapping more photosynthetically active radiation resulting in better dry matter production and grain yield.

4.3.5. Effect of intercropping arrangements on gross margins of grain amaranth

All intercropping arrangements with maize or beans gave positive gross margins. (Tables 20-21)

Table 20: Effect of intercropping on the gross margin of grain amaranth in Kisumu West district in 2008

	Maize+Amaranth				Beans+Amaranth			
Item	Sole maize	Sole amaranth	Single row	Double row	Sole beans	Sole amaranth	Single row	Double row
Yield (t/ha)								
Main crop yield	3.69	-	2.4	2.32	6.09	-	3.83	3.17
Grain amaranth yield	-	1.41	0.7	1.15	-	1.28	0.65	1.23
Adjusted yield (t/ha)								
Main crop yield	3.14		2.04	1.97	5.18		3.26	2.69
Grain amaranth yield		1.20	0.60	0.98		1.09	0.55	1.05
Ouput income (Ksh/ha)								
Main crop income	78,413	-	51,000	49,300	155,295	-	97,665	80,835
Grain amaranth income	-	80,300	39,865	65,493	-	72,896	37,018	70,049
Subtotal (Ksh)	**78,413**	**80,300**	**90,865**	**114,793**	**155,295**	**72,896**	**134,683**	**150,884**
Input costs (Ksh/ha)								
Seed	2,875	750	2,170	2,350	5,000	750	2,250	2,420
Fertilizer	2,670	2,670	2,670	2,670	2,670	2,670	2,670	2,670
Land preparation	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500
Planting, weeding and thinning	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Harvesting, cleaning and drying	4,000	6,400	7,200	10,000	5,000	5,000	8,300	11,200
Gunny bags	4,800	1,600	4,000	4,900	6,800	1,420	4,600	5,000
Subtotal(Ksh)	**30,345**	**27,420**	**32,040**	**35,920**	**35,470**	**25,840**	**33,820**	**37,290**
Gross margin/ ha/season(Ksh)*	**48,068**	**52,880**	**58,825**	**78,873**	**119,825**	**47,056**	**100,863**	**113,594**

Table 21: Effect of intercropping on the gross margin of grain amaranth in Kisumu West district in 2009

	Maize+Amaranth				Beans+Amaranth			
Item	Sole maize	Sole amaranth	Single row	Double row	Sole beans	Sole amaranth	Single row	Double row
Yield (t/ha)								
Main crop yield	3.75	-	2.52	2.49	6.27	-	3.74	3.41
Grain amaranth yield	-	1.2	0.55	1.01	-	1.23	0.63	1.18
Adjusted yield (t/ha)								
Main crop yield	3.19		2.14	2.12	5.33		3.18	2.90
Grain amaranth yield		1.02	0.47	0.86		1.05	0.54	1.00
Ouput income (Ksh/ha)								
Main crop income	79,688	-	53,550	52,913	159,885	-	95,370	86,955
Grain amaranth income	-	68,340	31,323	57,520	-	70,049	35,879	67,201
Subtotal (Ksh)	**79,688**	**68,340**	**84,873**	**110,432**	**159,885**	**70,049**	**131,249**	**154,156**
Input costs (Ksh/ha)								
Seed	2,875	750	2,170	2,350	5,000	750	2,250	2,420
Fertilizer	2,670	2,670	2,670	2,670	2,670	2,670	2,670	2,670
Land preparation	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500
Planting, weeding and thinning	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Harvesting, cleaning and drying	4000	5,000	7,200	10,000	5000	5,000	8,300	11,200
Gunny bags	4,800	1,420	4,000	4,900	6,800	1,420	4,600	5,000
Subtotal(Ksh)	**30,345**	**25,840**	**32,040**	**35,920**	**35,470**	**25,840**	**33,820**	**37,290**
Gross margin/ ha/season (Ksh)*	**49,343**	**42,500**	**52,833**	**74,512**	**124,415**	**44,209**	**97,429**	**116,866**

Intercropping grain amaranth with beans gave 64% higher gross margins than when intercropped with maize. This shows that intercropping grain amaranth with beans was more profitable than intercropping it with maize. These results suggest that all intercropping options with maize or beans are profitable. However, greater gross margins were achieved by intercropping grain amaranth than growing it as a sole crop. These results are similar to other studies which found that generally, pure stands of grain amaranth gave the highest yields but intercropping had yield advantages and in terms of gross returns, grain amaranth production was more profitable under intercropping (Susan and Mini, 2005; Ssekabembe, 2008; Muoneke and Ndukwe, 2008).

4.4. Conclusion and recommendations

Yield advantages were obtained in all intercrop arrangements as indicated by LER values that were greater than one. Both maize and beans were dominant over grain amaranth in single row intercrop arrangement as indicated by their higher values of relative crowding coefficient, competitive ratio and positive sign of the aggressivity. However, grain amaranth dominated the main crops under double row intercrop arrangement. Intercropping grain amaranth improved the net returns per unit area. Although maize was more competitive than beans in all plant arrangements, greater financial benefits were achieved by growing grain amaranth as an intercrop in beans. These results suggest that intercropping maize with grain amaranth is more compatible compared to bean/grain amaranth intercrop.

Bean/grain amaranth intercrop was however more profitable. Grain amaranth can therefore be intercropped with maize or beans in either single or double rows but preferably in double rows for greater yield advantages.

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CHAPTER 5: EFFECT OF INORGANIC AND ORGANIC FERTILIZERS ON THE PERFORMANCE OF GRAIN AMARANTH (*Amaranthus caudatus L.*) IN KISUMU WEST DISTRICT, KENYA

Abstract

Grain amaranth has the potential to substitute expensive animal protein and its production should thus be promoted. Production of the crop in Kisumu West District, Kenya is limited by low yields. The average grain yield is 1 t/ha compared to 2.5 t/ha and 3 t/ha achieved with optimal use of fertilizers in Kenya and other countries respectively. This study investigated the effects of inorganic nitrogen fertilizer and cattle manure on the performance of grain amaranth. Field experiments, laid out in randomized complete block design, were conducted at the Maseno University Research Farm during the short and long rain seasons of 2008 and 2009 respectively. The treatments were different fertilizer rates; 0, 30, 60 and 100 kg N/ha applied as Diammonium Phosphate at half rate at planting and topped up with CAN as a top dress. Cattle manure was applied at the rates of 0, 0.5, 1.0, 2.0 and 3.0 t/ha.

The highest plant height and inflorescent length were realized with application of 100 Kg N/ha and 3 t/ha of inorganic fertilizer and manure respectively. Inorganic fertilizer at the rate of 100 kg N/ha significantly increased days to 50% flowering. There were no significant differences in days to 50% flowering for manure application rates of 1, 2 and 3 t/ha. Grain and dry matter yields increased with increased rates of inorganic fertilizer and manure.

The grain yield and gross margins in response to fertilizer application increased with increase in fertilizer application rates. The highest grain yields were achieved at the N rate of 100 kg/ha (2.1 and 1.94 t/ha in 2008 and 2009) and manure rate of 3 t/ha (0.67 and 0.79 t/ha in 2008 and 2009). Regression analysis showed a linear response of grain yield to fertilizer application. The optimum inorganic fertilizer rates were 90 kg N/ha and 85 kg N/ha while the optimum manure rates were projected to be 10 t/ha and 8 t/ha in 2008 and 2009 respectively. Over the two years, regression analysis showed that the average optimum inorganic fertilizer rate was 87.5 kg N/ha while the average optimum manure level was projected to be 9 t/ha. The grain yield at the average optimum fertilizer rates was 1.84 t/ha. The highest profitability was achieved at the inorganic fertilizer rate of 87.5 kg N/ha and manure rate of 9 t/ha.

The findings of the current study show that grain amaranth responds well to fertilizer and application of 87.5 kg N/ha of inorganic fertilizer or 9 t/ha of cattle manure gives maximum yield and gross margins and is recommended. Further studies are however recommended to test the response of grain amaranth to combined application of inorganic and organic fertilizers.

5.1. Introduction

There is widespread and severe protein energy malnutrition in Kenya and other developing countries due to poverty and inability of vulnerable groups to access adequate amounts of expensive animal protein foods to meet dietary requirements (WHO, 2004). Grain amaranth has the potential to substitute expensive animal protein because it has comparable protein quality and quantity.

In Kenya, grain amaranth was introduced as a food security crop in 2004. Despite its nutritional qualities, its production and consumption is still limited. This is partly attributed to the fact that little research has been done to determine the best agronomic practices to maximize grain production. About 30% of increases in harvests by small scale farmers in the third world in the last three decades is attributable to the use of chemical fertilizers (Bunch, 1996). However, in view of their escalating prices, green manure crops, compost and boma manure are increasingly being used for soil fertility management and thus reducing dependency on outside sources of fertilizer (Bunch, 1996; Bernick, 2008).

In Kisumu West District, only 25% of the farmers use either inorganic or organic fertilizer in production of the crop. Moreover, the rates of fertilizer used are low. Nitrogen is applied at the rate of 28 kg N/ha compared to other areas where rates of up to 90 kg N/ha have been used. Manure is applied at the rate of 2 t/ha whereas the commonly advised manure rate is 5-10 t/ha. The average grain yield is 1 t/ha compared to 2.5 t/ha and 3 t/ha achieved with optimal use of fertilizers in

Kenya and other countries respectively. According to Mposi (1999) fertility needs for grain amaranth production varies significantly depending on rainfall amounts and distribution. Studies show that nitrogen is the most limiting nutrient under most environments. Phosphorous and potassium are only applied in soils that are especially deficient in these nutrients. Phosphorus at the rate of 50kg P/ha is considered optimum (Myers and Putnam, 1988; Ojo et al., 2007). Jefferson Institute (1999) reported that lower N rates can be used following legumes and that animal manure can also be used to provide N. Further research is hence needed to better define the nutrient needs for growing grain amaranth (Kauffman and Weber, 1990).

The current research was undertaken to better define the nitrogen fertilizer and manure requirements for production of grain amaranth in Western Kenya. It is hypothesized that optimized fertilization of grain amaranth with inorganic fertilizer or cattle manure could lead to yield improvements and increase production and profitability.

5.2. Materials and Methods

5.2.1. Site description

Field experiments were conducted during the short rain season of 2008 and the long rain season of 2009 at the Maseno University Research Farm, Maseno Division, Kisumu West District of Nyanza Province. The rainfall distribution is bimodal in nature with the long rains received from March to July and short rains from September to December (Jama et al., 1997). The area receives an annual average rainfall of 1750 mm and the temperature ranges from 15°C-31°C (Abednego et al., 2003). During the experimental period. 1672 mm annual rainfall was recorded in 2008 and 710.5 mm during the months of January-July, 2009. The mean temperature during the experimental period was 20^{0} C and the average maximum and minimum daily temperatures were 32^{0} C and 17^{0} C respectively.

The major soil type in the farm is acrisols (FAO, 2003). The initial soil characteristics were: Moderate total nitrogen (0.13%), low Mehlich phosphorus (3.95 ppm), high potassium (2.97 Cmol/kg), moderate organic carbon (1.37%), moderately acid (pH water; 5.03 and pH 0.01 $Cacl_{2:}$ 5.8). Prior to the commencement of the field experiments, the experimental farm had been under a weed fallow for a year.

5.2.2. Treatments and experimental design

The experimental layout was a stratified randomized complete block design in which separate experiments were set for inorganic fertilizer and manure with three replications conducted over two seasons. . The plot sizes were 5x4 m. The plots were 1 m apart with 1 m distance between the replicates. The treatments were different fertilizer rates: (i) Inorganic fertilizer at 0, 30, 60 and 100 kg N/ha applied as Diammonium Phosphate and Calcium Ammonium Nitrate (CAN 26% N). (ii) Organic fertilizer (cattle manure) at 0, 0.5, 1.0, 2.0 and 3.0 t/ha. Inorganic fertilizer and manure were tested separately because while the use of manure is on the increase due to the relatively low cost, the use of chemical fertilizers remains static due to rising prices.

5.2.3. Agronomic practices

Initial land preparation was done using a tractor powered disc plough and harrow. Thereafter, sole stands of grain amaranth were planted at a spacing of 30 x 60cm using hand hoes. Inorganic fertilizer was applied at half rate at planting in the form of Diammonium Phosphate (DAP 18:46:0) and the balance top dressed as Calcium Ammonium Nitrate (CAN 26% N) six weeks after sowing. Manure was incorporated in the soil before planting. Weeding was done three times; 3, 6 and 9 weeks after sowing in both years through row cultivation using hand hoes. Aphids were controlled by the use of pyrethrin based insecticides. Monkeys and birds were managed by stone throwing and use of scare crows.

5.2.4. Data collection

Plant sampling and grain yield determination: Plant height and inflorescent length of grain amaranth were measured on five grain amaranth plants randomly sampled from the inner rows of each plot weekly starting from 5 weeks after planting to harvesting. Days to 50% flowering for each treatment were determined by getting the average of the period it took for half of the plants in each plot to flower. Days to harvest for each treatment were determined by the average period to physiological maturity. Dry matter yields were determined by destructive harvesting of 5 plants from the inner rows of each plot at harvest to avoid the increase due to the relatively low cost, the use of chemical fertilizers remains static due to rising prices.

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5.2.5. Soil, plant sampling and analysis

Soil samples were obtained from the top soil (0-20 cm) for initial soil characterization. The soil samples were air dried and analyzed for N and P (Okalebo et al., 2002).

5.2.6. Statistical analysis

Data was subjected to Analysis of Variance using Genstat software and the differences in means compared by least significant difference at the 5% probability level. The data was analysed using one way ANOVA. Differences between the means for each treatment were determined to establish the effect of nitrogen fertilizer and manure on the measured grain amaranth parameters. Grain yields and gross margins were assessed by comparing results on different treatment plots. Financial analyses were based on the input costs and output income. Information on labour use was based on farmers' recall and work rates used at the University farm. Prices were collected from farmers and from local markets. Regression analysis was done to determine the optimal application rates for inorganic fertilizer and cattle manure (Mohsen and Majid, 2008). Sensitivity analysis was conducted to determine the effect of varying the rate of fertilizer,

fertilizer price and grain yield on the marginal rate of return (MRR) of grain amaranth production.

5.3. Results and Discussion

5.3.1. Effect of fertilizer on plant height and inflorescent length

Plant height: Application of N as either chemical fertilizer or manure increased plant height. For all fertilization regimes in the two years, the plant height increased slowly from planting up to six weeks after planting. The most rapid increase in height occurred at 7-10 weeks after planting and thereafter the increase was gradual towards the 12th week when the plant attained its maximum height (Figures 19-22).

Plant height might have increased slowly after germination because the grain amaranth seed is very small and therefore food reserves are fast exhausted. Plant growth improved thereafter due to root development which enabled the plant to use soil nutrients. On flowering and head development, the crop grew rapidly as a result of well established root system coupled with adequate foliage for increased trapping of solar energy required for photosynthesis. This could have led to increased photosynthesis and dry matter accumulation necessary for plant growth. Growth then declined after maturity towards harvesting period due to senescence. This growth pattern is similar to the growth trend described by Ojo et al. (2007) and Myers and Putnam (1988).

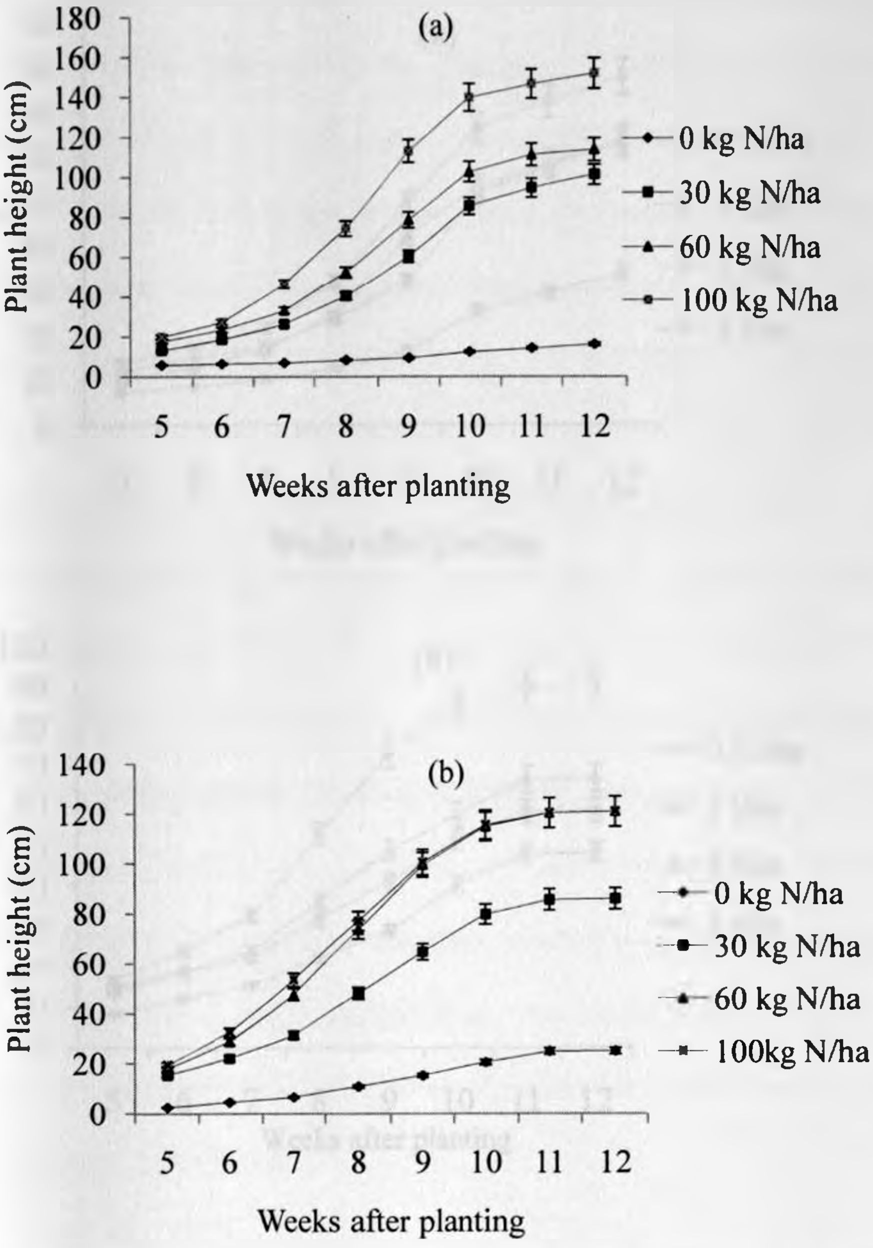


Figure 19: Effect of inorganic fertilizer on the height of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b). Vertical bars show LSD $_{0.05}$

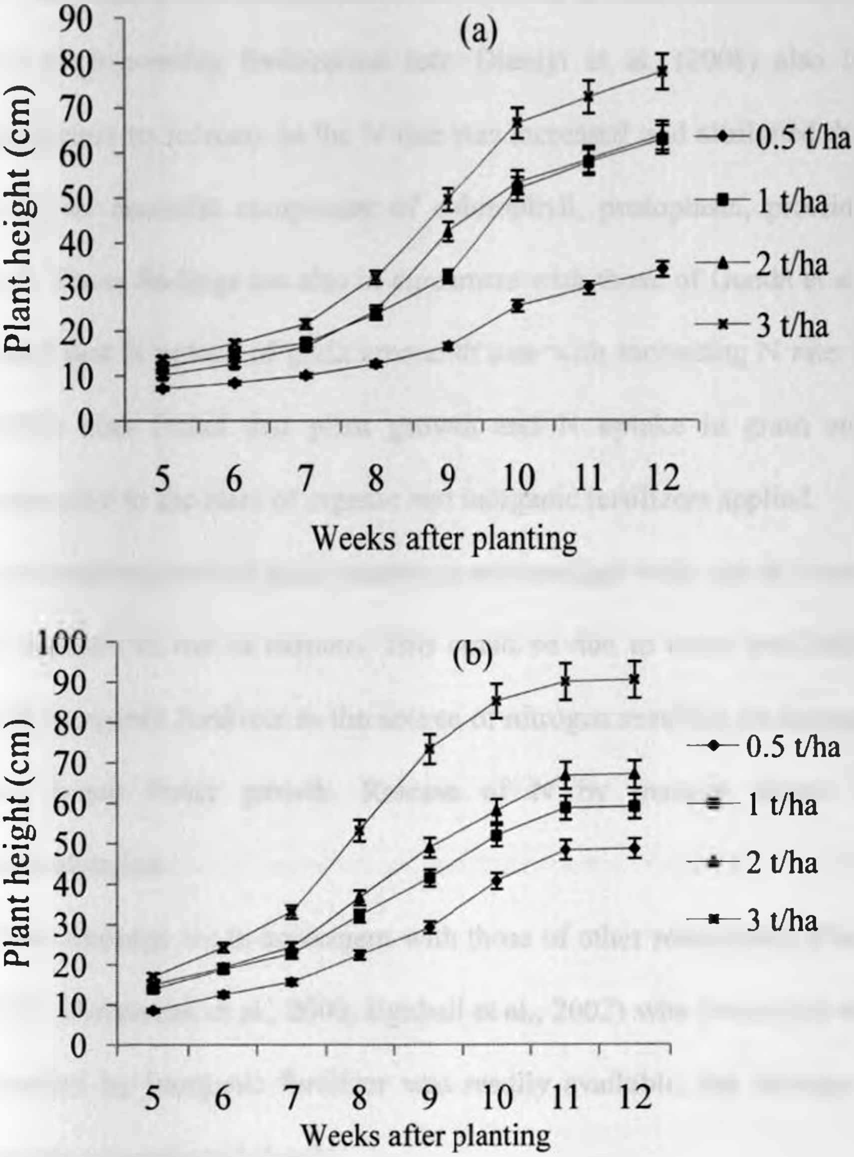


Figure 20: Effect of manure on the height of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b). Vertical bars show LSD $_{0.05}$

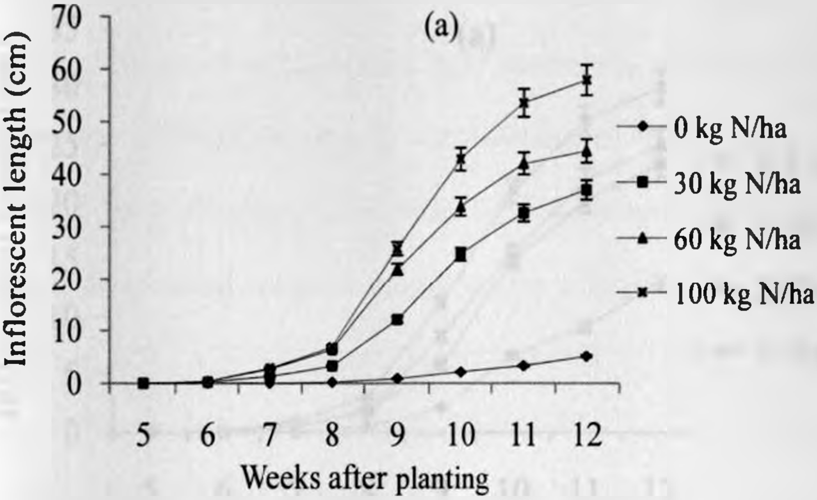
As the rate of fertilization was raised, the plant height also increased. The highest plant height was realized with application of 100 kg N/ha and 3 t/ha of inorganic fertilizer and manure respectively. This could be attributed to increased uptake of N with increasing fertilization rate. Olaniyi et al. (2008) also found growth parameters to increase as the N rate was increased and attributed this to nitrogen being an essential component of chlorophyll, protoplasm, protein and nucleic acid. These findings are also in agreement with those of Gunda et al. (2005) who found that N uptake of grain amaranth rose with increasing N rate. Akanbi et al. (2000) also found that plant growth and N uptake in grain amaranth were responsive to the rates of organic and inorganic fertilizers applied.

More rapid growth of grain amaranth was realized with use of chemical fertilizer as opposed to use of manure. This could be due to better availability of soil N with inorganic fertilizer as the source of nitrogen resulting in increased N uptake and hence faster growth. Release of N by manure occurs slowly after mineralization.

These findings are in agreement with those of other researchers (Pang and Letey, 2000; Hartemink et al., 2000; Eghball et al., 2002) who found that while nitrogen supplied by inorganic fertilizer was readily available, the nitrogen supplied by manure was released slowly.

The addition of nitrogen either as chemical fertilizer or manure significantly ($p < 0.05$) improved growth and yield of grain amaranth. This response of plant growth to soil fertilization could be due to increased availability of nutrients for plant growth. Similar findings on better plant growth with increased supply of soil nutrients by fertilizer have been reported (Materechera and Medupe, 2006; Mhlontlo et al., 2007; Spetter and Thompson, 2007; Bruce and Philipe, 2008).

Inflorescent length: Inflorescent length was measured as one of the growth parameters that determine grain yield. Application of inorganic fertilizer and manure increased inflorescent length (Figures 21-22). Inflorescent length increased as inorganic fertilizer and manure rates were raised from 0 kg N/ha to 100 kg N/ha and 0.5 t/ha to 3 t/ha respectively. The greatest inflorescent length was achieved when inorganic fertilizer was applied at 100 kg N/ha and manure applied at 3 t/ha. As fertilizer and manure rates increased, more plant nutrients were available for uptake resulting in increased inflorescent length. Greater inflorescent length was achieved in the first year than the second year probably due to lesser rainfall received in the latter period. Significantly better flowering occurred when inorganic fertilizer was applied than when cattle manure was used. This was because N from inorganic sources is readily available while that supplied by organic sources only becomes available for plant uptake after the process of mineralization.



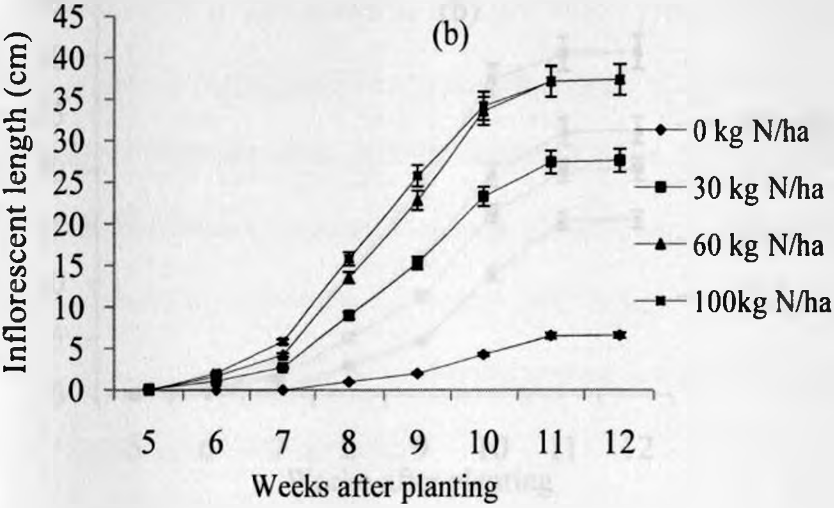


Figure 21: Effect of inorganic fertilizer on inflorescent length of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b). Vertical bars show $LSD_{0.05}$

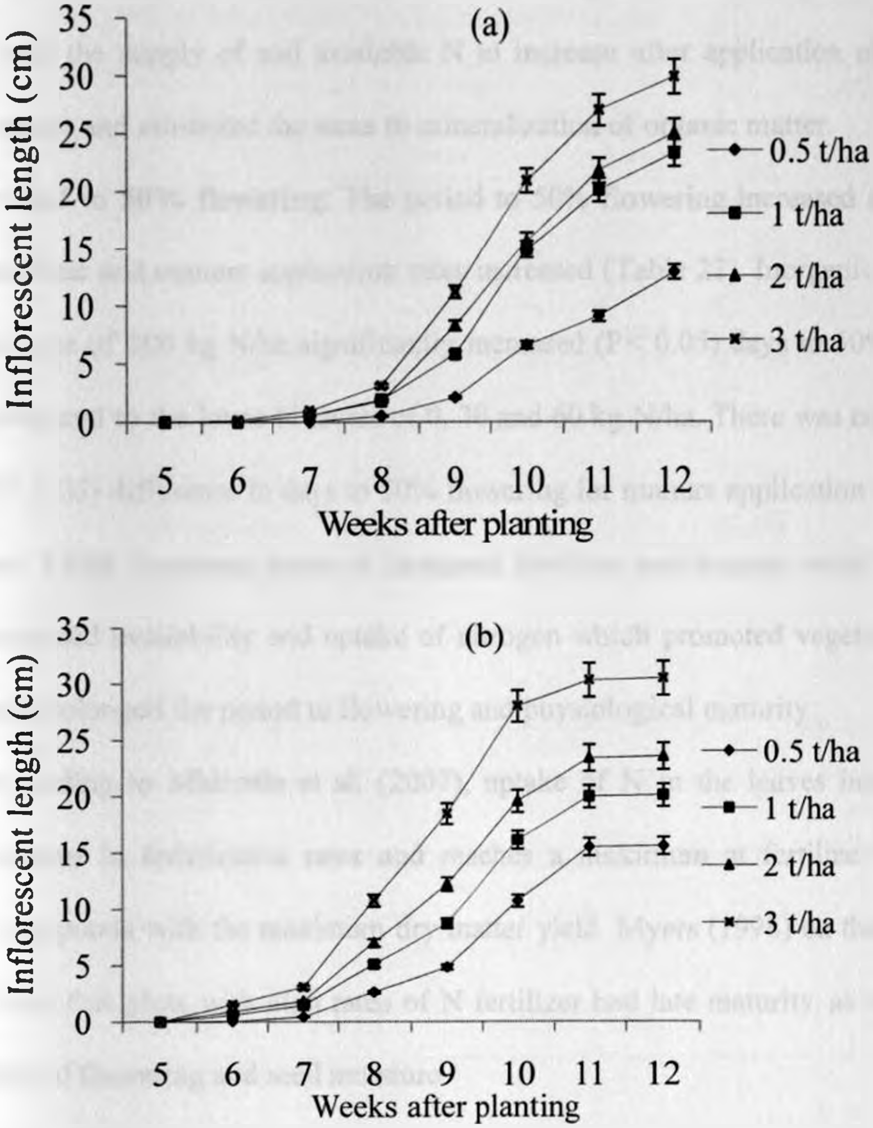


Figure 22: Effect of manure on inflorescent length of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b). Vertical bars show LSD $_{0.05}$

These results are in agreement with the findings of Onwonga et al. (2008) who found the supply of soil available N to increase after application of farm yard manure and attributed the same to mineralization of organic matter.

Period to 50% flowering: The period to 50% flowering increased as inorganic fertilizer and manure application rates increased (Table 22). Inorganic fertilizer at the rate of 100 kg N/ha significantly increased (P< 0.05) days to 50% flowering compared to the lower N levels of 0, 30 and 60 kg N/ha. There was no significant (P< 0.05) difference in days to 50% flowering for manure application rates of 1, 2 and 3 t/ha. Increased levels of inorganic fertilizer and manure could have led to increased availability and uptake of nitrogen which promoted vegetative growth and prolonged the period to flowering and physiological maturity.

According to Mhlontlo et al. (2007), uptake of N in the leaves increases with increase in fertilization rates and reaches a maximum at fertilizer rate which corresponds with the maximum dry matter yield. Myers (1998) on the other hand found that plots with high rates of N fertilizer had late maturity, as indicated by time of flowering and seed moisture.

Table 22: Effect of inorganic fertilizer and manure on duration to flowering and harvesting of grain amaranth in Kisumu West district

Type of fertilizer		2008		2009	
	Treatments	Mean days to 50% flowering	Mean days to harvest	Mean days to 50% flowering	Mean days to harvest
Inorganic fertilizer	0 kg N/ha	42.00	84.00	42.00	84.00
	30 kg N/ha	43.67	84.00	42.00	84.00
	60 kg N/ha	46.67	84.00	42.00	84.00
	100 kg N/ha	56.67	84.00	42.00	84.00
	LSD 5%	4.80	0.00	0.00	0.00
Manure	0.5 t/ha	45.70	84.00	42.00	84.00
	1 t/ha	50.70	84.00	42.00	84.00
	2 t/ha	51.30	84.00	42.00	84.00
	3 t/ha	56.00	84.00	42.00	84.00
	LSD 5%	6.72	0.00	0.00	0.00

5.3.2. Effect of fertilizer on amaranth yield and harvest index

Grain and dry matter yields: The grain and dry matter yields of grain amaranth increased as the rate of application of inorganic fertilizer and manure increased. The harvest index was not significantly affected by the rate of fertilization (Table 23).

Table 23 Effect of inorganic fertilizer and manure on yield and

		2008	
Fertilizer type	Fertilizer rate	Grain yield (t/ha)	Dry matter yield (t/ha)
Inorganic fertilizer	0 kg N/ha	0.29	0.74
	30 kg N/ha	0.90	2.31
	60 kg N/ha	1.55	3.61
	100kg N/ha	2.10	5.14
LSD 5%		0.573	1.220
Manure	0 t/ha	0.01	0.024
	0.5 t/ha	0.05	0.120
	1 t/ha	0.11	0.280
	2 t/ha	0.25	0.560
	3 t/ha	0.67	1.560
LSD 5%		0.093	0.179

Grain yield showed a linear response to inorganic fertilizer and manure. When inorganic fertilizer was used (Figure 23), the yield response followed the regression equations y= 0.019x + 0.29 (R^2=0.988) and y= 0.018x + 0.23 (R^2=0.980) in 2008 and 2009 respectively. In the first year, the grain yield increased to 1.96 t/ha with application of 90.0 kg N/ha. In the second year, the grain yield rose to 1.71 t/ha with the application of 85.0 kg N/ha. Over the two years, the grain response to inorganic fertilizer showed an optimum inorganic fertilizer application rate of 87.5 kg N/ha with an optimum grain yield of 1.84 t/ha.

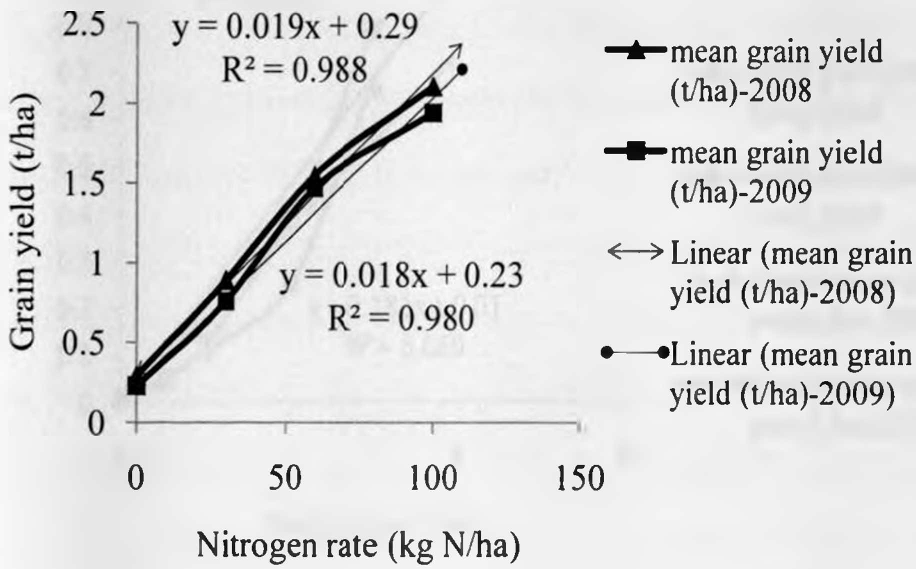


Figure 23: Regression analysis based on mean values of inorganic fertilizer on grain yield of grain amaranth in Kisumu West district

Similarly, when manure was used (Figure 24), the grain yield showed a linear response, y= 0.0181x + 0.01 (R^2=0.869) and y= 0.227x + 0.01 (R^2=0.923) in 2008 and 2009 respectively. However, the grain yield increased to 0.67 and 0.79 t/ha with application of manure at the rate of 3 t/ha in 2008 and 2009 respectively. Regression analysis showed that the optimum grain yield of 1.84 t/ha obtained with application of inorganic fertilizer could be obtained with a manure rate of 10.0 t/ha and 8.0 t/ha in 2008 and 2009 respectively. The optimum manure rate was therefore projected as 9.0 t/ha being the average for the two years.

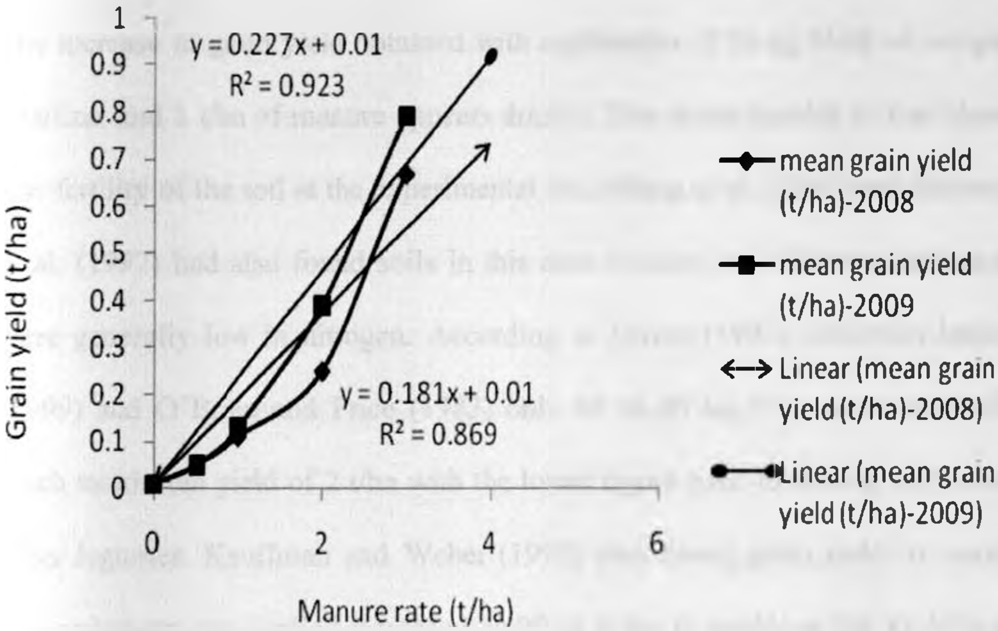


Figure 24: Regression analysis based on mean values of organic fertilization on grain yield of grain amaranth in Kisumu West district

These results are in agreement with the findings of Elbehri et al. (1993), Myers (1998) and Bruce and Philip (2008) who reported a linear response of grain amaranth yield to N fertilization. The increase in grain yield as fertilizer rates increased could have been due to increased levels of nitrogen in the the soil resulting in increased plant uptake and thus plant growth, flowering and grain filling. This responsiveness of grain amaranth yield to N fertilization is comparable to the findings of other researchers (Myers, 1996; Jefferson Institute, 1999; Bruce and Philipe, 2008).

The increase in grain yield obtained with application of 30 kg N/ha of inorganic fertilizer and 1 t/ha of manure appears drastic. This is attributable to the inherent low fertility of the soil at the experimental site. Niang et al. (1996) and Heineman et al. (1997) had also found soils in this area to have low inherent fertility and were generally low in nitrogen. According to Myers (1996), Jefferson Institute (1999) and O'Brien and Price (1983) only 45 to 90 kg N/ha were required to reach maximum yield of 2 t/ha with the lower figure used following soybeans or other legumes. Kauffman and Weber (1990) also found grain yield to increase when nitrogen was applied at rates up to 90 kg N/ha, to double at 100 kg N/ha and reduce at higher rates.

When grain amaranth was grown using manure, better grain yields were obtained in the second year across all manure rates. This might have been due to the tendency of organic N sources to supply nutrients for prolonged periods. This may have led to nitrogen carryover to the following season. This is in agreement with Stute and Posner (1995) and Onwonga et al. (2008) who reported that use of manures could help build soil fertility and increase N supply for the succeeding crops.

Harvest index: There was no significant difference in the harvest index when inorganic fertilizer was applied at the rate of 0, 30, 60 and 100 kg N/ha (Table 23). The similarity in the values of harvest index shows that there was no significant difference in the proportions of N that went towards grain and biomass production with application of the different rates of inorganic fertilizer. When manure was used, harvest indices followed a similar trend as for inorganic fertilizer. Gunda et al. (2005) also found no significant difference in the harvest index when N was applied at the rates of up to 120 kg N/ha.

5.3.3. Effect of fertilizer on grain amaranth profitability

Gross margin analysis: Gross margins were used to determine the profitability of grain amaranth production. Gross margins increased as fertilizer and manure rates were raised. This is attributable to better grain yields at higher fertilization rates. These findings compare well with those of Myers (1996) who reported increased gross margins with increasing fertilizer rates.

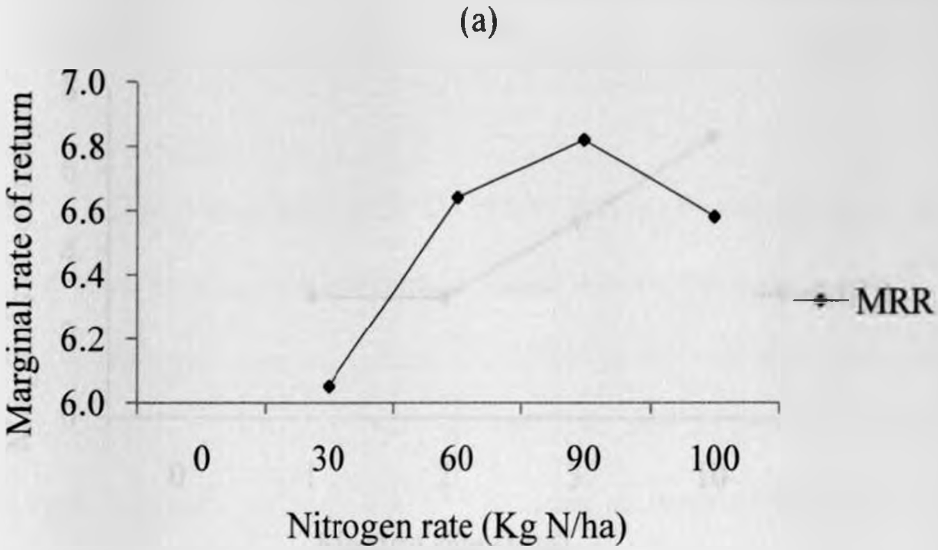
Effect of varying the rate of fertilizer on MRR: The marginal rate of return increased with increase in the rate of inorganic fertilizer up to the optimum rate before decreasing with further increase in fertilization.

Table 24: Effect of varying the rate of inorganic fertilizer and
in Kisumu West district

Fertilizer type	Year	Fertilizer rate	Total Variable Costs (Ksh./ha)
Inorganic fertilizer	2008	0 kg N/ha	18890.00
		30 kg N/ha	23820.00
		60 kg N/ha	28280.00
		90 kg N/ha	30950.00
		100 kg N/ha	32490.00
	2009	0 kg N/ha	18350.00
		30 kg N/ha	22500.00
		60 kg N/ha	26480.00
		85 kg N/ha	27520.00
		100 kg N/ha	30050.00
Manure	2008	0 t/ha	17120.00
		1 t/ha	18570.00
		2 t/ha	20610.00
		3 t/ha	23650.00
		10 t/ha	30460.00
	2009	0 t/ha	17120.00
		1 t/ha	18430.00
		2 t/ha	20880.00
		3 t/ha	23360.00
		8 t/ha	28160.00

In the first year, the marginal rate of return (MRR) increased with increase in the rate of inorganic fertilizer from 0 to 90.0 kg N/ha reaching a maximum of 6.82 before declining with further increase in the rate of fertilization. Similarly, during the second year, the marginal rate of return increased with increase in the rate of fertilization from 0 to 85.0 kg N/ha reaching a maximum of 8.19 before decreasing with increase in the rate of inorganic fertilizer (Figure 25). Averaged over the two years, the greatest marginal rate of return of 7.51 would be achieved with application of inorganic fertilizer at the economic optimum rate of 87.5 kg N/ha, a value also obtained through regression analysis.

When manure was used, the marginal rate of return increased with increase in the rate of manure application up to the projected optimum rate of 10.0 and 8.0 t/ha in 2008 and 2009 respectively. In 2008, the MRR remained stable with increase in the rate of manure up to 2 t/ha before increasing steadily as the rate of manure was raised to 3 t/ha. Thereafter, the MRR was projected to increase and reach a maximum of 6.81 at a manure rate of 10.0 t/ha. However, during 2009, the MRR increased steadily with increase in the rate of application of manure from 0 to 3 t/ha. The MRR is projected to have increased further with increase in the rate of fertilization reaching a maximum of 8.44 at manure application rate of 8.0 t/ha (Figure 26). Averaged over the two years, the highest marginal rate of return of 7.63 would be achieved with application of manure at the optimum rate of 9.0 t/ha, a rate also obtained through regression analysis.



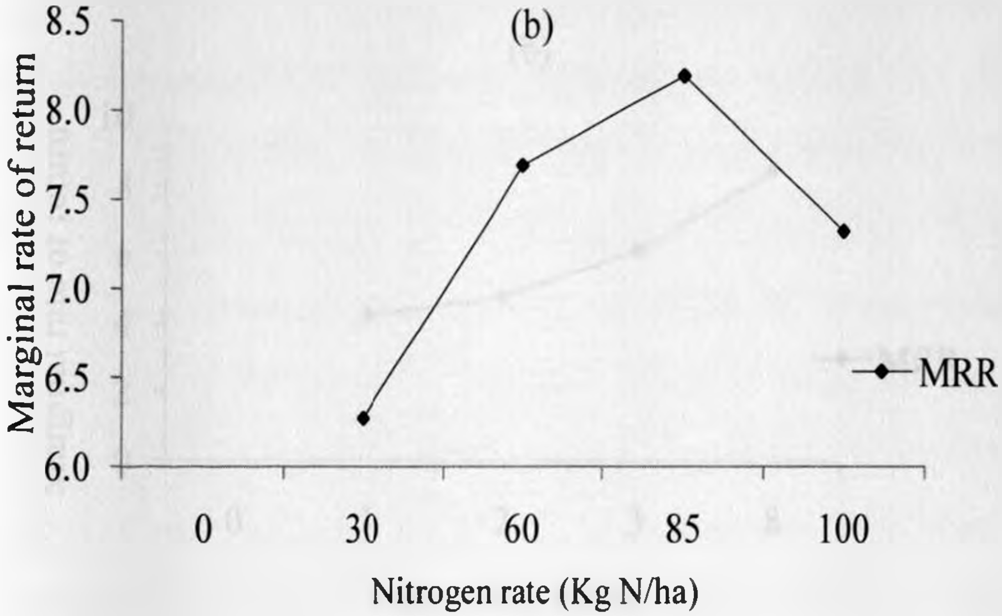


Figure 25: Effect of varying inorganic fertilizer rates on the marginal rate of return of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b)

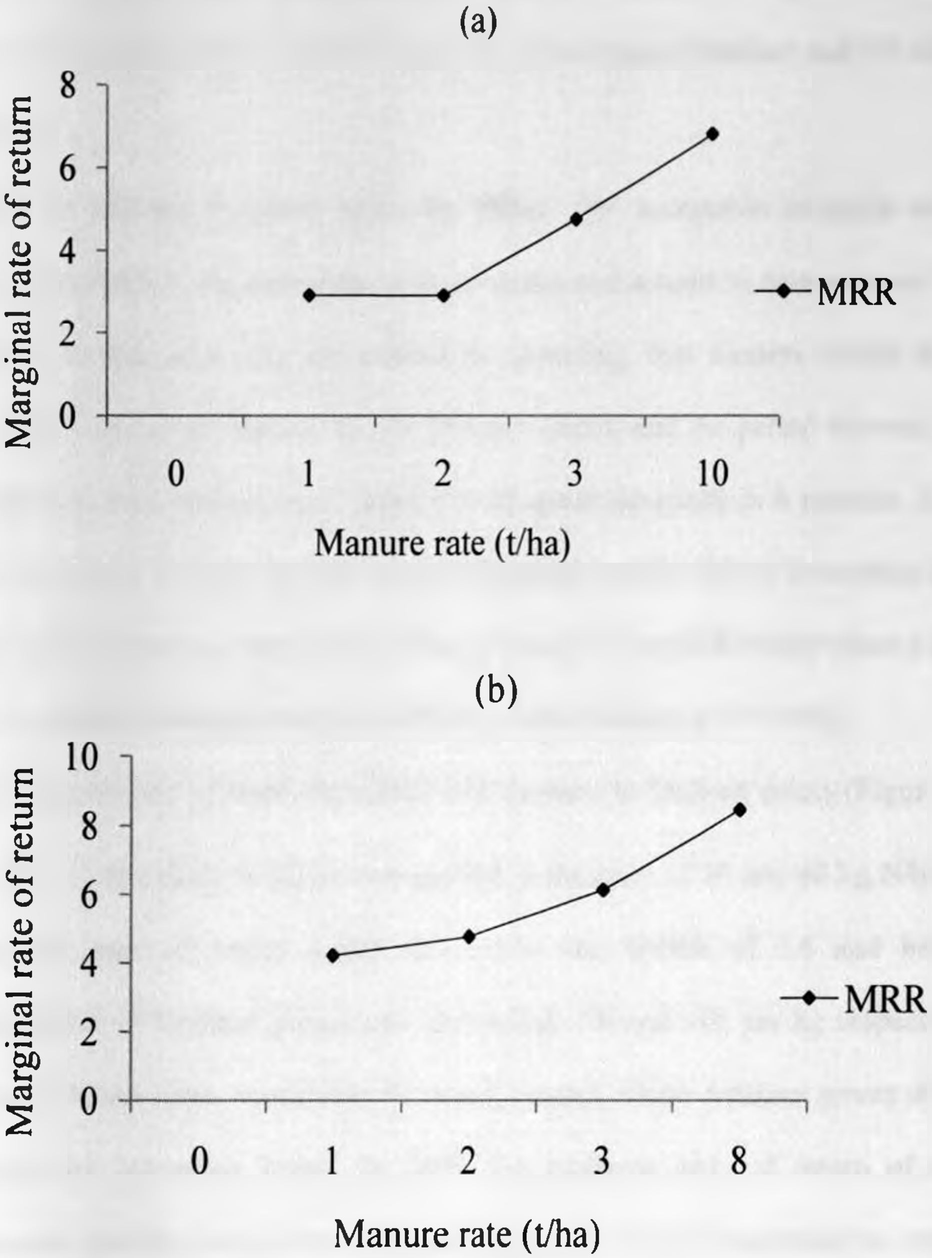
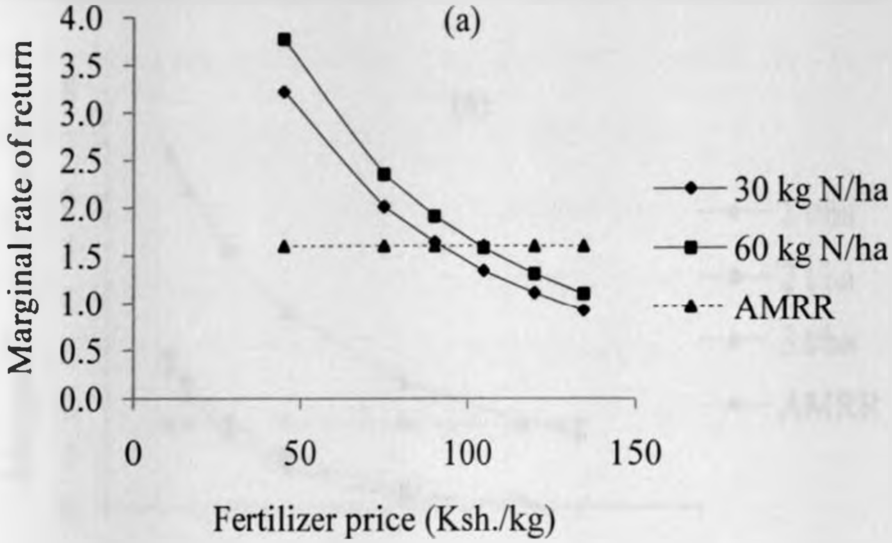


Figure 26: Effect of varying manure rates on the marginal rate of return of grain amaranth in Kisumu West district in 2008b (a) and 2009 (b)

Therefore, the optimum fertilizer rates obtained through both regression analysis and sensitivity analysis were 87.5 kg N/ha of inorganic fertilizer and 9.0 t/ha of manure.

Effect of varying fertilizer price on MRR: The acceptable marginal rate of return (AMRR) is the sum of the cost of capital and returns to management. The AMRR in this case was determined by assuming that farmers would access informal loans at an interest rate of 10% per month and the period between land preparation and realization of income from grain amaranth is 6 months. At the interest rate of 10% per month, the cost of capital is 60% (10% x 6 months). If the majority of farmers in the area consider an enterprise profitable only when it gives 100% returns to management, the AMRR will be 160% (i.e 60 + 100).

The marginal rate of return decreased with increase in fertilizer prices (Figure 27). In 2008, if inorganic fertilizer was applied at the rates of 30 and 60 kg N/ha, the marginal rates of return would fall below the AMRR of 1.6 and become unprofitable if fertilizer prices rose above Ksh. 90 and 105 per kg respectively. These fertilizer rates would only be recommended where fertilizer prices did not exceed the respective levels. In 2009, the marginal rates of return of using inorganic fertilizer at the rates of 30 and 60 kg N/ha would drop below the AMRR of 1.6 and become unprofitable if the price of fertilizer increased beyond Ksh. 82 and 120 per kg respectively. Application of inorganic fertilizer at these rates would be unprofitable if fertilizer prices rose above the respective levels



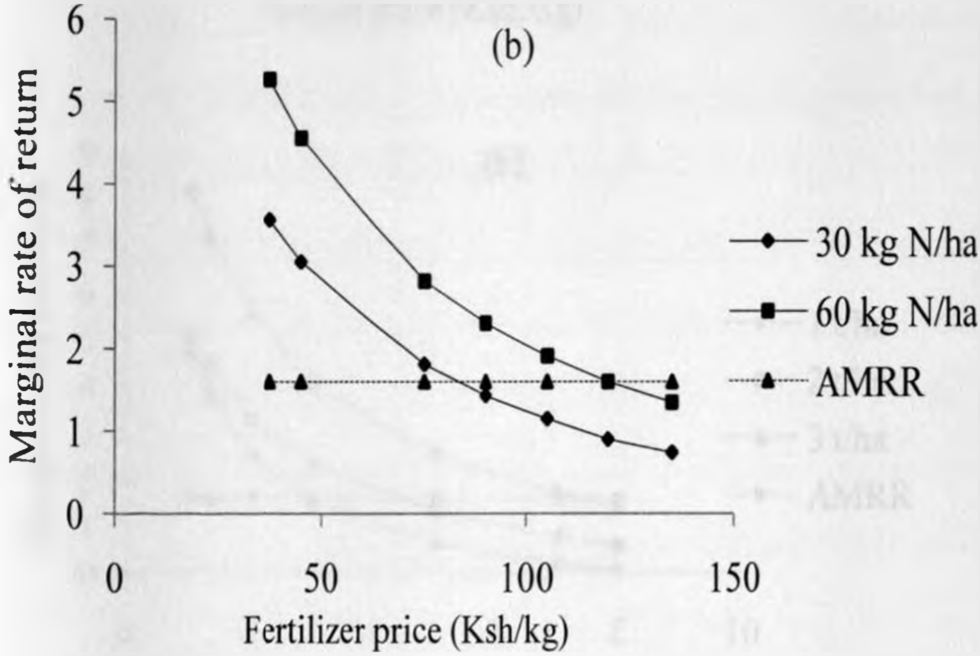


Figure 27: Effect of varying fertilizer price on the marginal rate of return of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b)

The marginal rate of return decreased with increase in manure prices (Figure 28)

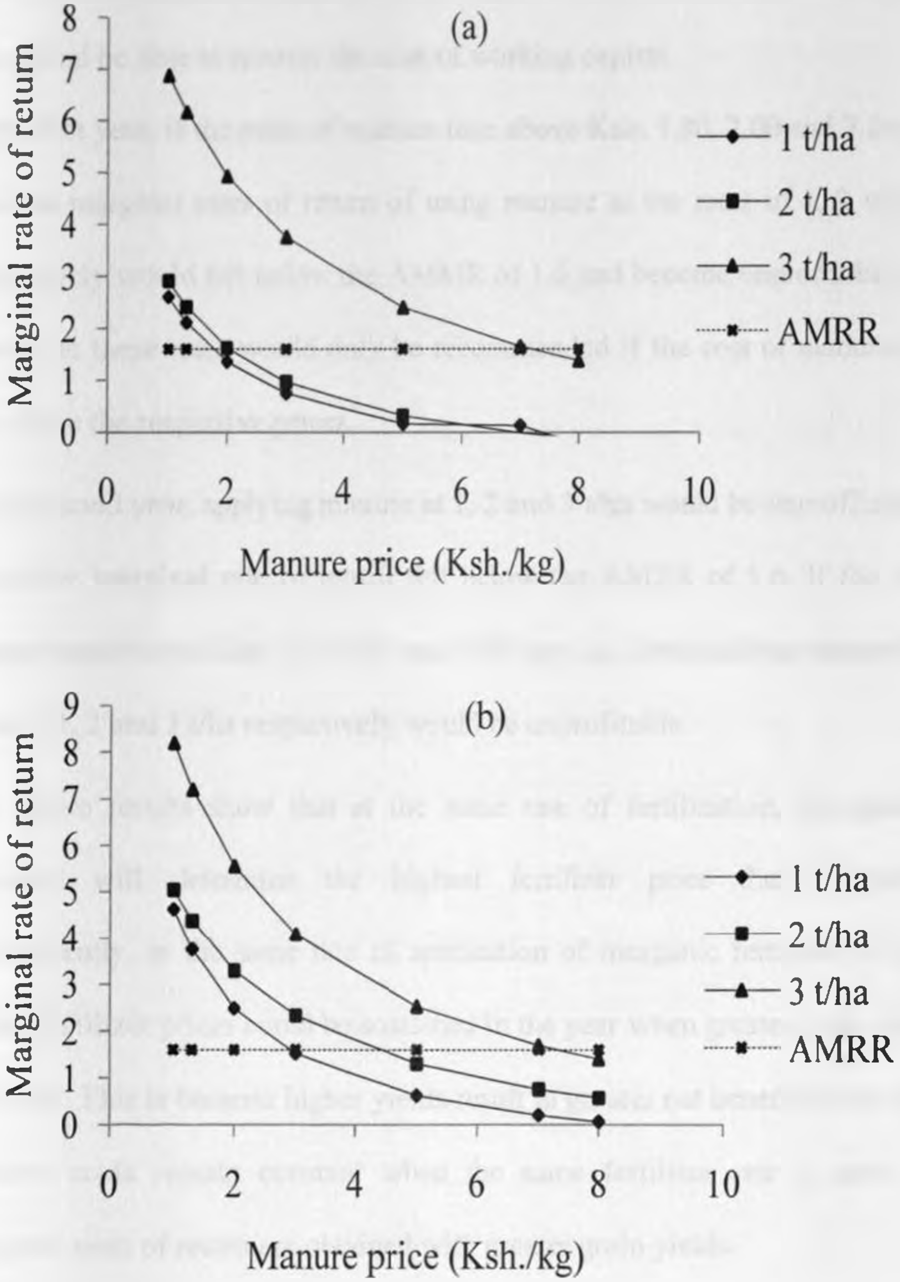


Figure 28: Effect of varying manure price on the marginal rate of return of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b)

Farmers will adopt the use of manure if they consider it profitable. Most farmers believe an enterprise is profitable if it can give 100% returns to their management efforts and be able to recover the cost of working capital.

In the first year, if the price of manure rose above Ksh. 1.80, 2.00 and 7.20 per kg, then the marginal rates of return of using manure at the rates of 1, 2 and 3 t/ha respectively would fall below the AMMR of 1.6 and become unprofitable. Use of manure at these rates would only be recommended if the cost of manure did not rise above the respective prices.

In the second year, applying manure at 1, 2 and 3 t/ha would be unprofitable if the respective marginal rate of return fell below the AMRR of 1.6. If the price of manure rose above Ksh. 3.0, 4.20 and 7.00 per kg, then applying manure at the rates of 1, 2 and 3 t/ha respectively would be unprofitable.

The above results show that at the same rate of fertilization, the grain yield achieved will determine the highest fertilizer price that is profitable. Consequently, at the same rate of application of inorganic fertilizer or manure, higher fertilizer prices could be sustained in the year when greater grain yield was achieved. This is because higher yields result in greater net benefits since the total variable costs remain constant when the same fertilizer rate is used. Better marginal rates of return are obtained with greater grain yields.

Effect of varying grain yield on MRR: A farmer will adopt grain amaranth production if the grain yield achievable can enable him to recover all (100%) the working capital invested and pay interest on borrowed funds. Assuming such a farmer can access informal credit at the interest rate of 10% per month and the crop has a gestation period of 6 months, the interest payable will be 60% (10% x 6 months). The acceptable marginal rate of return (AMRR) will therefore be 160% (100% + 60%).

The marginal rate of return increased with increase in grain yield when inorganic fertilizer was applied at various rates (Figure 29). In the first year, the marginal rates of return of using inorganic fertilizer at the rates of 30 and 60 kg N/ha would fall below the AMMR of 1.6 and become unprofitable if grain yields dropped below 0.32 and 0.47 t/ha respectively. These fertilizer rates would therefore not be recommended where farmers' management practices do not allow them to achieve the respective minimum grain yields. In the second year, application of inorganic fertilizer at the rates of 30 and 60 kg N/ha would only be profitable if minimum grain yields of 0.25 and 0.40 t/ha respectively would be achieved. Hence, these fertilizer rates would only be recommended where farmers could obtain the respective minimum grain yields.

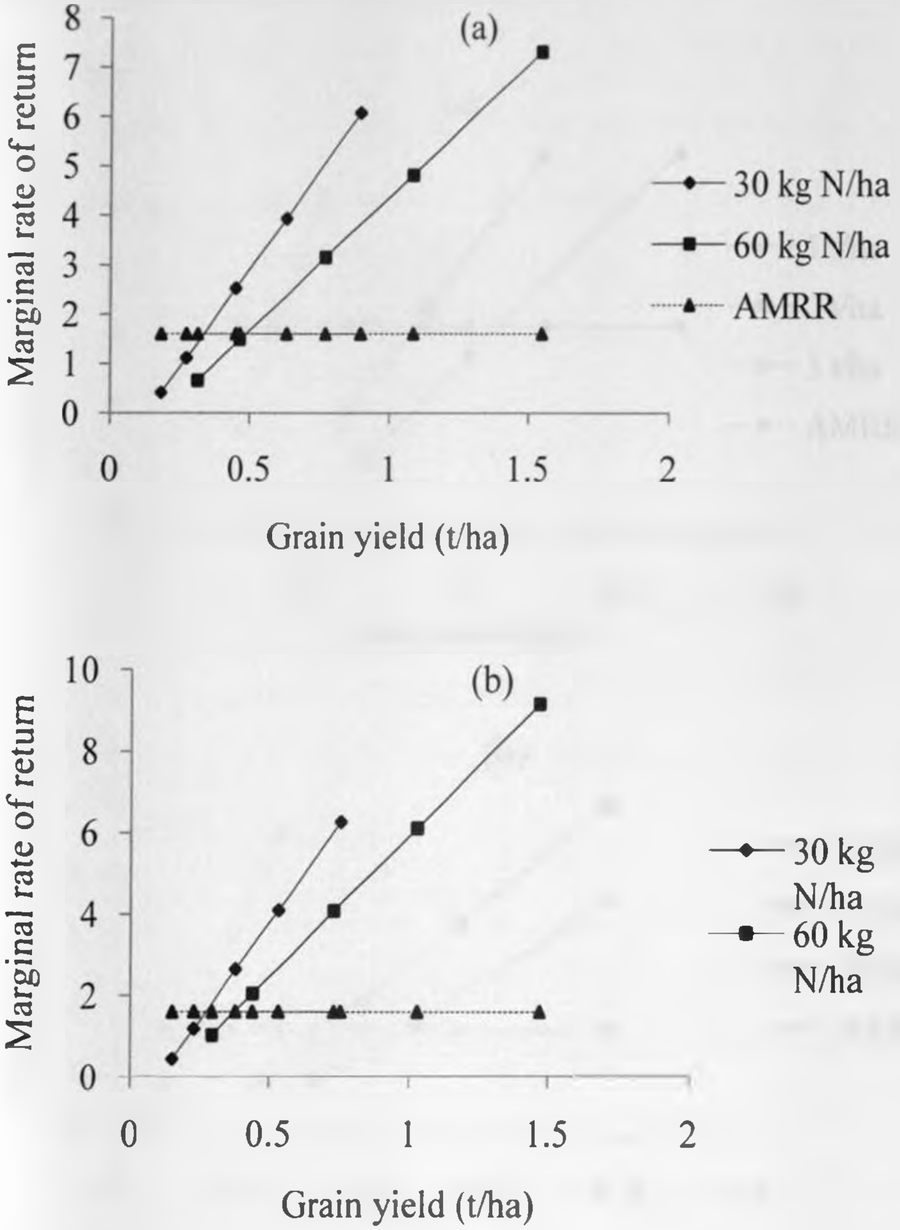


Figure 29: Effect of varying grain yield on the marginal rate of return of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b)

The marginal rate of return increased with increase in grain yield when inorganic fertilizer was applied at various rates (Figure 30).

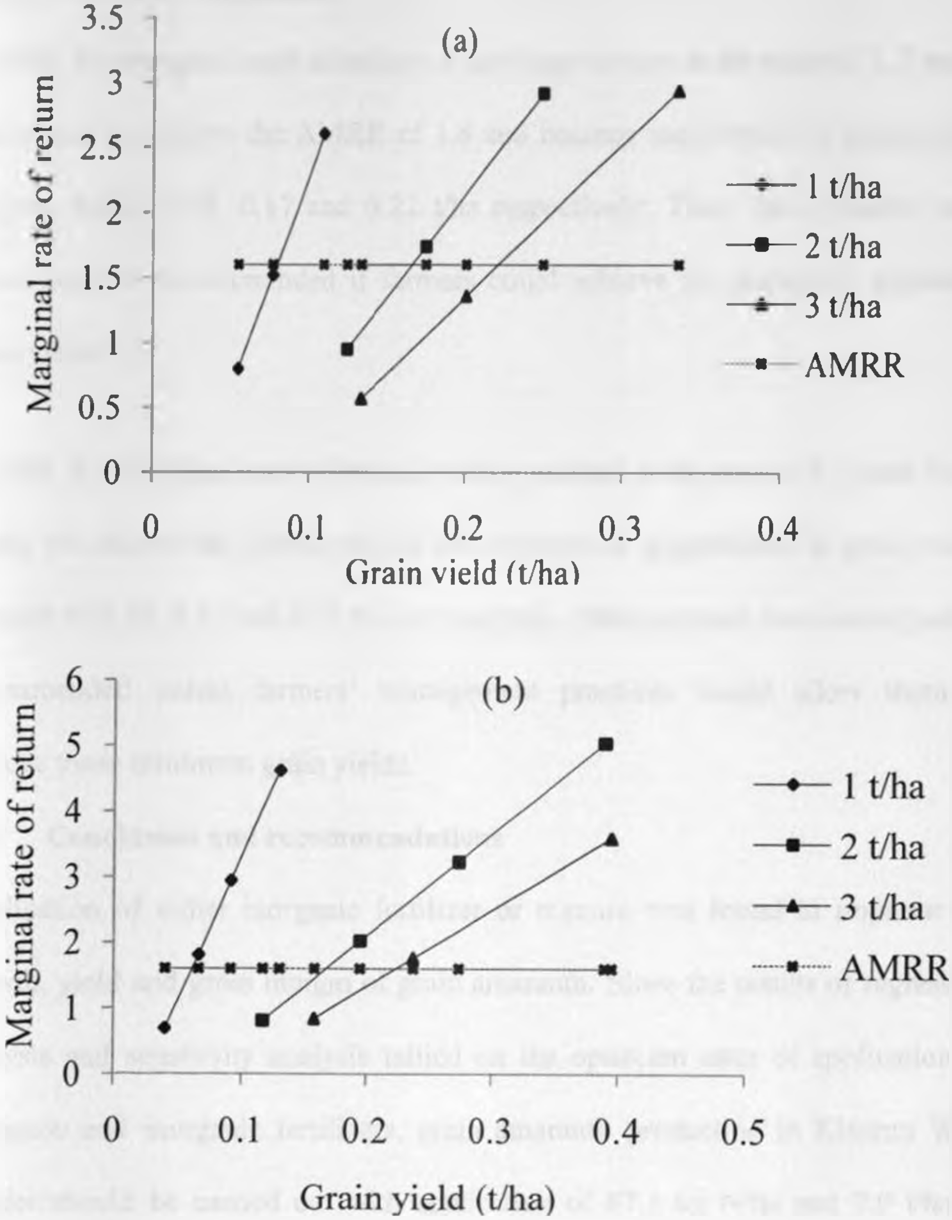


Figure 30: Effect of varying grain yield on the marginal rate of return of grain amaranth in Kisumu West district in 2008 (a) and 2009 (b)

Use of manure in grain amaranth production by farmers is subject to their ability to obtain grain yields that can give a minimum of 100% return on management and interest on working capital.

In 2008, the marginal rates of return of applying manure at the rates of 1, 2 and 3 t/ha would fall below the AMRR of 1.6 and become unprofitable if grain yields dropped below 0.08, 0.17 and 0.22 t/ha respectively. Thus, these manure rates would only be recommended if farmers could achieve the respective minimum grain yields.

In 2009, the marginal rates of return of using manure at the rates of 1, 2 and 3 t/ha would fall below the AMRR of 1.6 and become be unprofitable if grain yields dropped to 0.06, 0.17 and 0.22 t/ha respectively. These manure rates would not be recommended unless farmers' management practices would allow them to achieve these minimum grain yields.

5.4. Conclusion and recommendations

Application of either inorganic fertilizer or manure was found to improve the growth, yield and gross margin of grain amaranth. Since the results of regression analysis and sensitivity analysis tallied on the optimum rates of application of inorganic and inorganic fertilizers, grain amaranth production in Kisumu West district should be carried out with application of 87.5 kg N/ha and 9.0 t/ha of inorganic fertilizer and cattle manure respectively based on economics. Further studies are however recommended to test the response of grain amaranth to combined application of inorganic and organic fertilizers. A study on the socio-economic implications for introducing grain amaranth should be done to determine the socio-economic factors that would influence the adoption of grain amaranth production.

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CHAPTER 6: GENERAL DISCUSSION, CONCLUSION AND RECOMMENDATIONS

6.1. General Discussion

Most farmers expressed willingness to venture into production of grain amaranth or even increase production and utilization. However, they face the following economic and environmental constraints; drought; lack of awareness about the crop; lack of seed; lack of market; lack of value addition equipment; low and fluctuating prices; lack of packaging knowledge; inadequate capital and; pests and diseases. Farmers' knowledge levels, attitudes and practices related to grain amaranth production, value addition and utilization were found to be relatively low due to inadequate technical support for the fairly new crop.

Maize and beans were found to be more competitive and aggressive and dominated grain amaranth in single row intercrop arrangements. However, in double row intercrops, grain amaranth proved more competitive and utilized resources more aggressively thereby dominating maize and beans.

Application of either inorganic fertilizer or manure was found to improve the growth, yield and gross margin of grain amaranth. The economic optimum inorganic fertilizer level for grain amaranth was found to be 87.5 kg N/ha while the optimum manure rate was 9.0 t/ha.

6.2. Conclusions

There is need for concerted efforts to be made by all stakeholders in the grain amaranth industry to address production, processing, value addition and marketing challenges in a holistic manner for sustainable crop production.

Intercropping of grain amaranth with maize was found to be more compatible but intercropping it with beans more profitable. Generally, intercropping grain amaranth improved the net returns per unit area. These results suggest that it is better to grow grain amaranth intercropped with either maize or beans than growing it as a sole crop.

Based on these findings, grain amaranth production in Kisumu West District should therefore be carried out with application of inorganic fertilizer and cattle manure rate at the rates of 87.5 kg N/ha and 9.0 t/ha respectively.

The study concluded that grain amaranth production can be promoted as a sole crop or intercropped with either maize or beans with the use of inorganic or organic fertilizers.

6.3. Recommendations

The following are recommendations for sustainable production and consumption of the crop in the district.

1. There is need to address the problems faced by grain amaranth farmers in the region in a holistic way to enhance production, value addition, marketing and consumption of the crop.
2. Further studies should be done on grain amaranth marketing in order to bring out all possible difficulties when it comes to large scale production of the crop.
3. Efforts should be made to provide market for current farmers as a factor for influencing other farmers' perception of the crop.
4. Entrepreneurs and food processors should be encouraged to integrate grain amaranth in widely consumed products to increase utilization.
5. A study on the socio-economic implications for introducing grain amaranth should be done to determine the socio-economic factors that would influence the adoption of grain amaranth production.
6. Further work should be done to establish the effects of intercropping grain amaranth in various patterns and with other crops grown in the region such as sunflower, cowpeas, sorghum and millet.
7. The performance of the crop with application of a combination of organic and inorganic fertilizers should also be studied.

8. Other varieties of grain amaranth, maize and beans should be evaluated.
9. Similar field experiments and survey should be done in other agro-ecological zones.
10. Adoption of grain amaranth will be enhanced if efforts are made to develop markets by encouraging entrepreneurs and food processors to integrate grain amaranth in widely distributed products.

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Appendices

Appendix 1: Rainfall data for Maseno University Farm in Kisumu West district during the experimental period in 2008 and 2009

Year	Rainfall (mm)*											
	J	F	M	A	M	J	J	A	S	O	N	D
2008	34.2	52.9	83.7	222.4	246.2	159.5	116.1	149.3	233.3	146.2	124.1	104.1
2009	100.7	18.7	63.1	201.4	152.5	158.7	15.4					

*In 2008, the growing period was mid September 2008-mid January, 2009.

The growing period for 2009 was April-July 2009.

Appendix 2: Chemical and physical soil properties at the study site in Kisumu West district

Properties	Level
pH Water	5.03
pH 0.01Cacl$_2$	5.8
% C	1.37
% N	0.13
K (Cmol/Kg)	2.97
Na (Cmol/Kg)	Trace
Ca (Cmol/Kg)	4.72
Mg (Cmol/Kg)	0.85
CEC (Cmol/Kg)	8.92
P (ppm)	3.95
Zn (ppm)	6.40
Cu (ppm)	5.70
Fe (ppm)	112.80
Mn(ppm)	51.60

Appendix 3: Effect of inorganic N and manure on the gross margin of grain amaranth in Kisumu West district in 2008

	Fertilizer rate (kg N/ha)				Manure rate (t/ha)			
Item	0 kg N/ha	30 kg N/ha	60 kg N/ha	100 kg N/ha	0.5 t/ha	1 t/ha	2 t/ha	3 t/ha
Grain yield (t/ha)	**0.29**	**0.9**	**1.55**	**2.1**	**0.05**	**0.11**	**0.25**	**0.67**
Adjusted yield (t/ha)	**0.25**	**0.77**	**1.32**	**1.79**	**0.04**	**0.09**	**0.21**	**0.57**
Output price (Ksh./ t)	67,000	67,000	67,000	67,000	67,000	67,000	67,000	67,000
Income (Ksh/ha)	16,516	51,255	88,273	119,595	2,848	6,265	14,238	38,157
Input costs (Ksh/ha)								
Seed	750	750	750	750	750	750	750	750
Fertilizer/manure	-	1,650	3,300	5,500	500	1,000	2,000	3,000
Land preparation	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500
Planting, weeding and thinning	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Harvesting, cleaning and drying	1,800	4,350	6,400	7,750	310	690	1,560	3,110
Gunny bags	340	1,070	1,830	2,490	60	130	300	790
Total variable costs (Ksh./ha)	**18,890**	**23,820**	**28,280**	**32,490**	**17,620**	**18,570**	**20,610**	**23,650**
Net benefit (Ksh./ha)	**(2,375)**	**27,435**	**59,993**	**87,105**	**(14,773)**	**(12,306)**	**(6,373)**	**14,507**

Appendix 4: Effect of inorganic N and manure on the gross margin of grain amaranth in Kisumu West district in 2009

	Fertilizer rate (kg N/ha)				Manure rate (t/ha)			
Item	0 kg N/ha	30 kg N/ha	60 kg N/ha	100 kg N/ha	0.5 t/ha	1 t/ha	2 t/ha	3 t/ha
Grain yield (t/ha)	**0.23**	**0.76**	**1.47**	**1.94**	**0.05**	**0.13**	**0.39**	**0.79**
Adjusted yield (t/ha)	**0.20**	**0.65**	**1.25**	**1.65**	**0.04**	**0.11**	**0.33**	**0.67**
Output price (Ksh./ t)	67,000	67,000	67,000	67,000	67,000	67,000	67,000	67,000
Income (Ksh/ha)	13,099	43,282	83,717	110,483	2,848	7,404	22,211	44,991
Input costs (Ksh/ha)								
Seed	750	750	750	750	750	750	750	750
Fertilizer/manure	-	1,650	3,300	5,500	500	1,000	2,000	3,000
Land preparation	8,500	8,500	8,500	8,500	8,500	8,500	8,500	8,500
Planting, weeding and thinning	7,500	7,500	7,500	7,500	7,500	7,500	7,500	7,500
Harvesting, cleaning and drying	1,370	3,200	4,700	5,500	310	590	1,830	3,060
Gunny bags	230	900	1,730	2,300	60	90	300	550
Total variable costs (Ksh./ha)	**18,350**	**22,500**	**26,480**	**30,050**	**17,620**	**18,430**	**20,880**	**23,360**
Net benefit (Ksh./ha)	**(5,252)**	**20,782**	**57,237**	**80,433**	**(14,773)**	**(11,027)**	**1,331**	**21,631**

Appendix 5: Questionnaire used in the survey in Kisumu West district

Questionnaire

Interviewer...Date.....................
....

1. Demographic data

Name	
Sex	
Indicate if household head	
Group	
Role in group	
Education level	
Zone	
Location	
Division	
District	

2. Background information

a) How did you learn about grain amaranth? ....
....
b) Why are you growing grain amaranth? ....
....
c) How long have you been growing it? ....
d) Which of the varieties grown do you prefer? ....
e) Why? ....

f) What are your sources of seeds? ....
....

g) How long do the grains take to mature from planting to harvesting?..............................

h) What acreage do you plant grain amaranth? (Specify land size) ....

i) How much do you harvest from this piece of land? (Specify land size). What is the measurement, bags, kg, etc? ....

j) What do you do with the harvested crop?
   i. Sell...
   ii. Home consumption...
   iii. Share with group member...
   iv. Others, indicate...

k) Do you know other people growing grain amaranth?

   i. Family...
   ii. Other locations...
   iii. Beyond here...
   iv. In your opinion, how is the coverage in your location? (every home, most homes, a few homes)..
   v. What is the average acreage? ....

l) Who provides technical support on grain amaranth? (agricultural extension, financial, etc)
....

3. Production

a) Please outline the production process from land preparation to harvesting ....
....
....
....

b) At each of these stages, who is responsible in your family? ....
....
....

c) How do you choose the land to grow grain amaranth? ....
....

d) When do you prepare land for grain amaranth? ....

e) How do you ensure the land is ideal for planting grain amaranth? ....
....

f) How do you select seeds for planting?...
....

g) How do you sow the seeds?...

h) When do you weed?...

i) How many times do you weed?...

j) Which fertilizer/ manure do you use when planting grain amaranth?.................................

k) How much do you use?...

l) Which other fertilizer do you use during the growing period? ....

m) What other agronomic practices do you undertake? (e.g. Thinning) ....
....

n) When do you undertake these practices?...
....

o) What are the main constraints in producing grain amaranth in this region? List and rank in order of importance.
....
....

p) Which pests and diseases attack grain amaranth?...
....

q) How do you control the pests and diseases?...
....

4. Harvesting

a) How do you tell that the grains are ready for harvesting?..
....
b) How do you harvest them?...
....
c) How do you dry them?..
....
d) How long do they take to dry?...
....
e) How do you tell that they have dried properly?..
....

5. Storage

a) Where do you store the grains?..
b) In what type of containers?..
c) How long do they keep before getting spoilt?...
d) How do you tell they are spoilt?..
e) How do you control storage pests?...
f) What damages the grains during storage?
   i. Which storage pests attack your grain?..
   ....
   ii. Other problems associated with storage…………………………………………….
   ……………………………………………………………………………………………

6. Processing

Please indicate the type of value addition processing you undertake on grain amaranth

	Process				
	Milling into flour	Porridge making	Ugali cooking	baking	popping
Equipment					
Where(home/ commercial place)					
Product					
Sell (S)/ Home consumption (H)					
Price (Sell)					

7. Consumption information and patterns

Who consumes the grain amaranth, in what form? Fill in the following form.

	Type of processed product e.g. porridge				
	Porridge	Ugali	Chapati	Mandazi	Popped amaranth
What else is added?					
How is it prepared?(e.g cooking process)					
How is the product stored?					
How long does					

it keep before it goes bad? (shelf life)					
Who consumes this product?					
How often do they eat it?					
How often would they prefer to eat it?					
Why are they not consuming as they would like?					
Who else prefers this product in the house? (e.g. children, patients)					
Why do they eat these products?					
Effects					

For those using grain amaranth as medicine

	What disease do they treat?						
Persons being treated							
Part of plant used							
Form of administration							
Frequency of administration							
How is it prepared?							

8. Marketing

a) How much of the total grain amaranth production do you usually sell?...................
b) In what form do you sell the grain amaranth?...
c) When do you sell grain amaranth products? (Shortly after harvest, after some storage period)……………………………………………………………………………
d) Where do you sell grain amaranth and its products?..
....
e) To whom do you sell the grain amaranth products?...
....
f) How do you sell the products?..
g) What is the selling price for a kilo of grain amaranth grain?.....................................
h) What other products of grain amaranth do you sell? (e.g. Vegetables)……………
………………………………………………………………………………………

i) What is the selling price of these products?...
....
j) In what way do you think you can make more money from grain amaranth?...........
....
k) Who makes decisions regarding sale of grain amaranth and its products?................
....
l) Who controls the revenues from grain amaranth and its products?..........................
....

9. Challenges

a) What challenges do you experience in growing and harvesting grain amaranth?,,,,
....
....
b) How do you cope with these growing and harvesting challenges?..........................
....
....
c) How else could you cope but are not able under the current circumstances?..........
....
....
d) What challenges do you experience in processing grain amaranth?.........................
....
....
e) How do you cope with these processing challenges?..
....
....
f) How else could you cope but are not able under the current circumstances?..........
....
....

g) What challenges do you experience in marketing grain amaranth?..........................
....
....

h) How do you cope with these marketing challenges?..
....
....

i) How else could you cope but are not able under the current circumstances?..........
....
....

10. Aspirations for grain amaranth

a) What are your future plans for grain amaranth on:
   i. Production...
   ....
   ii. Household consumption...
   ....
   iii. Processing..
   ....
   iv. Selling for income..
   ....

b) What other ideas do you have about new grain amaranth products?
....
....