EFFECTS OF FERTILIZER APPLICATION AND PINCHING ON THE YIELD OF GRAIN AMARANTH (*Amaranthus hypochondriacus*)

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DECLARATION

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

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We confirm that the work reported in this thesis was carried out by the candidate under our supervision.

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DEDICATION

This work is dedicated to my husband Enosh and children Milkah, Irene and Nelson for the moral support and understanding they accorded me during the course of my study.

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ABSTRACT

Inadequate food and imbalanced nutrients are major causes of human malnutrition for the poor, sick, children, elderly and People Living with HIV/AIDS (PLWAS) who are the most vulnerable. These groups have high protein requirements but are unable to access adequate amounts from animal sources due to high cost. Therefore, there is need to explore cheap plant foods with comparable protein quality and quantity as animal protein foods such as grain amaranth (*Amaranthus hypochondriacus*). The current level of production is quite low (0.25 ï 1 t ha^{-1}) as compared to the potential of 3 t ha^{-1}. This study investigated the effects of combined organic and inorganic fertilizer, fertilizer pelleting and pinching on the growth and yield of grain amaranth. The study was carried out at the Maseno University demonstration farm during the short rains in 2010 and the long rains in 2011 in two experiments which were laid out as Randomized complete block design (RCBD) with split plot arrangement and replicated three times. For fertilizer and pinching experiment study, the main plots were pinching at different times and the subplots were the different inorganic and organic fertilizer combinations, while in pelleting study, the main plots were pelleting and the subplots were three different levels of manure and inorganic fertilizer combinations. The data collected was on days to 50 % germination, days to 50 % flowering, days to 50 % maturity, average plant height, stem width, number of leaves, height of flower head, canopy, plants dry matter weight, grain yield and 1000 seed weight. The data were subjected to Analysis of Variance and significant means separated by the least significant difference at $P<5\%$. A regression of yield and growth parameters was done to determine the factor with the greatest influence on yield. To assess the effect of organic and inorganic fertilizer combination and fertilizer pelleting on the soil and plant tissues nutrient status during growth and development of amaranth, soil and leaf samples were taken at seedling, flowering and at harvesting growth stages and analyzed for nitrogen (N), phosphorous (P) and potassium (K) .The soil and leaf nutrient data was subjected to regression analysis. Regression analysis was used to observe the influence of the nutrient levels in the soil and leaves on the crop yields. Pinching at 28 days after planting was the best practice for increased stem width, number of flowering stems, canopy, number of leaves and yield. Fertilizer combination of 75 % organic N and 25 % inorganic N had the highest grain yield of 1.185 t ha^{-1}while fertilizer combination of 25 % organic and 75 % inorganic recorded the lowest grain yield of 0.665 t ha^{-1}both in 2010 and 2011. Stepwise multiple regressions of the factors with yield showed plant height to have the highest influence on yields. All the pellet fertilizer treatments had better growth parameters, higher dry matter weight, 1000 seed weight and grain yield than the control. In 2011, pellet fertilizer treatment with 75 % organic N and 25 % inorganic N had mean grain yield of 743 kg ha^{-1}, while non- pellet fertilizer of the same treatment had mean grain yield of 533 kg ha^{-1}. In the same season pellet fertilizer treatment with 25 % organic N and 75 % inorganic N had mean grain yield of 413 kg ha^{-1} while the non-pellet fertilizer of the same treatment had mean grain yield of 231 kg ha^{-1} (Least Significant Difference = 141.3). The regression models were statistically significant at $P<5\%$ in estimating the linear dependency of; % N in leaves on % N in the soil at both seedling and flowering stages, yield on the level of potassium in the soil and in the leaves at both seedling and flowering stages. The regression models using fertilizer pellets showed positive correlation between % N levels in the leaves and % N levels in the soil at flowering stage representing a normal curve. The regression models positively related P levels in the soil and yield at seedling stage which is normally the case. The study recommends the use of a mixture of 6.75 kg ha^{-1} organic manure and 22 kg ha^{-1} inorganic N to ensure prolonged source of nutrients to the plant and to enhance yield. Coating of fertilizers containing high leachable nutrients or pelleting with manure is also recommended.

CHAPTER ONE: INTRODUCTION

1.1 GENERAL INTRODUCTION

Poverty and inability to access adequate amounts of expensive animal protein foods to meet dietary requirements is a major reason for the widespread and severe malnutrition among vulnerable groups such as the poor, children, elderly and people living with HIV/AIDS. As such, exploration of a cheap plant food with comparable protein quality and quantity as animal protein foods is needed. Grain amaranth (*Amaranthus hypochondriacus*) is one such plant.

Grain amaranth contains 12 to 18 % crude protein (dry matter basis), which is higher than most grains except soybeans (Teutonico and Knorr, 1985; Keckesova et al, 2013). The grain protein contains substantial amounts of essential amino acids; 5 % lysine and 4.4 % methionine (Peter et al., 2003). The lysine content is twice that of wheat protein, three times that of maize, and as much as is found in milk (BOSTID, 1984). The amino acid composition of amaranth protein compares with the FAO/WHO protein standard (FAO, 1973; Teutonico and Knorr, 1985; Mlakar et al, 2010). In addition, the total lipid content of grain amaranth ranges from 5.4 to 17.0 % dry matter which is generally higher than that for cereals. Amaranth lipid has a high level of un-saturation (about 75 %) and almost 50 % linoleic acid (Becker et al., 1981; Mlakar et al, 2013). Grain amaranth contains dietary minerals such as iron, calcium, potassium, phosphorous, magnesium, copper and manganese (Mlakar et al, 2013). The calcium content is twice that of milk. It also contains tocotrienols (a form of vitamin E) which has cholesterol-lowering activity in humans (Railey, 1993). Grain amaranth grows fast, is high yielding under a wide range of agro-climatic conditions, is easily digestible even by convalescents and is tasty in a variety of forms.

Researchers have reported that the water requirement for growing grain amaranth is 42-47 % that of wheat, 51-62 % that of maize and 79 % that of cotton (Mwangi, 2003). In general amaranth is extremely drought tolerant (Kauffman and Weber, 1990). Some grain will be produced as long as there is enough moisture in the soil for the seeds to germinate, and as long as there is enough rainfall about three weeks after emergence. Grain amaranth can be grown in areas receiving 390mm to 550 mm annual rainfall.

Grain amaranth, with its desirable characteristics, is thus a choice crop for food and nutrition security and more importantly as an adaptation/mitigation strategy to climate change. Nevertheless, a survey done in 2008 in the Lake Victoria Basin, farmers indicated that lack of awareness on crop husbandry and utilization limits the production of grain amaranth (Nyankanga et al., 2012).

1.2 PROBLEM STATEMENT AND JUSTIFICATION

Grain amaranth yields in Kenya are depressed averaging one ton ha^{-1} (Poverty Eradication commission, 2006). The crop is grown by small scale resource poor farmers who cannot apply recommended rates of nutrients; hence net negative nutrient balances. This leads to low production and contributes to food insecurity. Nutrients can be supplied from either inorganic or organic sources. The short term benefits from use of inorganic sources include fast release of nutrients to meet crop demand and convenience in application. However inorganic fertilizers are expensive, out of reach of poor farmers and the nutrients are easily leached leading to pollution of water sources. Slow release fertilizers dissolve gradually, thereby delaying nutrient release to curb pollution. Fertilizer pelleting is one of the slow release technologies and has been tried in other crops and further information on its use in grain amaranth is required. Livestock manure which is available in most homesteads can supply crop nutrients. The use of manure has long term benefits that include release of nutrients to plants slowly and for a prolonged period of time in addition to improving the soil physical properties. However the use of livestock manures alone cannot meet crop nutrient demand because of limited quantities available, low nutrient content and the slow release of nutrients during periods of peak crop nutrient demand. To enhance crop nutrient use efficiency, a fertilizer augmented soil enrichment approach is applied which is based on making the best use of organic matter and manure with the addition of limited amounts of mineral fertilizer to maintain the supply of essential elements such as phosphorus and nitrogen. A survey done in 2008 in the Lake Victoria Basin, indicated lack of information on use of fertilizer augmentation in grain amaranth production (Nyankanga et al., 2012). In addition there is insufficient information indicating effects of pinching on amaranth grain production. Hence there is need for further study to evaluate the effects of combined organic and inorganic nutrient sources, fertilizer pelleting and pinching on the performance of grain Amaranth (*Amaranthus hypochondriacus)*.

1.3 OBJECTIVES

1.3.1 Broad objective:

The overall objective of this study is to increase production of grain amaranth through pinching and the use of inorganic fertilizer and manure.

1.3.2 Specific objectives:

1. To determine the effect of pinching and inorganic and organic fertilizer combinations on the growth and grain yield of *Amaranthus hypochondriacus*.
2. To determine the best inorganic and manure argumentation level to maximize grain production of *Amaranthus hypochondriacus.*

3. To evaluate the effect of pelleting of inorganic and organic fertilizer combinations on the growth and grain yield of *Amaranthus hypochondriacus.*

4. To assess the effect of combined organic and inorganic fertilizers on soil properties and plant tissues nutrient status during growth and development of *Amaranthus hypochondriacus*.

CHAPTER TWO: LITERATURE REVIEW

2.1 GENERAL INTRODUCTION

2.1.1 Origin

The name amaranth originates from the Greek word for ñnever ï flower.ò The plant is an annual herb, not a ñtrueô grain and it is a relative of pigweed. Grain amaranth is a non-grass cereal classified in a very unique food group called pseudo- cereal. It originated from India and Ethiopia and was later taken to Incas in Mexico where it was used to cover the deserts (Poverty Eradication Commission, 2007). Grain amaranth species have been important in different parts of the world and at different times for thousands of years. It was the staple food in the diets of the pre- Columbian Aztecs, who believed it had supernatural powers and incorporated it into their religious ceremonies.

2.1.2 Botany

The grain amaranth is a bushy plant that grows 5 to 7 feet (150 to 210 cm), with broad leaves and a showy flower head of small, red or magenta, clove like flowers. The seed heads resemble maize tassels, but are somewhat bushier. The grains are tiny (0.9 to 1.7mm diameter or 1/32ò); lenses shaped, and are golden to creamy tan in color. Each plant is capable of producing 40,000 to 60,000 seeds (Railey, 1993). The weight of 1000 seeds varies from 0.7 to 0.9 g.

2.1.3. Species

There are about 60 *Amaranth* species, several of which are cultivated as leaf vegetables, cereals, or ornamental plants, while others are weeds. There are three species of grain amaranth: *A. hypochondriacus*, *A. cruentus* and *A. caudatus* and many varieties within these 3 species produce either white, yellow, or pink seeds.

The above three species have been identified as having the potential to increase world food production (NAS, 1975). Grain amaranth can further be divided into tall and short types.

2.1.4 World distribution

Grain amaranth is currently grown in many parts of the world mainly in the USA, South and Central America, Russia, China and most countries in Africa. In Kenya grain amaranth is considered a newly introduced crop. The Ministry of Agriculture registered grain amaranth in 1991 as a crop. Grain amaranth production is being promoted in the country by many stakeholders including the Ministry of Agriculture, Poverty Eradication Commission (PEC), NGOs and the private sector. The main production areas in Kenya include parts of Eastern, Central, Nyanza and Western regions. It is grown by small scale farmers scattered in these areas. Grain amaranth is known by different cultural names in Kenya; the Swahili is *mchicha*, the Kikuyu's *terer*e, the luhya's *omboga*, the Luo's *ododo*, the Pokot's *sikukuu* or *chepkuratian*, the Turkana's *lookwa* or *epespes*, the Teso's *Ekwala* (Alemu, 2005).

Production of grain amaranth is promoted for various reasons: food security, commercial crop to improve family income and earn foreign exchange and for promotion of urban agriculture among others. The country currently produces about 400 tons of amaranth grain annually (Amaranth news, 2007). Unfortunately promotion of grain amaranth is hampered by unavailability of adequate literature on agronomic practices and value addition technologies.

2.2. AGRONOMY

2.2.1. Ecological Requirements

Grain amaranth is adaptable to a wide range of climatic conditions. It grows best under humid conditions but has the ability to withstand hot climates. Grain amaranth is extremely drought tolerant but requires wet conditions during germination and early establishment (Putnam et al*.,* 1989). Its water requirement is reported to be 42-47 % that of wheat, 51-62 % that of maize and 79 % that of cotton (Mwangi, 2003). Amaranthôs drought tolerance is as a result of its deep and extensive root system and a C4 metabolism (OôBrien and Price, 1983). However it requires adequate moisture for good production but can be grown in areas receiving 390 mm to 550 mm annual rainfall. Grain amaranth responds well to high sunlight and warm temperatures (Putnam et al*.,* 1989). It requires soil temperatures ranging from 18 ^{0}C to 24 ^{0}C for optimal growth (Gelinas and Seguin, 2008).

Grain amaranth is adaptable to different soils- sandy, loamy, alkaline or saline types but prefers soil pH of 6.0 to 7.5. The type of soil can affect germination. This is because of the tiny seeds which germinate into tiny and fragile seedlings. The seedlings can easily be blocked from emergence by a thin crust on the soil formed after a rain. Selecting soils that are lower in clay and managing the seedbed to minimize chance of crusting can help ensure getting good stand.

2.2.2 Cultural practices

Planting

The grain amaranth seeds are quite tiny and present a special challenge in producing the desired plant stand. The seeds are planted in finely prepared soil, shallowly planted, and packed to assure good seed-to-soil contact. A planting depth of more than one cm has been shown to delay and decrease emergence (Webb et al, 1987), although in dry land areas, a planting depth of more than one cm may be necessary to obtain adequate moisture for germination. A seeding depth of 2.5 cm may be practical in friable soils if seeding rates are adjusted to compensate for reduced emergence associated with increased depth. Amaranth germinates quickly when soil temperatures are from 15°C to 18°C (Webb et al., 1987). The crop is usually grown as a row crop to allow weed control by cultivation.

Fertilizer requirements

There is only limited information available on the fertility requirements of amaranth but nitrogen is reported to be the primary limiting factor in amaranth production (Pospisil et al, 2006). Various studies have shown that yield differences of amaranth cultivars were due to nitrogen availability (Myers, 1998; Pospisil et al., 2006) and individual cultivar traits (Henderson et al., 2000; Sleugh et al., 2001; Stordahl et al., 1999, Nyankanga et al, 2012).

Nitrogen fertilization

The N needed for the growth of a crop will vary depending on the N status of the soil and potential for the mineralization. Therefore, optimum N amount for maximum amaranth growth substantially differs with different researchers, the reported range varying from 50-200 kg N h^{-1} (Bharat and Wayne, 1996). Manga (2001) reported that application of nitrogen fertilizer at the rate of 50 kg N ha^{-1} was optimum for growth and yield of grain amaranth in the savanna ecological zones of Nigeria. Nyankanga et al, (2012) reported that 87.5 kg N $ha^{-1}$of inorganic N, to be the optimum requirement for maximizing grain amaranth yield in Western Kenya. Endres (1986) reported that no yield advantage noted at higher N rate than 100 kg ha^{-1}. Nitrogen can be supplied from different sources.

Inorganic nitrogen fertilizer

Inorganic nitrogen can be supplied from different fertilizer blends. The main ones are; Calcium Ammonium Nitrate (CAN) with 26 % nitrogen, Diammonium Phosphate (DAP) with 18 % nitrogen and urea. Bharat and Wayne (1996) realized a linear increase in plant height, leaf area, stem width, leaf fresh and dry weights with increased nitrogen fertilization until 90 kg ha^{-1}. Ainika et al, (2011) and Manga (2001) reported that application of nitrogen at the rate of 50 kg ha^{-1} significantly increased the vegetative growth and development of *Amaranthus cruentus* through increased plant height, plant dry matter weight and leaf area index. Nyankanga et al, (2012) reported a linear increase in yield of *Amaranthus hypochondriacus* with application of inorganic nitrogen (N) up to 87.5 kg N ha^{-1}.

Manure application

The use of organic manure in crop production has been studied by many scientists. Cattle manure is widely used by subsistence farmers though its use in large scale farming is limited. Manure has high organic matter content; application of manure often helps restore depleted organic matter in arable land, especially land with heavy erosion (Zhang et al, 2006). Nutrients added through manure application are in organic form and they become available to plants over a longer period of time compared to inorganic fertilizer. Ainika et al, (2011) reported that application of farmyard manure at the rate of 4 t ha^{-1} significantly increased the vegetative growth and development of grain amaranth (*Amaranthus cruentus*) through increased plant dry weight, leaf area index and crop growth rate but grain yield was not affected. Experiments done to study the effect of manure application on yield and quality of grain amaranth in western Kenya recommended the use of 9 t ha^{-1} cow dung manure (Nyankanga et al., 2012). For the small scale farmer large quantities of farm yard manure will be too expensive and also inconveniencing to transport and apply.

Combined use of manure and inorganic fertilizers

Since the level of decomposition of manure is not easy to determine, high and sustained crop yield can be obtained with judicious and balanced nitrogen and organic matter amendments (Makinde, 2007). The combined application of farm yard manure and fertilizer has been tried in different crops. In sorghum, Alemu and Bayu (2005) reported that grain yield was significantly enhanced due to application of farm yard manure, mineral fertilizers and their interaction effects. Results of the analysis of the post-harvest soil samples, revealed that the soil total N, organic carbon (C), available phosphorous (P), Potassium (K) and Magnesium (Mg) contents were significantly ($P<0.01$) increased in linear response ($P< 0.01$) to farm yard application in the 0-20 cm soil depth. Ainika et al, (2011), while working on *Amaranthus cruentus* reported that a combination of 50 kg N ha^{-1} with 4 t ha^{-1} of farmyard manure showed superiority in terms of yield. The yield was 1295.9 kg ha^{-1} as compared to 1138.3 kg $ha^{-1}$when the amount of N is doubled or 1211.3 kg $ha^{-1}$when the amount of manure is doubled. Ayuso et al, (1996), and Akanbi and Togun (2002), reported that a combination of maize stover compost and urea fertilizer at the rate of 3 t ha^{-1} + 30 kg N ha^{-1} significantly enhanced amaranth growth and yield attributes. Studies done in Western Kenya recommended the use of 9 t ha^{-1} of manure alone or 87.5 kg ha^{-1}inorganic N as sufficient for production of 1.84 t ha^{-1}. These amounts of fertilizer are too high and the cost implication is also high for the small scale farmer. The study tried to determine the level of fertilizer combination for maximum grain production.

Use of fertilizer pellets

Pelleting is interaction between particles of materials and applied forces, through process of biomass densification, to increase its bulk density and decrease volume (Reza-Bagheri et al, 2011). Biomass densification is the use of some form of mechanical pressure to reduce the volume of grind material and conversion of this material to a solid form (pellets), which is easier to handle and store than the original material, with long-term effects including reduced leaching losses and enhanced nitrogen uptake, as well as positive effects on both health and soil nutrients (Erickson and Prior, 1990; Hernandez et al., 2006). Masayuki (1998) made pellets from livestock manure and found that the fertilizer efficiency of pelleting compost does not differ essentially from that of the compost which was used as the raw matter. He further recommended that pellets can be applied to crops according to the present standard application rates for organic fertilizer.

The use of fertilizer pellets has been tried in several crops. Jeiran et al, (2008) tried pellets made by mixing urea and dry cow dung on wheat and reported an increase in harvest index, number of spikes/m^2, 1000 grain weight, the biological yield, the grain yield and grain protein content per hectare, and hence recommending the use of pellet fertilizer as a suitable alternative to urea in wheat. Reza-Bagheri et al, (2011) also reported that the application of pellet fertilizer made by mixing urea with cow dung improved the quantity and quality of corn yield and its components compared to urea alone. There is scanty literature relating the use fertilizer pellets in grain amaranth. The recommended fertilizer rates both organic and inorganic are too high and the use of pellets could decrease the volume of application of manure and reduce leaching of N nutrient.

Pinching

Pinching is a form of pruning that encourages branching on the plant. It involves the removing of the terminal bud of an herbaceous plant. The terminal bud produces auxins which prevents other nodes from opening up to release their buds. The overall effect being increased height of the main stem. Pinching is a standard practice in many cut flower productions (Ecke and Matkin, 1976). It is also practiced in herbs (Phetpradap et al 1994: Hammo, 2008). Once the terminal bud is removed, several buds on the stem open up before a new terminal bud accumulates auxins to stop the process (Walston, 2001). Pinching is done by hand or sharp pair of pruning shears when plants are well established, about 4 to 6 weeks after planting. The stems are pinched back at the fourth or fifth node. This is done in order to force the plant to produce more flowering stems for increased flower production. In herbs, it is done to encourage the plant to produce more desirable forage and seeds (Hammo, 2008).

In carnations, pinching delays flowering and hence harvesting (Iftikhar, 2007). In chrysanthemums, the first few flower stems are normally pinched to ensure uniform development of basal rosette (MOA et al, 2003). Phetpradap et al, (1994) while working with dahlia observed that pinching reduced the spread of flowering and resulted in seed heads at approximately the same height above ground level. They attributed this to the promotion of lateral branch length. However, they observed no increase in seed yield. Rathore et al, (2011) while studying the effect of pinching and plant bio regulators on marigold reported that pinching decreased plant height, increased the number of primary branches and number of flowers per plant. Gnyandev (2006), reported that pinching China Aster increased seed weight per plant and also per hectare and 1000 seed weight. Hammo, (2008) worked on *Nigella Sativa* L. and reported increased vegetative dry weight, fruit number and seed yield per plant with pinching and nitrogen fertilization. Pinching is a common practice in amaranth grown for potherbs to increase foliage through increased branching. There is very scanty literature available regarding pinching in amaranth for purpose of increasing grain yield.

Pest management

Weeds

Amaranth seedlings grow slowly the first few weeks and are easily overtaken by early weeds. There are no herbicides recommended for control of weeds in grain amaranth (Aynehband, 2008). Multiple tillage before planting; one to sprout the weeds, and another one a week or so later to kill the weed sprouts, is recommended (Jefferson Institute, 1999). Also cover crops and no-till planting can help prevent weed seeds from germinating. Once amaranth gets to be 15 to 20 centimeters tall, it will begin growing rapidly, and can shade and out compete late emerging weeds (Myers and Putman, 1988)

Diseases

There are no diseases of economic importance known to affect amaranth especially in drier areas. But in poorly drained soils, seedlings could be affected by soil borne pathogens (*Fusarium, Pithium* and *Bacterium ssp*) that cause dumping off. There are no fungicides recommended (Jefferson Institute, 1999).

Insect pests

The tarnished plant bug (*Lygus lineolarious*), is the worst insect pest on amaranth. It is a sucking insect that routinely shows up in amaranth heads, attacking flowers and seeds. It prevents flowers from developing into seeds and reduces seed weight. It can therefore, cause substantial yield loss. In Central America, blister beetles and alfalfa webworm are leaf feeders known to cause yield loss. Pyrethrins are effective in controlling these insects (Jefferson Institute, 1999).

Other pests include doves which eat the mature seed before harvesting and monkeys which eat the young plants.

Harvesting, utilization and storage

Grain amaranth matures in 60 to 90 days. Most varieties maintain high moisture content in the stem and leaves. Harvesting is done when the leaves turn yellow and inflorescence start dropping. This time the grain should be physiologically mature (at hard milk stage). The whole plant and inflorescence is cut with sickle/secateurs at about 30 cm above the ground. The inflorescence is spread on canvas to dry for two to three days under direct sunshine and then the tiny grains are threshed out by beating with sticks. Winnowing is done to separate the chaff and grains. The grains are further dried to about 11-12 % moisture content. The dry grains are then packed in gunny bags and stored away from dampness. In developed countries like USA and Mexico, harvesting is done by combine harvesters. Yields of grain amaranth are highly variable and depend on many factors. Weather patterns and cultural practices play a particularly important role. In Kenya, yields in farmers' fields have ranged from 40 kg ha^{-1} to 169 kg ha^{-1} (Amaranth news, 2007). With good rains and proper husbandry, yields of up to 1000 kg ha^{-1} have been reported. Nyankanga et al, (2012) reported a yield of 1.84 t $ha^{-1}$when using 9 t ha^{-1} manure or 87.5 kg ha^{-1} inorganic N.

Nutritional value

The nutritional composition of both grain and vegetable amaranth has been extensively studied (Becker et al. 1981; Teutonico and Knorr 1985; Pedersen et al., 1987; Bressani, 1990; NAS, 2006). Amaranth grain is considered to have a unique composition of protein, carbohydrates, and lipids. Grain amaranth has 12 to 18 % crude protein (dry matter basis), which is higher than most grains except soybeans (Teutonico and Knorr, 1985; NAS, 2006). Amaranth proteins are of high quality. They contain essential amino acids; lysine 5 %, methionine 4.4 % and tryptophan 0.18-0.28 % that are lacking in other cereals (Senft, 1980; Venskutonis and Kraujaris, 2013). The lysine content is nearly twice that of wheat protein, three times that of maize protein, and as much as is found in milk (BOSTRID, 1984). The amino acid composition of amaranth protein compares well with the FAO/WHO protein standard (FAO, 1973; Teutonico and Knorr, 1985). The grain therefore, has the potential to substitute expensive animal protein in the diets of vulnerable people who cannot afford the animal protein sources, by complementing cereals. For instance, when amaranth flour is mixed in the ratio 30:70 with either rice, maize, or wheat flour, the protein quality rises from 72 to 90, 58 to 81, and 32 to 52, respectively (Bressani, 1989). Although amaranth protein itself is low in leucine, this amino acid is found in excess in conventional plant protein sources. 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). Consequently, amaranth protein is well protected from damage during processing.

The carbohydrates in amaranth grain consist primarily of starch made up of both glutinous and non-glutinous fractions. 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 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 amaranth starch in food preparation of custards, pastes, and salad dressing have been studied (Singhal and Kulkarni, 1990). The total lipid content of grain amaranth ranges from 5.4 to 17.0 % dry matter which is generally higher than that for cereals. Amaranth lipid has a high level of un-saturation (about 75 %) and almost 50 % linoleic acid (Becker et al., 1981).

Grain amaranth is high in fiber, which is five times that of wheat. It contains calcium, potassium, phosphorous, vitamins A and C. The calcium content is twice that of milk. It also contains tocotrienols (a form of vitamin E) which have cholesterol-lowering activity in humans (Railey, 1993). Amaranth grain contains vitamin B complex, Vitamin C and lactic acid.

Utilization

Utilization of grain amaranth starts either as ground flour or as popped cereal. It is eaten along with staple foods to complement their nutrient density, improve the taste and to promote health. The seeds can be cooked with other whole grain or added to soups and stews as a dense thickening agent. Sprouted seeds are used in salads and sandwiches (Jefferson Institute, 1999)

Utilization studies have shown that, the grain amaranth flour can be blended with other cereal flours at 50 % or even 70 % (by weight) levels in different nutritional products. The blended flour is used to make porridge, ugali, chapattis, or mandazi. It is also used in multigrain products like breads, noodles, pancakes, cookies and breakfast cereals (Hackman and Myers, 2003; Muyonga et al., 2008). The popped grains are used as a snack. Popped grains can be mixed with sugar to make confectionary. The grain is also used in fortified food where the staple food is low in certain elements (Mnkeni et al., 2006). Amaranth grain does not contain gluten and can be used as a substitute for wheat in baking products for people who are allergic to gluten in wheat and other products (Marjorie, 1984).

Medicinal value

Grain amaranth has been found to have medicinal values. It has been used in management of diabetes, migraines, hypertension, liver disease, hemorrhage, TB, HIV/AIDS, wounds, kwashiorkor, marasmus, stunting, diarrhea and skin diseases. It contains dietary fibersô important in prevention of coronary heart disease and cancer of the colon. Grain amaranth consumption facilitates evacuation of placenta after birth as well as help in secretion of milk (Mwangi, 2003).

Processing and Economic Usage

Grain amaranth can be used to produce more nutritious industrial products such as bread, pastry, biscuits, flakes, crackers, ice-cream, and lysine rich baby foods. In such products, the toasted grain seed flour, which lacks functional gluten, is blended with wheat flour, which contains gluten. The grains can also be poached, milled and used in gluten-free bread and pan cake-like chapattis (NAS, 2006).

Because grain amaranth has high protein, as well as a high fat content, there is the potential to use it as a high energy food. Milled and toasted amaranth products were found to be highly digestible and absorbable in human feeding studies (Morales et al. 1988). The balance of carbohydrates, fats, and protein, allow amaranth the opportunity to achieve 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 (Lara and Ruales, 2002).

CHAPTER THREE: GENERAL MATERIALS AND METHODS

3.1 SITE DESCRIPTION AND LOCATION

The study was carried out in Maseno University Research Farm in Kisumu County. The farm is located on latitude N 0^{o} 1ô-S 0^{o} 12ôand longitude E 34^{o}24ô - E30^{oô}47ô, at 1515 m above sea level. The farm is in lower midlands sub humid (LM2) ecological zone. The rainfall distribution is bimodal with the long rains being received in March to July and the short rains being received in September to December (Jama et al., 1997). The farm receives an annual average rainfall of 1750 mm and temperature ranges from 15^{o}C to 31^{o}C (Abednego et al., 2003). During the experimental period, 1278 mm of rainfall was received in 2010 and 1088.5 mm during the months of January to September, 2011. The mean temperature in 2010 was 25.5^{o}C and 25.3^{o}C in 2011.

The major soil type in the experimental farm is classified as Acrisols (FAO, 2003). The measured initial soil properties were: Moderate in nitrogen (0.15 %), low in phosphorus (2.00 ppm), very low potassium (0.25 Cmol/kg), moderate organic carbon (1.44 %) and moderately acidic (pH water; 5.52 and pH 0.01$Cacl_2$ 4.54).

3.2 EXPERIMENTAL DESIGN AND TREATMENTS

The study was carried out in two experiments which were laid out as Randomized complete block design (RCBD) with split plot arrangement and replicated three times. In the experiment to study the effect of fertilizer application and combination on the growth and yield, the details are explained in 4.3.2. In the experiment to assess the effect of fertilizer combination and pelleting, the details are explained in 5.3.2.

3.4 DATA COLLECTION

Days to 50 % germination were determined by averaging the period it took for half of the plants in each plot to germinate. Days to 50 % flowering were determined by averaging the period it took for half of the plants in each plot to flower. Days to harvest for each treatment were determined by average period it took for half of the plants in each plot to attain physiological maturity. Five plants per plot were randomly sampled from the inner rows. From these plants, the number of leaves per plant was noted weekly up to the 5th week. Measurements of plant height, stem width and span of canopy were taken every week starting from 4th week after sowing. Plant height was the height between soil surface and the tip of the central shoot. Stem width was the width of the stem at the point where branches arise. Canopy span was the widest distance of foliage. Number of stems was determined for the pinched plants and was the number of stems originating from the pinch area. Dry matter content of selected plants per treatment at flowering and at harvesting was determined by destructive harvesting of two plants from the inner rows of the plots. The plants sampled were at average, representatives of plot population. The plants were uprooted whole, and soil from the roots washed off. The plants were then placed in brown envelops and dried at in an oven until brittle dry. The average weight of the dried plants was used to determine the dry matter weight per plot.

3.5 SOIL AND LEAF SAMPLING

The soil and leaf sampling were done at seedling, flowering and maturity stages. Details are explained in chapter 6.3.2.

3.6 HARVESTING

Harvesting was done when all the plants had reached maturity and flower heads had turned brown. Time to harvest was determined by squeezing the seeds. The mature ones did not produce milk when squeezed. Harvesting was done by cutting off the inflorescences and placing them in separate containers for each plot. All the middle plants per plot were harvested and the harvested area measured in m^2. The produce was sundried, threshed and winnowed. The seeds were weighed and the plots yields determined by extrapolation. 1000 seeds per plot were weighed.

The daily rainfall (mm), temperature (^{0}C) and humidity (%) were obtained from Kenya Forestry Research Institute which is located one kilometer from the farm. The readings of the rainfall were used to calculate the amount of rainfall received during the cropping season.

3.7 STATISTICAL ANALYSIS

The data was subjected to Analysis of Variance using (ANOVA) Genstat statistical package, 13th version. Fisherøs least significant difference (LSD) test was used to separate difference in means at 5% significant level.

CHAPTER FOUR: EFFECT OF PINCHING AND FERTILIZER APPLICATION ON GROWTH AND GRAIN YIELD OF AMARANTH (*AMARANTHUS HYPOCHONDRIACUS)*

4.1 ABSTRACT

Grain amaranth yields in Kenya are low due to poor agronomic practices. In other crops pinching and fertilization have been shown to increase yields. Pinching reduces the apical dominancy and allows lateral growth, increasing branching and yield. Despite all this benefits their practice has not been enacted in the production of amaranth. A study was carried out at the Maseno University Research Farm in Kisumu County in 2010 short rain and 2011 long rains growing seasons. The experiment was laid out as a Randomized complete block design with split plot arrangement and replicated three times with main plots being pinching treatments and subplots being five levels of organic and inorganic fertilizer combinations. Pinching 28 days after planting was the best practice to increase stem width, number of flowering stems, canopy and number of leaves. None pinched plants had highest yields of 0.732 t ha^{-1} in 2010. Fertilizer combination of 75 % organic N and 25 % inorganic N had the highest grain yield of 1.185 t ha^{-1} while fertilizer combination of 25 % organic and 75 % inorganic recorded the lowest grain yield of 0.665 t ha^{-1} in 2011. Stepwise multiple regressions of the factors with yield showed plant height to have the highest influence on yields. The results of this study show a combination of organic and inorganic fertilizers at 75 % organic N and 25 % inorganic N respectively gave the highest grain yield of amaranth grown in Western Kenya. It also indicated that pinching is a good agronomic practice to increase yield of grain amaranth but this depends on the time it is carried out. The interaction of pinching and fertilizer combination did not have significant ($p = 0.05$) effect on any growth parameter or yield of grain amaranth in 2010 and in 2011.

4.2 INTRODUCTION

Although the superior nutrition quality of amaranth grain has been long known and the health and nutrition benefits of consuming it noted in malnourished children and people living with HIV/AIDS, its production and consumption is still limited. The farmers and extension officers lack adequate guidelines on best agronomic practices for growing the grain amaranth. There is little research done to determine the best agronomic practices to maximize grain production (Nyankanga et al., 2012). There is limited and preliminary information available on the fertility requirements of amaranth (Olaniyi et al, 2008). However studies done have shown that nitrogen is the most limiting element affecting the yield of amaranth (Alemu and Bayu., 2005).

In Kenya, grain amaranth is grown by small scale growers who are resource poor and cannot afford mineral fertilizers. This leads to low production and contributes to food insecurity. A key resource that could be useful in reversing this trend is livestock manure which is available at the farm level (Alemu and Bayu., 2005). In addition to releasing nutrients slowly into the soil, livestock manure also improves the soil structure. However, the use of organic manures alone cannot meet crop nutrient demand over large areas because of the limited quantities available, the low nutrient content of the materials and the high labor demand for processing and application (Palm et al, 1997). Thus to enhance the quality and effectiveness of organic manures many researchers have recommended a fertilizer- augmented soil enhancing strategy which involves the combined use of manures and mineral fertilizers. This approach combines the short term benefits of mineral fertilizers with the long term values of organic manures (Alemu and Bayu, 2005).

The combined use of inorganic N fertilizers and farmyard manure in grain amaranth has been studied (Ainika et al, 2011; Akanbi and Tugon in 2002). Ainika et al (2011), reported that the application of inorganic nitrogen at the rate of 50 kg N ha^{-1}combined with 4 t ha^{-1} of farm yard manure significantly increased the growth and development of amaranth through increased plant height, plant dry matter weight and leave area index. These results were similar to those obtained when 100 kg N ha^{-1} of inorganic fertilizer were used or when 4 t ha^{-1} farmyard manure was used. Akanbi and Tugon (2002) reported that a combination of maize stover compost and urea fertilizer at the rate of 3 t ha^{-1} + 30 kg ha^{-1} respectively significantly enhanced amaranth growth and yield attributes. Studies done in Western Kenya showed that 87.5 kg N ha^{-1}(from DAP and CAN) alone or 9 t ha^{-1} farm yard manure is the requirement for optimum production of grain amaranth (Nyankanga et al, 2012). For the small scale farmer the recommended quantities of either inorganic fertilizer or farm yard manure is not affordable. Hence a complementary mix of inorganic fertilizer and farm yard manure that has significantly same effect on yield of the crop is required. There is scanty information on the use of combined organic and inorganic fertilizer in grain amaranth production. In this study, the level of combined organic and inorganic fertilizer for optimum grain production was determined.

Pinching is an agronomic practice that has been used in cut flowers to stimulate multiple stems for increased production. It is also used in potherbs including amaranth, to increase foliage through increased branching and number of leaves. There is no sufficient literature available indicating its application in amaranth for increased grain production. It is assumed that if grain amaranth is pinched at the appropriate time, will result to more flowering stems hence higher grain yield. This study therefore, aimed at evaluating the effects of combined organic (cattle manure) and inorganic nitrogen and pinching on the grain yield of Amaranth (*Amaranthus hypochondriacus)*.

4.3 MATERIALS AND METHODS

The study was done in Maseno University Research Farm using seeds obtained from Hortitech Seed Company in Naivasha. The conditions are as described on page 25.

4.3.1 Experimental design and treatments

The experiment was laid out as a Randomized complete block design with split plot arrangement and was replicated three times. The main plot was pinching treatment and the subplot was organic and inorganic fertilizer combinations at five different levels. The main plots measured (17x6) $m^2$and the treatments were, Pinching at 28 days after planting (P1), Pinching at 49 days after planting (P2) and No pinching (P3). The subplots measured (3x6) $m^2$and had 5 treatments of inorganic and organic fertilizer combinations as shown in table 4.1. A distance of 1.0 m and 0.5 m was left between the plots and subplots respectfully to prevent contamination of neighboring treatments.

Dry cattle manure (1 year old) from Maseno University Livestock Unity was used as the organic source of N. Before planting, the manure was analyzed for chemical composition (Table. 4.2).

Table 4.1 Subplot treatments fertilizer combinations

Subplot treatment	**Quantities of organic and inorganic N**	**Proportions of organic and inorganic N**
T1	9 t ha^{-1} manure	100 % organic N
T2	6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic N	75 % organic N and 25 % inorganic N
T3	4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N	50 % organic N and 50 % inorganic N
T4	2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N	25 % organic N and 75 % inorganic N
T5	87.5 kg ha^{-1} inorganic N	100 % inorganic N

The manure for each plot was weighed separately, spread evenly and incorporated into the soil before planting. The inorganic fertilizer was applied in two splits; 46% was applied at planting as Diammonium Phosphate (DAP) 54% was top dressed as Calcium Ammonium Nitrate (CAN) 6 weeks after planting. The application rates were based on the recommendations of 87.5 kg inorganic N ha^{-1} and 9 t cattle manure ha^{-1} (Nyankanga et al., 2012). Top dressing was done after the plants were thinned to one plant per planting hole. The treatments quantities of DAP and CAN applied are shown in table 4.2.

Table4.2: Quantities of DAP and CAN applied to the treatments

Subplot treatment	T1	T2	T3	T4	T5
Amount of DAP	0	55.5 kg ha^{-1}	111 kg ha^{-1}	166.5 kg ha^{-1}	222 kg ha^{-1}
Amount of CAN	0	45.75 kg ha^{-1}	91.5 kg ha^{-1}	137.25 kg ha^{-1}	183 kg ha^{-1}

The seed bed was ploughed and harrowed to fine tilth prior to planting. The manure and DAP were mixed with soil before placing the seeds. The seeds were sown in shallow holes at a spacing of 60 x 30 cm. Several seeds were put in each planting hole and left uncovered. Three weeks after sowing the seedlings were thinned to three per hole and to one seedling five weeks after sowing. Weeding was done using hand holes twice in all treatments. Gapping up was done within same plot but where the plot did not have sufficient seedlings for gapping, seedlings from plots of other blocks with similar treatments were used.

The 1st pinching (P1) was done 28 days after planting and the 2nd pinching (P2) was done 49 days after planting in both seasons. Pinching was done just above the fourth node in each case. Aphids and the tarnished plant bug (*Lygus lineolarious*) were the main pests. They were controlled by use of Dimethoate insecticides. There was no disease of major importance noted during the two seasons.

The data collected was on days to 50 % germination, days to 50 % flowering, days to 50 % maturity, average plant height, stem width, number of leaves, height of flower head, canopy, plants dry matter weight, grain yield and 1000 seed weight.

4.3.2 Data collection

Days to 50 % germination were determined by averaging the period it took for half of the plants in each plot to germinate. Days to 50 % flowering were determined by averaging the period it took for half of the plants in each plot to flower. Days to harvest for each treatment were determined by average period it took for half of the plants in each plot to attain physiological maturity. Five plants per plot were randomly sampled from the inner rows. From these plants, the number of leaves per plant was noted weekly up to the 5th week. Measurements of plant height, stem width and span of canopy were taken every week starting from 4th week after sowing. Plant height was measured between soil surface and the tip of the central shoot. Stem width was the width of the stem at the point where branches arise. Canopy span was the widest distance of foliage. Number of stems was determined for the pinched plants and was the number of stems originating from the pinch area.

Dry matter content of selected plants per treatment at flowering and at harvesting was determined by destructive harvesting of two plants from the inner rows of the plots. The plants sampled were at average, representatives of plot population. The plants were uprooted whole, and soil from the roots washed off. The plants were then placed in brown envelops and dried in an oven until constant weight. The average weight of the dried plants was used to determine the dry matter weight per subplot.

Harvesting was done when all the plants had reached maturity and flower heads had turned brown. Time to harvest was determined by squeezing the seeds. The mature ones did not produce milk when squeezed. Harvesting was done by cutting off the inflorescences and placing them in separate containers. All the middle plants per plot were harvested and the harvested area measured in m^2. The produce was sun dried, threshed and winnowed. The seeds per plot were weighed and the yields per hectare determined by extrapolation. 1000 seeds per plot were weighed.

The daily rainfall (mm), temperature (^{0}C) and humidity (per cent) were obtained from Kenya Forestry Research Institute which is located one kilometer from the farm. The readings of the rainfall were used to calculate the amount of rainfall received during the cropping season.

4.3.3 Data analysis.

The data was subjected to analysis of variance (ANOVA) for split plot design, using Genstat statistical software (Payne et al., 2006). Fisherõs least significant difference (LSD) test was used to separate the means ($P \leq 0.05$). Step wise regression was done to determine the growth parameters that mostly determine the grain yield.

4.4 RESULTS AND DISCUSSION

The chemical composition of the manure used for planting is shown in table 4.2.

Table 4.3: Chemical composition of manure used for planting

Soil property	pH (H_2O)	pH (0.01M $Cacl_2$)	% Carbon	% Nitrogen	K (cmol/ kg)	Ca (cmol/ kg)	Mg(cmol/ kg)	P(ppm)
Composition	7.60	7.20	6.65	0.83	9.50	13.50	8.50	950.0

4.4.1 Effect of pinching and fertilizer application on growth and yield of grain amaranth

The interaction of pinching and fertilizer combination did not have significant ($p = 0.05$) effect on any growth parameter or yield of grain amaranth in 2010 and in 2011.

4.4.2 Effect of pinching on the plant vegetative growth

Pinching had significant ($p = 0.05$) effect on number of shoots, days to flowering and 1000 seed weight of grain amaranth.

Number of shoots

Pinching did not have significant (p = 0.05) effect on the number of shoots of grain amaranth in 2010 but had significant (P = 0.025) effect on number of shoots in 2011(Figure 4.1).

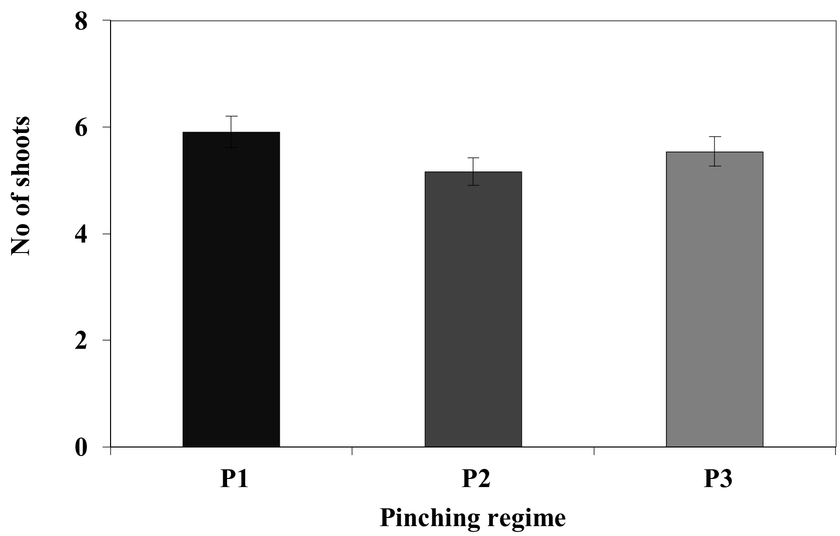

Figure 4.1: Effect of pinching on the No. of shoots of grain amaranth.

Note: P1 = Pinching at 28 days after planting, P2 = Pinching at 49 days after planting and P3 = No pinching. The error bars represent standard error of difference (SED) for the two way interaction between number of shoots and pinching regime.

Pinching increased the number of shoots. Plants that were pinched 28 days after planting had the highest number of shoots originating from the pinch area while those pinched 49 days after planting had the least number of shoots. Pinching removes the apical dominancy of the central stem thus allowing other buds on the stem to open up and develop into lateral stems. Scientist working on cut flowers reported similar results. Iftikhar et al, (2007) while working on carnations and Rathore et al, (2011) while working on marigold reported that pinching reduced flower height and increased number of flowering stems.

Days to flowering

Pinching increased significantly ($p < 0.001$) the numbers of days to flowering with plants that were pinched 49 days after planting taking longer to flower (Figure 4.2). Plants that were not pinched (P3) took the least number of days to flower in both seasons. Pinching removes the apical dominancy of the central stem. This promotes vegetative growth hence delayed flowering. Iftikhar et al, (2007), while studying the effect of pinching approaches on vegetative and reproductive growth of carnation reported that pinching promoted vegetative growth resulting in delayed flowering. Similarly, Gnyandev (2006) reported that, days to 50% flowering of China Aster, differed significantly due to pinching treatment and was significantly more in pinched plants than in non-pinched plants. Grawal et al, (2004) reported delayed flowering in pinched chrysanthemum plants. These results are attributed to pinching altering the source-sink relationship thereby advancing the reproductive phase (Gnyandev, 2006).

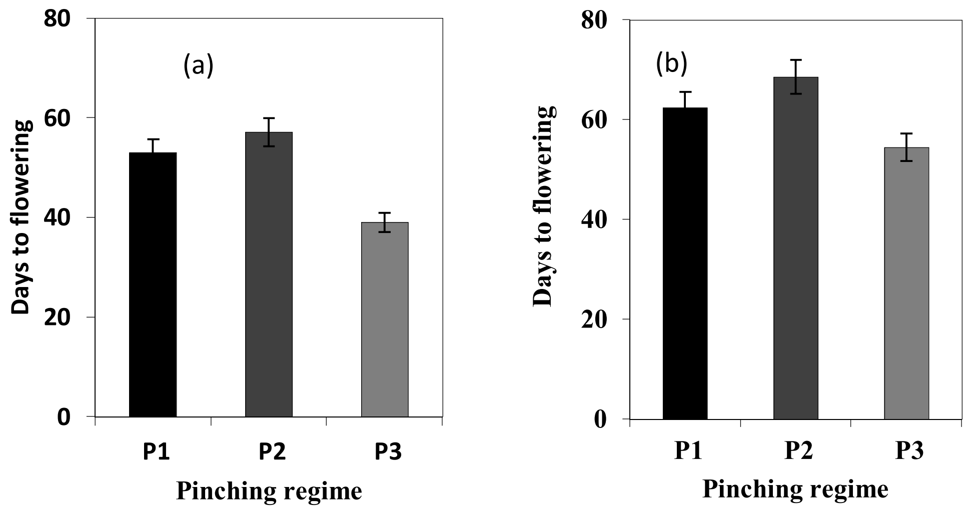

Figure 4.2: Effect of pinching on the number of days to flowering of grain amaranth in 2010 (a) and 2011 (b)
Note: P1 = Pinching at 28 days after planting, P2 = Pinching at 49 days after planting and P3 = No pinching. The error bars represent standard error of difference (SED) for the two way interaction between days to flowering and pinching regime.

1000 seed weight

Pinching had significant ($p = 0.05$) effect on the 1000 seed weight of grain amaranth in 2011 (Figure 4.3). Plants that were not pinched (P3) had the highest weight of 1000 seeds while the plants that were pinched 28 days after planting had the least weight. Pinching increased the number of flowering stems. This coincides with the fact that plants that were not pinched flowered earlier than the pinched ones. This means the plants that were not pinched had more time to feed the grains before physiological maturity resulting to heavier grains (Amul and Dunham, 1979).

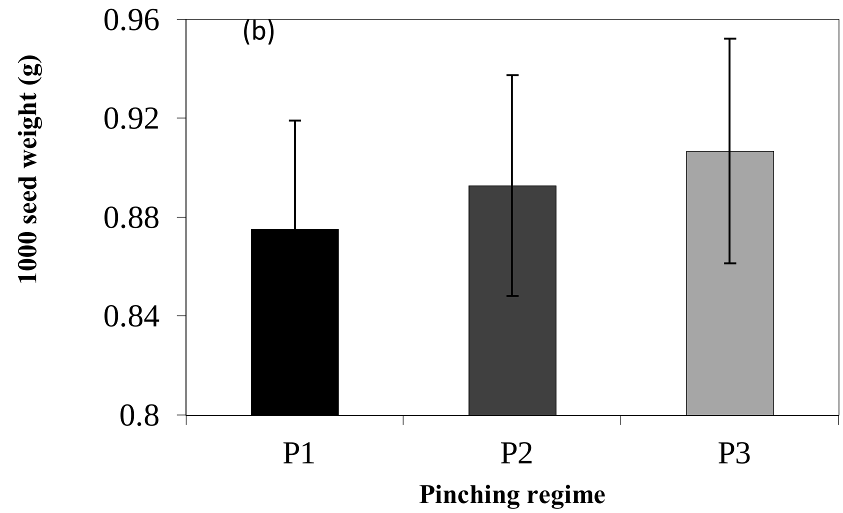

Figure 4.3: Effect of pinching on 1000 seed weight of grain amaranth (2011)
Note: P1 = Pinching at 28 days after planting, P2 = Pinching at 49 days after planting and P3 = No pinching. The error bars represent standard error of difference (SED) for the two way interaction between 1000 seed weight and pinching regime.

Amul and Dunham (1979) studied the effect of pinching on growth, floral initiation and development of container grown rhododendron. They reported that late pinched plants had insufficient time to develop flower buds before the end of the growing period. The reduced weight of 1000 seeds as a result of pinching could be because of photosynthates partitioning to more growing points (Iftikhar et al., 2007). These results are contrary to observations made by Gnyandev (2006) while working on China aster who reported that pinching increased significantly the seed yield and 1000 seed weight. He also reported that pinching increased the number of flowering stems, the number of flowers per plant and the number of seeds per plant. In this experiment, although pinching increased the number of flowering stems, the stems were thin with small size of flower heads and light seeds as shown by the results of 1000 seed weight. Apaza et al, (2002) studied the relationship of plant density and yield of grain amaranth. They reported stem diameter as one with the highest effect on grain yield of amaranth and related the results to the ability of the plant to store nutrients on the stem. Pinching results to more slender stems that may not have enough stored nutrients to feed the seeds resulting to less seed weight.

4.4.3 Effect of pinching on vegetative growth

Pinching had significant effect on number of leaves, plant height, stem width, canopy and plant dry matter weight of grain amaranth.

Number of leaves

The number of leaves per plant increased significantly ($p < 0.001$) with time after pinching, with pinching 28 days after planting (P1) having the highest number of leaves in 2010 (Figure 4.4). In 2011, the effect of pinching on the number of leaves was not significant. In 2010, the least number of leaves was observed in plants that were not pinched (P3) while in 2011, plants that were pinched 49 days after planting (P2) had the least number of leaves.

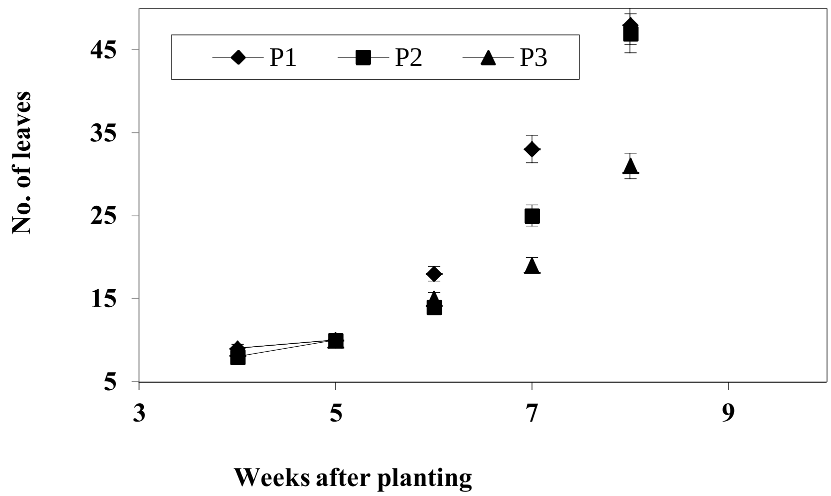

Figure 4.4: Effect of pinching regimes on the number of leaves of grain amaranth.
Note: P1 = Pinching at 28 days after planting, P2 = Pinching at 49 days after planting and P3 = No pinching. The error bars represent standard error of difference (SED) for three way interaction between number of leaves, weeks after planting and pinching regime.

The difference in means of the number of leaves for the different pinching regimes was significant one week after the 1st pinching (Figure 4.4). Pinching increased the number of flowering stems. This also increased the number of leaves which increased with sampling time. The increased number of leaves is due to the increased vegetative growth. Iftikhar et al, (2007) reported similar results from works on carnation flowers.

Plant height

Pinching decreased significantly ($p < 0.001$) the average plant height of grain amaranth in both seasons. Pinching and time had an interactive effect on plant height of grain amaranth, with plants that were not pinched (P3) being the tallest after first pinching and those that were pinched during the second weeding being the shortest after 7th week up to harvesting (Figure 4.5 (b))

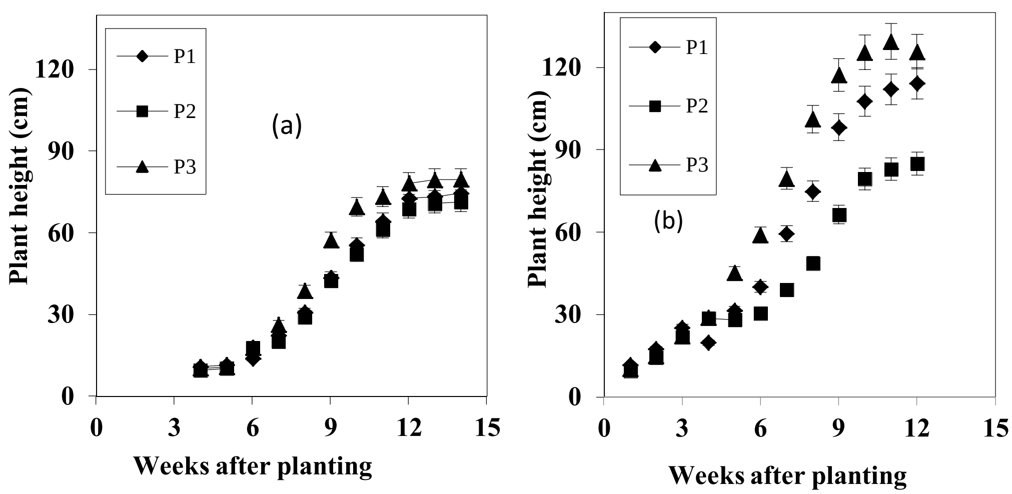

Figure4.5: Effect of pinching and time on plant height of grain amaranth in 2010 (a) and 2011 (b) Note: P1=Pinching at 28 days after planting, P2 = Pinching at 49 days after planting and P3 = No pinching. The error bars represent standard error of difference (SED) for three way interaction between plant height, weeks after planting and pinching regime.

Generally plants in 2011 were taller than plants in 2010 (Figure 4.5). This could be because the temperatures in 2011 season were higher resulting to faster growth. Pinching removes the apical dominancy of the central stem thus allowing other buds on the stem to open up and develop into lateral stems. Once pinched the plant concentrates on regrowing dormant buds other than growing height (Iftikhar et al., 2007). This results to reduced height and increased time to flowering. Rathore et al, (2011) reported that pinching marigold reduced flower height, and increased number of flowering stems. The increased number of flowering stems also causes the increase in dry matter weight.

Stem width

Stem width increased gradually as the plants developed. Pinching had significant ($p < 0.001$) effect on the stem width of grain amaranth in 2010 and in 2011 (Figure 4.6).

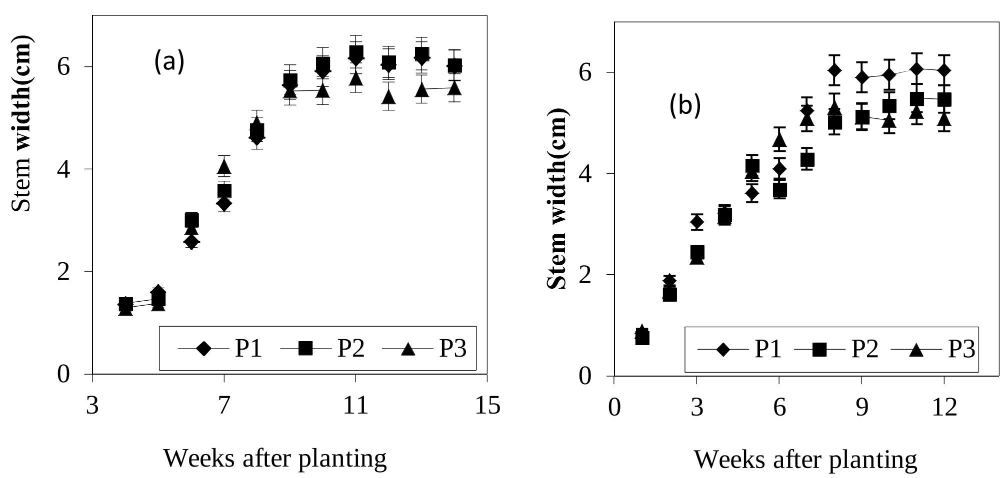

Figure 4.6: Effect off pinching and time on the stem width of grain amaranth in 2010 (a) and 2011 (b)

Note: P1= Pinching at 28 days after planting, P2 = Pinching at 49 days after planting and P3 = No pinching. The error bars represent standard error of difference (SED) for three way interaction between stem width, weeks after planting and pinching regime.

In 2010, the difference in stem width was not significant between the two levels of pinching, but the non-pinched plants had the lowest stem width (Figure 4.6 a). In 2011, Plants that were pinched 28 days after planting had wider stems followed by plants that were not pinched up to the 7^{th} week after planting. After the 7^{th} week the plants that were pinched 49 days after planting had wider stems than those that were not pinched at all (Figure 4.6 b). Pinching removes the apical dominancy of the central stem thus allowing development of lateral stems. This results to increased stem width necessary to support the increased number of stems. Similar results were reported by Iftikhar et al, (2007) while working on carnation flowers.

Dry matter weight

Pinching increased significantly ($p < 0.001$) dry matter weight of grain amaranth in 2011 (Figure 4.7). At both flowering and harvesting, plants that were pinched 28 days after planting had significantly higher dry matter weight followed by plants that were not pinched. Plants that were pinched 49 days after planting (P2) had the least dry matter weight.

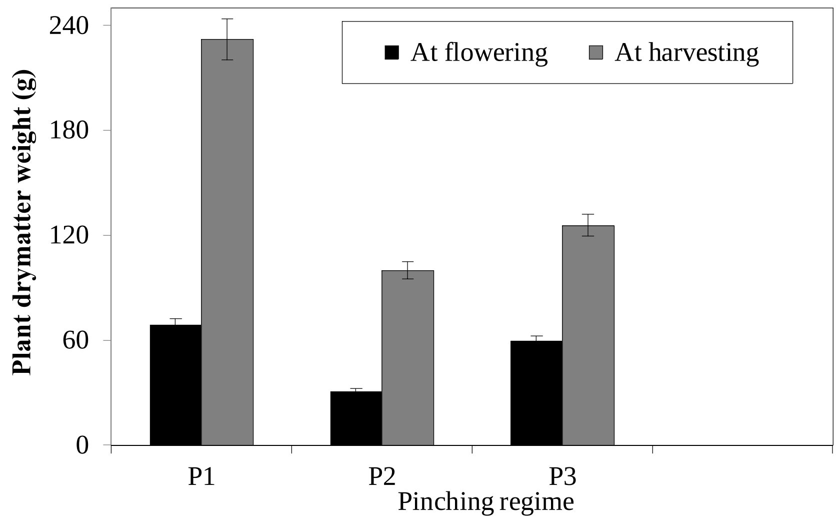

Figure 4.7: Effect of pinching on dry matter weight of grain amaranth in 2011.
Note: P1 = Pinching at 28 days after planting, P2 = Pinching at 49 days after planting and P3 = No pinching. The error bars represent standard error of difference (SED) for three way interaction between plant dry matter weight, pinching regime and stage of development.

Pinching results to increased branching and vegetative growth all resulting to increased biomass. Sawwan and Samawi (2000) reported similar response of carnation flowers to pinching.

4.4.4. Effect of organic and inorganic fertilizer application on the vegetative growth and yield of grain amaranth

The application of combined organic and inorganic fertilizer had significant ($p = 0.05$) effect on number of leaves and yield of grain amaranth.

Number of leaves

Organic and inorganic fertilizer combination had significant ($p = 0.006$) effect on the number of leaves in 2011 (Figure 4.8).

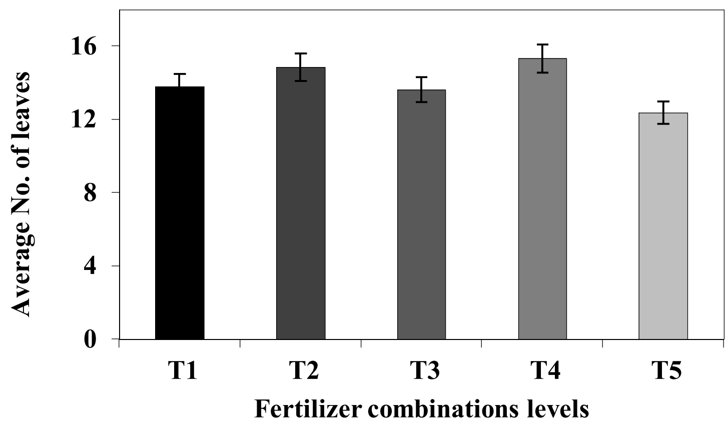

Figure 4.8: Effect of organic and inorganic fertilizer combination levels on the number of leaves of grain amaranth in 2011.
Note: T1= 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic, T3 = 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 =87.5 kg ha^{-1} inorganic. The error bars represent standard error of difference (SED) for the two way interaction between average number of laves and fertilizer combination levels.

In 2011, treatment T4 (25 % organic N +75 % inorganic N) had the highest number of leaves followed by treatment T2 (75 % organic N + 25 % inorganic N). T3 (50 % organic N + 50 % inorganic N) had the least number of leaves. The difference between the means of T4 and T2 was not significant. In the controls treatment T1 (100 % organic N) had more leaves than T5 (100 % inorganic N) and the difference was significant. Results of 2010 were not significant.

Nitrogen is an essential component of chlorophyll, protoplasm, protein and nucleic acid and its absence at appropriate levels could cause yellowing of leaves and stunting of plant growth (Bergman, 1992). These results show a decrease in number of leaves as the amount of organic N decreased. The increase in number of leaves as inorganic N rates increased, reconfirmed the role of nitrogen in promoting vigorous vegetative growth in leafy vegetables (Tisdale and Nelson, 1990) in which amaranths belong. Nutrients added through manure application are in organic form and they become available to plants over a longer period of time than with application of inorganic fertilizer. Manures also hold nutrients preventing them from being leached and release them steadily over time. Manures also improve soil fertility status by activating the soil microbial processes. This explains the decrease in number of leaves as amount of organic manure decreased.

Grain yield

Organic and inorganic fertilizer combination had significant ($P = 0.019$) effect on grain yield of amaranth in 2011 (Figure 4.9). In 2010, 100% inorganic fertilizer treatment had the highest yields while 100% manure had the highest yield in 2011

(Figure 4.9). Among the fertilizer combinations, T2 (75% organic N + 25% inorganic N) had the highest yields while T4 (25 % organic N +75 % inorganic N) had the least grain yield in both seasons but these differences were not significant in 2010.

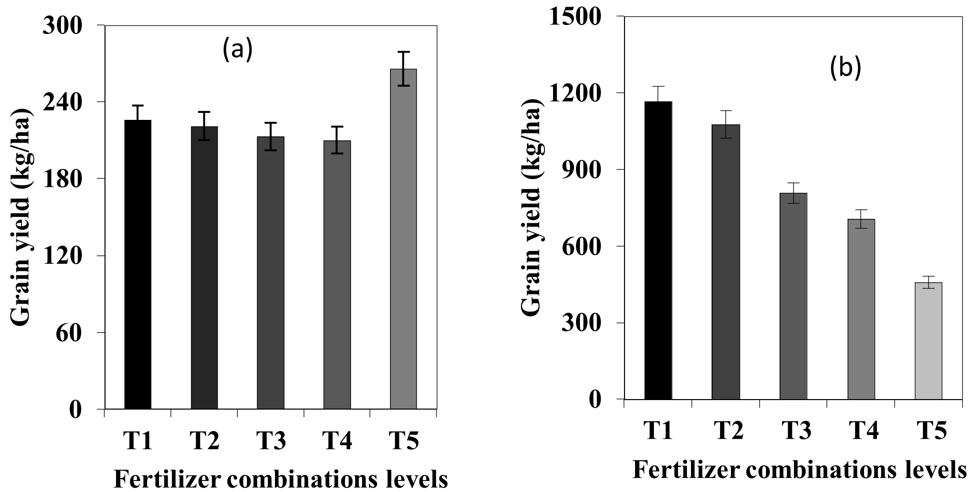

Figure 4.9: Effect of different levels of organic and inorganic fertilizer combination on the grain yield of amaranth in 2010 (a) and 2011 (b).

Note: T1= 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic, T3 = 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 = 87.5 kg ha^{-1} inorganic. The error bars represent standard error of difference (SED) for the two way interaction between grain yield and fertilizer combination levels.

In 2011 these differences were quite significant (p = 0.019). The results show a trend of reducing yield as the amount of organic fertilizer reduces among the fertilizer combined treatments. These results are similar to those of Ainika et al,

(2011) who reported that the application of inorganic nitrogen at the rate of 50 kg N ha^{-1}combined with 4 t ha^{-1} of farm yard manure significantly increased the growth and development of amaranth through increased plant height, plant dry matter weight and leave area index and that the results were significantly the same as when he used 100 kg N ha^{-1}(inorganic) alone or 4 t ha^{-1}farmyard manure alone. Nyankanga et al, (2012) reported that grain amaranth grown using manure alone had better yields than grain amaranth grown using inorganic fertilizer alone. These results also agree with those of Ayuso et al, (1996) and Akanbi and Togun (2002), who reported that a combination of maize stover compost and urea fertilizer at rate of 3.0 t ha^{-1} + 30 kg N ha^{-1} significantly enhanced amaranth growth and yield attributes. According to Makinde (2007), high and sustained crop yield can be obtained with judicious and balanced nitrogen combined with organic matter amendment. Alemu and Bayu (2005) while working on sorghum also reported that grain yield was significantly enhanced due to application of farm yard manure, mineral fertilizer and their interactions.

4.4.5 Relationship of yield and other growth parameters

The regression of yield and growth parameters; plant height, stem width, canopy, shoots and height of flower head was significant (Appendix IV). Yield was positively correlated to plant height, stem width, number of shoots and height of flower head (Appendix IV). The accumulated analysis of variance resulted to a final model:

Yield = 581.6 + 13.3height + 0.003height of flower head + 0.82 canopy +0.459 stem width + 0.002 shoots

These results shows that plant height had the highest effect on yield followed by canopy size, stem width, height of flower head then number of shoots. Pinching enhances these parameters. Plant height determines exposure of leaves to sunlight. Tall plants have more leaves exposed to sunlight for photosynthesis. With photosynthates partitioning this means more photosynthates are translocated to developing seeds making them heavier. This explains why the non-pinched plants had higher yields than the pinched plants in this experiment. The treatment of 75 % organic N and 25 % inorganic N was the best combination. This is in agreement to the findings of Apaza et al, (2002) who studied the response of grain amaranth to density and fertilization in Tarija, Bolivia. They reported stem diameter to have the highest effect on yield per plant. The two valuables (plant height and stem width) decreased quadratically with increased plant density. Therefore grain yield per unit area might be directly related to the ability of the plant to store nutrients on the stem.

4.5 CONCLUSION

Pinching and time of pinching increased vegetative growth of amaranth through increased number of leaves, canopy, stem width, plant height and plant dry matter weight though it had no effect on yields of grain amaranth. In this study, 28 days after planting was the most appropriate time to pinch in order to enhance amaranth growth. The combination of cattle manure and inorganic fertilizer increases grain yield of amaranth. The treatment containing 75 % organic N and 25 % inorganic N is the best fertilizer augmentation for grain amaranth growth and yield in western Kenya according to this study.

4.6 RECOMMENDATIONS

Since pinching increases vegetative growth of amaranth it is recommended to farmers growing amaranth for vegetables or for livestock feeds. The pinching should be done after plants have established but not later than 28 days after planting. Further studies to establish the effect of spacing and pinching on grain yield of amaranth are recommended. Mineral fertilizers are expensive. For the farmers with available cattle manure 9 t ha^{-1} alone or a combination of 6.75 t ha^{-1} manure and 22 kg inorganic N $ha^{-1}$is enough for maximum production of grain amaranth in Western Kenya.

CHAPTER FIVE: EFFECT OF FERTILIZER PELLETS ON THE GROWTH AND YIELD OF *AMARANTHUS HYPOCHONDRIACUS*

5.1 ABSTRACT

The use of fertilizer pellets ensures better distribution of the period of N-availability during the growing season and thereby reducing potential losses. A field experiment was conducted to assess the effect of pellet fertilizer, produced by mixing Calcium Ammonium Nitrate (CAN) and dry cow dung manure, on growth and yield of *Amaranthus hypochondriacus.* The study was carried out during the 2010 short rains and the 2011 long rains at Maseno University experimental farm. The experiment was laid out as Randomized complete block design (RCBD) with split plot arrangement and replicated three times. The main plots treatments were fertilizer pellets and the sub plot treatments were fertilizer pellets made by mixing Calcium Ammonium Nitrate (CAN) and cattle manure. All the pellet fertilizer treatments had better growth parameters than the control treatments. The pellet fertilizer treatments had higher dry matter weight, 1000 seed weight and grain yield than the non-pellet fertilizer treatments. In 2011, pellet fertilizers of treatment T2 (75 % organic N and 25 % inorganic N) had mean grain yield of 743 kg ha^{-1}, while none pellet fertilizer of the same treatment had mean grain yield of 533 kg ha^{-1}. In the same season pellet fertilizers of treatment T4 (25 % organic N and 75 % inorganic N) had mean grain yield of 413 kg ha^{-1} while the none pellet fertilizer of the same treatment had mean grain yield of 231 kg ha^{-1}. The use of pellet fertilizer is therefore a better option due to its slow and continuous nutrient release for plant uptake at different stages of its growth. In addition the combination of CAN and cattle manure in making the pellets improves the soil structure that is key to sustainable production.

5.2 INTRODUCTION

The increased use of nitrogen (N) fertilizer in agricultural production has raised concerns, because the N surplus is at risk of leaving the plant-soil system and thereby causing environmental contamination (Jeiran et al., 2008). This is in addition to increased costs associated with the manufacture and distribution of nitrogen fertilizer (Alizadeh and Ghadeai, 2006; Farhad et al., 2009). Livestock manure is an important resource for agriculture, as it contains a high level of nutrients and organic matter. In addition, use of livestock manure ensures optimal biological activities which maintain soil fertility (Farhad et al., 2009). But the use of livestock manure has several challenges; bulkiness and cost of transport, inconveniences and environmental pollution during application in the field. More over the nutrient content is not stable and depends on what the livestock had fed on and the level of decomposition is not easy to determine (Masayuki, 2001).

Numerous strategies such as use of nitrogen sources, slow release fertilizer, placement techniques and nitrification inhibitors have been devised to reduce nitrogen losses and improve fertilizer use efficiency (Jeiran et al., 2008). One such strategy is fertilizer pelleting. Pelleting is interaction between particles of materials and applied forces, through process of biomass densification, to increase its bulk density and decrease volume. Biomass densification is the use of some form of mechanical pressure to reduce the volume of grind material and conversion of this material to a solid form (pellets), which is easier to handle and store than the original material (Alizadeh and Ghadeai., 2006). Pellet fertilizer therefore is a type of slow-release N fertilizer with long term effects including reduced leaching losses and enhanced N uptake, as well as positive effects on both health and soil nutrient levels (Reza-Bagheri et al., 2011).

The use of fertilizer pellets in crop production has been embraced by several scientists in the recent past. However, most studies have assessed the use of fertilizer pellets on corn ((Reza-Bagheri et al., 2011) and wheat (Jeiran et al., 2010) with few studies having been conducted on grain amaranth. Masayuki, (2001) while working on fertilizer pellets from livestock manure found that the fertilizer efficiency of pelletized compost does not differ essentially from that of the compost which was used as the raw material. Hence the pellets can be applied to crops according to the present standard application rates for organic fertilizer. Since the level of decomposition of manure is not easy to determine, high and sustained crop yield can be obtained with judicious and balanced nitrogen and organic matter amendments (Makinde, 2007).

The objective of this study was to determine the effect of pellet fertilizer, produced by mixing Calcium Ammonium Nitrate (CAN) and cow dung manure combined at different proportions on the growth and yield of *Amaranthus hypochondriacus.*

5.3 MATERIALS AND METHODS

The study was done in Maseno University Research Farm during the 2010 short rains and 2011 long rains using seeds obtained from Hortitech Seed Company in Naivasha. The conditions are as described on page 25.

5.3.1 Experimental design and treatments

The experiment was laid out as a Randomized complete block design (RCBD) with split plot arrangement and replicated three times. The main plot treatments were fertilizer pellets while the subplot treatments were three levels of fertilizer combinations and the controls. The main plots measured (17 x 6) m^2 with one meter in between. The main plot treatments were; Pe ï Pellet fertilizer and, Po ï Non- pellet fertilizer. The subplots measured (3 x 6) m^2 with one meter in between and five treatments. The subplot treatments were of fertilizer combinations as follows: T1- 100 % organic N(9 t ha^{-1}manure), T2 ï 75 % organic N and 25 %

inorganic N (6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic N), T3 ï 50 % organic N and 50 % inorganic N (4.5 t ha^{-1} manure and 43.8 t ha^{-1} inorganic N), T4- 25 % organic N and 75 % inorganic N (2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N), and T5 - 100 % inorganic . Dry cattle manure obtained from a maasai boma in Kitengela was used as the organic fertilizer. Calcium Ammonium Nitrate was used as the source of inorganic nitrogen. The N content of the manure was 2.45 % and the nutrient composition of the pellets was as shown inTable5.1.

Table 5.1: Nutrient content of the various pellet fertilizer treatments

NUTRIENT	T1 - manure	T2 - 83.25 kg ha^{-1} CAN + 6.75 T ha^{-1} manure	T3-168.5 kg ha^{-1} CAN + 4.5 ha^{-1} manure	T4 - 252.75 kg ha^{-1} CAN + 2.25 T ha^{-1} manure
N- %	2.45	2.10	2.80	3.5
P- %	0.34	0.45	0.33	0.27
K- %	3.20	2.51	2.91	2.09
Ca- %	3.08	4.22	3.47	2.22
Mg- %	0.47	0.50	0.59	0.40
Fe- mg/kg	258	1028	926	918
Cu- mg/kg	21.8	18.3	23.5	21.2
Mn- mg/kg	777	836	902	759
Zinc- mg/kg	61.7	43.5	43.5	28.3

The pellets were made using a disk type pelleter (Figure 5.1).

Figure 5. 1:Disk pelleter

5.3.2 Agronomic practices

The seed bed was ploughed and harrowed to fine tilth prior to planting. The fertilizer treatments were mixed with soil before placing the seeds. The seeds were sown in shallow holes at a spacing of 60 x 30 cm. Several seeds were put in each planting hole and left uncovered to avoid burying them deep into the soil. Three weeks after sowing the seedlings were thinned to three per hole and to one seedling five weeks after sowing. Weeding was done using hand hole twice in all treatments. Gapping up was done within same plot but where the plot did not have sufficient seedlings for gapping, seedlings from plots of other blocks with similar treatments were used. Aphids and the tarnished plant bug (*Lygus lineolarious*) were the main pests. They were controlled by use of Dimethoate insecticide which was bought from a stockistôs shop in Maseno town. There was no disease of major importance noted during the two seasons.

5.3.3 Data collection

Days to 50 % germination were determined by averaging the period it took for half of the plants in each plot to germinate. Days to 50 % flowering were determined by averaging the period it took for half of the plants in each plot to flower. Days to maturity for each treatment were determined by average period it took for half of the plants in each plot to attain physiological maturity. Five plants per plot were randomly sampled from the inner rows. From these plants, the number of leaves per plant was recorded weekly up to the 5^{th} week. Measurements of plant height, stem width and span of canopy were taken every week at 7 days interval starting from 4^{th} week after sowing. Plant height was the height between soil surface and the tip of the central shoot. Stem width was the width of the stem at the point where branches arise. Canopy span was the widest distance of foliage.

Dry matter content of selected plants per treatment at flowering and at harvesting was determined by destructive harvesting of two plants from the inner rows of the plots. The plants sampled were at average, representatives of plot population. The plants were uprooted whole, and soil from the roots washed off. The plants were then placed in brown envelops and dried in an oven until constant weight. The average weight of the dried plants was used to determine the dry matter weight per plot.

Harvesting was done when all the plants had reached physiological maturity and flower heads had turned brown. Time to harvest was determined by squeezing the seeds. The mature ones did not produce milk when squeezed. Harvesting was done by cutting off the inflorescences and placing them in separate containers. All the middle plants per plot were harvested and the harvested area measured in m^2. The produce was sundried, threshed and winnowed. The seeds were weighed and the plots yields determined by extrapolation. 1000 seeds per plot were weighed.

The daily rainfall (mm), temperature (^{0}C) and humidity (%) were obtained from Kenya Forestry Research Institute which is located one kilometer from the farm. The readings of the rainfall were used to calculate the amount of rainfall received during the cropping season.

5.3.4 Statistical analysis.

The data was subjected to analysis of variance (ANOVA) for split plot design, using Genstat statistical software (Payne et al., 2006). Fisherọs least significant difference (LSD) test was used to separate significant treatment means ($P \leq 0.05$).

5.4. RESULTS AND DISCUSSION

5.4.1 Effect of pelleting and fertilizer combination on the number of Days to Germination (DG) of grain amaranth.

There was significant ($P < 0.001$ in 2010, $P = 0.011$ in 2011) interactive effect of fertilizer combinations and pellets on the number of days plants took to germinate in 2010 and 2011 (Figure 5.2). Among the fertilizer combination treatments, non pellet fertilizer treatments (Po) took longer to germinate than the pellet fertilizer treatments (Pe) with treatment T3 taking the longest time of 8 days followed by treatment T2 with 7.7 days in 2010. Amongst the pellet fertilizer combinations, T1 took the longest time to germinate (8 days) followed by T5 and T2 (7.3 days) in 2010. Plants with treatment T4 took (5.65 days) the shortest time to germinate. This shows a trend of decreasing days to germination with increasing inorganic fertilizer for the pellets.

The number of days to germination (DG) of seeds could be related to the readily availability of nitrogen required for germination and seed emergency. Inorganic fertilizer provides nitrogen at instant hence the decreasing days to germination with increasing inorganic nitrogen. The number of DG could also be related to the effect of fertilizersô contact with germinating seeds. Fertilizer scorches germinating seeds or seedlings when it comes into contact. This explains why treatment T5 (100% inorganic) had more DG than the fertilizer combined treatments. For T1 (9 t ha^{-1}manure alone) this could be due to the release of ammonia which scorches the seed thus delaying germination (Alemu and Bayu, 2005).

For the pellet fertilizer treatments, pellets provided a more aerated and conducive environment for emergence of seedlings, hence seeds took fewer days to germinate than those in the non-pellet fertilizer treatments. Among the non- pellet fertilizer treatments, there was the effect of scorching and ammonia affecting the seeds.

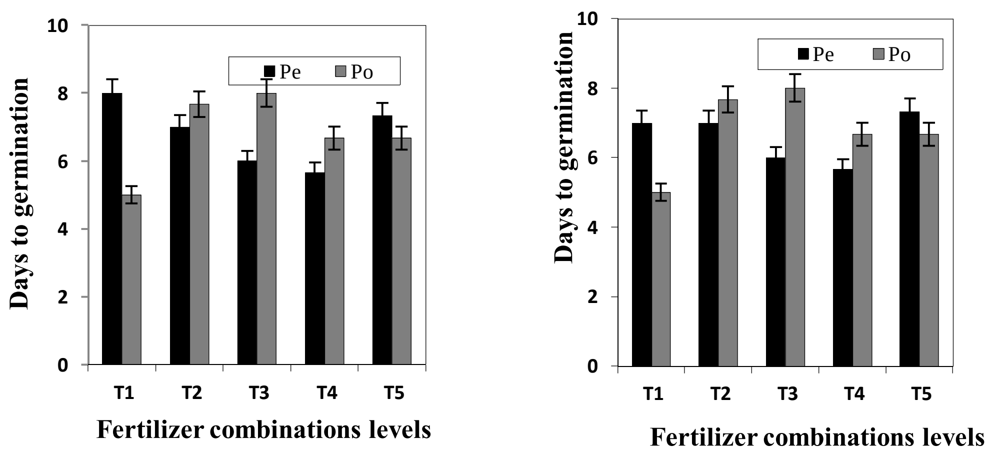

Figure 5.2: Effect of fertilizer application and pellets on the number of days to germination of grain amaranth in 2010 (a) and in 2011 (b).
Note: Pe = Pellet fertilizer treatments, Po = none pellet fertilizer treatments, T1= 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic, T3 = 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 = 87.5 kg ha^{-1} inorganic. The error bars represent standard error of difference (SED) for three way interaction between days to germination, fertilizer combination levels and pellet treatments.

5.4.2: Effects of fertilizer application on the height of flower head and 1000 seed weight of grain amaranth

Fertilizer application had significant effect on the height of flower head and 1000 seed weight of grain amaranth.

Height of flower head

Height of flower head was measured as one of the parameters that determine grain yield. There was significant effect ($p < 0.001$) of fertilizer combinations (CAN and manure) on height of flower head of grain amaranth in 2010. Height of flower head decreased with decreased proportions of manure (Figure 5.3). Treatment T1 (100% manure) had an average of 28.4 cm flower height while T5 (100% CAN) had an average of 18.4 cm flower height (Figure 5.3). Results of 2011 were not significant.

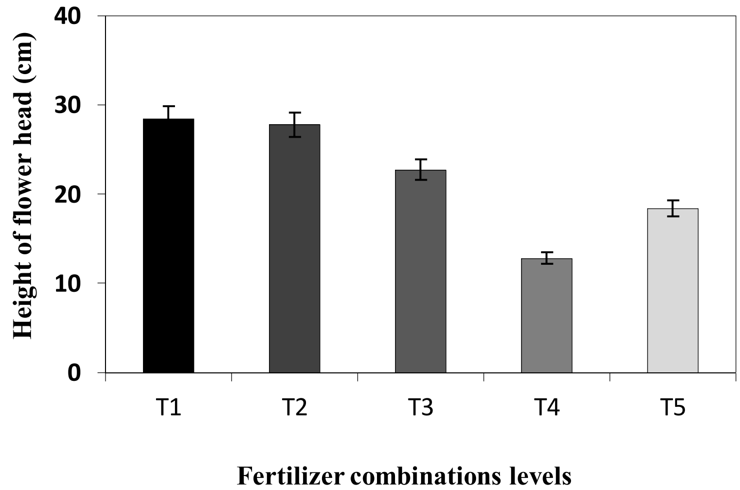

Figure 5.3: Effect of fertilizer application on the height of flower height of grain amaranth in 2010 Note: T1 = 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic, T3 = 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 = 87.5 kg ha^{-1} inorganic. The error bars represent standard error of difference (SED) for the two way interaction between height of flower head and fertilizer combination levels.

These results are attributed to presence of manure and the slow release of nutrients that ensures supply of nutrients to the plant for prolonged period of time. This enhanced plant growth including the flower head. Other scientists have reported improved crop growth by integrated use of organic and inorganic fertilizers. Ainika et al, (2011) reported that growth and yield parameters of amaranth increased significantly in response to the application of farmyard manure. Mortesa et al, (2011) reported increased yield attributes of rice when organic fertilizers were used.

1000 seed weight

There was significant (P = 0.006) effect of fertilizer combinations (CAN and manure) on 1000 seed weight of grain amaranth in 2010 (Figure 5.4). The 1000 seed weight increased with increased proportions of manure. Treatment T3 had the highest 1000 seed weight of 1.18 g while treatment T4 had the least 1000 seed weight of 0.97 g (Figure 5.4). Results of 2011 were not significant.

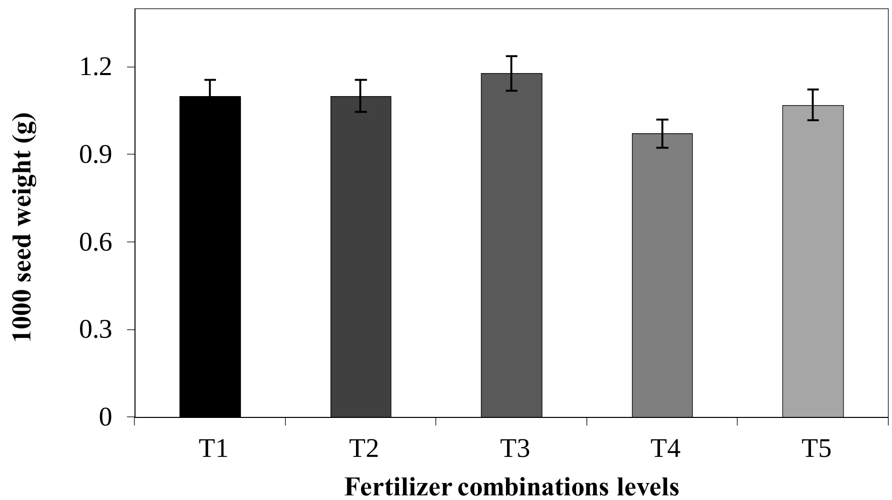

Figure 5.4: Effect of fertilizer application on the 1000 seed weight of grain amaranth in 2010

Note: T1 = 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic, T3 = 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 = 87.5 kg ha^{-1} inorganic. The error bars represent standard error of difference (SED) for the two way interaction between 1000 seed weight and fertilizer combination levels.

The results show the complementary role played by combining manure and CAN in the release of nutrients steadily over time. Akanbi and Tugon (2002) reported that a combination of maize stover compost and urea fertilizer at the rate of 3.0 t ha^{-1} + 30 kg N ha^{-1} significantly enhanced amaranth growth and yield attributes. Morteza et al (2011) while working on rice reported maximum weight of 1000 seeds with 2 t ha^{-1} organic fertilizer. The results confirm the report of Makinde (2007) that, high and sustained crop yield can be obtained with judicious and balanced nitrogen combined with organic matter amendment.

5.4.3 Effects of fertilizer application and time on vegetative growth of grain amaranth.

Fertilizer application and had significant effect on number of leaves, canopy, plant height, stem width and plant dry matter weight of grain amaranth.

Number of leaves

Leaves are important organs which have an active role in photosynthesis. To achieve high yield, maximization of leaf area is an important factor (Morteza et al, 2011). Different fertilizer combinations had significant ($P < 0.001$) effect on the number of leaves of grain amaranth in 2010 and 2011 (Figure 5.5). The number of leaves per plant increased gradually with time. Treatment T1 (9 t ha^{-1} manure) had the highest number of leaves throughout the growing period followed by treatment T2 (6.8T ha^{-1} manure and 83.25 kg ha^{-1} CAN). The two treatments were not significantly different. In 2010, the highest number of leaves was observed in treatment T2 (6.8 t ha^{-1} manure and 83.25 kg ha^{-1} CAN) followed by the control treatment T1 (9 t ha^{-1} manure). However these two treatments did not differ significantly among themselves. The least number of leaves was observed in treatment T5 (337 kg ha^{-1} CAN) followed by T4 (2.3 t ha^{-1}manure and 252.75 kg ha^{-1} CAN). These also did not differ significantly among themselves. The difference in means for the treatments with the highest and lowest number of leaves was significant. In 2011, the treatment T1 had the highest number of leaves followed by T3 (4.5 kg ha^{-1} manure and 168.5 kg ha^{-1} CAN) then T2 (6.8 t ha^{-1} manure and 83.25 kg ha^{-1} CAN) but these were not significantly different. The number of leaves decreased as the amount of organic fertilizer decreased. These results show the complementary role of combining organic and inorganic fertilizer.

The increase in number of leaves due to enough nutrition can be explained in terms of possible increase in nutrient absorption capacity of plant as a result of better root development and increased translocation of carbohydrates from source to growing points (Morteza et al, 2011).

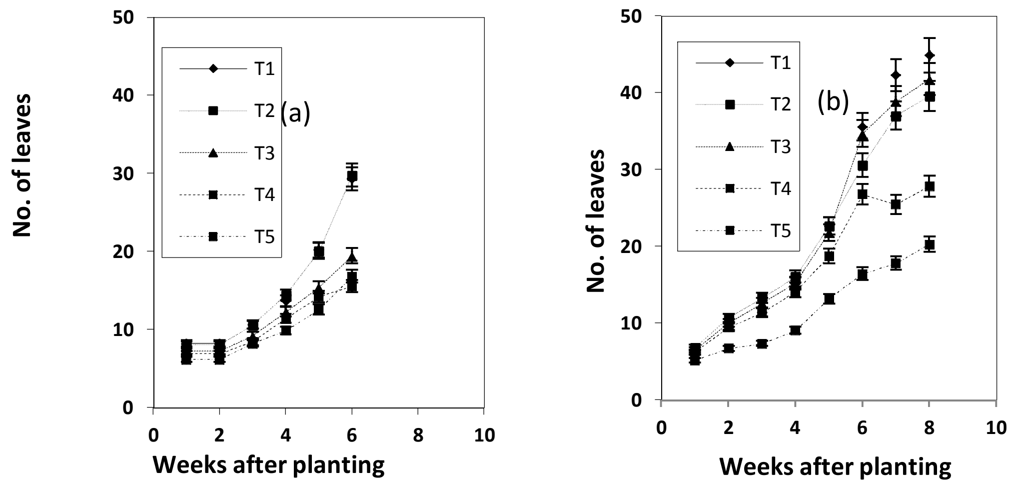

Figure 5.5: Effect of fertilizer application and time on the number of leaves of grain amaranth in 2010 (a) and 2011 (b).

Note: T1 = 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic N, T3 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 = 87.5 kg ha^{-1} inorganic. The error bars represent standard error of difference (SED) for three way interaction between number of leaves, weeks after planting and fertilizer combination levels.

These results are attributed to beneficial effect of manure. The little quantity of CAN in T2 (6.8 t ha^{-1} manure and 83.25 kg ha^{-1} CAN) was essential to ensure initial supply of nitrogen to the plant for production of leaves. Later manure released nutrients to the plant making them available throughout the growth period. In T5 (control), a lot of nitrogen was leached from the CAN and only a fraction of the amount applied being available to the plant. The result confirms the role played by farmyard manure in supplying nutrient, gradual release of nutrient and impacting physical effects on soil condition through good aeration, water holding capacity, structure and increased microbial activity (Ainika et al., 2011).

Similar results were reported by Cook (1982) while working on fertilizing for maximum yield. He found that farmyard manure supply both its physical effects on soil condition, the nutrient it supplies and the way it supplies the nutrient thereby sustaining cropping system.

Canopy size

Organic and inorganic fertilizer combinations with time had significant ($P < 0.001$) effect on canopy of grain amaranth in 2011 (Figure 5.6). Results of 2010 were not significant.

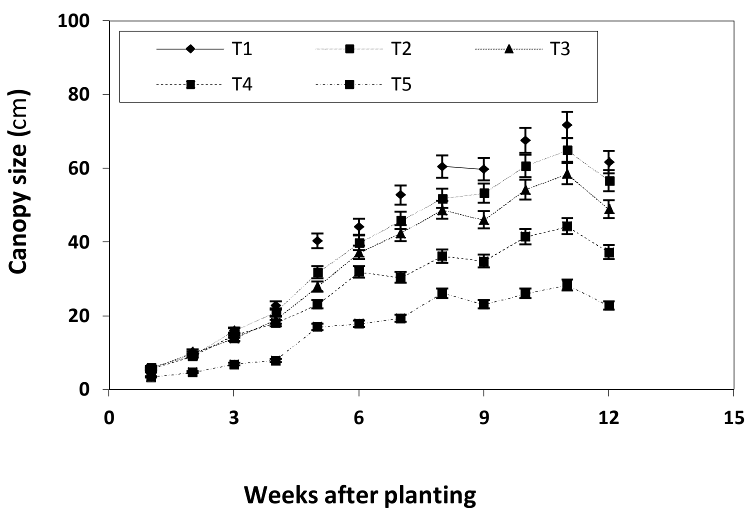

Figure 5.6: Effect of fertilizer application and time on the canopy size of grain amaranth in 2011
Note:T1 = 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic, T3 = 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 = 87.5 kg ha^{-1} inorganic. The error bars represent standard error of difference (SED) for three way interaction between canopy size, weeks after planting and fertilizer combination levels.

Among the fertilizer combinations, treatment T2 (6.8 t ha^{-1} manure and 83.25 kg ha^{-1} CAN) had the highest canopy size with time while T4 (2.3 t ha^{-1}manure and 252.75 kg ha^{-1} CAN) was the combination with the narrowest canopy. T1 (100% organic) had the widest canopy while T5 (9 t ha^{-1} inorganic) had the narrowest. Canopy of a plant refers to all the above ground foliage (leaves, branches and reproductive organs). Any factor that supports growth and development also supports canopy growth. These results are similar to those of leaves and plant height. They are attributed to the additive nutrient supply and to a better synchrony of nutrient availability with crop demand, i. e the immediate availability of nutrients from mineral fertilizers and slow release from manure (Alemu and Bayu, 2005).

Plant height

Fertilizer combination and time had significant ($P< 0.001$) effect on plant height in 2010 and 2011(Figure 5.7).

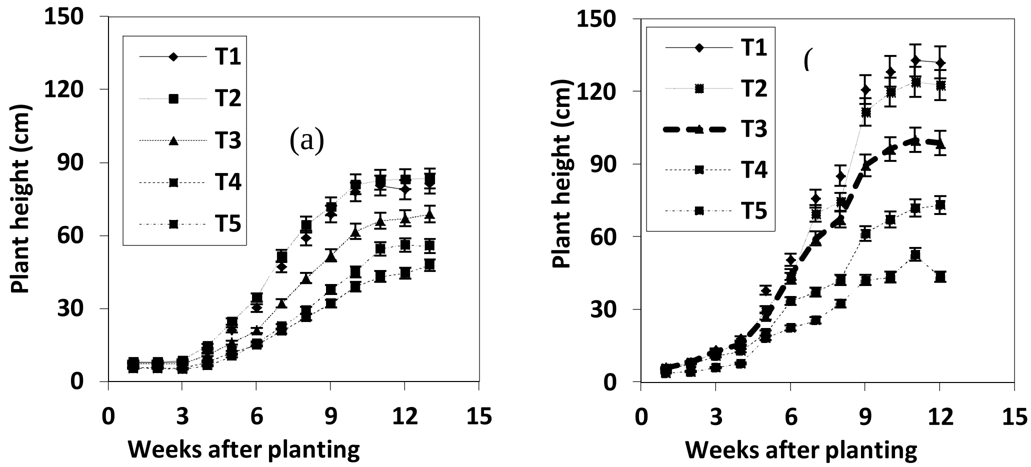

Figure 5.7: Effect of fertilizer application and time on the plant height of grain amaranth in 2010 (a) and 2011 (b)
Note: T1 = 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic, T3 = 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 = 87.5 kg ha^{-1} inorganic. The error bars represent standard error of difference (SED) for three way interaction between plant height, weeks after planting and fertilizer combination levels.

In both seasons the difference in means became significant from the fourth week after planting. Treatment T1 (9 t ha^{-1} manure) had significantly higher heights. Among the different fertilizer combinations, treatment T2 (6.8 t ha^{-1}manure and 83.25 kg ha^{-1} CAN) had the highest plant heights followed by treatment T3 (4.5 t ha^{-1} manure and 168.5 kg ha^{-1} CAN). However these treatments did not differ significantly among themselves (LSD = 11.173 in 2010 and 17.899 in 2011). The lowest heights were observed in the control treatment T5 (337 kg ha^{-1} CAN) followed by the treatment T4 (2.3 t ha^{-1}manure and 252.75 kg ha^{-1} CAN).

The average plant height decreased with decreasing quantities of manure. These results are attributed to the additive nutrient supply and to a better synchrony of nutrient availability with crop demand, i. e the immediate availability of nutrients from mineral fertilizers and slow release from manure (Alemu and Bayu, 2005). Ainika et al (2011) reported that application of farmyard manure at the rate of 4 t ha^{-1} significantly increased the vegetative growth and development of grain amaranth.

Stem width

Stem width is a parameter that indicates growth and development of a plant. And it is a component of the yield. Fertilizer combinations and time had significant ($P < 0.001$) effect on the stem width of grain amaranth in both 2010 and 2011 seasons (Figure 5.8). The stem width increased gradually after planting and the difference in means for the different treatments became significantly different at five weeks after planting (Figure 5.8 a). In 2010, treatment T2 (6.8 t ha^{-1}manure and 83.25 kg ha^{-1}CAN) had the highest width followed by the control T1 (9 t ha^{-1} manure) and these two differed significantly. The lowest stem width was observed in treatment T5 (337 kg ha^{-1} CAN). There was decreasing stem width with decreasing proportion of manure. In 2011, treatment T1 (control) had the widest stem followed by treatment T2 (6.8 t ha^{-1}manure and 83.25 kg ha^{-1}CAN) while treatment T5 (control) had the narrowest stem followed by T4 (

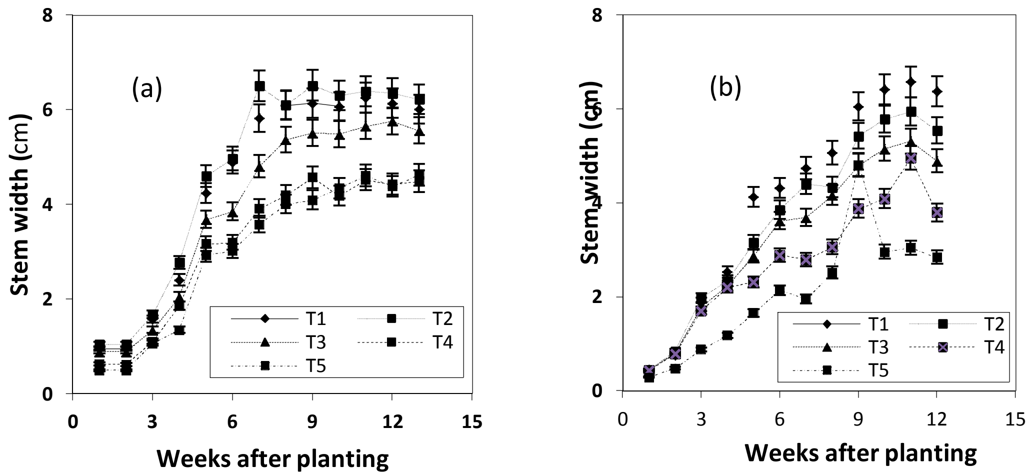

Figure 5.8: Effect of fertilizer application and time on stem width of grain amaranth in 2010 (a) and 2011 (b)

Note: T1 = 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic, T3 = 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganicN, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 = 87.5 kg ha^{-1} inorganic. The error bars represent standard error of difference (SED) for three way interaction between stem width, weeks after planting and fertilizer combination levels.

These results are attributed to the presence of manure and slow release of nutrients that was available to plant during the growing period. The little CAN in treatment T2 (6.8 t ha^{-1} manure and 83.25 kg ha^{-1} CAN) provided the required nitrogen for early establishment of seedlings and development of leaves.

Plant dry matter weight

Fertilizer combinations and time were observed to have a significant (P = 0.017) effect on the plants dry matter weight in 2010 (Figure 5.9).

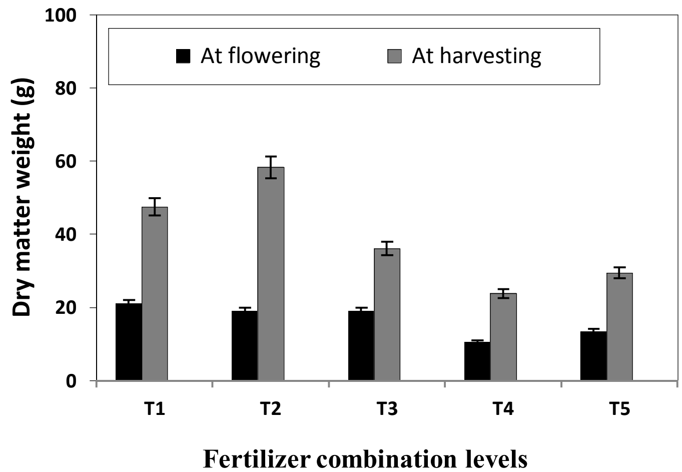

Figure 5.9: Effect of fertilizer combination and time on the dry matter weight of grain amaranth in 2010.

Note: T1 (9 t organic manure), T2 (6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic), T3 (4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N), T4 (2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N), T5 (87.5 kg ha^{-1} inorganic). The error bars represent standard error of difference (SED) for three way interaction between dry matter weight, fertilizer combination levels and crop development stage.

Results of 2011 were not significant. At flowering, the highest dry matter weight was observed in T1 (9 t ha^{-1} manure) and lowest in T4 (252.75 kg ha^{-1} CAN and 2.3 t ha^{-1}manure). At harvesting, the highest dry matter weight was observed in T2 (83.25 kg ha^{-1} CAN and 6.8 t ha^{-1}manure) while the lowest was observed in T4 (252.75 kg ha^{-1} CAN and 2.3 t ha^{-1}manure) fertilizer treatments. The dry matter weight is shown to decrease with decreasing proportions of manure. This trend is attributed to the presence of manure and slow release of nutrients to the plant for a prolonged period of time. Similar results were observed by Alemu and Bayu

(2005) who reported that stover yield of sorghum was enhanced by an integrated application of farm yard manure and inorganic fertilizers.

5.4.4 Effects of fertilizer pellets and time on height of flower head of grain amaranth

The size of flower head is an indicator of expected grain yield in crops such as grain amaranth. Fertilizer pellets and time had significant ($p < 0.001$) effect on height of flower head of grain amaranth in 2010 (figure 5.10). The highest height of flower head was observed in treatment T1 (9 t ha^{-1} manure) which did not differ significantly with treatment T2 (6.8 t ha^{-1}manure and 83.25 kg ha^{-1} CAN). The lowest height of flower head was observed in treatment T4 (2.3 t ha^{-1}manure and 252.75 kg ha^{-1} CAN). The non-pellet fertilizer combinations had a higher height of flower head compared to the pellet fertilizer combinations at the same proportion of inorganic and organic combinations (Figure 5.10).

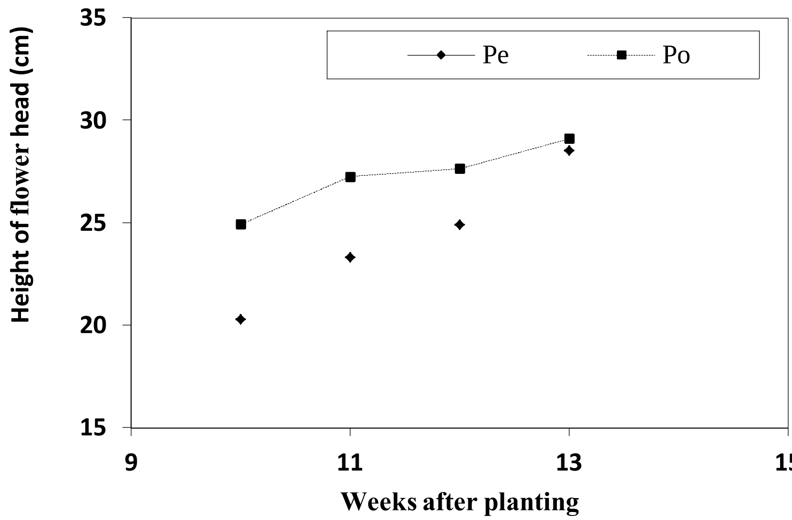

Figure 5.10: Effect of fertilizer pellets and time on the height of flower height of grain amaranth in 2010.
Note: Pe = pellet fertilizer treatments, Po = non - pellet fertilizer treatments. The error bars represent standard error of difference (SED) for three way interaction between height of flower head, weeks after planting and pellet treatment.

Among the pellet fertilizer treatments, T1 (9 t ha^{-1} manure) had the highest height of flower head. Treatment T4 (2.3 t ha^{-1} manure and 252.75 kg ha^{-1} CAN) had the lowest. In non-pellet fertilizer treatments, T2 (6.8 t ha^{-1} manure and 83.25 kg ha^{-1} CAN) had the highest height of flower head which did not differ significantly with T3 (4.5 t ha^{-1} manure and 168.5 kg ha^{-1} CAN). The lowest height of flower head was observed in T4 (2.3 t ha^{-1}manure and 252.75 kg ha^{-1} CAN) followed by T5 (337 kg ha^{-1} CAN). Results of 2011 were not significant.

Increase in size of flower size was gradual for none fertilizer treatments and steady for the pellet fertilizer treatments. The two means almost coincided at maturity of the crop (13 weeks after planting). The observed trend is because pellets are leached of their bases and release nitrate nitrogen several weeks later than ordinary compost. Therefore an anaerobic state is maintained inside the pellets, so that nitrification is slow and continues for prolonged period of time. Therefore the effect of pellets is not different from that of ordinary compost from which the pellets are made (Masayuki, 2001).

5.4.5 Effect of fertilizer pellets on yield of grain amaranth

Grain yield is a function of interaction among various yield components that are affected differently by the growing conditions and crop management practices (Farhad et al, 2009). Fertilizer pellets had significant ($p = 0.011$) effect on grain yield of amaranth in 2011(Figure 5.11). The pellet fertilizer treatments had higher grain yield than none (Po) pellet treatments which decreased with decreased proportions of manure.

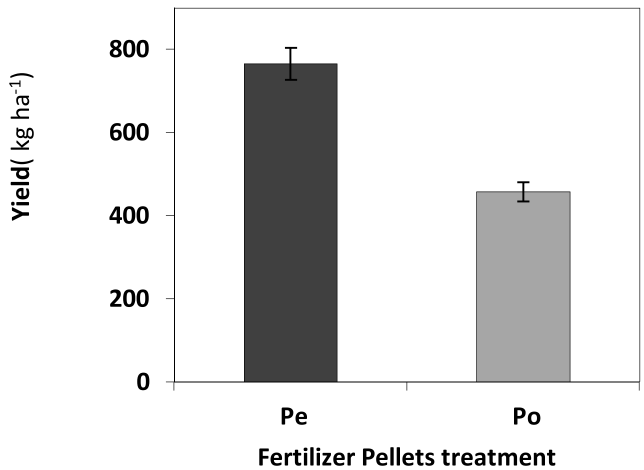

Figure 5.11: Effect of fertilizer pellets on the grain yield of amaranth in 2011.
Note: Pe = pellet fertilizer, Po = non-pellet fertilizer. The error bars represent standard error of difference (SED). The error bars represent standard error of difference (SED) for the two way interaction between yield and fertilizer pellet treatments.

Treatment T2 of pellets had an average yield of 743 kg ha^{-1} and 533 kg ha^{-1} for none pellets. Treatment T4 had an average yield of 413 kg ha^{-1} for pellets and 231 kg ha^{-1} for non-pellets (Table 5.2). Results of 2011 were not significant.

The increase in grain yield could be due to increase in yield attributes (number of leaves, plant height, stem width, height of flower height and dry matter weight). These results could be attributed to the beneficial effect of coating of CAN which thus regulated nutrient release to the plant. This is in addition to the reduction of N losses through leaching and hence a constant supply of nutrients to the roots.

Besides, the manure component of the pellet fertilizer released N and P slowly as well as contributing to the soil organic matter (Reza- Bagheri et al., 2011, Jeiran et al., 2008, Jeiran et al., 2010).

Table 5.2: Effect of fertilizer pelleting on grain yield of amaranth in 2011

Grain yield (kg ha^{-1})	Fertilizer combination					
	T1	T2	T3	T4	T5	Means
Pe	1412	743	654	413	601	765
Po	441	533	628	231	452	457
LSD $_{Pellets}$	141.3					

Note: T1 = 9 t organic manure, T2 = 6.8 t ha^{-1} manure and 22 kg ha^{-1} inorganic, T3 = 4.5 t ha^{-1} manure and 43.8 kg ha^{-1}inorganic N, T4 = 2.3 t ha^{-1} manure and 65.6 kg ha^{-1} inorganic N, T5 = 87.5 kg ha^{-1} inorganic. Pe = pellet fertilizer, Po = non- pellet fertilizer.

For the pellets, all the treatments were significant with exception of T3. For fertilizer combination T1 was significant from the rest of the treatments while for pellets x fertilizer combination T1xPe were significant.

Bagheri et al, (2009) reported higher grain weight in corn with application of pellet fertilizer comprising of 92 kg N ha^{-1} and 600 kg ha^{-1}cow manure. Jeiran et al, (2010) also found out that application of fertilizer pellets comprising of 50 kg ha^{-1} urea and 100 kg ha^{-1} manure had higher 1000 seed weight and grain yield of wheat than other treatments.

5.5 CONCLUSION

The use of organic and inorganic fertilizer combination is useful in grain amaranth production, as it ensures continued supply of nutrients to the plant resulting in sustainable crop production. The manure component also improves soil structure. Application of cow dung manure at the rate of 6.8 t ha^{-1} in combination with CAN at the rate of 83.25 kg ha^{-1} significantly increased the growth, development and yield of grain amaranth through increased number of leaves per plant, individual plantsô canopy size, plant height, stem width, plant dry matter weight and 1000 seed weight.

The use of fertilizer pellets is a good alternative to use of CAN in grain amaranth production. It also ensures safe and healthy environment besides minimizing the bulky transport of manure. In addition the production of pellet fertilizer by combining dry cow dung manure and CAN also contributes to the improvement of soil organic matter that is required for sustainable agricultural production.

Fertilizer pellets is a good way of reducing N leaching. However the quantities of available slow release nutrients need to be considered while fertilizer pellets are made. Fertilizer pellets increased height of flower head and yield of grain amaranth. Fertilizer pellets made from 4.5 t ha^{-1} manure and 168.5 kg ha^{-1} CAN seems to be the least combination while 6.8 t ha^{-1}manure and 83.25 kg ha^{-1} CAN is the most economically viable combination of fertilizer mix for making fertilizer pellets for growing grain amaranth in Western Kenya.

5.6 RECOMMENDATIONS

Since application of manure and CAN improves growth, development and 1000 seed weight of grain amaranth it is recommended to farmers growing amaranth for grain. Application of 6.8 t ha^{-1} cow dung manure in combination with 83.25 kg ha^{-1} CAN is recommended in western Kenya. And since mineral fertilizers are expensive, 9 t ha^{-1} cow dung manure is adequate. This amount of manure is expensive to transport and also poses environmental risks during application. Pellet fertilizer of the same quantities of cow dung manure and CAN is recommended for increased yields of grain amaranth in Western Kenya.

CHAPTER 6: EFFECT OF FERTILIZER APPLICATION ON SOIL AND PLANT TISSUE NUTRIENTS DURING THE GROWTH OF *AMARANTHUS HYPOCHONDRIACUS*

6.1 ABSTRACT

During growth and development, different crops utilize N, P and K nutrients in different quantities, whereby the tissue nutrient content is dependent on amount available for uptake by plant roots. In order to assess the effect of combined organic and inorganic fertilizers and fertilizer pelleting on soil and plant nutrients during growth of *Amaranthus hypochondriacus,* a study was carried out at Maseno University Experimental farm. The study comprised two experiments which were laid out in a Randomized complete block design in a split plot arrangement and replicated three times. Benchmark soil samples at zero to 15 cm and 15 to 30 cm depth were taken from experimental field before planting to determine pH, organic carbon, nitrogen, phosphorous and potassium levels. At seedling, flowering and harvesting, soil samples were taken from the top 0-20 cm from each subplot and three of the youngest fully developed leaves were also taken from randomly selected plants from the middle rows. The samples were analyzed for N.P.K and organic carbon content. The data was subjected to regression analysis to assess the influence of the nutrients in soil and leaves on the yields. The regression models were statistically significant in estimating the linear dependency of; N in leaves on N in the soil at both seedling and flowering stages: yield on the level of K in the soil and in the leaves at both seedling and flowering stages: and yield on the P levels in the soil at seedling stage. The regression models for the pellets were significant in estimating the linear dependence of; N in the leaves on N in the soil at both seedling and flowering stages: and yield on K in the soil at seedling stage. For improved management of crop nutrients, N, P and K should be available to plants from seedling to flowering stages. It is also beneficial to use fertilizer pellets to ensure better nutrient supply to plants.

6.2 INTRODUCTION

Plant growth occurs through light interception during photosynthesis where carbon dioxide (CO_2) is converted into basic molecules for metabolism (University of Hawaii, 2013). The primary nutrients, nitrogen (N), phosphorous (P) and potassium (K) are required in large quantities and therefore, their management is very important (University of Hawaii, 2013). Nitrogen is required for seedling vigor and vegetative growth. Nitrogen is an essential element in all amino acids, is a component of nucleic acids and chlorophyll and its deficiency results to plantøs retarded growth, necrosis and reduced yields (Mulagoli et al, 2008). Phosphorous is required for root growth, energy transfer reactions, protein synthesis, and development of reproductive structures (Clain, 2011). It enhances crop maturity and quality especially in grain crops. Potassium is involved in many enzymatic reactions, is used in the synthesis of energy compounds required for translocation within the plant, N uptake and protein synthesis. K maintains water balance and stalk strength. Crops that are K deficient can have low N intake, yield and protein (Mulagoli et al, 2008).

Although plants require a balanced supply of the nutrients throughout their development, it is important to ensure plants are supplied with adequate nutrients during early stages in order to maximize on yield. Various growth stages require instant flow of nutrients and mineral fertilizers are the quickest and surest way of supplying the nutrients in known amounts, proportions and forms ready for uptake by plants (Clain, 2011). However, the use of inorganic fertilizers has raised concerns due to fertilizer leaching and environmental contamination. Appropriate combinations of organic and mineral fertilizers may be the best way of effecting soil fertility management to boost production and achieve sustainable yields.

Soil analysis appraises soil nutrient status and requirements and thus determines the right type of fertilizer material and the correct application rate for a given field (Mulagoli et al., 2008). When individual plants are grown with restricted access to a particular nutrient, growth is reduced and specific deficiency symptoms may occur. A general feature is increased allocation into roots and decreased allocation to leaves and stems (Poorter and Nagel, 2000). An increased allocation to roots enables the plant to explore greater soil volumes to capture nutrients necessary for continued leaf expansion.

In the soil, nitrate can be lost through nitrification and leaching particularly under wet soil conditions. Also both ammonium and nitrate can be tied up through immobilization by microorganisms in the soil as they decompose low-N organic residues (Alemi et al., 2010). Phosphorous in the soil is considered immobile however its availability can be affected by both P-sorption and P- precipitation (University of Hawaii, 2013). Potassium is a mobile nutrient in the soil and may be lost to leaching, retained by soil particles or precipitated as secondary mineral (Clain, 2011)

Grain amaranth is a shallow rooted crop and the domain root zone is usually 20 cm below the soil surface which can lead to considerable nitrate loss by leaching under irrigated or high rainfall conditions. According to Alizadeh and Ghadeai, (2006) and Jeiran et al, (2008), pelleting of nitrogenous fertilizers reduces N losses and improves fertilizer use efficiency. The objective of this study was to assess the effect of combined organic and inorganic fertilizers and fertilizer pelleting on soil and plant nutrients during growth of *Amaranthus hypochondriacus.*

6.3 MATERIALS AND METHODS

The study was carried out in Maseno University Research Farm during the 2010 short rain and 2011 long rain seasons using seed obtained from Hortitech seed Company in Naivasha. The conditions are as described on page 25.

Experimental design and treatments

The study was carried out in two experiments which were laid out in Randomized complete block design (RCBD) with split plot arrangement. The treatments are described on pages 32 and 57.

6.3.1 Data collection

Benchmark soil samples at zero to 15 cm and 15 to 30 cm depth were taken from experimental field before planting to determine pH, organic carbon, N, P and K. At seedling, flowering and at harvesting stages of growth, soil samples were taken from the top 0-20 cm from each subplot and three of the youngest fully developed leaves were taken from three randomly selected plants from the middle rows. The soil samples were taken from three randomly selected points in a zigzag manner from the middle rows. All samples from each subplot were mixed to get a homogenous single sample. The soil and leave samples were analyzed for N, P, K and organic carbon content. The samples were analyzed at soil Analysis Lab of Kabete Campus, University of Nairobi using the acid/alkaline digestion method of analysis as described by Okalebo et al, (2002). The Mehlich- method was used to extract P and K.

6.3.2 Statistical Analysis

The soil and leaf data were subjected to regression analysis. The analysis results were used to observe the relationships of the interactions of the models and the influence of the nutrients in soil and leaves on the yields.

6.4 RESULTS AND DISCUSSIONS

6.4.1 Effect of fertilizer application and the relationship of nitrogen in the soil and leaves of grain amaranth

The linear regression model was significant at explaining the linear relationship between percentage nitrogen in the soil and in the leaves at both seedling and flowering stages of growth of grain amaranth in Western Kenya in 2010.

Seedling stage

At seedling stage the regression model was significant ($p = 0.033$) in estimating the linear dependence of percentage nitrogen in leaves on the percentage of nitrogen in the soil at 95% confidence interval (Figure 6.1). The equation obtained was $Y = 5.70375-7.53963\ x$. Thus one unit input of nitrogen in the soil decreased the nitrogen in the leaves by 7.53963 units at seedling stage.

The correlation of % of N in the soil and the % of N in the leaves had a negative value of - 0.55. This means that when N in the soil decreased the N in the leaves increased (figure 6.1). This could be because of the uptake of N from the soil to the leaves through the plants roots. At seedling stage the only source of N for the plant is soil.

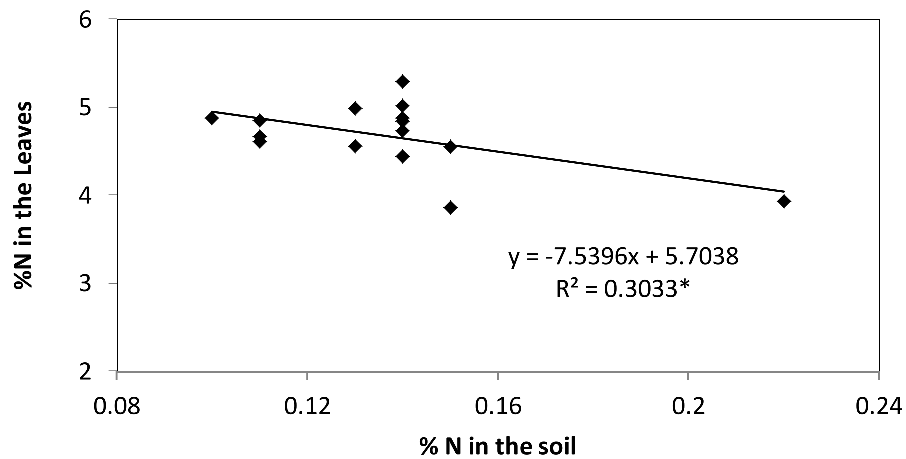

Figure 6. 1: The relationships between nitrogen in the soils and in the leaves at seedling stage of growth of grain amaranth.

At seedling stage, N is actively being removed from the soil by the plant, leaching or by denitrifying organism. The rate of N uptake is related to the rate of plant growth (Gastal and Lemaire, 2001). At seedling stage, the plants are small hence percentage of N concentration is high.

Flowering stage

At flowering stage the regression model was significant (p = 0.0068) in estimating the linear dependence of percentage nitrogen in leaves on the percentage of nitrogen in the soil at 95% confidence interval (Figure 6.2).. The result shows that one unit input of nitrogen in the soil increased the nitrogen in the leaves by 6.407 times.

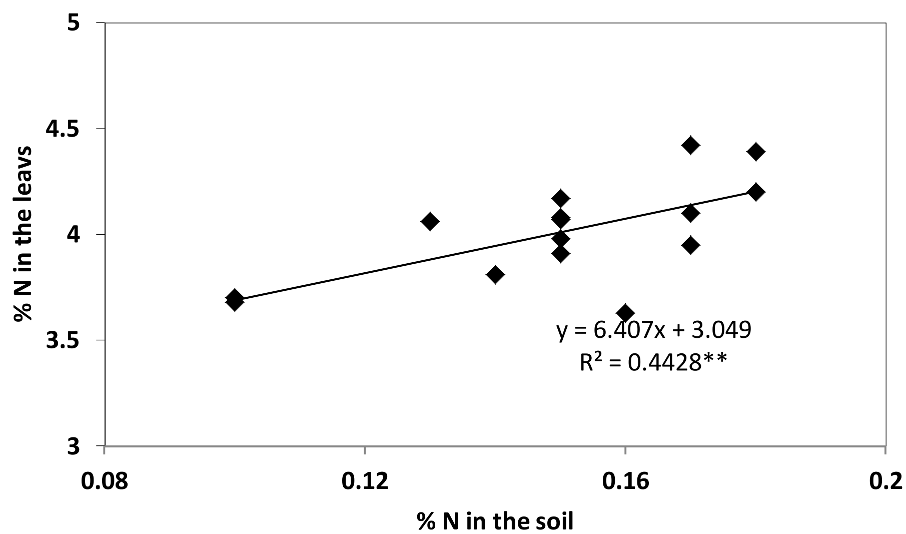

Figure 6. 2: Relationship of nitrogen in the soil and nitrogen in the leaves at flowering stage

The correlation of percentage of N in the soil and the percentage of N in the leaves had a positive value of 0.655. This means that when N in the soil increased, the N in the leaves increased also and vice versa. This could be due to the fact that regulation of N uptake being proportional to growth rate (Gastal and Lemaire, 2001). The more the N is taken up by the plants the more the growth rate and the more it is accumulated in the plant tissues. Nitrogen is required for processes such as photosynthesis, distribution of nutrients and leaf expansion. As the crop growth advances these processes become faster and so N is taken faster from the soil. Therefore, the N levels in the leaves at flowering stage of grain amaranth depended on the N levels in the soil. Similar results are reported by Noroa and Loomis (1981) and Sinclair and Shiraiwa (1993).

6.4.2 Effect of fertilizer application on phosphorous in the soil at seedling stage and yield of grain amaranth

The trend of P concentration in the soil and leaves is shown in figure 6.3.

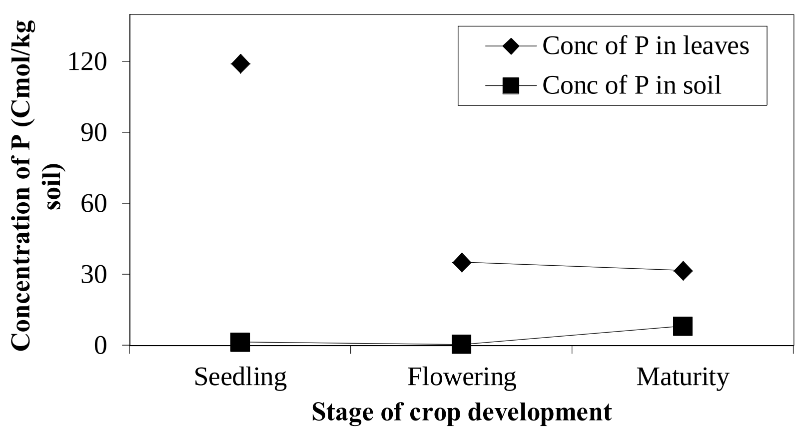

Figure 6.3: Changes in concentration of P during growth and development of grain amaranth in 2010

The graphs show that the concentration of P in the soil was low until seedling stage after which it increased gradually. This could have been due to reduced demand by the plant from seedling towards maturity and gradual release from organic sources. The concentration of P in the leaves decreased sharply from seedling to flowering stage which could have been due to dilution as the size of the plant increased. Thereafter the concentration decreased gradually probably due to movement from leaves to flowering buds.

The regression model was statistically significant ($p = 0.0283$) in estimating the linear dependence of yield to the amount of phosphorous in the soil at seedling stage at 95% confidence interval in 2010 (Figure 6.4) .

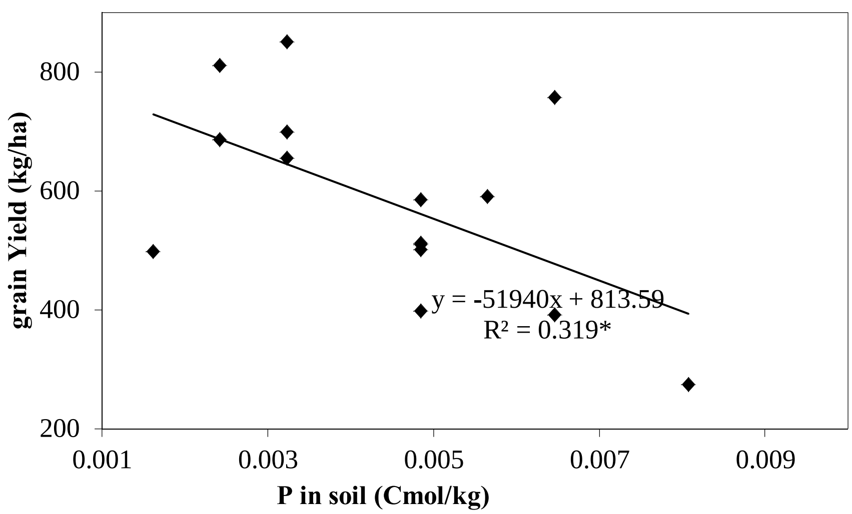

Figure 6.4: Relationship of yield and phosphorous in the soil at seedling stage

There was a negative correlation (-0.5684) between yield and phosphorous level in the soil at seedling stage. This indicates that for every unit increase of phosphorous in the soil, the yield decreased by o.5684 units.

Phosphorous is required by plants for root development, flower initiation, seed and fruit development. Increased P in the soil may means that P is tied by other elements and may not be available for uptake by the roots. This may finally lead to decreased yields since P is required for seed and food development.

6.4.3 Effect of fertilizer application on the level of potassium in the soil, leaves and yield

The trend of K concentration in the soil and leaves during growth and development of grain amaranth is shown in figure 6.5. The concentration of k in the soil remained quite low throughout the growing period. This means K is available in small quantities in the soil. The small increase at flowering suggests added K to the soil probably from organic sources.

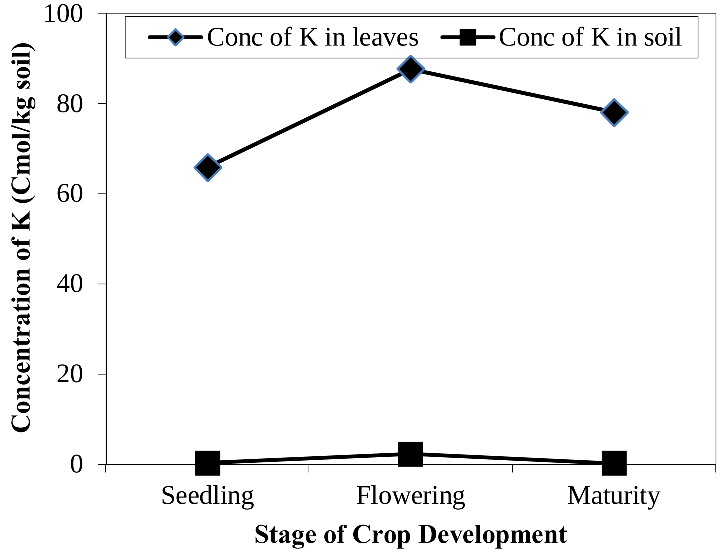

Figure 6.5: Changes in K concentration during growth and development of grain amaranth in 2010

The concentration of k in the leaves increased from seedling to flowering and thereafter decreased. The increase from seedling to flowering is due to the increased plant demand for K to support its functions. K is required for among other functions stem development.

Effect of potassium levels in the soil on yield at seedlings stage

The regression model was statistically significant ($p = 0.049$) in estimating the linear dependence of yield to the amount of Potassium in the soil at 95% confidence interval (Figure 6.6). There was a positive correlation between yield and Potassium level in the soil. The correlation value was 0.515. This indicates that as the amount of K in the soil increased the yields also increased. Potassium is required for water balance and stalk strength. It promotes energy generation which is required for movement of nutrients in the plant including N uptake and protein synthesis. Therefore, crops that are deficient in potassium can have low N uptake, low protein synthesis leading to low yields (University of Hawaii, 2007).

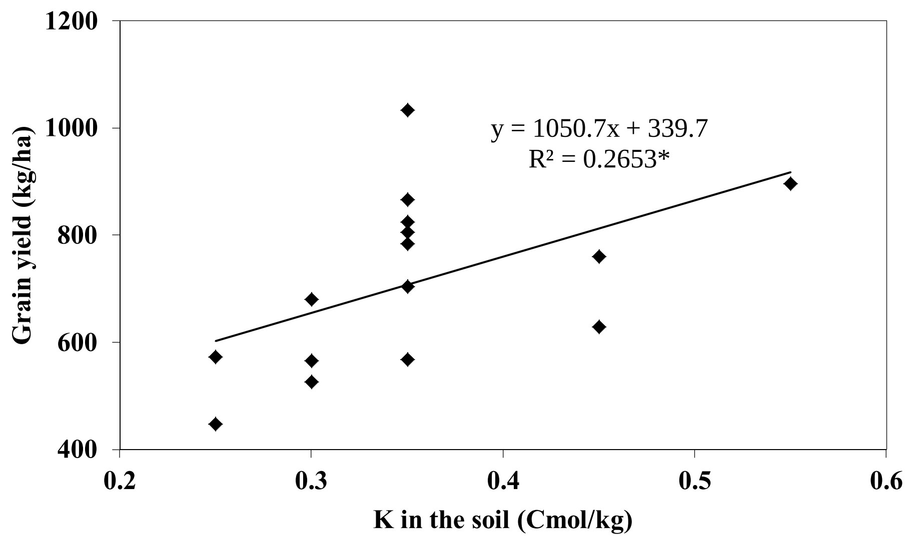

Figure 6.6: Relationship of potassium levels in the soil at seedling stage and yield of grain amaranth in 2010

Effect of potassium levels in the leaves on yield at seedling stage

The regression model was statistically significant ($p = 0.011$) in estimating the linear dependence of yield to the amount of potassium in the leaves at 95% confidence interval (Figure 6.7). There was a positive correlation between yield and K level in the leaves at seedling stage. The correlation value was 0.636. This indicates that for every unit increase of K levels in the leaves at seedling stage, the yield increased also by 0.636.

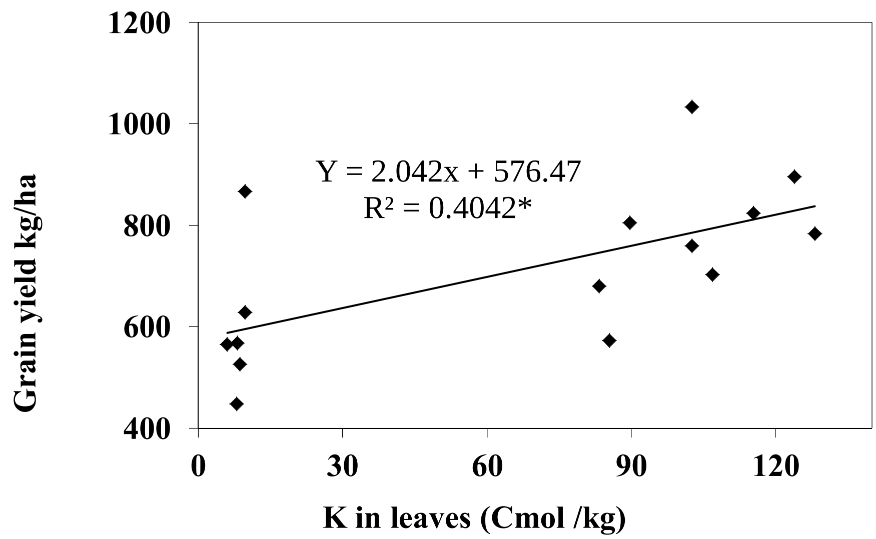

Figure 6. 7: Relationship of potassium in the leaves at seedling stage and yield of grain amaranth in 2010

This is because K is required for strong stem, nutrient uptake and protein synthesis which directly influence the yield (Clain, 2011). The nonlinear relationship (Fig.6.8) was significant ($p = 0.0019$) and shows that yield will increase to a maximum when potassium in the leaves reaches 80 Cmol/kg. Further increase of potassium in the leaves will cause yield to decrease. This could be due to the potassium getting to an injury level.

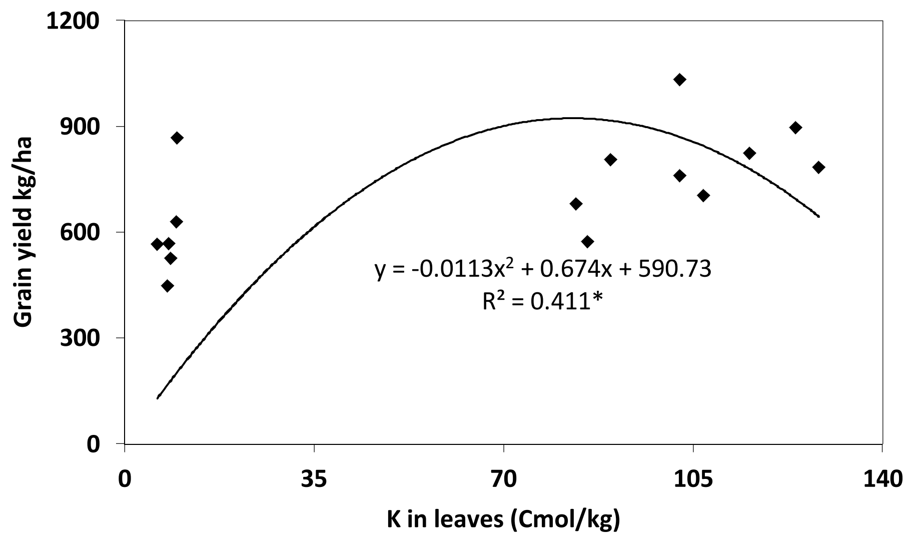

Figure 6.8: Regression based on pol. relationship of potassium in leaves at seedling stage and yield of grain amaranth

6.4.4 Effect of Fertilizer pellets on the nutrients in the soil, leaves and yield of grain amaranth

The trend of changing concentration of N in soil and leaves for the pellets and non-pellets is shown in figure 6.9. For both pellets and non- pellets, the concentration of N in the soil remained low with some remarkable slight increase at flowering. The graph shows N concentration in the leaves remaining high during the growing period for both pellets and non- pellets.

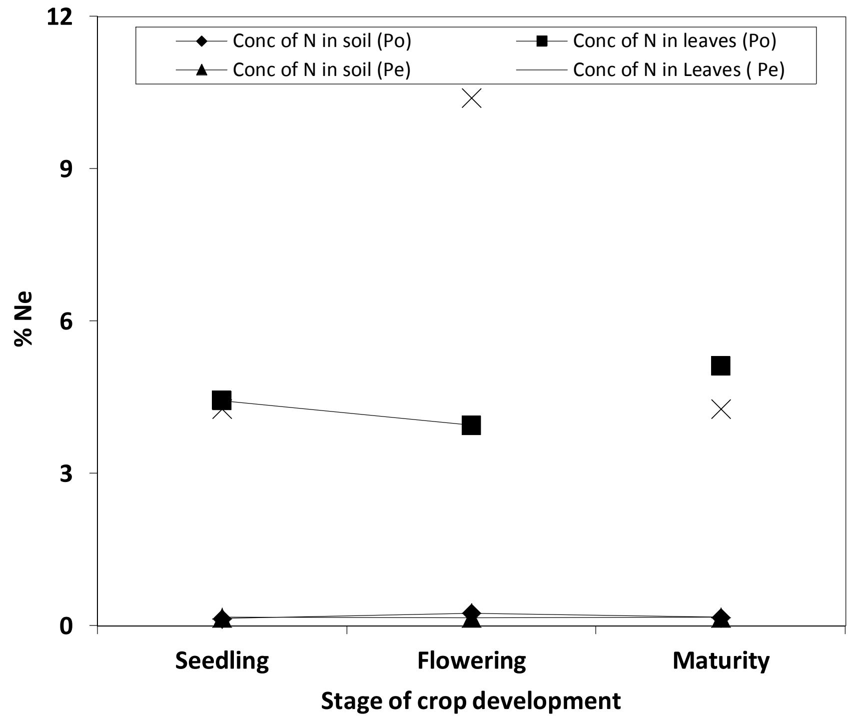

Figure 6.9: Changes in concentration of N during growth and development of grain amaranth for pelleted fertilizers.
Note: Po = non-pellet fertilizer, Pe = pelleted fertilizer

Effect on percentage of nitrogen in leaves and the percentage of nitrogen in the soil at flowering stage

The regression model was significant ($p = 0.007$) in estimating the effect of nitrogen in the soil on the nitrogen in the leaves for pellets at flowering stage at 95% confidence interval (Figure 6.10). However the model was not significant in estimating the effect of nitrogen in soil on nitrogen in the leaves for the non-pellets.

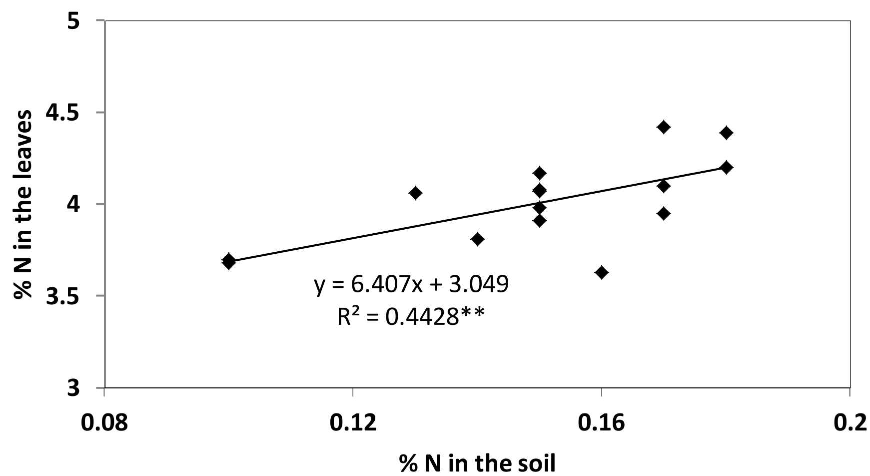

Figure 6.10: Relationship between the level of nitrogen in leaves and the level of nitrogen in the soil at flowering stage

Pellets release nutrients to the soil slowly and for a prolonged period. When applied at planting they supply nutrients to the plant throughout the growing period. Clain in 2011 reported that release of nutrients from the slow release or coated fertilizers resemble the desired cropǿs nutrient uptake curve.

Effect of on the relationship of nitrogen in leaves at flowering stage and yield of grain amaranth

The regression model was significant (p = 0.0433) in estimating the nonlinear relationship of nitrogen in the leaves at flowering stage and yield of grain amaranth in 2010 for pelleted fertilizer (Figure 6.11) . The graph shows that yield would increase as amount of nitrogen in the leaves increases up to a maximum of 20 Cmol kg^{-1} and as nitrogen levels increases further, the yield would decrease

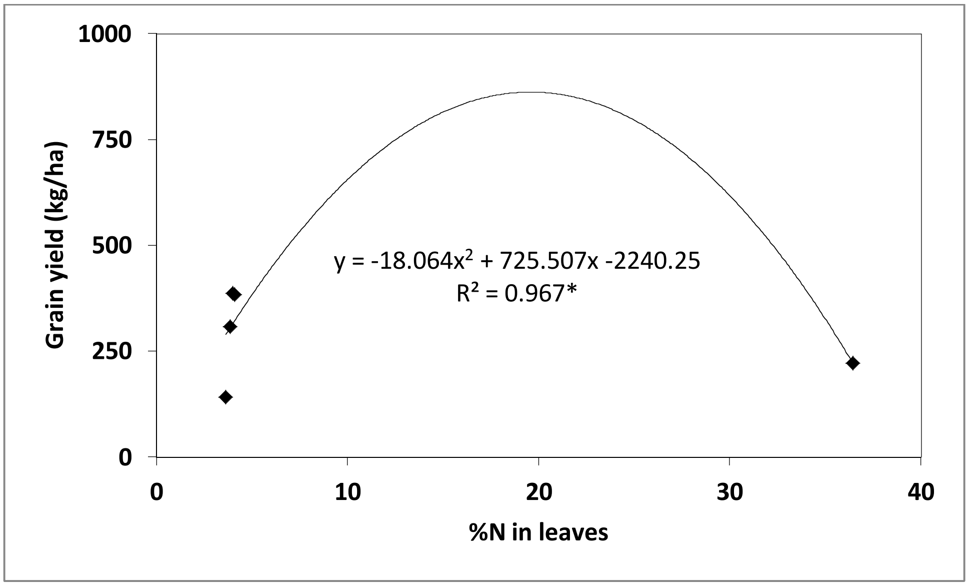

Figure 6.11: Non-linear relationship between nitrogen in the leaves and yield of grain amaranth at flowering stage for pelleted fertilizer

According to Clain (2011), approximately, 90% of nitrogen and phosphorous in the plant at flowering moves from the leaves and stem to the developing seed. Therefore nitrogen levels in the leaves could reach injury levels when there is no more demand by developing seeds. This could cause decrease in yields.

Effect of phosphorous levels in the soil at seedling stage on yield

The trend of the concentration of P in the soil and plant leaves is shown in figure 6.12. The trend shows low concentrations of P in the soil compared to concentration in the leaves throughout the growing period. The trend shows steady increase of P in the soil for both pellets and non-pellets from flowering to maturity stage.

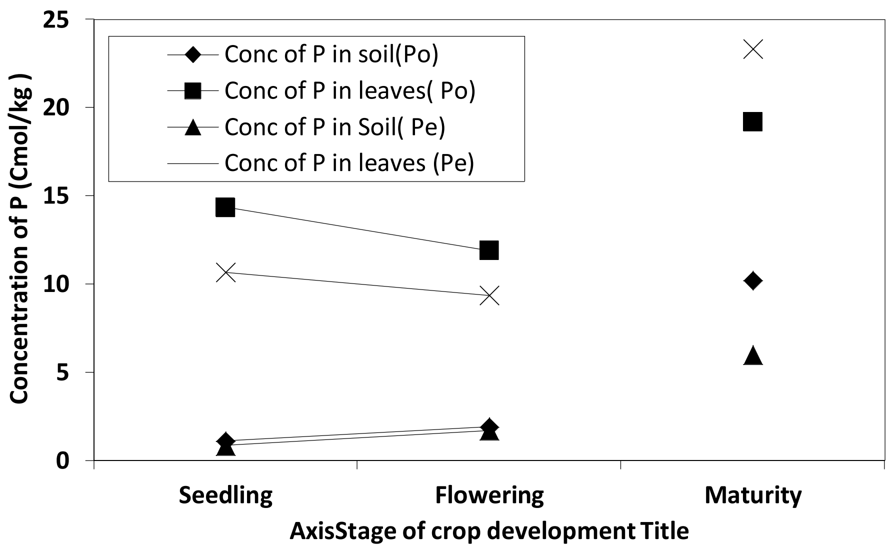

Figure 6.12: Changes in P concentration during growth and development of grain amaranth in 2010
Note: Po = non-pellet fertilizer, Pe = pelleted fertilizer

The trend show a decrease of P concentration in the leaves from seedling to flowering stage and thereafter a sharp increase for both pellet and non-pellets fertilizers.

The regression model was significant (p = 0.04) in estimating the effect of phosphorus in the soil on the yield for the non-pellets at seedling stage at 95% confidence interval (Figure 6.13). For the pellets the regression model was not significant.

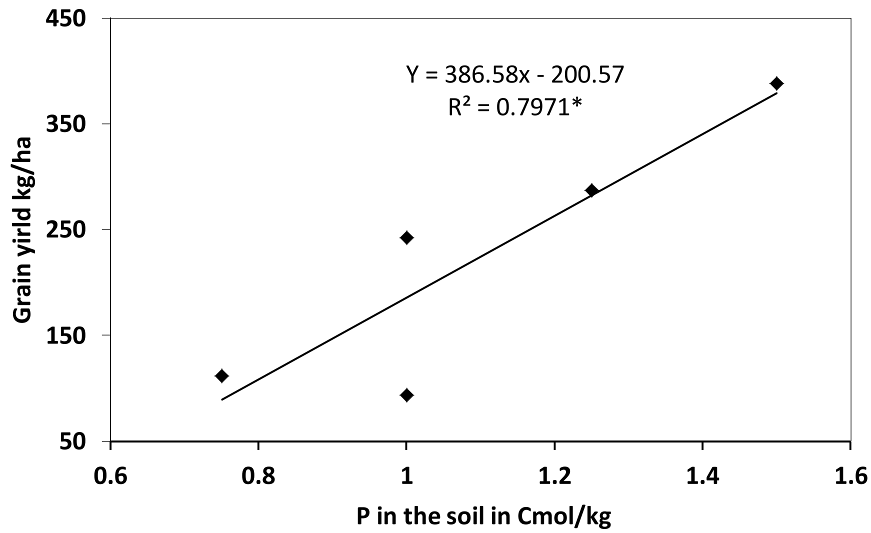

Figure 6.13: Regression based on the relationship between amount of phosphorous in the soil at seedling stage and grain yield of amaranth (for non- pellets)

Phosphorous enhances vigorous growth and seed development, crop maturity and quality especially in grain crops (Clain, 2011). Phosphorous uptake by roots depends on its availability in the soil such that the more there is in the soil the more the uptake and hence growth and yield.

Effect of potassium levels in the soil at seedling stage on yield

The trend of changing K concentration in the soil and in plant leaves is shown in figure 6.14. The trend shows that the concentration of K in the soil remains low throughout the growing period. The concentration in the leaves decrease up to flowering stage. From flowering to maturity the concentration in leaves increase steadily.

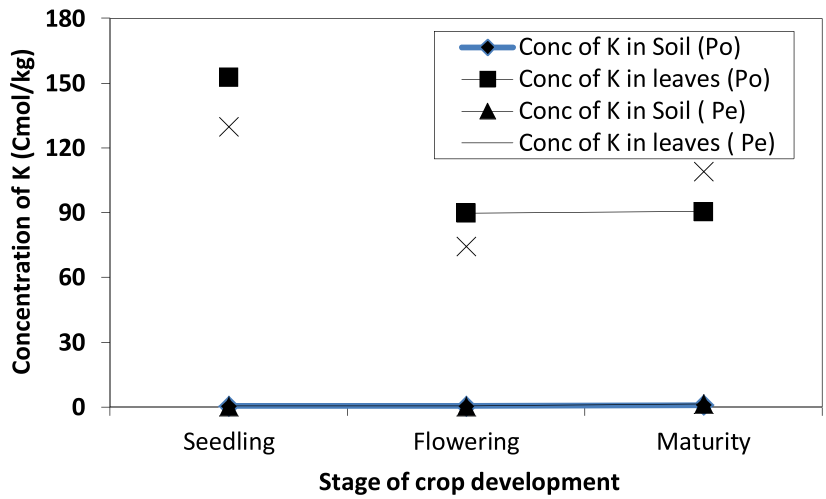

Figure 6.14: Changes in K concentration during growth and development of grain amaranth
Note: Po = non-pellet fertilizer, Pe = pelleted fertilizer

The regression model was significant in estimating the effect of potassium in the soil on the yield for the pellets (p = 0.029) at seedling stage at 95% confidence interval (Figure 6.15). The model was not significant for the non-pellets. Fertilizer pellets release nutrients slowly in the soil. Potassium is required for N uptake and protein synthesis. The use of fertilizer pellets can mean little is released when required and this may compromise yields.

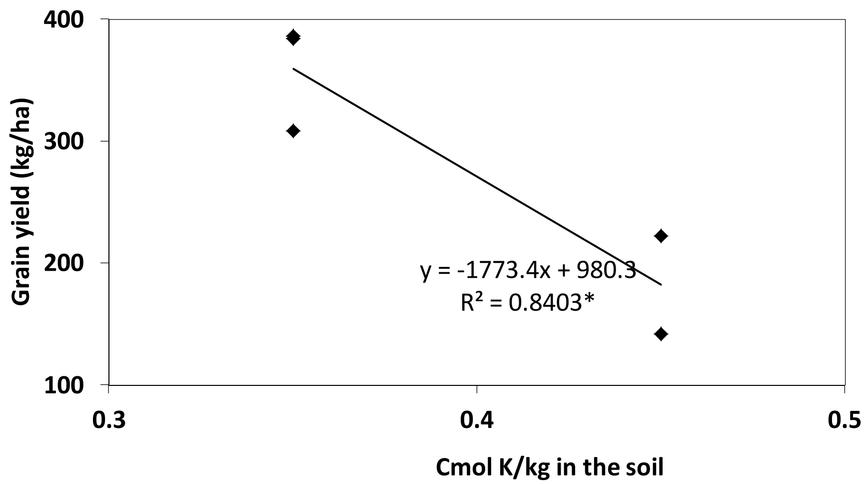

Figure 6. 15 Relationship between the amount of potassium levels in the soil at seedling stage and yield of grain amaranth in 2010

For soils that are deficient in K, inorganic fertilizer sources of K should be applied alongside fertilizer pellets or the pellets can be applied long before planting.

6.5 CONCLUSION

The combined application of farm yard manure and fertilizer has been tried in different crops. In this study the regression models relating N in leaves and N in the soil at both seedling and flowering stages were typical. The regression model relating P levels in leaves and yield represented a typical P nutrient uptake curve.

Therefore use of combined organic and inorganic fertilizer in plants nutrient management is encouraged. The regression models using fertilizer pellets showed positive correlation between N levels in the leaves and N levels in the soil at flowering representing a normal curve for the non-pellet fertilizer. This means that at flowering, nitrogen is actively used by the plant and tying it in the soil in pellets would slow down the process of flower and seed synthesis. The regression models positively related P levels in the soil and yield at seedling stage for non-pellet fertilizer which is normally the case. The negative correlation of K levels in the soil with yield at seedling stage could be suggesting that K is required in small quantities to support its functions in the plant and that K levels in the soil could accumulate to injury levels very fast.

6.6 RECOMMENDATION

As different plant nutrients are required for different functions and at different growth stages, fertilizer mixture of organic and inorganic sources in pellet form will ensure there is prolonged feeding to the plant for increased yields. But this is only the case for fast leaching nutrients like N. From the results of this study, this is recommended. Other forms of coating CAN to prevent leaching are also recommended. For P and K nutrients, pelleting or any form of coating is not required, hence not recommended.

CHAPTER SEVEN: GENERAL DISCUSSION, CONCLUSSION AND RECOMMENDATIONS

Inorganic fertilizer is a quick source for immediate release of nutrients to plants. However, inorganic fertilizers are expensive and most small scale farmers do not use. This leads to reduced productivity. Manure which is readily available in most cattle bomas has several challenges; cost of transport, bulkiness and labour requirement for application. Though manure improves soil structure, thus enhancing root penetration for nutrient absorption, it may not fully benefit short season crops such as amaranth since manure nutrients are released slowly. If the benefits of manure and inorganic fertilizer are combined, this would lead to improved soils for increased productivity.

This study aimed at recommending additional agronomic practices on grain amaranth to farmers and agricultural extension officers specifically effect of pinching, combined use of inorganic and organic fertilizer and use of fertilizer pellets. In this study, pinching reduced significantly plant height, increased number of leaves, and number of flowering stems as well the number of days to flowering. Pinching did not have significant effect on the yields. Ahmed et al (2007) reported that pinching of *Nigella sativa* increased branching but the branches were thin with smaller flower heads. Pinching at 28 days after planting had better growth parameters than pinching at 49 days after planting. This could be due to removal of apical portion which neutralizes the effect of epical dominance when pinching is done early (Ryagi et al, 2007).

Fertilizer combination has been tried in other crops and found to effectively increase yields and quality of the produce. In this study, mixing 75 % organic and 25 % inorganic fertilizer was found to be the best fertilizer argumentation for growing grain amaranth in Western Kenya.

Fertilizer pelleting is a technology that binds fast leached nutrients like nitrogen in a slow releasing material like manure. This ensures that the nutrient is available to the plant in a prolonged period. Application of pellets made from combining cow dung manure at the rate of 6.8 t ha^{-1} with CAN at the rate of 83.25 kg ha^{-1}) significantly increased the growth, development and yield of grain amaranth; through increased number of leaves per plant, individual plantsô canopy size, plant height, stem width, plant dry matter weight and 1000 seed weight. This means less measure of CAN fertilizer coated with manure can supply nitrogen to a plant for a longer time and this would hence increase productivity. From this study, the following are recommended;

1. A study to evaluate the effect of spacing on yield of pinched grain amaranth plants.

2. Study to evaluate the effect of combing organic and inorganic fertilizers on growth and yield of other crops.
3. Another study to evaluate the effect of combined organic and inorganic fertilizers on the grain nutrient content of amaranthus.
4. Combining 6.75 t ha^{-1} of manure and 22 kg ha^{-1} DAP at planting followed 183 kg ha^{-1}CAN top dressed six weeks after planting in grain amaranth production in western Kenya.
5. Application of pellets made from (cow dung manure at the rate of 6.8 t ha^{-1} in combination with CAN at the rate of 83.25 kg ha^{-1}) in grain amaranth production in western Kenya.

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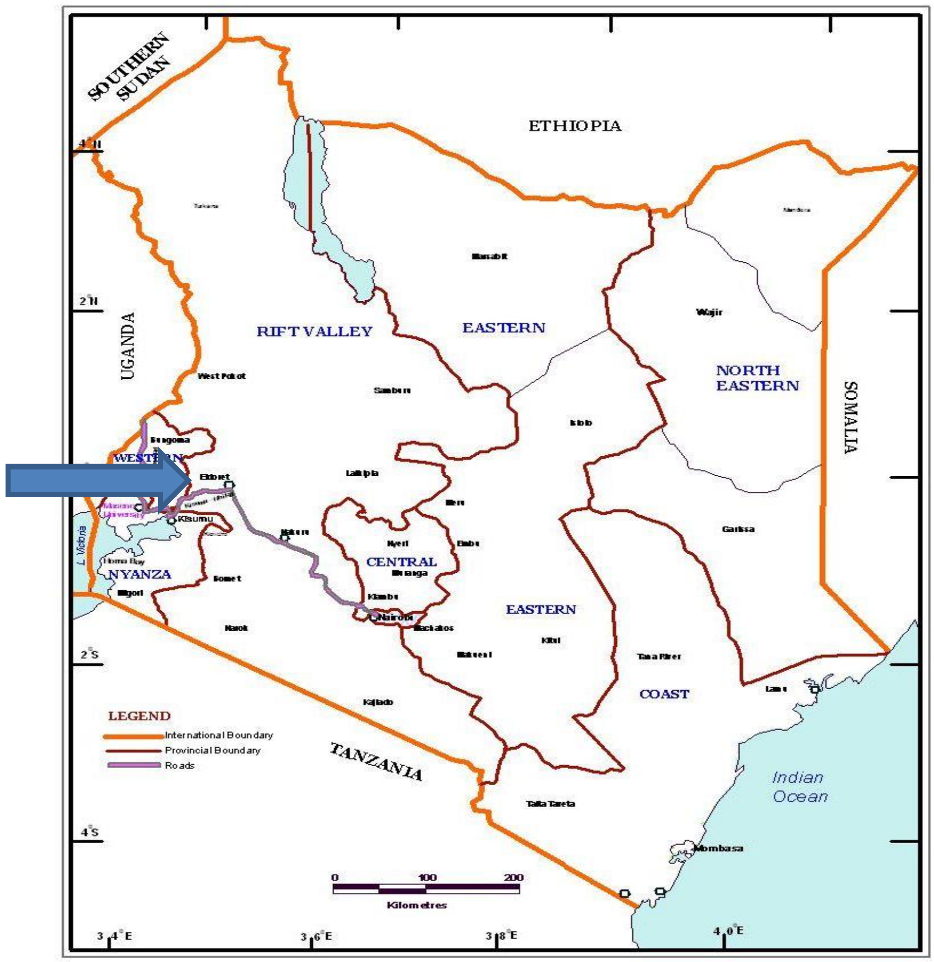
CHAPTER NINE: APPENDICES

Appendix1.1 Map of Kenya showing the position of Maseno University- The site for the Experiment.



Source: Author

APPENDIX 11: ANOVA TABLES EXPERIMENT ONE

Variate: Days_to_G- SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	4.0444	2.0222	0.98	
Block.Pinching stratum					
Pinching	2	3.2444	1.6222	0.79	0.514
Residual	4	8.2222	2.0556	4.74	
Block.Pinching.Fert_comb stratum					
Fert_comb	4	9.2444	2.3111	5.33	0.003
Pinching.Fert_comb	8	2.7556	0.3444	0.79	0.613
Residual	24	10.4000	0.4333		
Total	44	37.9111			

Variate: Days_to_G- SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.7333	0.8667	1.00	
Block.Pinching stratum					
Pinching	2	0.0000	0.0000	0.00	1.000
Residual	4	3.4667	0.8667	2.05	
Block.Pinching.Fert_comb stratum					
Fert_comb	4	4.8000	1.2000	2.84	0.046
Pinching.Fert_comb	8	2.6667	0.3333	0.79	0.617
Residual	24	10.1333	0.4222		
Total	44	22.8000			

Variate: Days_to_F – SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	3.3778	1.6889	1.00	
Block.Pinching stratum					
Pinching	2	2709.5111	1354.7556	802.16	<.001
Residual	4	6.7556	1.6889	2.92	
Block.Pinching.Fert_comb stratum					
Fert_comb	4	1.2444	0.3111	0.54	0.709
Pinching.Fert_comb	8	2.4889	0.3111	0.54	0.816
Residual	24	13.8667	0.5778		
Total	44	2737.2444			

Variate: Days_to_F- SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	392.711	196.356	4.02	
Block.Pinching stratum					
Pinching	2	1505.644	752.822	15.41	0.013
Residual	4	195.422	48.856	7.75	
Block.Pinching.Fert_comb stratum					
Fert_comb	4	65.467	16.367	2.60	0.062
Pinching.Fert_comb	8	88.133	11.017	1.75	0.138
Residual	24	151.200	6.300		
Total	44	2398.578			

Variate: Days_to_M – SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	108.93333	54.46667	0.97	
Block.Pinching stratum					
Pinching	2	448.93333	224.46667	4.00	0.111
Residual	4	224.53333	56.13333	2526.00	
Block.Pinching.Fert_comb stratum					
Fert_comb	4	0.08889	0.02222	1.00	0.427
Pinching.Fert_comb	8	0.17778	0.02222	1.00	0.461
Residual	24	0.53333	0.02222		
Total	44	783.20000			

Variate: Days_to_M – SSN 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		864.86	432.43	0.75	
Block.Pinching stratum						
Pinching	2		2461.68	1230.84	2.14	0.234
Residual	4		2305.62	576.40	9.50	
Block.Pinching.Fert_comb stratum						
Fert_comb	4		140.02	35.01	0.58	0.682
Pinching.Fert_comb	8		253.73	31.72	0.52	0.827
Residual	22	(2)	1334.90	60.68		
Total	42	(2)	7284.28			

Variate: No_leaves - SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1171.92	585.96	1.68	
Block.Pinch stratum					
Pinch	2	1820.70	910.35	2.61	0.188
Residual	4	1393.19	348.30	4.62	
Block.Pinch.Fertilizer_combination stratum					
Fertilizer_combination	4	767.47	191.87	2.55	0.066
Pinch.Fertilizer_combination	8	485.30	60.66	0.81	0.604
Residual	24	1807.88	75.33	2.74	
Block.Pinch.Fertilizer_combination.*Units* stratum					
Time	4	34354.78	8588.70	311.91	<.001
Pinch.Time	8	2482.96	310.37	11.27	<.001
Fertilizer_combination.Time	16	596.01	37.25	1.35	0.177
Pinch.Fertilizer_combination.Time	32	578.20	18.07	0.66	0.916
Residual	120	3304.29	27.54		
Total	224	48762.70			

Variate: No_leaves- SSN 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		1511.136	755.568	13.74	
Block.Pinch stratum						
Pinch	2		24.018	12.009	0.22	0.813
Residual	4		219.981	54.995	1.40	
Block.Pinch.Fertilizer_combination stratum						
Fertilizer_combination	4		737.392	184.348	4.69	0.006
Pinch.Fertilizer_combination	8		179.652	22.457	0.57	0.791
Residual	24		943.068	39.295	17.32	
Block.Pinch.Fertilizer_combination.*Units* stratum						
Time	7	(4)	12279.239	1754.177	773.29	<.001
Pinch.Time	6	(16)	42.102	7.017	3.09	0.008
Fertilizer_combination.Time	28	(16)	173.306	6.190	2.73	<.001
Pinch.Fertilizer_combination.Time	24	(64)	15.225	0.634	0.28	1.000
Residual	110	(220)	249.530	2.268		
Total	219	(320)	7166.487			

Variate: Plant_height – SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1430.91	715.45	0.15	
Block.Pinch stratum					
Pinch	2	5775.47	2887.73	0.61	0.588
Residual	4	19009.78	4752.45	5.21	
Block.Pinch.Fertilizer_combination stratum					
Fertilizer_combination	4	6333.70	1583.42	1.74	0.175
Pinch.Fertilizer_combination	8	5335.31	666.91	0.73	0.664
Residual	24	21900.12	912.51	14.30	
Block.Pinch.Fertilizer_combination.*Units* stratum					
Time	10	317431.13	31743.11	497.28	<.001
Pinch.Time	20	3106.80	155.34	2.43	<.001
Fertilizer_combination.Time	40	2030.53	50.76	0.80	0.808
Pinch.Fertilizer_combination.Time	80	2103.10	26.29	0.41	1.000
Residual	300	19149.85	63.83		
Total	494	403606.70			

Variate: Plant_height – SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	114992.3	57496.1	23.58	
Block.Pinch stratum					
Pinch	2	65886.8	32943.4	13.51	0.017
Residual	4	9753.7	2438.4	1.11	
Block.Pinch.Fertilizer_combination stratum					
Fertilizer_combination	4	15202.2	3800.6	1.73	0.176
Pinch.Fertilizer_combination	8	17254.2	2156.8	0.98	0.474
Residual	24	52749.7	2197.9	11.07	
Block.Pinch.Fertilizer_combination.*Units* stratum					
Time	11	711682.6	64698.4	325.84	<.001
Pinch.Time	22	42612.7	1936.9	9.75	<.001
Fertilizer_combination.Time	44	6006.4	136.5	0.69	0.935
Pinch.Fertilizer_combination.Time	88	7364.7	83.7	0.42	1.000
Residual	330	65525.1	198.6		
Total	539	1109030.3			

Variate: Width – SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	710.163	355.081	5.84	
Block.Pinch stratum					
Pinch	2	97.582	48.791	0.80	0.509
Residual	4	243.232	60.808	4.66	
Block.Pinch.Fertilizer_combination stratum					
Fertilizer_combination	4	72.765	18.191	1.39	0.266
Pinch.Fertilizer_combination	8	65.761	8.220	0.63	0.745
Residual	24	313.173	13.049	2.26	
Block.Pinch.Fertilizer_combination.*Units* stratum					
Time	11	1233.832	112.167	19.42	<.001
Pinch.Time	22	394.559	17.934	3.11	<.001
Fertilizer_combination.Time	44	140.324	3.189	0.55	0.991
Pinch.Fertilizer_combination.Time	88	258.745	2.940	0.51	1.000
Residual	330	1905.942	5.776		
Total	539	5436.079			

Variate: Canopy – SSN1

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		5531.60	2765.80	0.86	
Block.Pinch stratum						
Pinch	2		3566.34	1783.17	0.55	0.614
Residual	4		12902.28	3225.57	3.95	
Block.Pinch.Fertilizer_combination stratum						
Fertilizer_combination	4		1251.85	312.96	0.38	0.819
Pinch.Fertilizer_combination	8		5692.97	711.62	0.87	0.554
Residual	24		19614.01	817.25	37.38	
Block.Pinch.Fertilizer_combination.*Units* stratum						
Time	2	(8)	644.64	322.32	14.74	<.001
Pinch.Time	4	(16)	1794.46	448.61	20.52	<.001
Fertilizer_combination.Time	8	(32)	188.70	23.59	1.08	0.390
Pinch.Fertilizer_combination.Time	16	(64)	159.81	9.99	0.46	0.958
Residual	60	(240)	1311.87	21.86		
Total	134	(360)	17357.64			

Variate: Shoots -SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	3.9147	1.9573	0.18	
Block.Pinch stratum					
Pinch	2	1654.2836	827.1418	74.41	<.001
Residual	4	44.4658	11.1164	1.80	
Block.Pinch.Fertilizer_combination stratum					
Fertilizer_combination	4	51.9413	12.9853	2.10	0.112
Pinch.Fertilizer_combination	8	44.1298	5.5162	0.89	0.538
Residual	24	148.3129	6.1797	6.94	
Block.Pinch.Fertilizer_combination.*Units* stratum					
Time	5	124.2484	24.8497	27.90	<.001
Pinch.Time	10	68.7280	6.8728	7.72	<.001
Fertilizer_combination.Time	20	25.9004	1.2950	1.45	0.106
Pinch.Fertilizer_combination.Time	40	25.1698	0.6292	0.71	0.900
Residual	150	133.6000	0.8907		
Total	269	2324.6947			

Variate: Shoots- SSN 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		678.7167	339.3583	1993.55	Block.Pinch strat
Pinch	1	(1)	49.5181	49.5181	290.89	0.003
Residual	2	(2)	0.3405	0.1702	0.04	
Block.Pinch.Fertilizer_combination stratum						
Fertilizer_combination	4		37.9763	9.4941	1.99	0.145
Pinch.Fertilizer_combination	4	(4)	37.7300	9.4325	1.97	0.147
Residual	16	(8)	76.5208	4.7825	12.51	
Block.Pinch.Fertilizer_combination.*Units* stratum						
Time	8	(3)	203.7683	25.4710	66.63	<.001
Pinch.Time	7	(15)	19.8995	2.8428	7.44	<.001
Fertilizer_combination.Time	32	(12)	10.2775	0.3212	0.84	0.710
Pinch.Fertilizer_combination.Time	28	(60)	3.9411	0.1408	0.37	0.998
Residual	125	(205)	47.7847	0.3823		
Total	229	(310)	612.4746			

Variate: Height_of_flower_head – SSN 1

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		2472.146	1236.073	1.11	
Block.Pinch stratum						
Pinch	2		9510.724	4755.362	4.26	0.102
Residual	4		4460.568	1115.142	3.26	
Block.Pinch.Fertilizer_combination stratum						
Fertilizer_combination	4		2021.257	505.314	1.48	0.240
Pinch.Fertilizer_combination	8		2225.173	278.147	0.81	0.599
Residual	24		8213.733	342.239	212.63	
Block.Pinch.Fertilizer_combination.*Units* stratum						
Time	2	(8)	220.477	110.238	68.49	<.001
Pinch.Time	4	(16)	6.388	1.597	0.99	0.419
Fertilizer_combination.Time	8	(32)	18.672	2.334	1.45	0.195
Pinch.Fertilizer_combination.Time	16	(64)	14.440	0.902	0.56	0.900
Residual	60	(240)	96.571	1.610		
Total	134	(360)	8242.761			

Variate: Dry_matter_weight_g- Season 1

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		1788.4	894.2	0.26	
Block.Pinch stratum						
Pinch	2		329.6	164.8	0.05	0.953
Residual	4		13520.3	3380.1	5.85	
Block.Pinch.Fert_comb stratum						
Fert_comb	4		2877.8	719.4	1.25	0.318
Pinch.Fert_comb	8		1507.6	188.4	0.33	0.948
Residual	24		13855.3	577.3	1.26	
Block.Pinch.Fert_comb.*Units* stratum						
Time	1		49871.3	49871.3	108.70	<.001
Pinch.Time	2		2356.7	1178.4	2.57	0.094
Fert_comb.Time	4		1492.4	373.1	0.81	0.527
Pinch.Fert_comb.Time	8		3224.2	403.0	0.88	0.546
Residual	29	(1)	13304.6	458.8		
Total	88	(1)	102932.6			

Variate: Dry_matter_weight_g- SSN 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		182721.	91361.	7.02	
Block.Pinch stratum						
Pinch	2		113064.	56532.	4.34	0.099
Residual	4		52045.	13011.	2.69	
Block.Pinch.Fert_comb stratum						
Fert_comb	4		22254.	5564.	1.15	0.356
Pinch.Fert_comb	8		29746.	3718.	0.77	0.632
Residual	24		115920.	4830.	0.90	
Block.Pinch.Fert_comb.*Units* stratum						
Time	1		222377.	222377.	41.29	<.001
Pinch.Time	2		45748.	22874.	4.25	0.027
Fert_comb.Time	4		22720.	5680.	1.05	0.401
Pinch.Fert_comb.Time	8		22240.	2780.	0.52	0.832
Residual	23	(7)	123858.	5385.		
Total	82	(7)	919524.			

Variate: Yieldkg_Ha- SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block	2	59169.	29584.	0.32	0.730
Pinching	2	588554.	294277.	3.20	0.068
Fert_comb	4	91895.	22974.	0.25	0.906
Block.Pinching	4	1488544.	372136.	4.04	0.019
Block.Fert_comb	8	657618.	82202.	0.89	0.544
Pinching.Fert_comb	8	439028.	54878.	0.60	0.768
Residual	16	1472773.	92048.		
Total	44	4797581.			

Variate: Yield_Kg_Ha- SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	17827.	8914.	0.15	
Block.Pinching stratum					
Pinching	2	101312.	50656.	0.85	0.491
Residual	4	237353.	59338.	4.09	
Block.Pinching.Fert_comb stratum					
Fert_comb	4	30100.	7525.	0.52	0.723
Pinching.Fert_comb	8	81613.	10202.	0.70	0.686
Residual	24	348421.	14518.		
Total	44	816627.			

Variate: %1000_seed_wt_g- SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.0133378	0.0066689	3.38	
Block.Pinching stratum					
Pinching	2	0.0016311	0.0008156	0.41	0.687
Residual	4	0.0079022	0.0019756	2.54	
Block.Pinching.Fert_combination stratum					
Fert_combination	4	0.0019467	0.0004867	0.62	0.649
Pinching.Fert_combination	8	0.0038800	0.0004850	0.62	0.751
Residual	24	0.0186933	0.0007789		
Total	44	0.0473911			

Variate: %1000_seed_wt_g- SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.0133378	0.0066689	12.45	
Block.Pinching stratum					
Pinching	2	0.0073911	0.0036956	6.90	0.050
Residual	4	0.0021422	0.0005356	0.69	
Block.Pinching.Fert_combination stratum					
Fert_combination	4	0.0019467	0.0004867	0.63	0.647
Pinching.Fert_combination	8	0.0039867	0.0004983	0.64	0.734
Residual	24	0.0185867	0.0007744		
Total	44	0.0473911			

APPENDIX 111: ANOVA TABLES EXPERIMENT 2

Variate: Days_to_G - SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.6000	0.3000	3.00	
Block.Pellets stratum					
Pellets	1	0.0000	0.0000	0.00	1.000
Residual	2	0.2000	0.1000	0.24	
Block.Pellets.Fert_comb stratum					
Fert_comb	4	5.1333	1.2833	3.14	0.044
Pellets.Fert_comb	4	22.3333	5.5833	13.67	<.001
Residual	16	6.5333	0.4083		
Total	29	34.8000			

Variate: Days_to_G - SSN_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	0.0000	0.0000	0.00	
Block.Pellets stratum					
Pellets	1	0.3000	0.3000	0.75	0.478
Residual	2	0.8000	0.4000	0.51	
Block.Pellets.Fert_comb stratum					
Fert_comb	4	8.1333	2.0333	2.60	0.076
Pellets.Fert_comb	4	14.5333	3.6333	4.64	0.011
Residual	16	12.5333	0.7833		
Total	29	36.3000			

Variate: Days_to_F- SSN 1

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		46.557	23.279	3.12	
Block.Pellets stratum						
Pellets	1		15.830	15.830	2.12	0.283
Residual	2		14.938	7.469	0.85	
Block.Pellets.Fert_comb stratum						
Fert_comb	4		433.437	108.359	12.36	<.001
Pellets.Fert_comb	4		73.203	18.301	2.09	0.137
Residual	14	(2)	122.700	8.764		
Total	27	(2)	488.107			

Variate: Days_to_F - SSN 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		46.557	23.279	3.12	
Block.Pellets stratum						
Pellets	1		15.830	15.830	2.12	0.283
Residual	2		14.938	7.469	0.85	
Block.Pellets.Fert_comb stratum						
Fert_comb	4		433.437	108.359	12.36	<.001
Pellets.Fert_comb	4		73.203	18.301	2.09	0.137
Residual	14	(2)	122.700	8.764		
Total	27	(2)	488.107			

Variate: Days_to_M - SSN 1

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		80.19	40.10	4.02	
Block.Pellets stratum						
Pellets	1		1.13	1.13	0.11	0.769
Residual	2		19.93	9.97	0.31	
Block.Pellets.Fert_comb stratum						
Fert_comb	4		115.15	28.79	0.91	0.487
Pellets.Fert_comb	4		186.43	46.61	1.47	0.265
Residual	14	(2)	445.03	31.79		
Total	27	(2)	729.25			

Variate: Days_to_M - SSN 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		80.19	40.10	4.02	
Block.Pellets stratum						
Pellets	1		1.13	1.13	0.11	0.769
Residual	2		19.93	9.97	0.31	
Block.Pellets.Fert_comb stratum						
Fert_comb	4		115.15	28.79	0.91	0.487
Pellets.Fert_comb	4		186.43	46.61	1.47	0.265
Residual	14	(2)	445.03	31.79		
Total	27	(2)	729.25			

Variate: No_Leaves – SSN 1

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		99.552	49.776	0.27	
Block.Pellet stratum						
Pellet	1		141.612	141.612	0.76	0.476
Residual	2		375.101	187.550	4.57	
Block.Pellet.Fert_comb stratum						
Fert_comb	4		1864.380	466.095	11.35	<.001
Pellet.Fert_comb	4		195.815	48.954	1.19	0.352
Residual	16		657.230	41.077	4.84	
Block.Pellet.Fert_comb.*Units* stratum						
Time	5	(7)	5195.941	1039.188	122.52	<.001
Pellet.Time	5	(7)	15.163	3.033	0.36	0.876
Fert_comb.Time	20	(28)	692.893	34.645	4.08	<.001
Pellet.Fert_comb.Time	20	(28)	48.991	2.450	0.29	0.999
Residual	100	(140)	848.192	8.482		
Total	179	(210)	8347.249			

Variate: No_leaves - SSN_2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1054.45	527.23	20.57	
Block.Pellet stratum					
Pellet	1	141.37	141.37	5.52	0.143
Residual	2	51.27	25.63	0.13	
Block.Pellet.Fert_comb stratum					
Fert_comb	4	4468.55	1117.14	5.60	0.005
Pellet.Fert_comb	4	181.39	45.35	0.23	0.919
Residual	16	3191.10	199.44	7.61	
Block.Pellet.Fert_comb.*Units* stratum					
Time	7	26025.49	3717.93	141.88	<.001
Pellet.Time	7	97.18	13.88	0.53	0.811
Fert_comb.Time	28	2888.33	103.15	3.94	<.001
Pellet.Fert_comb.Time	28	226.91	8.10	0.31	1.000
Residual	140	3668.57	26.20		
Total	239	41994.60			

Variate: Plant_Height - SSN_1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	358.09	179.05	0.09	
Block.Pellet stratum					
Pellet	1	2202.64	2202.64	1.07	0.409
Residual	2	4112.35	2056.17	2.86	
Block.Pellet.Fert_comb stratum					
Fert_comb	4	34762.28	8690.57	12.09	<.001
Pellet.Fert_comb	4	2225.89	556.47	0.77	0.558
Residual	16	11500.28	718.77	19.12	
Block.Pellet.Fert_comb.*Units* stratum					
Time	12	223257.55	18604.80	494.84	<.001
Pellet.Time	12	638.67	53.22	1.42	0.159
Fert_comb.Time	48	15184.72	316.35	8.41	<.001
Pellet.Fert_comb.Time	48	1061.72	22.12	0.59	0.985
Residual	240	9023.46	37.60		
Total	389	304327.67			

Variate: Plant_Height - SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	2151.5	1075.8	0.35	
Block.Pellet stratum					
Pellet	1	4357.1	4357.1	1.44	0.353
Residual	2	6067.4	3033.7	0.88	
Block.Pellet.Fert_comb stratum					
Fert_comb	4	87101.9	21775.5	6.30	0.003
Pellet.Fert_comb	4	1179.2	294.8	0.09	0.986
Residual	16	55298.4	3456.2	19.85	
Block.Pellet.Fert_comb.*Units* stratum					
Time	11	431591.1	39235.6	225.37	<.001
Pellet.Time	11	2122.3	192.9	1.11	0.356
Fert_comb.Time	44	57011.4	1295.7	7.44	<.001
Pellet.Fert_comb.Time	44	3134.2	71.2	0.41	1.000
Residual	220	38301.4	174.1		
Total	359	688316.0			

Variate: Plant_W - SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1.4202	0.7101	0.11	
Block.Pellet stratum					
Pellet	1	5.3813	5.3813	0.86	0.451
Residual	2	12.4452	6.2226	1.94	
Block.Pellet.Fert_comb stratum					
Fert_comb	4	171.7597	42.9399	13.39	<.001
Pellet.Fert_comb	4	11.9443	2.9861	0.93	0.471
Residual	16	51.3164	3.2073	16.99	
Block.Pellet.Fert_comb.*Units* stratum					
Time	12	1278.7138	106.5595	564.53	<.001
Pellet.Time	12	2.2173	0.1848	0.98	0.470
Fert_comb.Time	48	36.2186	0.7546	4.00	<.001
Pellet.Fert_comb.Time	48	4.6482	0.0968	0.51	0.997
Residual	240	45.3021	0.1888		
Total	389	1621.3672			

Variate: Plant_W - SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	7.9721	3.9860	0.37	
Block.Pellet stratum					
Pellet	1	1.1972	1.1972	0.11	0.772
Residual	2	21.7701	10.8851	0.91	
Block.Pellet.Fert_comb stratum					
Fert_comb	4	183.7460	45.9365	3.86	0.022
Pellet.Fert_comb	4	17.6539	4.4135	0.37	0.826
Residual	16	190.3421	11.8964	13.48	
Block.Pellet.Fert_comb.*Units* stratum					
Time	11	908.2589	82.5690	93.53	<.001
Pellet.Time	11	11.8440	1.0767	1.22	0.275
Fert_comb.Time	44	74.2186	1.6868	1.91	0.001
Pellet.Fert_comb.Time	44	35.3028	0.8023	0.91	0.638
Residual	220	194.2172	0.8828		
Total	359	1646.5230			

Variate: Height_Flower Head —SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	56.646	28.323	0.13	
Block.Pellet stratum					
Pellet	1	265.494	265.494	1.26	0.378
Residual	2	419.883	209.942	1.94	
Block.Pellet.Fert_comb stratum					
Fert_comb	4	4038.032	1009.508	9.34	<.001
Pellet.Fert_comb	4	228.451	57.113	0.53	0.717
Residual	16	1730.212	108.138	32.08	
Block.Pellet.Fert_comb.*Units* stratum					
Time	3	593.534	197.845	58.69	<.001
Pellet.Time	3	71.102	23.701	7.03	<.001
Fert_comb.Time	12	46.103	3.842	1.14	0.347
Pellet.Fert_comb.Time	12	46.611	3.884	1.15	0.338
Residual	60	202.274	3.371		
Total	119	7698.342			

Variate: Canopy - SSN 1

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		1425.96	712.98	0.57	
Block.Pellet stratum						
Pellet	1		206.81	206.81	0.17	0.724
Residual	2		2499.85	1249.93	2.78	
Block.Pellet.Fert_comb stratum						
Fert_comb	4		16290.67	4072.67	9.06	<.001
Pellet.Fert_comb	4		1607.21	401.80	0.89	0.490
Residual	16		7188.76	449.30	32.00	
Block.Pellet.Fert_comb.*Units* stratum						
Time	4	(8)	22608.42	5652.11	402.52	<.001
Pellet.Time	3	(9)	103.15	34.38	2.45	0.072
Fert_comb.Time	12	(36)	250.09	20.84	1.48	0.156
Pellet.Fert_comb.Time	12	(36)	108.64	9.05	0.64	0.795
Residual	60	(180)	842.51	14.04		
Total	120	(269)	12465.22			

Variate: Canopy - SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	1356.71	678.36	0.89	
Block.Pellet stratum					
Pellet	1	620.31	620.31	0.81	0.463
Residual	2	1532.28	766.14	0.84	
Block.Pellet.Fert_comb stratum					
Fert_comb	4	29207.03	7301.76	7.97	<.001
Pellet.Fert_comb	4	1478.43	369.61	0.40	0.804
Residual	16	14667.51	916.72	26.53	
Block.Pellet.Fert_comb.*Units* stratum					
Time	11	93952.29	8541.12	247.20	<.001
Pellet.Time	11	286.97	26.09	0.76	0.685
Fert_comb.Time	44	9825.46	223.31	6.46	<.001
Pellet.Fert_comb.Time	44	1905.00	43.30	1.25	0.149
Residual	220	7601.28	34.55		
Total	359	162433.28			

Variate: Drymatter_wt - SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	468.35	234.18	2.28	
Block.Pellets stratum					
Pellets	1	313.50	313.50	3.05	0.223
Residual	2	205.34	102.67	0.42	
Block.Pellets.Fert_comb stratum					
Fert_comb	4	3765.83	941.46	3.86	0.022
Pellets.Fert_comb	4	1244.09	311.02	1.28	0.321
Residual	16	3902.11	243.88	2.75	
Block.Pellets.Fert_comb.*Units* stratum					
Time	1	7569.69	7569.69	85.49	<.001
Pellets.Time	1	68.25	68.25	0.77	0.390
Fert_comb.Time	4	1370.11	342.53	3.87	0.017
Pellets.Fert_comb.Time	4	592.60	148.15	1.67	0.196
Residual	20	1770.83	88.54		
Total	59	21270.69			

Variate: Drymatter_wt_g- SSN 2

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	703.	351.	0.10	
Block.Pellets stratum					
Pellets	1	7186.	7186.	2.03	0.290
Residual	2	7065.	3532.	0.44	
Block.Pellets.Fert_comb stratum					
Fert_comb	4	85773.	21443.	2.70	0.068
Pellets.Fert_comb	4	13556.	3389.	0.43	0.788
Residual	16	127266.	7954.	1.41	
Block.Pellets.Fert_comb.*Units* stratum					
Time	1	132387.	132387.	23.55	<.001
Pellets.Time	1	2913.	2913.	0.52	0.480
Fert_comb.Time	4	38187.	9547.	1.70	0.190
Pellets.Fert_comb.Time	4	13352.	3338.	0.59	0.671
Residual	20	112430.	5622.		
Total	59	540818.			

Variate: Yield_kg_ha - SSN 1

Source of variation	d.f.	s.s.	m.s.	v.r.	F pr.
Block stratum	2	40267.	20134.	0.48	
Block.Pellets stratum					
Pellets	1	30704.	30704.	0.73	0.482
Residual	2	83696.	41848.	0.86	
Block.Pellets.Fert_comb stratum					
Fert_comb	4	171508.	42877.	0.88	0.499
Pellets.Fert_comb	4	146030.	36507.	0.75	0.574
Residual	16	781495.	48843.		
Total	29	1253700.			

Variate: %1000_seed_weight- SSN 1

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		0.002628	0.001314	0.42	
Block.Pellets stratum						
Pellets	1		0.001006	0.001006	0.32	0.627
Residual	2		0.006210	0.003105	0.53	
Block.Pellets.Fert_comb stratum						
Fert_comb	4		0.132729	0.033182	5.68	0.006
Pellets.Fert_comb	4		0.023160	0.005790	0.99	0.445
Residual	14	(2)	0.081842	0.005846		
Total	27	(2)	0.221043			

Variate: %1000_seed_wt_g - SSN- 2

Source of variation	d.f.	(m.v.)	s.s.	m.s.	v.r.	F pr.
Block stratum	2		5.568	2.784	1.03	
Block.Pellets stratum						
Pellets	1		1.267	1.267	0.47	0.564
Residual	2		5.408	2.704	1.12	
Block.Pellets.Fert_com stratum						
Fert_com	4		10.032	2.508	1.04	0.420
Pellets.Fert_com	4		9.988	2.497	1.04	0.422
Residual	14	(2)	33.661	2.404		
Total	27	(2)	63.271			

APPENDIX 1V: PATH WAY REGRESSION

a) Determine the constant of the regression

Regression analysis

Response variate: Yield

Fitted terms: Constant

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	0	0.	*		
Residual	134	14392744.	107409.		
Total	134	14392744.	107409.		

%age variance accounted for 0.0

Standard error of observations is estimated to be 328.

Estimates of parameters

Parameter	estimate	s.e.	t(134)	t pr.
Constant	581.6	28.2	20.62	<.001

b) Initial investigation to assess the contribution by all the factors

Changes investigated by TRY

Change	d.f.	s.s.	m.s.
+ Plant_height	1	6684191.	6684191.
+ Width	1	1136470.	1136470.
+ Shoots	1	457781.	457781.
+ Height_of_flower_head	1	4026834.	4026834.
+ Canopy	1	2881264.	2881264.
Residual of initial model	134	14392744.	107409.

b) Run the model with height

Regression analysis

Response variate: Yield

Fitted terms: Constant, Plant_height

Summary of analysis

Source	d.f.	s.s.	m.s.	v.r.	F pr.
Regression	1	6684191.	6684191.	115.33	<.001
Residual	133	7708552.	57959.		
Total	134	14392744.	107409.		

%age variance accounted for 46.0
Standard error of observations is estimated to be 241.

Message: the following units have large standardized residuals.

Unit	Response	Residual
401	39.	-3.56
446	39.	-3.68
491	39.	-3.70

Message: the residuals do not appear to be random; for example, fitted values in the range 647. to 748. are consistently smaller than observed values and fitted values in the range 543. to 643. are consistently larger than observed values.

Message: the error variance does not appear to be constant; large responses are more variable than small responses.

Message: the following units have high leverage.

Unit	Response	Leverage
415	116.	0.054
460	116.	0.050

Estimates of parameters

Parameter	estimate	s.e.	t(133)	t pr.
Constant	-408.3	94.5	-4.32	<.001
Plant_height	13.33	1.24	10.74	<.001

c) Do a stepwise regression to decide which other factors to include in the model besides plant height

Stepwise (forward) analysis of variance

d) Regression analysis

Accumulated analysis of variance

Change	d.f.	s.s.	m.s.	v.r.	F pr.
+ Plant_height	1	6684191.	6684191.	129.20	<.001
+ Width	1	393309.	393309.	7.60	0.007
+ Shoots	1	93709.	93709.	1.81	0.181
+ Height_of_flower_head	1	496162.	496162.	9.59	0.002
Residual	130	6725372.	51734.		
- Width	-1	-34454.	34454.	0.67	0.416
Total	134	14392744.	107409.		

Final model: Constant + Plant_height + Shoots + Height_of_flower_head

All possible subset selection

Free terms:	(1)	Height_of_flower_head	(3)	Width
	(2)	Canopy	(4)	Shoots

* MESSAGE: probabilities are based on F-statistics, i.e. on variance ratios.

Best subsets with 1 term

Adjusted	Cp	Df	(1)	(2)	(3)	(4)
48.40	11.37	3	-	-	.009	-
47.86	12.85	3	-	-	-	.019
45.84	18.35	3	-	.476	-	-
45.80	18.44	3	.516	-	-	-

Best subsets with 2 terms

gre

Adjusted	Cp	Df	(1)	(2)	(3)	(4)
51.96	2.71	4	.001	-	-	.000
48.68	11.57	4	-	-	.081	.195
48.46	12.16	4	.287	-	.006	-
48.04	13.28	4	-	.773	.011	-
47.93	13.59	4	-	.280	-	.013
45.53	20.08	4	.627	.570	-	-

Best subsets with 3 terms

Adjusted	Cp	Df	(1)	(2)	(3)	(4)
51.83	4.05	5	.002	-	.416	.002
51.65	4.55	5	.001	.688	-	.000
48.45	13.13	5	-	.522	.131	.158
48.06	14.16	5	.307	.993	.007	-

Best subsets with 4 terms

Adjusted	Cp	Df	(1)	(2)	(3)	(4)
51.48	6.00	6	.003	.820	.459	.002

APPENDIX V: REGRESSION ANALYSIS EXPERIMENT ONE

<u>% N leaves vs %N at flowering</u>

Regression Statistics

Multiple R	0.665455
R Square	0.44283
Adjusted R Square	0.399971
Standard Error	0.184844
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	1	0.353024	0.353024	10.33221	0.006777
Residual	13	0.444176	0.034167		
Total	14	0.7972			

	Coefficients	Standard Error	t Stat	P-value
Intercept	3.048953	0.302769	10.07023	1.66E-07
%N soil	6.406977	1.993226	3.214376	0.006777

Yield Vs %N soil at flowering (POL)

Regression Statistics	
Multiple R	0.248662
R Square	0.061833
Adjusted R Square	-0.09453
Standard Error	168.5545
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	2	22469.81	11234.91	0.395447	0.681839
Residual	12	340927.4	28410.62		
Total	14	363397.3			

	Coefficients	Standard Error	t Stat	P-value
Intercept	194.1666	1313.395	0.147836	0.884927
NS2	-37641.1	68347.25	-0.55073	0.591922
%N soil	9235.315	19160.05	0.482009	0.638471

Yield Vs % N leaves at flowering (POL)

Regression Statistics	
Multiple R	0.202794
R Square	0.041125
Adjusted R Square	-0.11869
Standard Error	170.4045
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	2	14944.82	7472.409	0.257335	0.777269
Residual	12	348452.4	29037.7		
Total	14	363397.3			

	Coefficients	Standard Error	t Stat	P-value
Intercept	-6213.44	11976.95	-0.51878	0.613345
NL2	-409.23	744.2926	-0.54982	0.592526
%N Leaves	3373.22	5978.173	0.564256	0.582973

Yield vs %N soil at seedling (POL)

Multiple R	0.549063
R Square	0.30147
Adjusted R Square	0.185049
Standard Error	145.4429
Observations	15

ANOVA

	df	SS	MS	F	Significance F
Regression	2	109553.5	54776.74	2.58947	0.116174
Residual	12	253843.8	21153.65		
Total	14	363397.3			

	Coefficients	Standard Error	t Stat	P-value
Intercept	1614.667	752.8928	2.144618	0.053151
NS2	50246.16	30427.85	1.651321	0.12458
% N soil	-13747.5	9743.938	-1.41087	0.183678

Yield vs %N Leaves at seedling (POL)

Regression Statistics	
Multiple R	0.044265
R Square	0.001959
Adjusted R Square	-0.16438
Standard Error	173.8498
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	712.0277	356.0138	0.011779	0.988301
Residual	12	362685.2	30223.77		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	422.3058	5296.741	0.079729	0.937767
NL2	-10.0829	259.815	-0.03881	0.969682
%N Leaves	109.1817	2351.764	0.046425	0.963735

Yield vs P soil at seedling

Multiple R	0.145135	
R Square	0.021064	
Adjusted R Square		-0.05424
Standard Error	165.4231	
Observations	15	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	7654.677	7654.677	0.279727	0.605793
Residual	13	355742.6	27364.81		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	652.1361	119.1392	5.473732	0.000107
Cmol/kg P soil	42.52284	80.39981	0.528892	0.605793

Yield vs P soil at seedling stage (POL)

Regression Statistics		
Multiple R	0.251778	
R Square	0.063392	
Adjusted R Square		-0.09271
Standard Error	168.4144	
Observations	15	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	23036.49	11518.25	0.406095	0.675067
Residual	12	340360.8	28363.4		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	474.0182	270.5797	1.751862	0.105288
Pl2	-98.3053	133.491	-0.73642	0.475627
Cmol/kg P soil	327.3275	395.3102	0.828027	0.423818

Yield vs K soil at seedling

Regression Statistics	
Multiple R	0.515102
R Square	0.26533
Adjusted R Square	0.208817
Standard Error	143.3063
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	96420.1	96420.1	4.695013	0.049415
Residual	13	266977.1	20536.7		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	339.6991	175.2902	1.937924	0.074661
Cmol/kg K soil	1050.736	484.9259	2.166798	0.049415

Yield vs K soil at seedling (POL)

Regression Statistics	
Multiple R	0.599953
R Square	0.359943
Adjusted R Square	0.253267
Standard Error	139.2225
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	130802.4	65401.19	3.374168	0.068756
Residual	12	232594.9	19382.91		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-568.54	702.8756	-0.80888	0.434331
KS2	-6206.54	4660.059	-1.33186	0.207651
Cmol/kg K soil	5916.471	3683.594	1.606168	0.134215

Yield vs K leaves at seedling (POL)

Regression Statistics	
Multiple R	0.640851
R Square	0.41069
Adjusted R Square	0.312472
Standard Error	133.5894
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	149243.8	74621.89	4.181406	0.041885
Residual	12	214153.5	17846.12		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	590.7328	70.13778	8.422461	2.21E-06
KL2	0.011339	0.031114	0.364439	0.721871
Cmol/kg K leaves	0.67435	3.819669	0.176547	0.862809

Yield vs P soil at flowering (POL)

Regression Statistics	
Multiple R	0.229413
R Square	0.05263
Adjusted R Square	-0.10526
Standard Error	169.3792
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	19125.64	9562.819	0.333324	0.722965
Residual	12	344271.6	28689.3		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	690.1293	360.115	1.916414	0.079433
PS2	270.2218	1266.148	0.21342	0.834582
Cmol/kg P soil	-90.6949	1423.656	-0.06371	0.950254

Yield vs K soil at Flowering (POL)

Regression Statistics	
Multiple R	0.22034
R Square	0.04855
Adjusted R Square	-0.11003
Standard Error	169.7435
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	17642.89	8821.447	0.306164	0.74185
Residual	12	345754.4	28812.86		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	703.9542	463.9803	1.517207	0.155109
KS2	-8.84566	43.39675	-0.20383	0.8419
Cmol/kg K soil	26.82231	312.6341	0.085795	0.933045

Yield vs % N in leaves at Flowering (POL)

Regression Statistics	
Multiple R	0.202794
R Square	0.041125
Adjusted R Square	-0.11869
Standard Error	170.4045
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	14944.82	7472.409	0.257335	0.777269
Residual	12	348452.4	29037.7		
Total	14	363397.3			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	-6213.44	11976.95		-0.51878	0.613345
NL2	-409.23	744.2926		-0.54982	0.592526
%N Leaves	3373.22	5978.173		0.564256	0.582973

Yield vs K leaves at flowering (POL)

Regression Statistics		
Multiple R	0.408113	
R Square	0.166557	
Adjusted R Square		0.027649
Standard Error	158.8687	
Observations	15	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	60526.19	30263.09	1.199049	0.335164
Residual	12	302871.1	25239.26		
Total	14	363397.3			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	519.6157	181.1888		2.867814	0.014147
KL2	0.026804	0.062582		0.428306	0.676015
Cmol/kg K leaves-0.33213	7.08667		-0.04687	0.96339	

Yield vs P leaves at seedling

Regression Statistics		
Multiple R	0.585148	
R Square	0.342398	
Adjusted R Square		0.291813
Standard Error	135.5816	
Observations	15	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	124426.5	124426.5	6.768795	0.021936
Residual	13	238970.8	18382.37		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	800.4907	49.08901	16.30692	4.91E-10
Cmol/kg P leaves	-0.7512	0.288734	-2.60169	0.021936

Yield vs P leaves at seedling (POL)

Regression Statistics	
Multiple R	0.600487
R Square	0.360584
Adjusted R Square	0.254015
Standard Error	139.1528
Observations	15

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	131035.3	65517.65	3.383565	0.068344
Residual	12	232362	19363.5		
Total	14	363397.3			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	774.9128	66.74732	11.60965	6.98E-08
PL2	-0.00368	0.006304	-0.58421	0.569898
Cmol/kg P leaves	0.356529	1.91912	0.185777	0.855723

EXPERIMENT 2: PELLETS VS NON PELLETS

NITROGEN

At seedling

PELLETS (Pe)

%N leaves vs %N soil

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.880169
R Square	0.774697
Adjusted R Square	0.699596
Standard Error	7.975286
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	656.1143	656.1143	10.31542	0.04889
Residual	3	190.8156	63.60519		
Total	4	846.9299			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-69.9834	25.2782	-2.76853	0.069654
%N Soil	502.3462	156.4082	3.211763	0.04889

AT SEEDLING

P leaves vs Psoil

Regression Statistics	
Multiple R	0.067012
R Square	0.004491
Adjusted R Square	-0.11995
Standard Error	5.314912
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1.01938	1.01938	0.036086	0.854069
Residual	8	225.9863	28.24829		
Total	9	227.0057			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	11.30735	6.499451	1.73974	0.120092
Cmol/kg P soil	1.223249	6.439362	0.189964	0.854069

Yield vs P soil

Regression Statistics	
Multiple R	0.184581
R Square	0.03407
Adjusted R Square	-0.08667
Standard Error	118.388
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	3954.884	3954.884	0.282175	0.609707
Residual	8	112125.8	14015.72		
Total	9	116080.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	182.3781	144.7732	1.25975	0.243267
Cmol/kg P soil	76.19275	143.4348	0.531201	0.6097

<u>Yield vs P leaves</u>

Regression Statistics	
Multiple R	0.595445
R Square	0.354555
Adjusted R Square	0.273874
Standard Error	96.77534
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	41156.93	41156.93	4.394541	0.069334
Residual	8	74923.74	9365.467		
Total	9	116080.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	424.9776	85.9238	4.945982	0.001127
Cmol/kg P leaves		-13.4649	6.423124	-2.09632

AT FLOWERING
P leaves vs P soil

Regression Statistics	
Multiple R	0.114315
R Square	0.013068
Adjusted R Square	-0.1103
Standard Error	4.398083
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2.048976	2.048976	0.105928	0.753178
Residual	8	154.7451	19.34314		
Total	9	156.7941			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	13.95055	10.31442	1.352529	0.213191
Cmol/kg P soil	-1.84796	5.677901	-0.32547	0.753178

Yield vs P soil

Regression Statistics					
Multiple R	0.462609				
R Square	0.214007				
Adjusted R Square		0.115758			
Standard Error	106.7934				
Observations	10				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	24842.1	24842.1	2.17821	0.178218
Residual	8	91238.57	11404.82		
Total	9	116080.7			
	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	622.9273	250.4526		2.487206	0.037686
Cmol/kg P soil	-203.479	137.8696		-1.47588	0.178218

Yield vs P leaves

Regression Statistics					
Multiple R	0.101524				
R Square	0.010307				
Adjusted R Square		-0.1134			
Standard Error	119.8354				
Observations	10				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1196.463	1196.463	0.083316	0.780191
Residual	8	114884.2	14360.53		
Total	9	116080.7			
	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	286.0143	108.5081		2.635879	0.029904
Cmol/kg P leaves		-2.76239		9.570185	-0.28865

AT MATURITY

P leaves vs P soil

Regression Statistics	
Multiple R	0.729177
R Square	0.5317
Adjusted R Square	0.473162
Standard Error	3.081151
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	86.22984	86.22984	9.083048	0.016716
Residual	8	75.94793	9.493492		
Total	9	162.1778			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	31.06735	3.394754	9.151574	1.64E-05
Cmol/kg P soil	-1.20996	0.401472	-3.01381	0.016716

Yield vs P soil

Regression Statistics	
Multiple R	0.307826
R Square	0.094757
Adjusted R Square	-0.0184
Standard Error	114.6087
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	10999.44	10999.44	0.837405	0.386891
Residual	8	105081.2	13135.15		
Total	9	116080.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	367.3571	126.2737	2.909213	0.019613
Cmol/kg P soil	-13.6656	14.93344	-0.9151	0.386891

Yield vs P leaves

Regression Statistics		
Multiple R	0.071667	
R Square	0.005136	
Adjusted R Square		-0.11922
Standard Error	120.1481	
Observations	10	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	596.2117	596.2117	0.041302	0.844031
Residual	8	115484.5	14435.56		
Total	9	116080.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	215.8901	204.2071	1.057212	0.321291
Cmol/kg P leaves		1.917364	9.434548	0.203228

AT SEEDLING

K leaves vs K soil

Regression Statistics		
Multiple R	0.377613	
R Square	0.142592	
Adjusted R Square		0.035415
Standard Error	40.97387	
Observations	10	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	2233.624	2233.624	1.330442	0.282021
Residual	8	13430.87	1678.858		
Total	9	15664.49			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-0.89786	123.9074	-0.00725	0.994396
Cmol/kg K soil	359.8409	311.9697	1.153448	0.282021

Yield vs K soil

R Square	0.131238				
Adjusted R Square		0.022643			
Standard Error	112.2756				
Observations	10				

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	15234.19	15234.19	1.208505	0.303607
Residual	8	100846.5	12605.81		
Total	9	116080.7			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	139.3102	112.5024		1.238286	0.250713
% N Soil	784.9888	714.0674		1.09932	0.303607

Yield vs K leaves

Regression Statistics					
Multiple R	0.64689				
R Square	0.418467				
Adjusted R Square		0.345776			
Standard Error	91.85907				
Observations	10				

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	48575.97	48575.97	5.75675	0.043222
Residual	8	67504.71	8438.088		
Total	9	116080.7			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	505.3845	107.655	4.694481	0.001553	
Cmol/kg K leaves	-1.76097	0.733946	-2.39932	0.043222	

AT FLOWERING

K leaves vs K soil

Regression Statistics		
Multiple R	0.045641	
R Square	0.002083	
Adjusted R Square		-0.12266
Standard Error	31.19258	
Observations	10	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	16.24867	16.24867	0.0167	0.900367
Residual	8	7783.815	972.9769		
Total	9	7800.064			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	87.58176	43.91792	1.994215	0.081241	
Cmol/kg K soil	-13.8261	106.9897	-0.12923	0.900367	

Yield vs K soil

Regression Statistics		
Multiple R	0.567643	
R Square	0.322219	
Adjusted R Square		0.237496
Standard Error	99.16985	
Observations	10	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	37403.4	37403.4	3.803223	0.086967
Residual	8	78677.27	9834.659		
Total	9	116080.7			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	-8.676	139.6272		-0.06214	0.951978
Cmol/kg K soil	663.3551	340.1498	1.950185	0.086967	

Yield vs K leaves

Regression Statistics	
Multiple R	0.107901
R Square	0.011643
Adjusted R Square	-0.1119
Standard Error	119.7545
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	1351.493	1351.493	0.094239	0.766695
Residual	8	114729.2	14341.15		
Total	9	116080.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	290.8202	117.5257	2.474523	0.038438
Cmol/kg K leaves	-0.41625	1.355948	-0.30698	0.766695

AT MATURITY

K leaves vs LK soil

Regression Statistics	
Multiple R	0.353643
R Square	0.125063
Adjusted R Square	0.015696
Standard Error	21.06136
Observations	10

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	507.2425	507.2425	1.143517	0.316111
Residual	8	3548.648	443.581		
Total	9	4055.891			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	78.51746	21.00527	3.737988	0.005722
Cmol/kg K soil	18.3647	17.17365	1.069354	0.31611

Yield vs k soil

Regression Statistics		
Multiple R	0.023541	
R Square	0.000554	
Adjusted R Square		-0.12438
Standard Error	120.4244	
Observations	10	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	64.32693	64.32693	0.004436	0.948534
Residual	8	116016.3	14502.04		
Total	9	116080.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	249.0797	120.1037	2.073872	0.071796
Cmol/kg K soil	6.539921	98.19529	0.066601	0.948

Yield vs k leaves

Regression Statistics		
Multiple R	0.595836	
R Square	0.35502	
Adjusted R Square		0.274398
Standard Error	96.74042	
Observations	10	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	41211.01	41211.01	4.403493	0.069104
Residual	8	74869.66	9358.708		
Total	9	116080.7			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-61.5216	154.6851	-0.39772	0.701237
Cmol/kg K leaves	3.187598	1.519025	2.09845	0.069104

NON LINEAR REGRESSION (POL)

PELLETS (Pe)

Yield vs % N Soil at flowering (POL)

Regression Statistics	
Multiple R	0.787184
R Square	0.619658
Adjusted R Square	0.239316
Standard Error	92.42017
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	27831.83	13915.91	1.629214	0.380342
Residual	2	17082.98	8541.488		
Total	4	44914.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-5454.18	3198.161	-1.70541	0.230235
NS2	-205054	113602.6	-1.80501	0.212833
%N Soil	69367.76	38492.81	1.802097	0.213317

Yield vs P soil at flowering (POL)

Regression Statistics	
Multiple R	0.34972
R Square	0.122304
Adjusted R Square	-0.75539
Standard Error	140.395
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	5493.266	2746.633	0.139347	0.877696
Residual	2	39421.54	19710.77		
Total	4	44914.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-380.607	4269.949	-0.08914	0.937096
PS2	-251.324	1260.374	-0.1994	0.860381
Cmol/kg P soil	833.5023	4712.79	0.17686	0.875908

Yield vs K soil at flowering (POL)

Regression Statistics					
Multiple R	0.800655				
R Square	0.641048				
Adjusted R Square		0.282097			
Standard Error	89.78374				
Observations	5				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	28792.57	14396.28	1.785891	0.358952
Residual	2	16122.24	8061.119		
Total	4	44914.81			
	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	-8269.48	5440.998		-1.51985	0.26791
KS2	-49822.2	33594		-1.48307	0.276293
Cmol/kg K soil	41470.74	27136.38		1.528234	0.266044

Yield vs %N leaves at flowering (POL)

Regression Statistics					
Multiple R	0.978084				
R Square	0.956648				
Adjusted R Square		0.913296			
Standard Error	31.20219				
Observations	5				
ANOVA					
	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	42967.65	21483.83	22.06691	0.043352
Residual	2	1947.153	973.5766		
Total	4	44914.81			
	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	-2240.25	410.3172		-5.4598	0.031948
NL2	-18.0639	2.898708		-6.23171	0.024797
%N leaaves	725.5073	116.8228		6.210324	0.024961

<u>Yield vs %N leaves at flowering (POL)</u>

Regression Statistics		
Multiple R	0.978084	
R Square	0.956648	
Adjusted R Square		0.913296
Standard Error	31.20219	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	42967.65	21483.83	22.06691	0.043352
Residual	2	1947.153	973.5766		
Total	4	44914.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-2240.25	410.3172	-5.4598	0.031948
NL2	-18.0639	2.898708	-6.23171	0.024797
%N leaaves	725.5073	116.8228	6.210324	0.024961

<u>Yield vs P leaves at flowering (POL)</u>

Regression Statistics		
Multiple R	0.54412	
R Square	0.296066	
Adjusted R Square		-0.40787
Standard Error	125.7319	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	13297.76	6648.88	0.420588	0.703934
Residual	2	31617.04	15808.52		
Total	4	44914.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	309.0814	125.6286	2.460279	0.133026
PL2	2.888765	3.171137	0.910956	0.458478
Cmol/kg P leaves		-36.7165	43.17376	-0.85044

<u>Yield vs K leaves at flowering (POL)</u>

Regression Statistics

Multiple R	0.322737	
R Square	0.104159	
Adjusted R Square		-0.79168
Standard Error	141.8388 (POL)	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	4678.298	2339.149	0.11627	0.895841
Residual	2	40236.51	20118.25		
Total	4	44914.81			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	308.6388	141.8387		2.175985	0.161525
KL2	-0.10906	0.24655		-0.44232	0.70149
Cmol/kg K leaves		9.879901	23.13756		0.427007
	0.710949				

<u>NON-PELLETS</u>

<u>Yield vs K soil at flowering (POL)</u>

Regression Statistics

Multiple R	0.680165	
R Square	0.462624	
Adjusted R Square		-0.07475
Standard Error	127.9511	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	28188.28	14094.14	0.860896	0.537376
Residual	2	32742.95	16371.48		
Total	4	60931.23			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	189.1076	510.8346		0.370193	0.746766
KS2	2502.706	6277.68		0.398667	0.728674
Cmol/kg K soil	-983.683	3940.431		-0.24964	0.826166

Yield vs % N leaves at flowering (POL)

Regression Statistics		
Multiple R	0.787058	
R Square	0.619461	
Adjusted R Square		0.238922
Standard Error	107.6724	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	37744.52	18872.26	1.627852	0.380539
Residual	2	23186.71	11593.35		
Total	4	60931.23			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	24519.16	18674.4	1.312982	0.319609
NL2	1635.579	1205.058	1.357262	0.30757
%N leaaves	-12630.9	9499.952	-1.32957	0.315032

Yield vs P leaves at flowering (POL)

Regression Statistics		
Multiple R	0.498392	
R Square	0.248395	
Adjusted R Square		-0.50321
Standard Error	151.3213	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	15134.99	7567.493	0.330485	0.751605
Residual	2	45796.24	22898.12		
Total	4	60931.23			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-2834.31	4140.558	-0.68452	0.564322
PL2	-21.1994	27.57559	-0.76877	0.522401
Cmol/kg P leaves		516.2363	684.2072	0.754503

Yield vs K leaves at flowering (POL)

Regression Statistics		
Multiple R	0.383505	
R Square	0.147076	
Adjusted R Square		-0.70585
Standard Error	161.1982	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	8961.518	4480.759	0.172437	0.852924
Residual	2	51969.71	25984.86		
Total	4	60931.23			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2418.16	24137.06	0.100185	0.929336
KL2	0.346364	3.077152	0.11256	0.920659
Cmol/kg K leaves	-55.723	546.7665	-0.10191	0.928123

PELLETS (Pe) AT SEEDLING

Yield vs %N soil at seedling (POL)

Regression Statistics		
Multiple R	0.773615	
R Square	0.59848	
Adjusted R Square		0.196959
Standard Error	94.95845	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	26880.59	13440.3	1.490533	0.40152
Residual	2	18034.21	9017.106		
Total	4	44914.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	5948.134	3602.332	1.65119	0.240495
NS2	203471.5	124913.5	1.6289	0.244885
%N Soil	-68470.2	42779.8	-1.60053	0.250623

Yield vs P soil at seedling (POL)

Regression Statistics	
Multiple R	0.55748
R Square	0.310784
Adjusted R Square	-0.37843
Standard Error	124.4106
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	13958.81	6979.403	0.450924	0.689216
Residual	2	30956	15478		
Total	4	44914.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-473.382	1262.63	-0.37492	0.743745
PS2	-1679.68	2298.512	-0.73077	0.540935
Cmol/kg P soil	2403.287	3530.573	0.680707	0.566293

Yield vs %N leaves at seedling (POL)

Regression Statistics	
Multiple R	0.603057
R Square	0.363678
Adjusted R Square	-0.27264
Standard Error	119.5414
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	16334.52	8167.262	0.571531	0.636322
Residual	2	28580.28	14290.14		
Total	4	44914.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	514.613	639.9146	0.80419	0.505684
%N leaaves	-25.0851	135.4085	-0.18525	0.870115
PL2	-0.98369	0.956717	-1.02819	0.41195

Yield vs N leaves at seedling (POL)

Regression Statistics	
Multiple R	0.750591
R Square	0.563386
Adjusted R Square	0.126772
Standard Error	99.02127
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	25304.38	12652.19	1.290353	0.436614
Residual	2	19610.43	9805.213		
Total	4	44914.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-900.359	1325.415	-0.6793	0.56702
PL2	-10.7759	10.07322	-1.06976	0.39672
Cmol/kg P leaves	233.4169	237.634	0.982253	0.429541

Yield vs K leaves at seedling (POL)

Regression Statistics	
Multiple R	0.78457
R Square	0.61555
Adjusted R Square	0.2311
Standard Error	92.91794
Observations	5

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	27647.32	13823.66	1.60112	0.38445
Residual	2	17267.49	8633.743		
Total	4	44914.81			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	851.1958	2246.419	0.378912	0.741197
KL2	0.014071	0.098103	0.143432	0.899096
Cmol/kg K leaves	-6.33107	31.22547	-0.20275	0.858083

NON_PELLETS (Po) AT SEEDLING

Yield vs %N soil at seedling (POL)

Regression Statistics		
Multiple R	0.571075	
R Square	0.326126	
Adjusted R Square		-0.34775
Standard Error	143.2829	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	19871.28	9935.639	0.483958	0.673874
Residual	2	41059.95	20529.98		
Total	4	60931.23			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	63.8516	180.644		0.353466	0.757521
NS2	-15808.4	20668.83		-0.76484	0.52429
%N Soil	3821.503	4309.819		0.886697	0.46879

Yield vs P soil at seedling (POL)

Regression Statistics		
Multiple R	0.900292	
R Square	0.810526	
Adjusted R Square		0.621051
Standard Error	75.97668	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	49386.32	24693.16	4.277757	0.189474
Residual	2	11544.91	5772.455		
Total	4	60931.23			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	55.01814	696.204	0.079026	0.944207
PS2	209.2985	556.6422	0.376002	0.743053
Cmol/kg P soil	-88.363	1270.161	-0.06957	0.950867

<u>Yield vs K soil at seedling (POL)</u>

Regression Statistics					
Multiple R	0.90424				
R Square	0.81765				
Adjusted R Square		0.635299			
Standard Error	74.53468				
Observations	5				

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	49820.39	24910.2	4.483947	0.18235
Residual	2	11110.84	5555.418		
Total	4	60931.23			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	-12639.9	4347.998		-2.90705	0.100761
KS2	-81367.2	27216.22		-2.98966	0.096035
Cmol/kg K soil	64911.64	21798.47		2.977807	0.096694

<u>Yield vs %N leaves at seedling (POL)</u>

Regression Statistics					
Multiple R	0.852401				
R Square	0.726587				
Adjusted R Square		0.453175			
Standard Error	91.2671				
Observations	5				

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	44271.86	22135.93	2.657476	0.273413
Residual	2	16659.37	8329.684		
Total	4	60931.23			

	Coefficients	*Standard Error*		*t Stat*	*P-value*
Intercept	-7459.48	15558.75		-0.47944	0.678934
NL2	-291.259	750.2667		-0.38821	0.735289
%N leaaves	3028.723	6844.352		0.442514	0.701373

Yield vs P leaves at seedling (POL)

Regression Statistics		
Multiple R	0.572145	
R Square	0.32735	
Adjusted R Square		-0.3453
Standard Error	143.1527	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	19945.85	9972.925	0.486658	0.67265
Residual	2	40985.38	20492.69		
Total	4	60931.23			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	343.4611	476.0757	0.721442	0.545577
PL2	-0.19936	2.144007	-0.09299	0.934391
Cmol/kg P leaves	-4.98834	67.33455	-0.07408	0.947687

Yield vs K leaves at seedling (POL)

Regression Statistics		
Multiple R	0.999023	
R Square	0.998047	
Adjusted R Square		0.996095
Standard Error	7.713028	
Observations	5	

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	60812.25	30406.12	511.1064	0.001953
Residual	2	118.9816	59.4908		
Total	4	60931.23			

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	2114.157	60.91218	34.70828	0.000829
KL2	0.103462	0.003653	28.3221	0.001244
Cmol/kg K leaves	-29.0372	0.979496	-29.645	0.001136