

UNIVERSITY FOR DEVELOPMENT STUDIES, TAMALE

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EFFECT OF DIFFERENT SOIL AMENDMENT RATES (CHICKEN MANURE AND
NPK FERTILIZER 15-15-15) ON THE GROWTH AND YIELD OF VEGETABLE

AMARANTH

(AMARANTHUS HYBRIDUS)



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BY

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FACULTY OF AGRICULTURE, UNIVERSITY FOR DEVELOPMENT STUDIES IN
PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF
MASTERS OF PHILOSOPHY DEGREE IN HORTICULTURE

SEPTEMBER, 2015



DECLARATION

Student

I hereby declare that the work herein submitted towards the Master of Philosophy (Horticulture) degree is the result of my own investigation; it has not been accepted for the award of any other degree of the University or elsewhere except for references to other people's work which have been duly acknowledged by reference to their authors.

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Supervisors'

I hereby declare that the preparation and presentation of the dissertation was supervised in accordance with the guidelines on supervision of dissertation laid down by the University of Development Studies.

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Name: Dr. Hypolite Bayor



ABSTRACT

Two separate experiments were undertaken at the farming for the future of Faculty of Agriculture of University for Development Studies (UDS), Nyankpala of Tolon District in the Northern Region of Ghana. The first study examined “the effect of different soil amendment rates (chicken manure and NPK fertilizer) on the growth and yield of vegetable Amaranth from 02 June to 14 November, 2013. The second study examined “the effect of chicken manure and NPK (single and split applications) on the growth and yield of vegetable Amaranth from 5th October 2014 to 14th February, 2015. The objectives of the experiments were to determine the effect of chicken manure application at different levels and different rates of NPK 15-15-15 fertilizer application on the growth and yield of the crop, to assess the growth and yield response of *Amaranthus hybridus* to chicken manure and NPK fertilizer application (single and split applications). The experimental design was 3 x 4 factorial experiment laid out in Randomized Complete Block Design with 4 blocks for experiment 1 and 2 x 3 x 2 factorial experiment laid out in Completely Randomized Design with 4 replications for experiment 2. The treatments for experiment 1 were Chicken Manure at 4 levels; 0 t / ha, 10 t / ha, 15 t / ha, 20 t / ha and NPK (15 - 15 - 15) fertilizer at three levels; 0 kg / ha, 250 kg / ha and 300 kg / ha. Treatments for experiment 2 were Chicken Manure at two levels; 0 t / ha and 25 / ha and NPK at 3 levels; 0 kg / ha, 250 kg / ha and 300 kg / ha. Number of application at 2 levels; single and split. The parameters measured were plant height, number of leaves, leaf area, canopy spread, chlorophyll level, fresh weight and dry matter of the plants. It was deduced from the experiment 1 that, the yield of *Amaranthus hybridus* responded to the



main effects of NPK fertilizer and chicken manure. Thus, it is concluded that the application of 250 kg / ha NPK fertilizer to *Amaranthus hybridus* had the higher mean values for both growth and yield parameters for lower cost of production since it was not significant difference from 300 kg / ha NPK. In experiment 2 it was deduced that, split application of 300 kg / ha NPK to *Amaranthus hybridus* gave the highest mean values for almost all the parameters measured. It is therefore recommended that, farmers should split the application of 300 kg / ha NPK to *Amaranthus* for satisfactory plant responses pertaining to the growth and yield. It is also recommended that an experiment of this nature should be conducted on farm with the participation of the farmers themselves to observe and see the outcome of the study.



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DEDICATION

I wish to dedicate this to my family (alive and dead) and all those who helped in diverse ways for me to climb to this part of the educational ladder.





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CHAPTER ONE

1.0. INTRODUCTION

1.1. Background of the study

Modern agriculture has grown to be a major contributor to the economy of the world. However, in many countries, it has not done enough in addressing key issues of hunger and malnutrition (Aphane *et al.*, 2003). Major causes of hunger and malnutrition in the world are not only growing population and decline in crop yields but also destruction of natural plant resources and loss of food diversity (Dresher, 1997). Health problems associated with malnutrition are experienced more in developing countries and have consequences on growth, development and health among children (Aphane *et al.*, 2003). This problem threatens millions of people in sub-Saharan Africa, with 20 % or more of the communities suffering from food insecurity (Jansen *et al.*, 2004).

Foods of animal origin, which are known to be the major source of vitamins and proteins, are in most cases, too expensive for poor households (Aphane *et al.*, 2003; Wehmeyer and Rose, 1983). Vegetables could alternatively play a major role in alleviating problems associated with malnutrition as they could supply enough proteins, vitamins, calories and other nutrients needed in a balanced diet (Wehmeyer and Rose, 1983). However, harsh climatic and resources-poor conditions encountered in rural areas, where the problem of malnutrition occurs, make production of exotic vegetables difficult whereas a number of indigenous and traditionally grown plant species could tolerate these conditions



(Allenman *et al.*, 1996). Most indigenous plants are adapted to the prevailing conditions and require few agricultural inputs and perform well in areas unsuitable for introduced vegetables (Aphane *et al.*, 2003).

The most widely consumed of the more than 100 different indigenous leafy vegetable species occurring in Africa are *Amaranthus* species, melons and cowpeas (Jansen *et al.*, 2004; Laker, 2007). According to Rai and Yadav (2005), *Amaranthus* commonly known as Amaranth, is one of the commonest indigenous vegetables grown in most tropical African countries. It belongs to the family *Amaranthaceae* and genus *Amaranthus*. The main vegetable type, *Amaranthus tricolor* L. originated from South East Asia, particularly in India. Buddhist monks and Muslim traders took the crop to neighbouring countries. Another vegetable type *Amaranthus dubius*, shows diversity in Central America, Indonesia, India and Africa. *Amaranthus lividus* seems to have been a popular vegetable; it is cultivated throughout the year in the tropics. The genus *Amaranthus* include 50 – 60 species, cultivated for green leaf and grains and a few are wild species (Rai and Yadav, 2005). According to Olorode (1984), *Amaranthus cruentus* L. is a leafy vegetable commonly cultivated in Nigeria and other West African countries.

African indigenous vegetables play significant role in the food security of the underprivileged in both urban and rural settings (Schippers, 1997). They can serve as primary foods or secondary condiments to dishes. They are also valuable sources of energy and micro nutrients in the diets of isolated communities (Gravetti and Ogle, 2000). Further, they serve as income sources and may be marketed or traded locally, regionally or internationally. The primary importance of edible wild species during periods of drought



and or social unrest such as wars is well documented (Humphry *et al.*, 1993; Smith *et al.*, 1995; Smith *et al.*, 1996).

Traditional leafy vegetables (TLVs) including *Amaranthus* have formed part of rural household food security strategies for generations in Africa. These vegetables are usually rich in nutrients such as vitamin A and iron often lacking in the diets of children and pregnant women (Smith and Eyzaguirre, 2007). *Amaranthus* is a traditional leafy vegetable which has become an essential part of food for most indigenous people. This is especially so in the rural areas and the low income earning people in tropical Africa and sub-tropical countries (Vorster *et al.*, 2008). In most countries, because of its wide adaptation Amaranth was considered to be a weed and nonsensical plant which was to be eliminated completely (Vorster *et al.*, 2008). However, nowadays most African countries have become conscious of the increasing importance of indigenous fruits and vegetables in diets of their inhabitants (Ogle and Gravetti, 1985; Fox and Young, 1982; Smith and Eyzaguirre, 2007). The role of *Amaranthus* as a vegetable is increasing. Actually, higher institutions of learning have included indigenous or traditional vegetables in the curricula. The leaves and the softest portions of the shoots are usually boiled in water and then cooked with onions, tomatoes, oil and or other additives of modern culinary delights. Amaranth leaves are combined with condiments to prepare soup and stew. The flavour of raw and cooked vegetable Amaranth was reported as equal to or better than that of spinach or other similar greens (Vorster *et al.*, 2008; Van den Heever, 2008). It can also be dried for subsequent use during the dry season (Masarirambi *et al.*, 2010). Amaranth is one of the few dicotyledonous plants that have what is known as the C4 metabolism, a



much more efficient form of photosynthesis than the more common C3 and is linked to proficient production and drought resistance (Fox and Young, 1982).

Indigenous vegetables are important supplements to the staple diet and are better adapted to the marginal soils and erratic rainfall often experienced in Africa. Most of the important indigenous vegetables including *Amaranthus* have been identified as having potential for commercial exploitation and production for human consumption (Taylor and Moss, 1982). According to FAO (Food and Agriculture Organization, 1998), the important role of African indigenous vegetables in Tanzania's health sector, diets and as income source is threatened through extinction of the genetic resources of these species. Many land races of vegetables are in the process of being replaced by modern varieties.

The current high demand for vegetables in the city of Tamale has stimulated the growth of market gardening near dams and streams. Some farmers rely on irrigation water from streams, wells, dugouts, gutters and sewers to cultivate vegetables all year round.

Davis and Wilson (2012), defined soil amendment as any material added to the soil to improve its physical and / or chemical properties, such as water retention, permeability, water infiltration, drainage, aeration, structure and the nutrients for good crop growth and high yield. An amendment should be thoroughly mixed into the soil. If it is merely buried, its effectiveness is reduced, and it will interfere with water and air movement and root growth. There are two broad categories of soil amendments - organic and inorganic. Organic amendments come from something that is or was alive. Inorganic amendments on the other hand, are either mined or man-made. Organic amendments include



sphagnum peat, wood chips, grass clippings, straw, compost, manure, bio solids, sawdust and wood ash. Inorganic amendments include vermiculite, perlite, tire chunks, pea gravel and sand (Davis and Wilson, 2012).

The production and consumption of poultry products will continue to increase relative to the world's growing human population for improved life quality (Williams *et al.*, 1999; Zhang *et al.*, 2007). This will result in the generation of large volumes of poultry droppings which would be applied to the soil to increase crop production. Zublena *et al.*, (1990) observed that poultry manure application in crop husbandry must be done with sound soil fertility management practices to prevent soil nutrient imbalance and associated animal and human health risks, as well as surface-water and groundwater contamination. They recommended that poultry manure should be allowed to decompose properly before its application.

The agriculture industry relies heavily on the use of NPK fertilizer. But what makes up NPK fertilizer, and how does it work? Carlson (2012) stated that, there are numerous building blocks of life that plants need for healthy growth. Soils often lack these elements, either naturally, or as a result of over cultivation, and needs to have these building blocks put back into them. NPK fertilizers are primarily composed of three essential elements including Nitrogen (N), Phosphorus (P) and Potassium (K). Among other benefits, Nitrogen helps plants grow quickly and also increases the production of seeds and fruits, and better quality leaves of forage crops. Nitrogen is also a component of chlorophyll, the substance that gives plants their green colour, and also aids in photosynthesis.





Phosphorus is a key player in the processes of photosynthesis; it plays a vital role in a variety of the things needed by plants. Phosphorus supports the formation of oils, sugars, and starches. The transformation of solar energy into chemical energy is also aided by phosphorus, promotes the development of plants and their ability to withstand stress. Additionally, phosphorus encourages the growth of roots, and promotes blooming. Potassium is also an essential nutrient needed by plants to help promote fruit quality, building of protein, and the reduction of diseases. While these three elements only scratch the surface of healthy plant nutrition and growth, they are the main nutrients required in the development of healthy plants.

1.2. Problem Statement and Justification

Africa is endowed with a variety of indigenous vegetables, among which are wild grown ones that grow every year despite the erratic rainfall. The wild plants are harvested and consumed, especially by village dwellers, but there is an increasing concern that their use is declining in the rural areas (Schippers, 2000). Many people even look down on indigenous vegetables, which are gradually being replaced by exotic vegetables. The most common indigenous vegetables in Africa could have a significant impact on both food security and health among the continent's poorest if attention is given to them.

Amaranthus, one of the cultivated indigenous vegetables has short production cycle, high yielding with good nutritional value and few purchased inputs are needed for its production. The crop can therefore support rural, peri-urban and urban populations both in terms of subsistence and income generation, without requiring large capital

investments. *Amaranthus* an indigenous vegetable can also become popular with commercial growers if suitable quantity of organic manure is applied to promote rapid vegetative growth (Schippers, 2000).

Converting agro-industrial wastes such as poultry manures into organic fertilizers could minimize the environmental hazard they may pose (Ayeni, 2010). Consequently, environmental impacts of waste by-products of poultry industries are of increasing importance worldwide and the disposal of these wastes is a major environmental problem related to intensive livestock production (Jayathilakan *et al.*, 2012). The use of animal residue such as poultry manure for the production of vegetable and other crops had been advocated to compensate for the loss of nutrients because of their low cost and availability (Moyin-Jesu, 2002). There is the need to determine the independent influence of chicken manure (CM) and NPK 15-15-15 fertilizer on the growth and yield of fast growing vegetable like *Amaranthus* species as to justify the continuous mixture of both or otherwise.

It is therefore justified that, comparing the effect of chicken manure and NPK fertilizer and their combinations in the growth and yield of *Amaranthus* is important. Studies by Ayoola and Adeniyani (2006) revealed that the use of inorganic fertilizers has not been helpful in agriculture because it does not improve on the structure of the soil and sometimes renders the soil acidic. Agronomic use of manure also improves the physical conditions of soils, such as soil structure and soil chemical composition (Pagliai and Vignozzi, 1998).



1.3. Objectives

- To determine the effect of different levels of chicken manure application and different rates of NPK 15-15-15 fertilizer application on the growth and yield of *Amaranthus hybridus*.
- To assess the growth and yield response of *Amaranthus hybridus* to chicken manure and NPK fertilizer application. That is, single and split applications.



CHAPTER TWO

2.0. LITERATURE REVIEW

2.1. *Amaranthus*

Amaranth originated in America and is one of the oldest food crops in the world, with evidence of its cultivation reaching back as far as 6700 BC. The genus *Amaranth* consists of nearly 60 species, several of which are cultivated as leafy vegetables, grains or ornamental plants, while others are weeds. Grain *Amaranth* species have been important in different parts of the world and at various times during the past few thousand years (Department of Agriculture, Forestry and Fisheries, 2010). Vegetable *Amaranthus spp.* were and are presently utilized for food from such diverse geographic areas as southwestern United States, China, India, Africa, Nepal, South Pacific Islands, Caribbean, Greece, Italy, and Russia. While various species of grain and vegetable types can be distinguished, often both the grain and leaves are utilized from individual types for use as both human and animal food (Saunders and Becker, 1984; Tucker 1986). According to Stallknecht *et al.*, (1990), present American production is estimated to be between 2,000 - 3,000 hectares with the largest production in the Great Plains area, particularly Nebraska, with numerous smaller production areas throughout the Midwest. The stimulus for the present American production and marketing was initiated by the Rodale Foundation and the Rodale Research Center in the mid-1970s. The interest stimulated by the Rodale Foundation led to the establishment of the American Amaranth Institute in Brice Lyn, Minnesota, and numerous Amaranth marketing companies, several of which deal exclusively in the purchase, milling, and distribution of Amaranth



products. In approximately only 15 years, American Amaranth has gone from an obscure plant to a recognized grain.

2.2. Nutritive Value and Uses

The nutritive 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). Amaranth grain is considered to have a unique composition of protein, carbohydrates, and lipids. The unique protein composition with regard to quality and quantity has been studied and reviewed (Bressani, 1989; Lehman, 1989). Grain Amaranth has higher protein (12 to 18 %) than other cereal grains and has significantly higher lysine content. The high lysine content of Amaranth grain makes it particularly attractive for use as a blending food source to increase the biological value of processed foods (Pedersen *et al.*, 1987). The protein value of Amaranth grains is highlighted when Amaranth flour is mixed with other cereal grain flours. When Amaranth flour is mixed 30: 70 with either rice, maize, or wheat flour, the protein quality (based on casein) rises (Bressani, 1989). Amaranth seed protein also differs from other 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 other cereals.

The carbohydrates in Amaranth grain consist primarily of starch made up of both glutinous and non-glutinous fractions. The unique aspect of Amaranth grain starch is that the size of the starch granules are much smaller than found in other cereal grains. Due to the unique size and composition of Amaranth starch, it has been suggested that the starch





may possess unique gelatinization and freeze / thaw characteristics which could be of benefit to the food industry (Becker *et al.*, 1981; Lehman, 1988). Several considerations for the use of Amaranth starch in food preparation of custards, pastes, and salad dressing have been published (Singhal and Kulkarni, 1990 a, b, c). Amaranth grain consists of approximately 5 to 9 % oil which is generally higher than other cereals. The lipid fraction of Amaranth grain is similar to other cereals, being approximately 77 % unsaturated, with linoleic acid being the predominant fatty acid. The lipid fraction is unique however, due to the unusually high squalene content (5 to 8 %) of the total oil fraction. Also present in the Amaranth oil fractions were tocotrienols (forms of vitamin E) which are known to effect lower cholesterol levels in mammalian systems. In addition to the unique characteristics of the major components of proteins, carbohydrates, and lipids, Amaranth grain also contains high levels of calcium, iron, and sodium when compared to cereal grains (Becker *et al.*, 1981).

In contrast to grain Amaranth, vegetable Amaranth has received significantly less research attention. While vegetable Amaranth is used as a delicacy or a food staple in many parts of the world, use in the United States is limited to canned imports for ethnic uses, primarily in the New York City area. Vegetable Amaranth has been rated equal to or superior in taste to spinach and is considerably higher in calcium, iron, and phosphorous (Makus, 1984; Makus and Davis, 1984; Igbokwe *et al.*, 1988; Makus, 1990 a). Results indicate that the Amaranth used for human food should be heated for maximum nutritional benefit (Pond and Lehman, 1989). The leaves and the tender stem of *Amaranthus* are rich in protein, minerals, vitamin A and C. The composition of *Amaranthus* tender leaf and grain are given in table 2.1 below.

Table: 2. 1. Composition of *Amaranthus* Tender Leaf and Grain (Per 100 of Edible Portion)

Constituents	<i>Amaranthus</i> leaf	<i>Amaranthus</i> grain
Moisture (%)	85.75	9.3
Protein (g)	4.0	15.3
Fat (g)	0.50	7.1
Carbohydrate (g)	6.30	63.10
Calcium (mg)	397.0	490.00
Iron (mg)	25.5	22.40
Phosphorous (mg)	83.0	455.00
Vitamin A (IU)	9200	-
Vitamin C (mg)	99	-

Source: (Rai and Yadav, 2005)

The fresh tender leaves and stem of *Amaranthus* are delicious when cooked like other fresh leafy vegetables. The tiny seeds of grain *Amaranthus* are popped or parched and milled for flour or gruel. In taste, nutritional value and yield, it compares favourably with maize and other true cereals. It has also industrial uses. The flour of *Amaranthus* can be used for bread making, pastry making, biscuits, almond paste and flasks etc. (Rai and Yadav, 2005).



2.3.0. BOTANY

2.3.1. Taxonomy

The genus *Amaranthus* consists of approximately 60 species, however, only a limited number are of the cultivated types, while most are considered weedy species. *Amaranthus* germplasm is available in 11 countries (Sauer, 1967; Toll and von Sloten, 1982). Several thousand germplasm accessions are available in the United States at either the Rodale Research Institute, or the USDA North Central Regional Plant Introduction Station at Iowa State University, Ames. A taxonomic key for the cultivated species of *Amaranthus* has been developed by Feine-Dudley (Grubben and von Sloten, 1981).

2.3.2. Physiology

According to Stallknecht *et al.*, (1990), Amaranth, a C₄ plant, is one of a few dicotyledonous plants in which the first product of photosynthesis is a four carbon compound. The combination of anatomical features in Amaranth and C₄ metabolism, results in an increased efficiency to use CO₂ under a wide range of both temperature and moisture stress environments, and contribute to the plant's wide geographic adaptability to diverse environmental conditions. Measuring the levels of chlorophyll helps to determine the state of an organism and water quality. High levels of chlorophyll usually indicate that the sample is high in nutrients, usually nitrogen and phosphorous. Abnormally low levels of chlorophyll would indicate possible pollution, septic system leakage or runoff in the area (Susan, 1999).



2.3.3. Measurement of Chlorophyll in the Plants

Spectrophotometer and high-performance liquid chromatography (HPLC) are two methods used to measure the quantity of chlorophyll in a sample of water. Water is collected and filtered to isolate chlorophyll-containing organisms. The cells of these organisms are ruptured to extract the chlorophyll. The collected sample is placed in an acetone solution. The sample is either analyzed by spectrophotometer or the HPLC method. Spectrophotometer involves looking at the absorbency or fluorescent properties of the chlorophyll. The sample also may be analyzed by the HPLC method. The two laboratory methods of testing are measuring the sample's fluorescing capabilities. The samples are exposed to a certain wavelength of light (usually 663 and 645 nm), which makes the chlorophyll react by emitting a higher wavelength (Susan, 1999). The chlorophyll meter can usually be used to measure the chlorophyll level of live plants. Two LED lights shine on the surface of the sample, most likely a plant leaf. The red LED light has a peak wavelength of 650 nm and infrared LED at a peak of 940 nm. Part of the light is absorbed by the chlorophyll; the rest is absorbed throughout the sample. The proportion of chlorophyll to other measures of the sample is calculated within the meter and is displayed as an arbitrary unit between 0 and 199 (Susan, 1999). The chlorophyll levels are determined by any of the three methods and designated as a percentage or concentration level compared to the whole sample (Susan, 1999). The chlorophyll meter was used in this experiment.



2.3.4. Morphology

Grain type Amaranth plants have a main stem axis that terminates in an apical large branched inflorescence. The flowers are unisexual, purple, orange, red or gold in colour, and are developed on branched flower clusters (glomerules). A glomerule is described as a diachsial cyme that forms large flowering panicles. Vegetable types are generally smooth leafed, with an indeterminate growth habit which produces new succulent auxiliary growth. The floral buds arise directly in the leaf axils. Amaranth seeds are borne in a utricle, which are classified as dehiscent, semi-dehiscent, or indehiscent types (Brenner and Hauptli, 1990). The Amaranth seed is quite small (0.9 to 1.7 mm diameter) and seed weights vary from 1,000 to 3,000 seeds / g. Seed colours can vary from cream to gold and pink to black. Actual stature of the Amaranth plant will vary significantly dependent upon species and environment. In Montana, individual cultivars can vary in height from 91 to 274 cm in height and have stem diameters from 2.54 to 15 cm, dependent upon plant stand density and available soil moisture. Likewise, seed heads varied from 30 to 112 cm in diameter at the base and varied in height from 13 to 61 cm (Stallknecht *et al.*, 1990).

Leaf area is an important variable for most eco physiological studies in terrestrial ecosystems concerning light interception, evapotranspiration, photosynthetic efficiency, fertilizers, and irrigation response and plant growth (Blanco and Folegatti, 2005). Leaf area estimate is valuable in studies of plant nutrition, plant competition, plant-soil-water relations, plant protection measures, respiration, light reflectance, and heat transfer in plants (Mohsenin, 1986), and thus it is an important parameter in understanding





photosynthesis, light interception, water and nutrient use, and crop growth and yield potential (Smart, 1974; Williams, 1987). Leaf area estimation is often costly, time-consuming, and destructive (Marshall, 1968). Sestak *et al.*, (1971) provided an extensive description of the most common methodology available till date that includes counting squares on millimeter graph paper, hand-planimetry, the gravimetric method, dot counting, photoelectric planimetry, air-flow, linear measurements of leaves, leaf weighing, detached leaf counting, and the rating method. Well-known electronic meters can only be used if the plants have sparse and non-fragile leaves (Tieszen, 1982; Bleasdale, 1984). A variety of computerized image analysis equipment and software are also available (Brodny *et al.*, 1986). They measure quickly, accurately and nondestructively using a portable scanning planimeter (Daughtry, 1990); however, the method is suitable only for small plants with few leaves (Nyakwende *et al.*, 1997) and is expensive (Bignami and Rossini, 1996). Several combinations of measurements and models relating length and width to area have been developed for several fruit trees, such as grape (Montero *et al.*, 2000; Williams and Martinson, 2003), avocado (Uzun and Celik, 1999), pistachio (Ranjbar and Damme, 1999), Cherry (Demirsoy and Demirsoy, 2003), peach (Demirsoy *et al.*, 2004), and Chestnut (Serdar and Demirsoy, 2006). Some studies also use petiole length (Manivel and Weaver, 1974) and leaf weight (Sepulveda and Kliewer, 1983; Montero *et al.*, 2000) for area measurement. The most common approach is to develop ratios and regression estimators by using easily measured leaf parameters such as length and width (Kvet and Marshall, 1971). Lu *et al.*, (2004) proposed that the simple and linear relationships between leaf area and leaf dimensions (length, width) could be useful for nondestructive estimation of leaf area. Estimating leaf

area from equations using leaf dimensions is an inexpensive, rapid, and nondestructive alternative for accurately assessing leaf area. Nondestructive models for leaf area determination have been established for many species such as maize (Stewart and Dwyer, 1999), bean (Bhatt and Chanda, 2003), taro (Lu *et al.*, 2004), white clover (Gamper, 2005), sugar beet (Tsialtas and Maslaris, 2005), sunflower (Kvet and Marshall, 1971; Rouphael *et al.*, 2007), radish (Salerno *et al.*, 2005), zucchini (Rouphael *et al.*, 2006), strawberry (Demirsoy *et al.*, 2005), grapevines (Manivel and Weaver, 1974; Montero *et al.*, 2000), kiwi (Mendoza-de Gyves *et al.*, 2007), hazelnut (Cristofori *et al.*, 2007), eggplant (Rivera *et al.*, 2007). Leaves may have complex shapes making leaf area determination using ratios of leaf parameters difficult, time consuming, and subject to larger errors. Therefore, a simple method was developed, an equation for leaf area estimate which is insensitive to changes in leaf shape, and is cost-effective. That is, one centimeter graph paper method the reliability was tested using an electronic leaf area meter (Pandey and Singh, 2011).

2.4.0. Agronomy of *Amranthus*

To initiate Amaranth production, the producer should select and prepare a seed bed similar to that for small seeded vegetables or legumes, preferably on soils having a pH above 6.0 (Schulte *et al.*, 1991). According to Stallknecht *et al.*, (1990), the seedbed should be well worked and firmed by a packer prior to planting. A firm moist seedbed with soil temperatures above 15 °C and a soil pH between 4.5 and 8.0 are required to establish a good plant stand (National Academy of Sciences, 1984; Stallknecht and Schultz-Schaeffer, 1993; Palada and Chang, 2003). A very fine seedbed similar to that for



small seeded vegetables or legumes is recommended because *Amaranthus* seed is very small (Stalknecht and Schultz-Schaeffer, 1993). The seedbed should be of good tilth, well drained, and fairly level to help prevent rain from washing away the tiny seeds and seedlings (National Academy of Sciences, 1984). *Amaranthus* can be planted by direct seeding or transplanting (Palada and Chang 2003). Direct seeding is practiced only when plenty of seed is available and labour is limited (National Academy of Sciences, 1984; Palada and Chang, 2003). The recommended seeding rate is from 1.2 to 3.5 kg seed / ha planted on average depth of 1.3 cm and for vegetable *Amaranthus*, a density of up to about 220 000 plants / ha is acceptable (National Academy of Sciences, 1984; Mposi, 1999, Apaza-Gutierrez *et al.*, 2002). Where there is limited amount of seed and plenty of labour, transplanting is preferred (Palada and Chang, 2003). Singh and Whitehead (1993) obtained a maximum fresh shoot yield of 15 t / ha when an inter-row and intra-row spacing of 90 and 30 cm respectively were used.

2.4.1. Climatic Requirements

Amaranth is grown in temperate as well as tropical climatic conditions. In India, it is grown throughout the year. However, it is mainly grown in summer and rainy seasons. Severe winters are not desirable for its cultivation. It is reported that few species as *Amaranthus caudatus*, *Amaranthus cruentus* and *Amaranthus edulis* are short day, and *Amaranthus hypochondriacus* is a day neutral. Heavy rain falls with high winds are unfavourable conditions particularly for grain *Amaranthus*. However drought conditions may not match the grain types (Rai and Yadav, 2005).



2.4.2. Soil Conditions

Amaranth can be grown on a wide range of soil. However, leafy types require fertile soil of sandy loam in nature with well drained and slightly acidic. It does not do well on heavy, poorly drained or on sandy soils, which is very poor in water holding capacity and poor in fertility. It grows well only on the soil, which is thoroughly cultivated up to good tilth. The soil should be pulverized (Rai and Yadav, 2005).

2.4.3. Time of Sowing

The seeds are sown directly in the field of beds of 2.0 x 1.5 m or by transplanting. Amaranth can be grown throughout the year. However it is not advisable to grow in chilling cool weather during November to January in north Indian states and during hot season, May to June when irrigation facilities are not available. Amaranth should also not be grown in areas of heavy and continuous rains because water stagnation is common and that is harmful to the crop, particularly grain Amaranth fail to withstand rain with high winds this cause plants to fall leading to low productivity (Rai and Yadav, 2005).

2.4.4. Seed Rate, Method of Sowing and Planting Distances

According to Rai and Yadav, (2005) the seed rate per hectare is between 2 kg to 3 kg. However for cultivation of Amaranth for grain purpose, 1.5 kg seed will be sufficient for a hectare area, because it is sown at wider spacing. The seeds are sown thinly in lines. The distances between plant to plant 10 to 15 cm and row to row distance 45 cm. The distance between plants are maintained by thinning particularly when it is grown for



grain purpose. For vegetable purpose, if thinning is not done, yield will not be adversely affected. As far as possible, sowing of seeds should be done at the depth of 1 – 2 cm; this will cause uniform and rapid germination. The seeds are very small (thousand grains weigh 0.4 to 1.2 g) therefore, some quantity of sand or fine powder or leaf mold or soil is mixed to get uniform distributions. It will also help in maintaining seed rate per unit area (Rai and Yadav, 2005). Planting Amaranth on narrow row spacing of 18 cm or less may aid in weed control, by the shading effect of the Amaranth plants (Stallknecht *et al.*, 1990).

2.4.5. Manure and Fertilizers

Generally, the crop is grown under residual fertility of the previous crop. However, apply 35 – 40 t / ha of well-rotted farmyard manure at the time of preparation of land. Forty kg / ha of nitrogen is top dressed between rows just before irrigation (Rai and Yadav, 2005).

2.4.6 Fertilization of *Amaranthus*

Although *Amaranthus* is known to be a low management crop that can grow in poor soils, studies have shown that yield is improved by fertilizer (Palada and Chang, 2003). Myers (1998) and Schippers (2000) reported that *Amaranthus* responds well to good soil fertility and organic matter. Although Mhlontlo *et al.*, (2007) reported that sheep kraal manure rates as low as 2.5 t / ha produced significant increases in the fresh and dry matter yields of mono-cropped *Amaranthus*, information on fertility requirements of both grain and vegetable *Amaranthus* is scanty (Elbehri *et al.*, 1993). Elbehri *et al.*, (1993) noted that application of N-P-K fertilizer (at recommended rates) and irrigation during *Amaranthus*





production could increase grain yield from 700 kg / ha to 3000 kg / ha. Increased yields due to fertilizer application were observed by Spreeth *et al.*, (2004) at the University of Zululand, South Africa who applied 250 kg / ha of 2 : 3 : 2 compound fertilizer. Studies conducted by Schippers, (2000) indicated that the crop needs high potassium levels and best results were obtained with 400 kg / ha of compound fertilizer 10 – 10 – 20 (NPK). Plants grown with poultry manure had better yields when compared to those grown with kraal manure (Spreeth *et al.*, 2004). According to Walters *et al.*, (1988); Elbehri *et al.*, (1990); Makus, (1990 b); Putnam, (1990) fertility studies results in Arkansas, Minnesota, Montana, and Tennessee have been quite variable, for both vegetable and grain Amaranth types. A generally suggested fertility guide for Amaranth would be 112 to 135 kg / ha of total available N, with a soil test of 15 to 30 ppm P and 80 to 120 ppm K. Fertility needs will vary significantly, depending upon soil type, prior cropping, and fertilizer history. Higher applications of nitrogen would be applied in the high rainfall areas of the Midwest and under irrigated management as compared to the low rainfall production areas in the Great Plains. As the interest in Amaranth production increases, additional fertility studies will be needed for economic production practices (Walters *et al.*, 1988; Elbehri *et al.*, 1990; Makus, 1990 b; Putnam, 1990).

2.4.7. Animal Manure as a Potential Source of Nutrients for *Amaranthus*

Manure is usually a mixture of animal faeces, urine and plant materials (Lekasi *et al.*, 1998; Legget *et al.*, 1996; Yoganathan *et al.*, 1998). It contains all the nutrients required for plant growth although not in the desired proportions hence it is important to apply enough manure to meet crop requirements (Van Averbek and Yoganathan, 1997).



According to Mkile (2001), nutrient contents of cattle, sheep and goat manures differ. Goat manure had the highest N, P and K content followed by sheep and cattle. According to Schippers (2000), like most crops, growth and yield of *Amaranthus* improve enormously when enough manure is applied. Farmers in the Eastern Cape (South Africa) practice mixed farming which involves rearing of cattle, goats and sheep on communal owned rangelands whereas field crop production focuses mainly on growing of crops such as maize, beans and pumpkins on individual holdings of between 1 and 3 hectare and vegetable production of cabbage, spinach, onions, peas and carrots in gardens of about 0.1 to 0.3 hectares next to their homesteads (Mandiringana *et al.* 2005, Yoganathan *et al.*, 1998). During the night, cattle, sheep and goats are usually kept in kraals mainly for security reasons (Bembridge *et al.*, 1992). With time, the animals' excreta often mixed with fodder, accumulate in layers which are locally referred to as kraal manure (Yoganathan *et al.*, 1998). It is estimated that about 1.6 million tons of dry manure are produced in Eastern Cape (South Africa) each year (Mnkeni and Mkile 2006). Van Averbek and De Lange (1995); Mnkeni and Mkile (2006) and Mafu (2006) reported that farmers in the Eastern Cape use kraal manure in their maize-based cropping systems to address problems of declining soil fertility.

2.4.8. Nutritional Requirements and their Management

According to Rai and Yadav (2005), for good yield application of 20 - 30 t / ha farm yard manure is advisable during the last ploughing. Besides 30 to 40 kg / ha nitrogen, 40 to 50 / ha each phosphorous and potassium is applied in 3 or 4 splits. Generally nitrogen is **top**

dressed after each cutting. The whole quantity of phosphorous and potassium is applied as based dose just before sowing.

2.4.9. Intercultural Operations

Hoeing at early stage of crop growth will ensure good aeration and weed free crop. Being a short duration crop, weeds do not pose a problem (Rai and Yadav, 2005). Presently, there are no herbicides labeled for weed control in Amaranth, and it is unlikely that any chemicals will become cleared for commercial use. Weed control in Amaranth is achieved by cultivation, hand weeding, delayed planting, and by manipulation of plant populations using narrow row spacing. Late planting to avoid spring frosts (as the plant is very susceptible to frost) can aid in weed control, since early spring emerged weeds can be mechanically controlled (Schulz-Schaeffer *et al.*, 1988).

2.4.10. Water Requirements

According to Asare *et al.*, (2010), efficient application of scarce water could enhance water and nutrient use, as well as the productivity of vegetable crop and this could be achieved through the use of irrigation. CROPWAT is meant as a practical tool to help agro meteorologists, agronomists and irrigation engineers to carry out standard calculations for evapotranspiration and crop water use studies, and more specifically the design and management of irrigation schemes. It allows the development of recommendations for improved irrigation practices, the planning of irrigation schedules under varying water supply conditions, and the assessment of production under rain fed conditions or deficit irrigation (FAO 1992; Smith *et al.*, 1991 and Smith 1992). Water





requirements of crops depend mainly on environmental conditions. Plants use water for cooling purposes and the driving force of this process is prevailing weather conditions. Different crops have different water use requirements, under the same weather conditions. Crops will transpire water at the maximum rate when the soil water is at field capacity (Broner and Schneekloth, 2003). Knowing seasonal crop water requirements is crucial for planning your crop planting mixture especially during drought years. Adequate data on irrigation water requirements of most crops is not available in developing nations of the world. This is one of the reasons why for the failure of large scale irrigation projects in most developing countries of the world (Broner and Schneekloth, 2003).

According to Rai and Yadav (2005), since the seeds of *Amaranthus* are very small, if irrigation is done after sowing, there is risk for soil crust formation which will result in slow and poor emergence of seedlings. Therefore it is advisable to do pre-irrigation, so that sufficient moisture is made available for rapid and uniform germination. The leafy types require irrigation at frequent interval, better if each cutting follows irrigation. The grain types of Amaranth are drought resistant and hence crop can easily be taken as rain-fed crops.

2.4.11. Harvesting of *Amaranthus*

Vegetable Amaranth is ready for harvesting in 20 – 45 days after planting or sowing depending on cultivar (Palada and Chang, 2003). Once-off harvesting can be done for short maturing and quick growing cultivars (20 – 30 days after planting or sowing)



whereas multiple harvests at 2 - 3 weeks intervals are preferable to cultivars that mature late (more than 30 days after planting or sowing) (Palada and Chang, 2003). Harvesting is usually carried out by cutting the plants at above the second leaf from the ground, at a height of about 7.5 cm, after the plant leaves have attained marketable size. Harvesting may also be done by uprooting the whole plant and the plants are bunched together for sale after the roots have been washed (Mposi, 1999). A distinct advantage of indigenous vegetable crops is that they can be harvested repeatedly. Early maturity (21 days for leafy crops) and prolonged harvested periods were considered to be quality traits of different indigenous vegetable crop varieties because of higher productivity, while late maturity and short harvest periods in general were considered to be negative quality traits (Keller, 2004). Usually, after 25 to 30 days plants are pulled as a whole and washed properly. The root portion along with hard stem is removed. Instead of uprooting the whole plants, clipping of full-grown side leaves is done many times or tops of plants may also be cut. The first cutting is done 25 to 30 days after planting and thereafter at 6 to 8 days interval. Crop is over in 6 to 8 cuttings or so. The average yield of green is 6 - 8 t / ha depending upon climatic conditions and management of crop. Amaranth leaves are very perishable in nature. They cannot store more than few hours under ordinary conditions. Rai and Yadav (2005) have observed that, under zero (0) energy cool chamber, Amaranth can be stored up to 3 days (May to June) with weight loss 10.98 %.

2.4.12. Harvest Maturity

Most Amaranth cultivars grow rapidly and may be harvested from 30 to 55 days from sowing, when they reach a height of 0.6 m (Department of Agriculture, Forestry and Fisheries, 2010) South African.

2.4.13.0. Pests and Diseases

Pests and diseases have been reported to be a serious problem in *Amaranthus* production. In Nigeria, many *Amaranthus* lines suffered wet rot of leaves and young stalks as a result of *Choenophora cucurbitarium* (Mposi, 1999). Insect pests such as lygus bug (*Lygus lineolaris*), Lixus weevil (*Lixus masterii*), fall armyworm (*Spodoptera frugiperda*), beet leafhopper (*Circulifer temellus*), which transmit curly top virus disease, leaf rollers, cabbage looper (*Trichoplusia ni*), corn ear worm (*Heliothis zea*), cutworms, aphids, flea beetles and mites, can cause severe losses in *Amaranthus* production if no corrective measures are taken (Mposi, 1999; Palada and Chang, 2003; Stalknecht and Schultz-Schaeffer, 1993). No literature could be accessed on prevalent pests' species in the Eastern Cape, but where pests are prevalent, selective pesticides such as Biobit and Cypermethrin that target specific insects are recommended. Pesticides that kill or inhibit development of beneficial organisms are to be avoided (Palada and Chang, 2003).



2.4.13.1. Leaf Spot (*Cercospora sp*)

Small brown spots grow on leaves of Amaranth. Spots are roundish with concentric rings in the beginning which later increase and may coalesce. The affected plant leaves can be removed as a control measure (Rai and Yadav, 2005).

2.4.13.2. White Rust (*Albugo citrikuntaze*)

According Rai and Yadav (2005), white powders appear on the lower surface of the leaf and opposite each blister on the upper surface, a yellow patch develops. Leaves may wilt and die when incidence become severe. Crop rotation is the control measure. Spray dithane M - 45 at 0.2 % (Rai and Yadav, 2005).

2.4.13.3. Bacterial Spot of Amaranth (*Xanthomonas campestris p.v amaranthusicola*)

This disease is only noticed on leaves in native plants. It produces a few water soaked spot on the lower surface, become visible on the upper surface of leaf within 5 – 6 days as pale, brown round areas surrounded with yellowish halo. These water soaked spots looks translucent against light and measure 0.5 millimeter in diameter. On the advancement of disease the spots become deep brown and depressed on lower surface, whereas at upper surface, spots are raised at margin and sometimes bacterial ooze are present in the centre. Stem and petiole get infected under constructive environmental conditions when inoculated artificially. In advance stage of the disease, side of the stem gets cracked becoming black, whereas the central portion remains grey. Increase petioles,



cracked portion remains brownish. Control measure information is not available (Rai and Yadav, 2005).

2.4.13.4. Amaranth Mosaic

This disease is characterized by a distinct mosaic mottle in young as well as old leaves. The extent of large symptom expression varies from severe yellowing of veins to irregular chlorotic patches, alternation with dark green areas over the entire lamina. The mottling is usually marked and the infected plants can be located even from a distance. The mosaic causing virus is transmitted by sap as well as grafting. No insect vector is reported. Therefore, information on control measure is not available (Rai and Yadav, 2005).

2.4.13.5. Insect Pest of *Amaranthus*

According to Rai and Yadav (2005), many insects do not harm Amaranths seriously. However, insects like leaf webber, leaf hopper, stem weevil, caterpillar and ants are seen in the crop. On leaf type Amaranths where cutting of the leaves are regularly practiced and hence, insect may not be problem, one spray of malathion at the ratio of 1.5 to 2 ml per litre of water may be done at the initial stages of growth. It is not advisable to use insecticides in Amaranth because leaves are cooked as a vegetable. On the borders around the beds, sevin dust (a pesticide) can be spread in a band 10 cm to 15 cm wide, so that insects crawling into the Amaranth plot or coming out from Amaranth plot will die. The most common insect and disease problems of Amaranth have been described in 1990 Amaranth Grain Production Guide and the 4th National Amaranth Conference (Weber *et*



al., 1990; Wilson, 1990). In Montana, we have observed extensive damage to young seedlings caused from the potato flea beetle, *Epitrix cucumeris*. We have also identified serious problems induced by the curly top virus disease which is transmitted by the beet leafhopper, *Circulifer tenellus* (Stallknecht *et al.*, 1990). Both insect problems appear to be associated with large areas of sugar beets grown in south-central Montana, which is a host to these insects. The only chemical which has been approved for insecticidal use on grain Amaranth is Pyrenone Crop Spray (Wilson, 1990).

2.5.0. Neem Extract

The neem tree (*Azadirachta Indica A. Juss*) belongs to the order Rurales and the family Meliaceae (Panhwar, 2005).

2.5.1. Geographic Distribution of Neem in Ghana

Neem is thought to have originated in India and Myanmar where it is common throughout the central dry zone and the Siwalik Hills, although the exact origin is uncertain (National Research Council, 1992). The neem tree is now widely distributed by introduction into tropical and subtropical zones of Asia, America, Australia, South Pacific Islands and Africa. According to Childs *et al.*, (2001), the cultivation of neem spread to Africa in the 1920's when it was introduced to Ghana, Nigeria and the Sudan, and the species is now well established in more than 30 countries.





2.5.2. Introduction and Distribution of Neem in Ghana

In Ghana, neem has been growing on the plains near Accra, since the 1920s. The trees have naturalized, and their spread has been boosted by birds and bats that feed on the fruits and spit out the seeds while sitting on the branches. Neem is now scattered all over the area. There are now millions of neem trees growing in Ghana, especially in the coastal and interior savannahs (Schmutterer, 1998). Many of these trees are used for the production of firewood and charcoal, but other potential uses remain under-exploited. In recent years, there has been interest in neem in Ghana for crop protection, both in the field and storage. The German Development Cooperation (GTZ), through the Goethe Institute in Accra, has held two conferences, the first in 1998 on 'The potential of the neem tree in Ghana' and the second in 1999 on 'Commercialization of neem in Ghana' (Childs, *et al.*, 2001). These conferences have succeeded in promoting awareness of neem to a number of institutions within Ghana and have also helped to network the activities of these institutions. As a result of the 20 conferences in 1998, three working groups were set up within Ghana: 'Neem as a pesticide,' 'Neem as a cosmetic' and 'Neem for afforestation' (Childs *et al.*, 2001).

2.5.3. Active Ingredients of Neem

Neem products have been used for many years, especially in India and neighbouring countries, in the control of insect pests. Despite the limited scientific investigations, the beneficial properties of neem have been appreciated by the people in these areas (Ogemah, 2003). About 413 different species / subspecies of insect pest listed by

Schmutterer, (1995) have been found to be susceptible to neem products. The listed species / subspecies belong to different insect orders most of them were *Lepidoptera* and *Coleoptera* (Schmutterer, 1995).

Several biologically active compounds have been isolated from different parts of neem tree. Several vilasinin derivatives, salanins, salanols, salasnolactomes, vepaol, isovepaol, epoxyazadirachdone, gedunin, 7 - deacetylgedunin have been isolated from neem kernels. Azadirachtin is however, the most potent growth regulator and antifeedant (Butterworth and Morgan, 1968; Warthen, *et al.*, 1978; Ahmed, 2000).

2.5.4.0. Mode of Action of Neem Products

2.5.4.1. Insect Growth Regulation

To understand the mode of action of azadirachtin with respect to growth and metamorphosis, it is important to have a general understanding of the hormonal control of growth and development in insects. Hormones are responsible for the regulation of growth and development. The most important are the moulting hormones (Ecdysteroids) and juvenile hormones which are synthesized in the prothoracic glands of insects (Ogemah, 2003). The synthesis of ecdysone is triggered by the prothoracicotropic hormone (PTTH), which in turn is synthesized in the lateral neurosecretory cells and released through the corpus cardiacum and corpus allatum. During the feeding period of the larva, juvenile hormone inhibits ecdysone synthesis (Chapman, 1998). Contrary to earlier expectations, it has been shown that azadirachtin does not act directly on





prothoracic glands and it also does not bind to ecdysteriod receptors (Koul, *et al.*, 1987; Koolman, *et al.*, 1988). Azadirachtin depresses the synthesis of neurohormones from the brain as well as their release from the corpus cardiacum. The insect growth regulation effects of azadirachtin manifest as developmental aberrations in immature insects and are both dose and time dependent; can cause death before and during the moult, or delay of the moult (Rembold, 1995). Azadirachtin also inhibits the synthesis and release of Juvenile hormone possibly by affecting the release of allatotropins into the corpus allatum. Many of the manifestations of azadirachtin effect on moulting may therefore be linked to the balance between both the presence and absence of ecdysone and juvenile hormone (Rembold, 1995). These include delay in moulting (Langewald and Schmutterer, 1992), lack of differentiation of tissues (Schluter, 1985, 1987), and black spots (Hori *et al.*, 1984; Malczewska, *et al.*, 1988).

2.5.4.2. Oviposition behaviour

The females of some *lepidopterous* insects are repelled by neem products on treated plant parts or other substrates and will not lay eggs on them under laboratory conditions. This has been observed in the cabbage webworm, *Crocidolomia binotalis*, the Afro-Asian cotton bollworm, *Helicoverpa armigera*, and the fall armyworm, *Spodoptera frugiperda* (Schmutterer, 1997; Panhwar, 2005). The dipterous insect, *Lucilia serricata*, was also deterred from egg lying, as were some beetles (*Callosobruchus spp.*) (Ahmed, 2000).

2.5.4.3. Reproduction

Neem and azadirachtin have shown several adverse effects on ovarian development, fecundity, and fertility of various insects (Karnavar, 1987). Azadirachtin has been shown to inhibit oogenesis and ovarian synthesis in *Locusta migratoria* (Rembold and Sieber, 1981). Reduced fecundity was demonstrated in *Spodoptera exempta* (Tanzulbil and McCaffrey, 1990).

2.5.5.0. Advantages of the Utilization of Neem Products

2.5.5.1. Safety to Beneficial and Non - Target Species

One of the major problems with synthetic insecticides is their toxicity to non - target species. Many synthetic insecticides have been known to kill beneficial species and in some cases leading to the emergence of more difficult pest problems (Tetteh and Glover, 2008). Neem on the other hand has proved to be fairly safe to beneficial species. Sontakke and Dash (1996) noted that the number of the beneficial pollinator bees (*Apis flora*) in mustard was normal after the use of neem insecticides. Neem products have also been known to be safe against various predaceous spiders and mite (Mansour, *et al.*, 1987, 1993, 1997). Schmutterer (1997) concluded that neem products are, despite the effect on numerous insect pests, safe to spiders, adults of many beneficial insects and eggs of predators. Ogemah (2003) noted that the number of *Teretriosoma nigrescens*, a predator of *Prostephanus truncatus* was not significantly reduced when treated with **neem formulations.**



2.5.5.2. Low Mammalian Toxicity

Neem generally has limited or no toxicity to humans. Its long - term direct use such as mixing with food during storage, consumption in medicinal concoctions and utilization of stems as tooth brush, is a clear demonstration of this. Again, neem leaves have been chewed for a long time without any adverse effects (Schmutterer and Acher, 1987). This according to Boeke *et al.*, (2004) makes neem useful in the control of storage pests since it may be mixed with food and safely consumed. Boeke *et al.*, (2004) concluded that considering that there are many cases of chemical poisoning in the world, the use of neem products would reduce cases that occur during application of chemicals and consumption of treated food.

2.5.6. Pest Resistance

The problem of pest resistance to insecticide has increased over the last decade and has become a major obstacle to increased food production. The problem of multiple resistances poses an even greater danger to agricultural production (National Research Council, 1992). Interestingly, neem has been demonstrated to control agricultural insect pests showing resistance such as *Spodoptera littoralis* (Behera and Satapathy, 1996). The National Research Council (1992) attributed this partly to the many complex compounds found in neem products and its unique mode of action related to growth regulation only in insects. So far no insect has shown complete resistance to neem products although some cases have been reported, mostly involving refined neem products (Panhwar, 2005).



2.5.7. Availability of Neem Products

According to Boeke *et al.* (2004), many of the small scale farmers in many developing countries are unable to purchase chemicals for the control of field and storage insect pests. In some cases, the chemicals are only available in the major towns. Since neem trees can be grown by farmers on their own farms, it would increase the availability and affordability of neem products for stored products (Boeke *et al.*, 2004).

2.5.8. Use of Neem Products

Neem has found application in a wide range of areas. This is particularly useful to its acceptability. Neem products are useful for insect pest control in crop production, medicinal, industrial products, public health, reforestation, birth control, provision of fuel wood, provision of timber and soil fertility improvement (National Research Council, 1992).

2.5.9. Some Constraints in the Use of Neem Products

The use of neem products is not without constraints and limitations. It is important to view these limitations and constraints as challenges whose solving could create new opportunities in the utilization of neem products (Ogemah, 2003). One of the greatest limitations that the use of neem products poses is the lack of standardization of the products. Most often it is quite difficult to recommend specific dosages since products differ considerably in their contents (Isman, 2006). For instance in Ghana, it has been



reported that farmers have had successes with 30 g of seed kernel / litre of water in controlling some insect pests of cabbage (FAO, 2000). In Sudan, 50 g of seed kernel / litre of water have been reported to be effective against some insect pests of okra (Ahmed, 2000). Childs *et al.*, (2001) have suggested 25 - 50 g of seed kernel / litre of water to be effective against most insect pests. It is therefore obvious that there is the need for standardization in the use of neem products. Handling and application of crude neem products are also difficult since bulky quantities are involved. Therefore the use of such products in large - scale agriculture may not be practical in the near future (Ogemah, 2003). Again some neem products have been reported to be unstable, and degrade fast under the sun's ultraviolet rays (National Research Council, 1992). Furthermore, neem products are slow acting, and occasionally result in incomplete mortality compared to conventional synthetic insecticides and may hence not be readily acceptable to farmers (Isman and Port, 1990).

2.5.10. Neem Kernel Extract (NKE)

50 g of neem kernel is required for use in 1 litre of water. The neem kernel is pounded gently. It should be pounded in such a way that no oil comes out. The outer coat is removed before pounding; this is used as manure. If pounded with seed coat 1 1/2 times (75 g) seeds are required. The seeds that are used for preparation of neem kernel extract should be at least 3 months old and should not be used after 8 - 10 months. Before 3 months or after 8 months, the azadirachtin quantity is quite low in the seed and hence it cannot efficiently be used for pest control. The pounded neem kernel powder is gathered in a muslin pouch and this is soaked overnight in the water. The pouch is squeezed and



the extract is filtered. To the filtrate, an emulsifier like teepol, sandovit, soap oil or soap cake powder is added. One ml of emulsifier is added to one litre of water. The emulsifier helps the extract to stick well to the leaf surface [_ \(www.neemfoundation.org/neem-articles/neem-in-organic-farming/pest-management/101-pics.html\)](http://www.neemfoundation.org/neem-articles/neem-in-organic-farming/pest-management/101-pics.html).



CHAPTER THREE

EXPERIMENT 1

EFFECT OF DIFFERENT RATES OF CHICKEN MANURE AND NPK FERTILIZER ON THE GROWTH AND YIELD OF VEGETABLE AMARANTH

(AMARANTHUS HYBRIDUS)

3.0. MATERIALS AND METHODS

3.1. Location of the Experiment

Experiment 1 was carried out on the field under rain fed condition during 2012 / 2013 cropping season. The study was carried out at the farming for the future site at University for Development Studies (UDS), Nyankpala Campus. Nyankpala is located in the Tolon District of Northern Region of Ghana. The area experiences one rainy season in a year which usually occur from April to October. The annual mean rainfall is about 1,000 mm and the mean monthly temperature is between 17 and 40 ° C (Tolon – Kumbungu District Assembly, 2006).

The staple crop farming is highly restricted by the short rainfall duration. The mean diurnal temperature range is from 33 ° C to 39 ° C while mean night temperature is about 22 ° C. The area is characterized with both short and tall grass interspersed with drought resistant trees such as shea trees, neem, dawadawa and mahogany (Tolon-Kumbungu District Assembly profile, 2001). According to SARI Annual Report (2008), the



minimum and maximum relative humidity of the area are 46.6 % and 76.8 % respectively.

3.2. Experimental Design and Materials Used

Experiment 1 was 3 by 4 factorial experiment which was laid out in Randomized Complete Block Design (**RCBD**) with four (4) blocks. The treatments were as follows:

Chicken Manure at four (4) levels

- + 0 g chicken manure per experimental unit (equivalent to 0 t / ha)
- + 1600 g chicken manure per experimental unit (equivalent to 10 t / ha)
- + 2400 g chicken manure per experimental unit (equivalent to 15 t / ha)
- + 3200 g chicken manure per experimental unit (equivalent to 20 t / ha)

N P K (15 - 15 - 15) fertilizer levels

- + 0 g N P K fertilizer per plant (equivalent to 0 kg / ha)
- + 4 g N P K fertilizer per plant (equivalent to 250 kg / ha)
- + 5 g N P K fertilizer per plant (equivalent to 300 kg / ha)

The levels of each factor were combined with the levels of all the other factors as the treatment combinations. Table 3.1 below shows the treatment combinations:



Table 3.1: The treatment combinations

NPK / C M	Chicken Manure (0 t / ha C M)	Chicken Manure 10 t / ha (C M)	Chicken Manure (15 t / ha C M)	Chicken Manure (20 t / ha C M)
0 kg / ha NPK	0 t / ha T1	10 t / ha T2	15 t / ha T3	20 t / ha T4
250 kg / ha NPK	250 kg / ha T5	250 kg / ha, 10 t / ha T7	250 kg / ha, 15 t / ha T8	250 kg / ha, 20 t / ha T9
300 kg / ha NPK	300 kg / ha T6	300 kg / ha, 10 t / ha T10	300 kg / ha, 15 t / ha T11	300 kg / ha, 20 t / ha T12





3.3. Experimental Land Size

The total land area for experiment 1 was 12.9 m x 7.9 (101.91 m²) and each block was 12.9 m x 1.6 m (20.64 m²) with twelve (12) experimental plots in each block. The path separating blocks and beds were 0.5 m and 0.3 m respectively. A bed measured 1.6 x 0.8 (1.28 m²). Each bed contained eight (8) plants.

3.4. Soil Sampling, Sample Preparation and Analysis

Sample of the soil was collected from 0 - 20 cm depth, air dried for seven (7) days and sieved using 2 mm mesh sieve to remove debris and stones. Soil pH was determined using 1 : 2.5 soil water ratio, soil organic matter content (O.C), total nitrogen of the soil, available phosphorus of the soil, the exchangeable cations (Ca²⁺, Mg²⁺, Na⁺ and K⁺) were also determined.

3.5. Collection and Analysis of Chicken Manure

The chicken manure was obtained from layers under battery cage system at University for Development Studies poultry farm, decomposed and analyzed. Three different samples of 100 g each were taken into containers for analysis at Kwame Nkrumah University of Science and Technology laboratory, Kumasi. The following parameters were measured; nitrogen, phosphorus, potassium, magnesium and calcium.



3.6. Decomposition of the Chicken Manure

The chicken manure was decomposed for two (2) months before incorporating it into the soil three days before transplanting. After collecting the chicken manure, it was sent to the glasshouse of the University for Development Studies for further processing 02 June, 2013. A wide black polyethylene was spread on the floor and the chicken manure moistened on it and covered. After the manure had about two (2) weeks of maintained hot temperature, it was rotated into a new black polyethylene and covered. There was great number of organisms (maggots) in the decomposing chicken manure after the second week. After four (4) weeks, the temperature and the organisms (maggots) started declining. It was turned again for another two (2) weeks. After the six (6) weeks the pile was left on the bare ground with only the top covered to let manure cure. Stirring was done every week till the eighth (8th) week when it was ready for use. When the manure was dried, it fell apart easily and was nice and dark.

3.7. Incorporation of the Decomposed Chicken Manure into the Soil

The manure was incorporated into the soil in a ratio 3: 1 (3 parts of soil to 1 part manure). This ratio was obtained by taken the quantity of the manure as one part and measuring three times the quantity of the manure from the top soil of the prepared beds, mixed and spread on each experimental plot.

3.8. Neem Seed Extract

Neem seed extract was prepared using the following materials:

- ☐ Neem seed,
- ☐ Chilli pepper (grinded),
- ☐ A piece of bar soap

The neem seed was cracked using grinding stone and the seed was separated from the shell by winnowing. Chilli pepper and the neem seed were measured in the ratio 3 : 2 using a match box (21.4 cm³) for one litre of water. The neem seed and the chilli pepper were pounded together with a reasonable amount of soap using pestle and mortar. This mixture was soaked in one litre of water and mixed thoroughly and left over night. The suspension was sieved the next morning and applied as early as possible as pesticides to the *Amaranthus* before sunrise.

3.9.0. Agronomic Practices

3.9.1. Raising of Seedlings

The seedlings were raised at the plant nursery house of University for Development Studies – Nyankpala for experiment 1. The seeds were obtained from Vansado Enterprise, a certified agro input distributor in Tamale. The medium in which the seedlings were raised was river sand. The sand was sterilized using the dry straw method. The sand was moistened on a platform and some straw was spread on the moistened medium and set fire on it. After the medium got cool, it was collected into the nursery containers and left for a day. After one day, the seeds were mixed with fine sand in the ratio 1: 2 and sown by broadcasting in nursery containers which were filled with river



sand on the 8th August, 2013. Seedlings emerged on the 11th of the same month. That is, three (3) days after sowing. Transplanting was done twenty-eight (28) days after seedling emergence.

3.9.2. Fertilization (Chicken Manure and NPK)

The decomposed manure was incorporated into the soil three (3) days before transplanting for experiment 1. The NPK was applied seven (7) days after transplanting.

3.9.3. Transplanting

Seedlings were transplanted on the 9th September, 2013 when they were twenty-eight (28) days old. Watering of seedlings growing in the containers was done the previous day before seedlings were lifted. This was to reduce the destruction of roots of seedlings prior to transplanting. A dibber was used to make the holes at 40 cm by 40 cm. Eight (8) plants were transplanted to each experimental plot in experiment 1.

3.9.4. Watering

Experiment 1 was undertaken under rain fed condition. Watering was only done during the time of transplanting. That is, before and few days after transplanting for good establishment of the seedlings.



3.9.5. Weed Control

Weeds were controlled manually using hoe and hand picking to avoid crop-weed competition. This was done anytime there was weed growth.

3.9.6. Pest Management

Pests such as caterpillars and grasshoppers were on the field; these pests were controlled using neem seed extract. The neem seed extract was applied three (3) times in the cultivation of the crop. That is, fifteen (15) days after transplanting, seven (7) days after the first harvest and seven (7) days after the second harvest. The remaining pests were subsequently handpicked and destroyed physically.

3.9.7. Harvesting

The cutting method of harvesting was used thirty days after transplanting. The cutting was done at 20 cm height from the ground level. Three (3) harvesting were done at fourteen (14) days interval from 10th October to 07 November, 2013.

3.10.0. Sampling and Data Collection

Data was collected at ten (10) days interval on the growth parameters except the yield parameters, fresh weight and dry matter which were determined after harvest. Harvesting was done at 14 days interval. The chlorophyll level was also determined on the thirtieth (30th) day after transplanting.



3.10.1. Plant Height (cm)

A metre rule was used to take the height of four (4) plants in each experimental unit and the mean was calculated per unit. The height was measured from the ground level to the apical meristem.

3.10.2. Number of Leaves

Leaves of four (4) plants were counted in each experimental unit and the mean determined per unit. Only fully opened leaves were counted.

3. 10.3. Leaf Area (cm²)

Three (3) plants were sampled in each experimental unit and the areas of three matured leaves (counting from the top after four leaves) were measured using the graphical method. The mean leaf area was calculated.

Below is the procedure used in measuring the leaf area of the plants:

- ☐ The leaves to be measured were laid on a 1 cm grid (graph) sheet and trace their outlines.
- ☐ The numbers of square centimeters were counted. The area of the partial squares were estimated (that is, if a partial square was at least half covered by the leaf was considered as one; partial squares that were less than half covered were not counted)
- ☐ The area of the stem (petiole) was not included in the calculations.



3. 10.4. Canopy Spread (cm)

The canopy spread of each of the sampled plants was determined at two directions at right angles using a straight edge. The point of the tips of the leaves at opposite direction was marked and the spread measured. This was repeated for two opposite leaves at the opposite direction. The mean of the two spread was calculated for each plant and the average per plot recorded. The cross-method of canopy spread measurement was used. The average crown spread or canopy spread is the average of the lengths of longest spread from edge to edge across the crown or canopy and the longest spread perpendicular to the first cross-section through the central mass of the crown. Crown spread is taken independent of trunk position. Spread should be measured to the tips of the limbs, not to “notches” in the crown shape, and at approximately right angles from each other (Blozan, 2004, 2006 and 2008).

$$\text{Average crown spread} = (\text{longest spread} + \text{longest cross-spread}) / 2$$

The surveyor locates the point on the ground immediately below the branch tip on one end of the measurements and marks that position. He then moves to opposite side of the crown and locates the point under that branch tip. The spread along that line is the horizontal distance between those two positions. The same is repeated perpendicular to the first cross-section through the central mass of the crown (Blozan, 2004, 2006 and 2008)





3. 10.5. Chlorophyll Level (%)

The chlorophyll levels of three sampled plants in each experimental plot were determined. The chlorophyll meter was used to measure this data thirty (30) days after transplanting. According to Susan (1999), you can use a meter to test chlorophyll levels, usually of live plants. Two LED lights shine on the surface of the sample, most likely a plant leaf. The red LED light has a peak wavelength of 650 nm and infrared LED at a peak of 940 nm. Part of the light is absorbed by the chlorophyll; the rest is absorbed throughout the sample. The proportion of chlorophyll to other measures of the sample is calculated within the meter and is displayed as an arbitrary unit between 0 and 199.

3. 10.6. Determination of Fresh Leaf Weight of the Plants (g)

The leaves of the harvested parts were separated from the stalks. The leaves and the stalks were separately weighed fresh to determine the fresh weight of both leaves and stalks and the mean was calculated to obtain the average fresh weight for each experimental unit. The average fresh weight of leaves and stalks were added to get the fresh leaf weight of the plants.

3. 10.7. Determination of the Leaf Dry Matter of the Plants (g)

The separated parts of the leaves and the stalks were then sun dried for a week (7 days) and weighed to determine the dry matter. The mean was calculated to obtain the average dry matter for each experimental unit. The average dry matter of leaves and stalks were added to get the leaf dry matter of the plants.

3.11. Data Analysis

Residual Maximum Likelihood (REML) Method in GENSTAT was used in the analysis of the data collected. Treatment means were separated by the Least Significant Difference (LSD). The results were presented in tables and figures. Data for plant height, number of leaves, leaf area, canopy spread, fresh weight and dry matter were recorded at three different dates. Data for the three (3) time periods were analysed together in a repeated measures model using the dates as time points. The fixed part of the model was specified as:

$$Y_{ijklm} = \mu + B_i + M_k + F_l + B_{Mik} + B_{Fli} + M_{Fkl} + B_{MFikl} + \epsilon_{(ijkl)m}$$

$$i = 1, 2, 3, 4; j = 1; k = 1, 2, 3, 4; l = 1, 2, 3; m = 1.$$

Where

Y_{ijklm} = The yield of the *amaranthus*

μ = The overall mean

B_i = The i^{th} blocking effect (assumed random factor)

M_k = The k^{th} organic manure effect (fixed factor)

F_l = The l^{th} inorganic fertilizer (fixed factor)

B_{Mik} = The ik^{th} interaction effect of the i^{th} blocking and k^{th} organic manure application



B_{il} = The i^{th} interaction effect of the i^{th} blocking and l^{th} inorganic fertilizer application

MF_{kl} = The interaction effect of the k^{th} organic manure application and the l^{th} inorganic fertilizer application

BMF_{ikl} = The interaction effect of the i^{th} blocking effect and k^{th} organic manure application and the l^{th} inorganic fertilizer application

$\epsilon_{(ijkl)m}$ = The error due to $ijkl^{th}$ measurement and the m^{th} replication.

However, the block effects and its interactions were not significant and were therefore dropped from the final model after simplification.



CHAPTER FOUR

EXPERIMENT 1

4.0. RESULTS

4.1. Physical and Chemical Analysis of Soil

Pre-cropping chemical analysis of the experimental soil was carried out before land preparation to determine the nutrient status of the soil (Table 4.1).



Table: 4.1. Properties of the soil used during the study

Soil properties	Values
pH 1:2.5 H ₂ O	4.28
% O.C	0.93
% N	0.08
% P	Trace
% K	Trace
% Ca	0.21
% Mg	0.12
CEC (cmo / kg)	5.05
% Sand	45.63
% Clay	9.55
% Silt	44.83
Texture	Loam

4.2. Nutritional Composition of the Chicken Manure used

The chicken manure used was decomposed and analyzed to determine its nutrient composition. The result of the nutrient composition of the manure is shown in table 4.2 below.



Table 4.2: Properties of the chicken manure used during the study

Nutrients	Quantity (%)
Nitrogen	4.37
Phosphorus	1.05
Potassium	4.10
Magnesium	4.78
Calcium	4.47

4.3. Plant Height

The results showed that, the interaction between NPK levels by chicken manure levels was not significant but significant differences were observed in the main effects of NPK and manure. The NPK application was significantly different because; the no NPK (26.98 cm) produced significantly shorter plants than both 250 kg / ha NPK (29.32 cm) and 300 kg / ha NPK (30.07 cm) using LSD at 5 %. The 250 kg / ha NPK and 300 kg / ha NPK practically had the same effect (Figure 4.1 a). There were significant differences among the no manure treatment (24.12 cm) and the manure treatments; 10 t / ha (29.92 cm), 15 t / ha (31.01cm) and 20 t / ha (30.10 cm) however, there were no significant differences among the manure treatments (Figure 4.1 b).



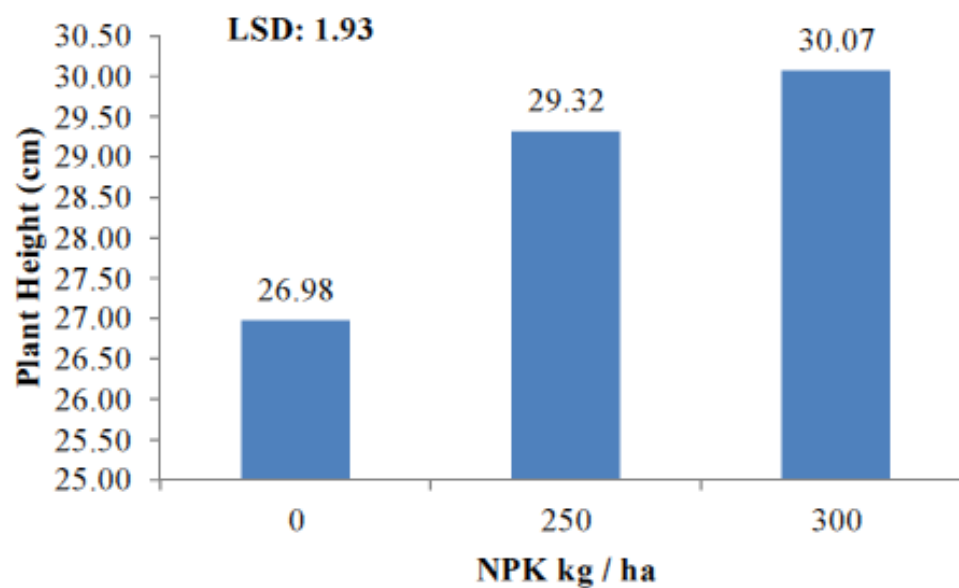


Figure 4.1 a: The main effect of NPK on Plant Height

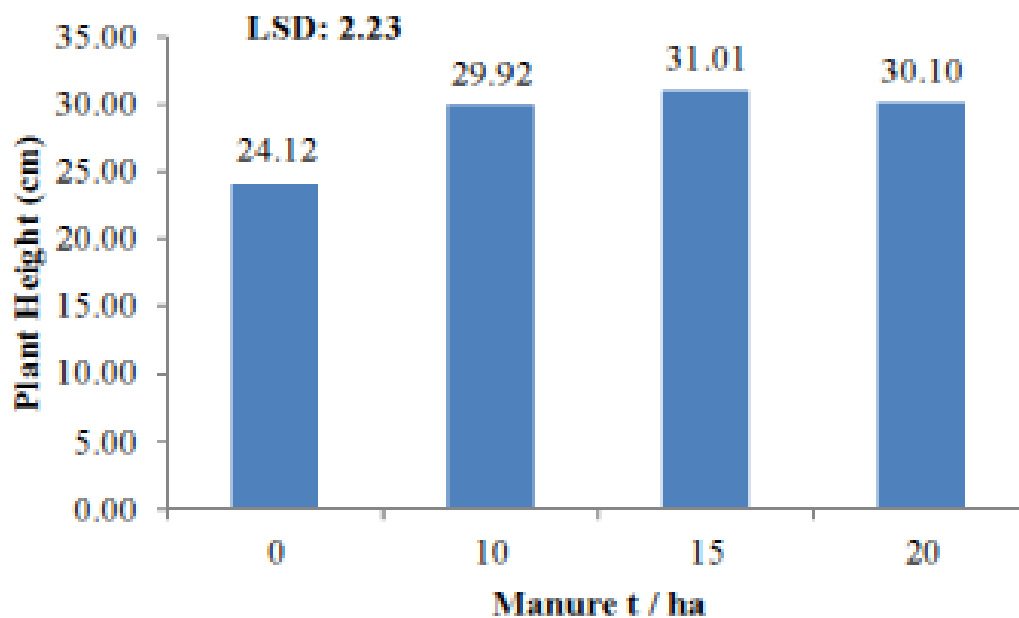


Figure 4.1 b: The main effect of Manure on Plant Height

4.4. Number of Leaves

The interaction effect of NPK and manure was not significant for the number of leaves. No significant difference was found in the main effect of NPK either, except in the main effect of manure where 0 t / ha was significantly lower than 10 t / ha, 15 t / ha and 20 t / ha (Figure 4.2).

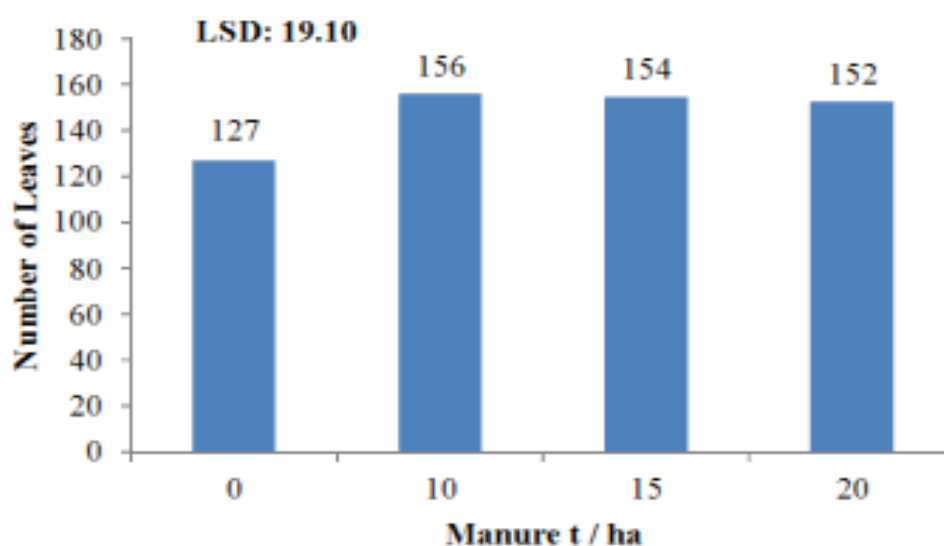


Figure 4.2: The main effect of Manure on Number of Leaves

4.5. Leaf Area (cm²)

The interaction between NPK and manure levels was not significant for leaf area except the main effects; NPK and manure. Both 250 kg / ha (49.05 cm²) and 0 kg / ha (44.64 cm²) had similar effect on leaf area. 300 kg / ha (52.79 cm) also performed statistically the same as 250 kg / ha but 300 kg / ha statistically produced broader leaves than 0 kg /



ha (Figure 4.3 a). Statistically, 10 t / ha, 15 t / ha and 20 t / ha chicken manure produced significantly higher leaf area (51.34 cm^2 , 55.39 cm^2 and 53.28 cm^2 respectively) than 0 t / ha (35.29 cm^2) (Figure 4.3 b).

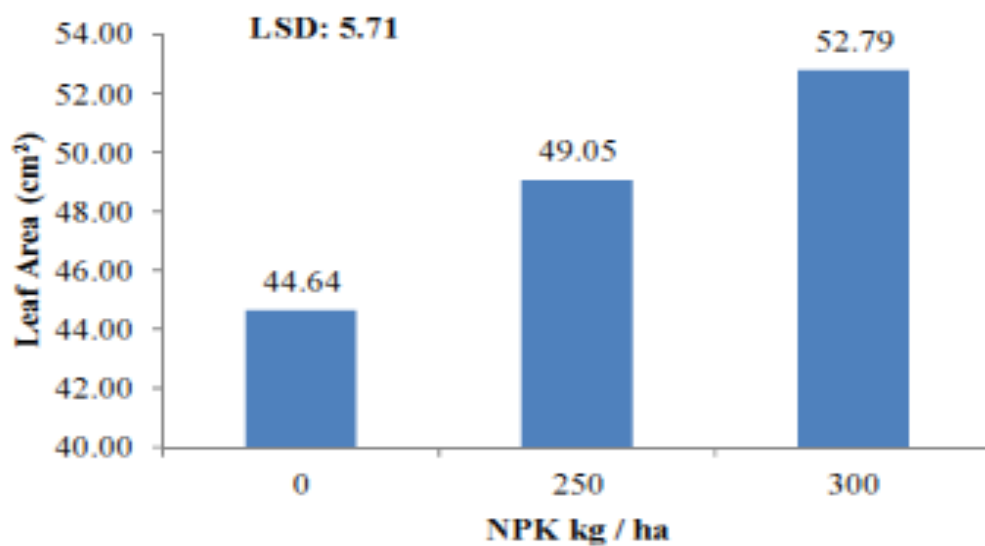


Figure 4.3 a: The main effect of NPK on Leaf Area



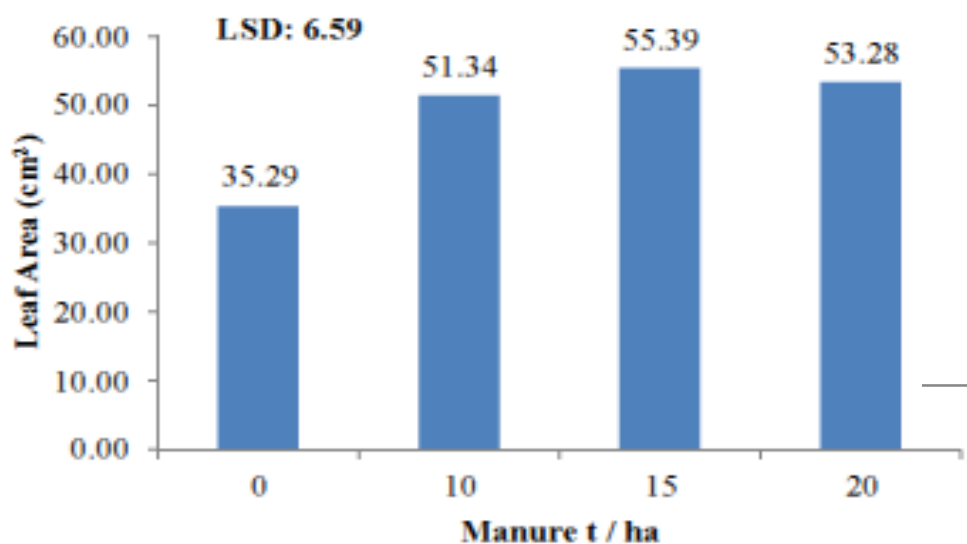


Figure 4.3 b: The main effect of Manure on Leaf Area

4.6. Canopy Spread (cm)

The interaction effect of NPK and manure on canopy spread was not significant. However, the control (no NPK) was significantly lower in canopy spread (33.13 cm) than 250 kg / ha NPK (36.94 cm) and 300 kg / ha NPK (37.63 cm). 250 kg / ha NPK produced statistically the same canopy spread as 300 kg / ha NK (Figure 4.4 a). The 10 t / ha, 15 t / ha and 20 t / ha chicken manure had similar canopy spread, but produced significantly higher canopy spread than 0 t / ha (Figure 4.4 b).



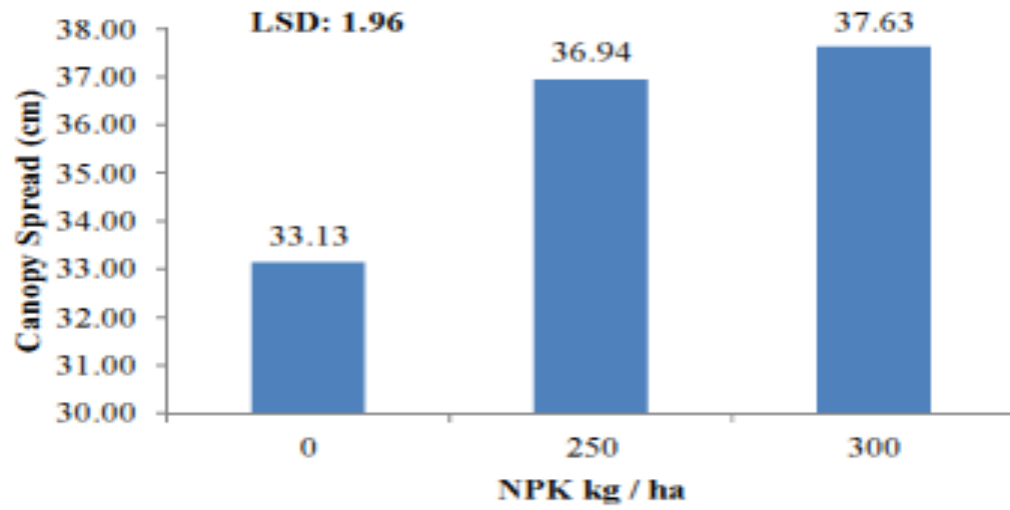


Figure 4.4 a: The main effect of NPK on Canopy Spread

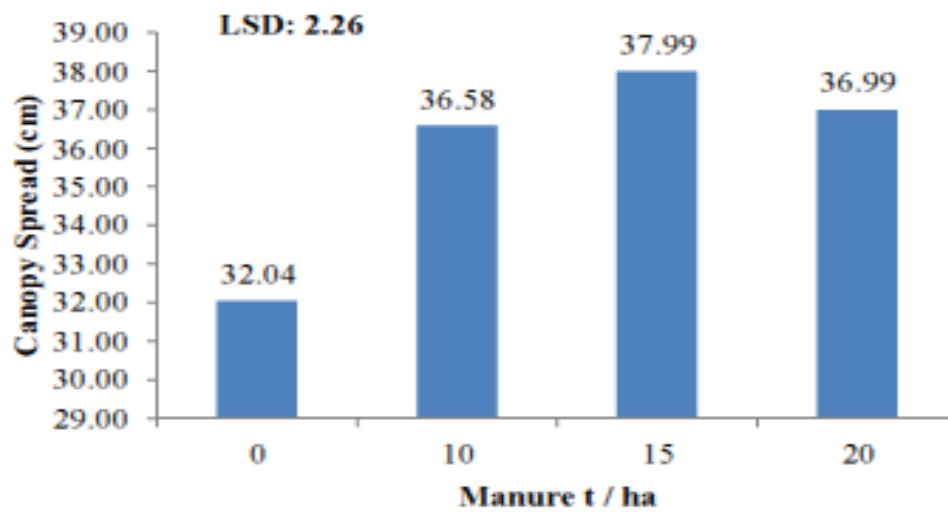


Figure 4.4 b: The main effect of Manure on Canopy Spread

4.7. Chlorophyll Level (%)

The interaction effect of manure and NPK was not significant. The main effect of manure and NPK was not significant (Table 4.3).

Table 4.3: The interaction effect of NPK and Manure on Chlorophyll Content

NPK by Manure	0 t / ha	10 t / ha	15 t / ha	20 t / ha
0 kg / ha	43.86	41.47	42.60	43.76
250 kg / ha	42.78	40.86	42.22	43.68
300 kg / ha	43.27	42.98	43.91	41.77
P-value				
LSD (0.05)		6.05		

4.8. Fresh Leaf Weight (g)

The interaction effect of NPK and manure on fresh weight of the plants was not significant. However, 250 kg / ha NPK (167.10 g) and 300 kg / ha NPK (187.10 g) produced significantly higher fresh leaf weight than the no NPK (129.50 g) (Figure 4.5 a). The 10 t / ha (168.60 g), 15 t / ha (178.00 g) and 20 t / ha (166.90 g) chicken manure treatments produced significantly higher fresh leaf weight than 0 t / ha (131.90 g) (Figure 4.5 b). However, the treatment of the NPK and manure levels were not significantly different within themselves



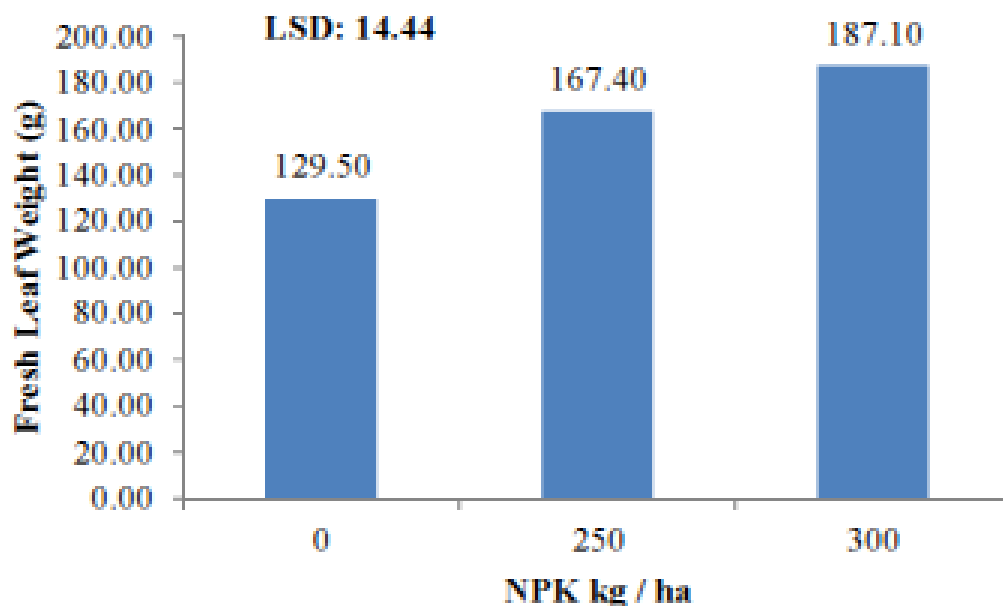


Figure 4.5 a: The main effect of NPK on Fresh Leaf Weight

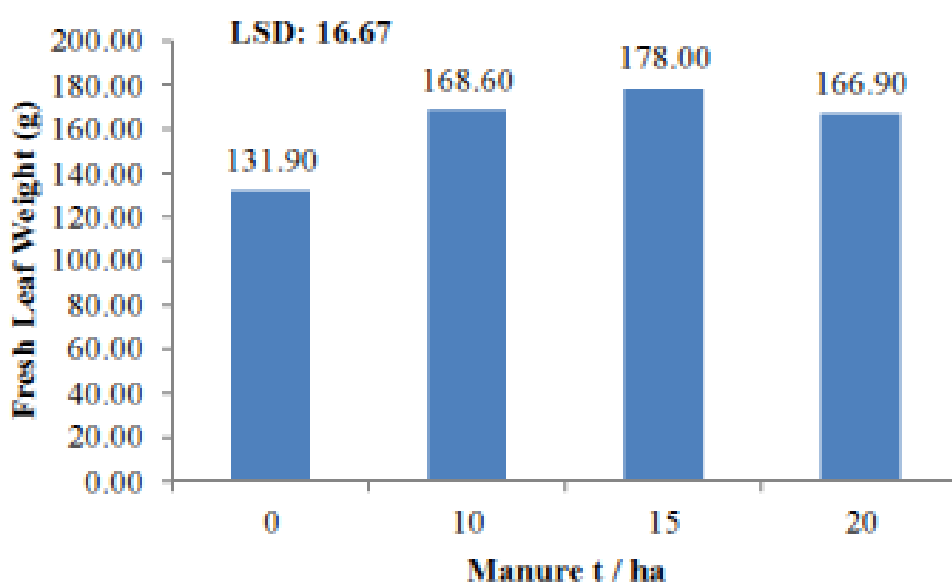


Figure 4.5 b: The main effect of Manure on Fresh Leaf Weight

4.9. Leaf Dry Matter (g)

The interaction effect of NPK and manure on leaf dry matter was not significantly difference. Nevertheless, the NPK main effect produced significantly much higher leaf dry matter in the 250 kg / ha (6.42 g) and 300 kg / ha (7.12 g) than no NPK (4.74 g) (Figure 4.6).

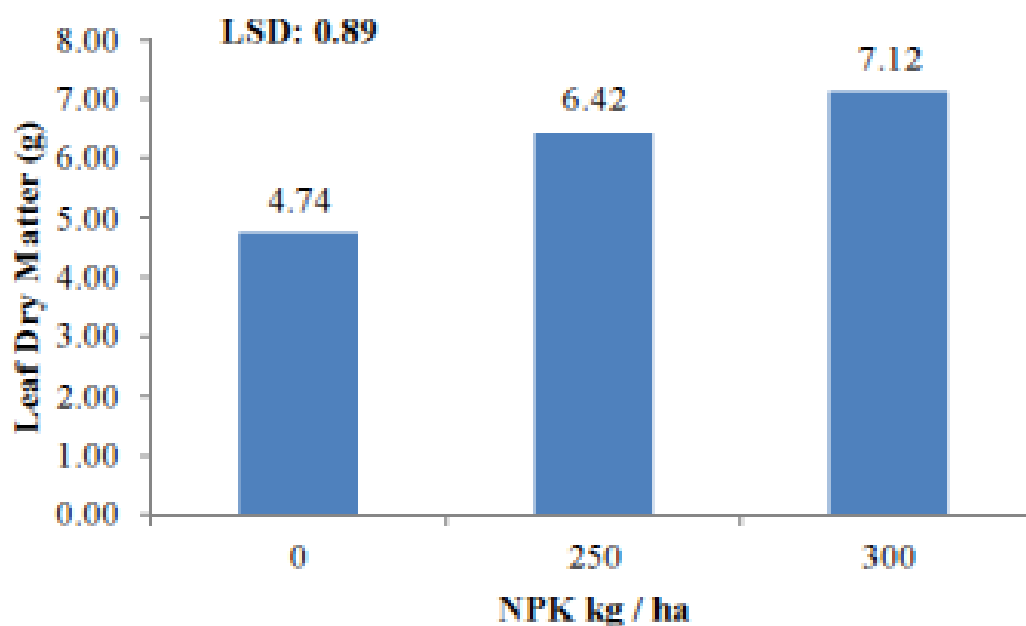


Figure 4.6: The main effect of NPK on Leaf Dry Matter



CHAPTER FIVE

EXPERIMENT 1

5.0. DISCUSSION

5.1. Physical and Chemical Analysis of Soil

The results of soil analysis indicated that, nitrogen was low (deficient) in the experimental soil which is one of the major nutrients needed by leafy vegetables like *Amaranthus*. The deficiency of the nutrient (nitrogen) calls for the increase of the nutrient in the cultivation of the plant under study in the soil.

5.2. Plant Height (cm)

The results indicated that the plant height was significantly higher in 250 kg / ha NPK and 300 kg / ha NPK suggesting that the 300 kg / ha could have offered the plants higher nutrients for a better increase in the height of the plant immediately it was applied. Palada and Chang, (2003) reported that, *Amaranthus* is known to be a low management crop that can grow in poor soils but yield can be improved by fertilizer application. The Chicken manure application showed significant effect as well, and it could be that the soil amendment had effect on both soil nutrients and soil structure. Van Averbek and Yoganathan (1997) reported that, chicken manure contains all the nutrients required for plant growth and hence it is important to apply enough manure to meet crop requirements. Myers (1998) and Schippers (2000) reported that *Amaranthus* response well to good soil fertility and organic matter.





5.3. Number of Leaves

The results revealed that, the better performed treatments were the plots amended with manure. The results also indicated that, aside the no manure amendment there were no significant differences among the other manure treatments (LSD = 0.05). This could be that the base soil used was deficient in nitrogen and hence amendment could have added more nitrogen to the soil that could have led to the significant difference between no amendment and amended fields. It could also be due to that, *Amaranthus* takes short period to mature (short lived plant) and manure slowly releases nutrients into the soil that might have slow response among the chicken manure amended plots. Van Averbek and Yoganathan, (1997) explained that, chicken manure has all the nutritional requirements for plant growth and that it is important to apply enough of it to meet the crop needs.

5.4. Leaf Area (cm²)

Applying NPK at 250 kg / ha or 300 kg / ha had no significant effect on the leaf area as indicated by the results. This might be due to the effect of nutrient leaching. The significant difference between no chicken manure treatment and the amendment treatments could be that, the soil used was deficient in nitrogen which is one the major nutrients for leafy vegetables and hence the amendment increase the nitrogen content of the soil.

5.5. Canopy Spread (cm)

Both NPK fertilizer treatments and manure treatments showed positive effect on canopy spread of the plant probably because the base soil was deficient in nitrogen.

The significant effect shown by both NPK fertilizer and the chicken manure amendment treatments could be that, the nutrient composition of the base soil was improved, though manure is a slow released fertilizer but its effect was still significant.

5.6. Fresh Leaf Weight (g)

The soil analysis indicated low nitrogen in the base soil and NPK applications had positively increased the nitrogen composition of the soil. This resulted in significant difference within all the levels of NPK applied on the fresh leaf weight of the crop. The significant effect shown in fresh leaf weight due to chicken manure treatments could be that, the amendment had positive effect on the output notwithstanding the slow release of its nutrients. Also, it could be that the chicken manure was able to bind the soil particles together for better soil water retention thereby making water available for the plants use. Pagliai and Vignozzi (1998) stated that, agronomic use of manure improves the physical conditions of soils, such as soil structure as well as the chemical compositions of the soil. Studies by Ayoola and Adeniyi (2006) however, revealed that the use of inorganic fertilizers has not been helpful in agriculture because it does not improve on the structure of the soil.



5.7. Leaf Dry Matter (g)

The NPK only increased the dry matter of Amaranthus. . The story was different in the chicken manure treatments because, the water holding capacity of the soil could have been increased by the chicken manure leading to the higher fresh leaf weight of the plants treated with manure.



CHAPTER SIX

EXPERIMENT 1

6.0. CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

It is concluded that the application of 250 kg / ha NPK and 300 kg / ha NPK fertilizer to *Amaranthus hybridus* had the highest mean values for both growth and yield parameters.

What could be the reason(s) for that?

6.2. Recommendations

- ☐ It is recommended that, an experiment using split application should be conducted on the rates of NPK to find out whether nutrient lost affected the response of the two levels of the NPK.
- ☐ It is also recommended that, an experiment should be conducted on a higher quantity of chicken manure at least 25 t / ha compared to a control.



CHAPTER THREE

EXPERIMENT 2

THE EFFECT OF CHICKEN MANURE AND NPK (SINGLE AND SPLIT APPLICATIONS) ON THE GROWTH AND YIELD OF VEGETABLE AMARANTH

(AMARANTHUS HYBRIBUS)

3.12. MATERIALS AND METHODS

Experiment 2 was an outdoor containerized experiment under irrigation. This was carried out at the farming for the future site at University for Development Studies (UDS), Nyankpala Campus. This experiment was carried out from 5th October 2014 to 14th February, 2015 in the dry season of 2014 / 2015 cropping season. The decomposition of manure was from 5th October to 15th December, 2014. Seedling nursing was from 30th November to 18th December, 2014 and transplanting was done on the 18th day of December, 2014, the final harvesting was done on 14th February, 2015.

3.13. Experimental Design and Materials Used

The experiment was 2 x 3 x 2 factorial experiment with two treatment combinations which was laid out in Completely Randomize Design (CRD) with ten (10) treatments and four (4) replications. The treatments were as follows:



Chicken Manure at two (2) levels

- + 0 g chicken manure (equivalent to 0 t / ha)
- + 93.5 g chicken manure (equivalent to 25 t / ha)

NPK 15 – 15 – 15 at three (3) levels:

- + 0 g NPK 15 – 15 – 15 (equivalent to 0 kg / ha)
- + 0.94 g NPK 15 – 15 – 15 (equivalent to 250 kg / ha)
- + 1.12 g NPK 15 – 15 – 15 (equivalent to 300 kg / ha)

Number of applications at two (2) levels:

- + Single application (1 application)
- + Split application (2 applications)

NPK fertilizer with 0 g could not be split and so split applications were missing. The levels of each factor were combined with the levels of all the other factors as the treatment combinations. Table 3.3 below shows the treatment combinations:



Table 3.2: The treatment combinations

<u>NPK / Manure / Number of applications</u>	0 kg / ha NPK	250 kg / ha NPK 1	250 kg / ha NPK 2	300 kg / ha NPK 1	300 kg / ha NPK 2
Chicken Manure 0 t / ha	Control T1	250 kg NPK 1, 0 t CM T3	250 kg NPK 2, 0 t CM T5	300 kg NPK 1, 0 t CM T7	300 kg NPK 2, 0 t CM T9
Chicken Manure 25 t / ha	0 kg NPK, 25 t CM T2	250 kg NPK 1, 25 t CM T4	250 kg NPK 2, 25 t CM T6	300 kg NPK 1, 25 t CM T8	300 kg NPK 2, 25 t CM T10





3.14. Experimental Unit Size

The containers used as the experimental units had the following dimensions; 24 cm for the top diameter, 16 cm for the bottom diameter and with a depth of 22.5 cm.

3.15. Decomposition of Chicken Manure

The manure was decomposed as described in experiment 1.

3.16.0. Agronomic Practices

3.16.1. Raising of Seedlings

The seedlings were raised at the plant nursery house of University for Development Studies – Nyankpala from 30th November to 18th December, 2014.

The seeds were obtained from a reputable source (“Vansado” Enterprise Tamale). The seeds were mixed with sterilized fine sand in the ratio 1: 2 and sown in containers filled with sand as in experiment 1 on the 30th November, 2014 and emerged five (5) days after planting.

3.16.2. Site Preparation

Eleven (11) kg of top soil was put into the containers and the decomposed chicken manure was incorporated into the soil of the experimental unit. The quantity of chicken manure for each treatment was weighed and replicated four (4) times.

3.16.3. Transplanting

Seedlings were transplanted on the 18th December, 2014 when they were thirteen (13) days old. The seedlings were watered the previous day before transplanting. A dibber was used to make the transplanting holes. One plant was transplanted per experimental unit in experiment 2.

3.16.4. Watering

The soil was filled to field capacity. This was done through the following procedure. Three (3) of the experimental pots were filled with eleven (11) kg of top soil with perforated holes under. The containers with the soil were put in three (3) basins containing four (4) litres of water each and allowed for the water to rise up to the surface of the pots through capillary action through the perforated holes. After the water was shown on the surface of the pots with the top soil, they were taken off from the basins and the remaining water in each basin was measured and subtracted from the initial amount of water. The average of the absorbed water was calculated which gave the amount of water to field capacity in each experimental unit before transplanting. Field capacity is the amount of soil moisture or water content held in the soil after excess water has drained away and the rate of downward movement has decreased ([http://en.wikipedia.org/wiki/soil moisture](http://en.wikipedia.org/wiki/soil_moisture)).

One litre of water was applied in each experimental unit any time the plants needed water.





3.16.5. Fertilization (Chicken Manure and NPK)

The decomposed manure was incorporated into the soil same as in experiment 1. The NPK was first applied seven (7) days after transplanting when the seedlings were fully established and subsequently applied ten (10) days after the first application.

3.16.6. Weed Control

Weeds were controlled manually by hand picking to avoid crop-weed competition. This was done anytime there was weed growth.

3.16.7. Pest Management

There were caterpillars and grasshoppers on the crop, these pests were handpicked and destroyed physically.

3.16.8. Harvesting

The cutting method of harvesting was used. The cutting was done at 20 cm height from the ground level. Three (3) harvesting were done at fourteen (14) days interval.

3.17. Data Collection

Data collection was done same as experiment 1.

- ☐ Plant Height (cm)
- ☐ Number of Leaves

- ☐ Leaf Area (cm²)
- ☐ Canopy Spread (cm)
- ☐ Determination of Fresh Leaf Weight (g)
- ☐ Determination of Leaf Dry Matter (g)

3.18. Data Analysis

The Residual Maximum Likelihood (REML) Method in GENSTAT was used to analyse the data. Treatment means were separated by the Least Significant Difference (LSD). The results were presented in tables and graphs. Below is the fixed part of the linear model for the experiment.

$$Y_{ijkl} = \mu + M_i + F_j + N_k + MF_{ij} + MN_{ik} + FN_{jk} + MFN_{ijk} + \epsilon_{(ijk)l}$$

$i = 1, 2; j = 1, 2, 3; k = 1, 2; l = 1, 2, 3, 4.$

Y_{ijkl} = The yield of the *amaranthus*

μ = The overall mean

M_i = The i^{th} manure effect (fixed factor)

F_j = The j^{th} fertilizer (fixed factor)

N_k = The k^{th} number of application (fixed factor)

MF_{ij} = The ij^{th} interaction effect of the i^{th} manure and j^{th} fertilizer



MN_{ik} = The ik^{th} interaction effect of the i^{th} manure and k^{th} number of application

FN_{jk} = The jk^{th} interaction effect of the j^{th} fertilizer and k^{th} number of application

MFN_{ijk} = The ijk^{th} interaction effect of the i^{th} manure, j^{th} fertilizer and k^{th} number of application

$\epsilon(ijk)l$ = The error due to ijk^{th} measurement and the l^{th} replicate.

The expected mean square table for the above linear model is shown in table 3.6.

3.19. Method of Analysis

Residual Maximum Likelihood (REML) Method in GENSTAT was used to analysed the data taken. Data for plant height, number of leaves, leaf area and canopy spread were recorded at three different dates. All days were combined and the days were used as random variable in the model specification. Square root transformation was used for Leaf Area analysis. The design was unbalanced in the treatment structure because two treatment combinations were not applicable, namely; zero NPK could not be split into single and double application. Simple ANOVA would produce incorrect results in GENSTAT. Therefore Residual Maximum Likelihood Method was used to analyse the data.



CHAPTER FOUR

EXPERIMENT 2

4.10. RESULTS

4.11. Plant Height (cm)

The analysis showed that, the 3 – way interaction term was not significant. Only one of the 2 – way interactions was significant and that was NPK by Number of application interaction (Figure 4.7). This is significant because, at 250 kg / ha NPK application, single application (19.88 cm) and split application (19.03 cm) had practically the same effect. At 300 kg / ha NPK application, split application (28.64 cm) performed much better (significantly higher) than single application (18.45 cm). There were significant differences in the main effects, specifically NPK and Number of application. The NPK application was significant different because; the 250 kg / ha NPK and 300 kg / ha NPK produced significantly taller plants than no NPK using LSD at 5 %. For the Number of application, the split application recorded significantly taller plants than the single application.



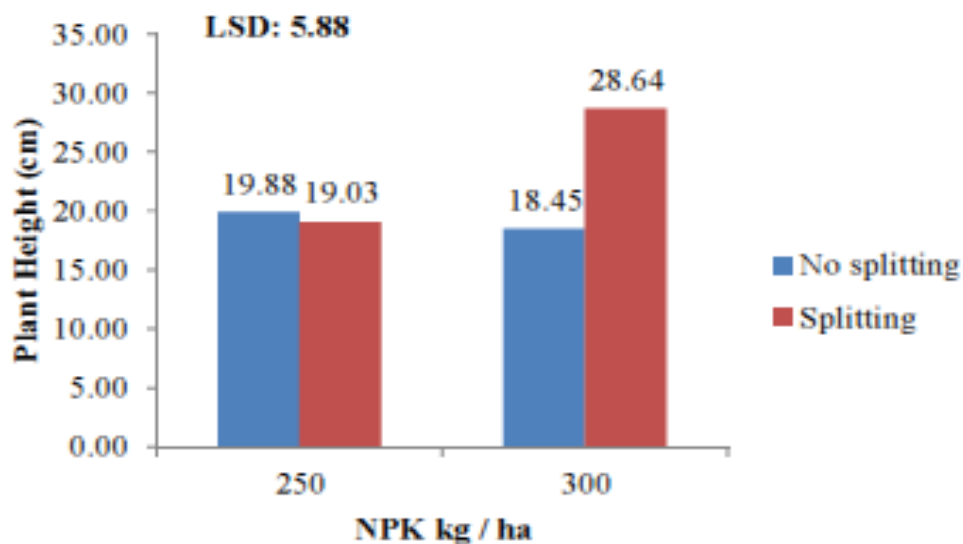


Figure 4.7: The interaction effect of NPK by Number of application on plant height

4.12. Number of Leaves

The 3 – way and the 2 – way interactions were not significant. In the main effects, NPK was significantly different. The no NPK produced statistically the same number of leaves (16 leaves / plant) as when 250 kg / ha NPK (23 leaves / plant) was applied, 250 kg / ha NPK also produced statistically the same number of leaves as when 300 kg / ha NPK was applied. Significant difference only existed between no NPK and 300 kg / ha NPK. With chicken manure and the number of applications main effects, there was no significant difference (Figure 4.8).



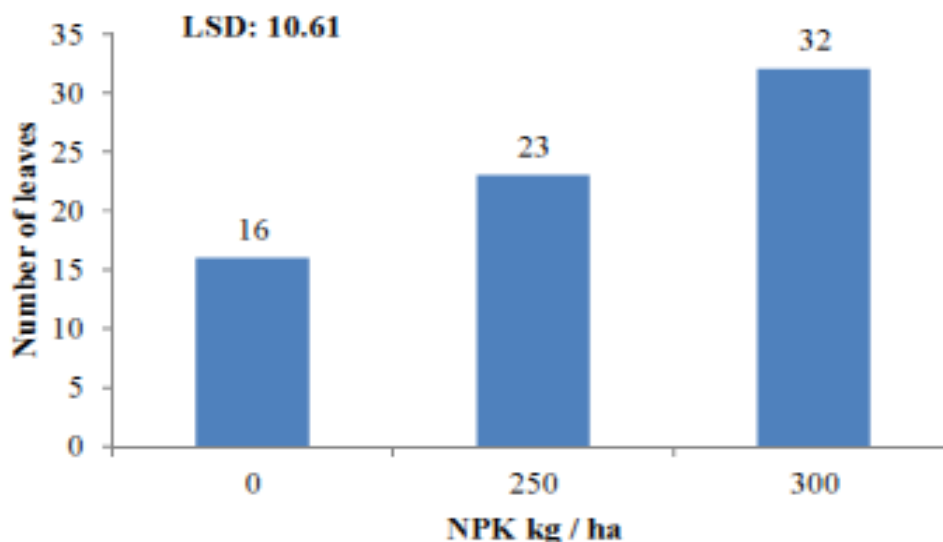


Figure 4.8: The main effect of NPK on number of leaves

4.13. Leaf Area (cm²)

The square root transformation was applied to the leaf area before the data was analysed. According to the analysis, the 3 – way interaction was not significant. Only one of the 2 – way interactions was significant, namely; Manure by NPK interaction. In the absence of NPK the addition of manure statistically increased leaf area, but in the presence of NPK there is less dramatic effect in the leaf area compared with no manure. The main effect of NPK was significant different largely due to the fact that both 250 kg / ha and 300 kg / ha produced larger leaves (4.93 cm² and 5.01 cm²) respectively than no NPK (3.52 cm²) but with no significant difference between 250 kg / ha and 300 kg / ha NPK (Figure 4.9).



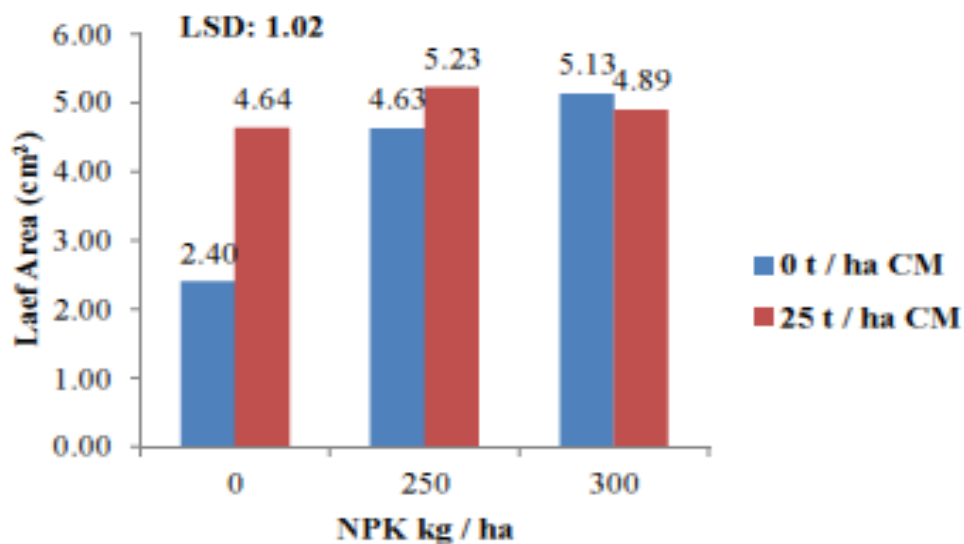


Figure 4.9: The interaction effect of NPK by Manure on leaf area

4.14. Canopy Spread (cm)

No significant difference was shown in the 3 – way interaction, but two of the 2 – way interactions were significant, namely; NPK interacting with Number of application and Manure interacting with NPK. With NPK interacting with Number of application, when 250 kg / ha NPK was applied, the split and the single applications produced similar results in terms of canopy spread (18.38 cm, 17.19 cm) but when 300 kg / ha NPK was applied (15.63 cm, 24.7 cm), significantly much wider canopy spread were produced in the split application than the single application (Figure 4.10 a).



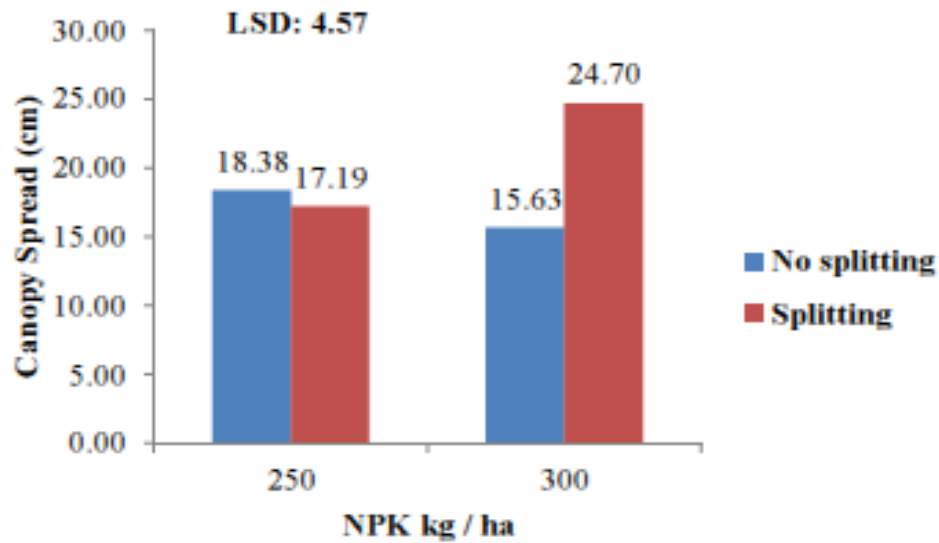


Figure 4.10 a: The interaction effect of NPK by Number of application on canopy spread
In the absence of NPK, addition of manure increases canopy spread statistically (from 5.65 cm to 16.68 cm). However, in the presence of NPK (250 kg / ha and 300 kg / ha) addition of manure does not show any statistical increase in the canopy spread (Figure 4.10 b).



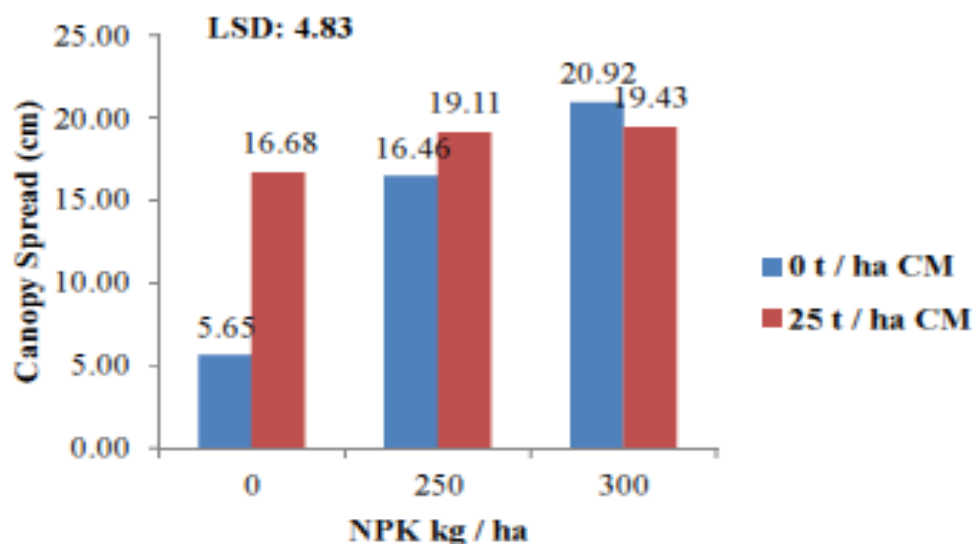


Figure 4.10 b: The interaction effect of NPK by Manure on canopy spread

The main effects significantly differ in the NPK between no NPK and the other 2 NPK levels (250 kg / ha NPK and 300 kg / ha NPK) but there was no significant difference between 250 kg / ha NPK and 300 kg / ha NPK. The split application results in much broader canopy spread compared to the single application in the Number of application main effect.

4.15. Fresh Leaf Weight (g)

There were no significant differences in the 3 – way, 2 – way interaction terms likewise the main effects in the fresh weight of the harvested part of the plant. This was shown by the analysis (Figure 4.11).

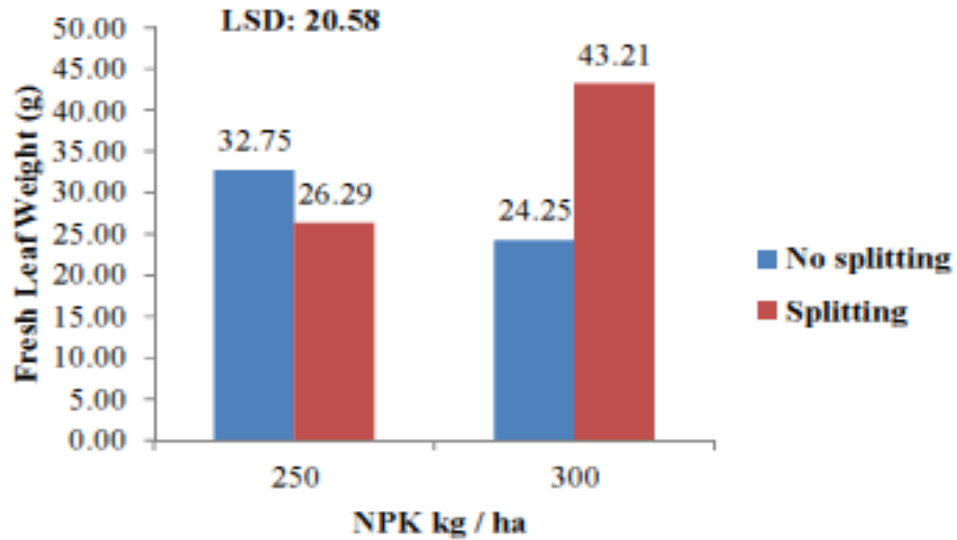


Figure 4.11: The interaction effect of NPK by Number of Application on fresh leaf weight

4.16. Leaf Dry matter (g)

The Residual Maximum Likelihood (REML) showed that, the 3 – way interaction term was not significant. Only one of the 2 – way interactions was significantly different, namely; NPK by Number of application interaction. This is significant because, 250 kg / ha NPK application produced similar results for leaf dry matter whether single or split applied but at 300 kg / ha NPK the split application produced much higher leaf dry matter than single application. The leaf dry matter of the plant was significantly higher in the split application compared to the single application in the Number of application main effect. 25 t / ha chicken manure produced significantly higher leaf dry matter than no manure (Figure 4.12).

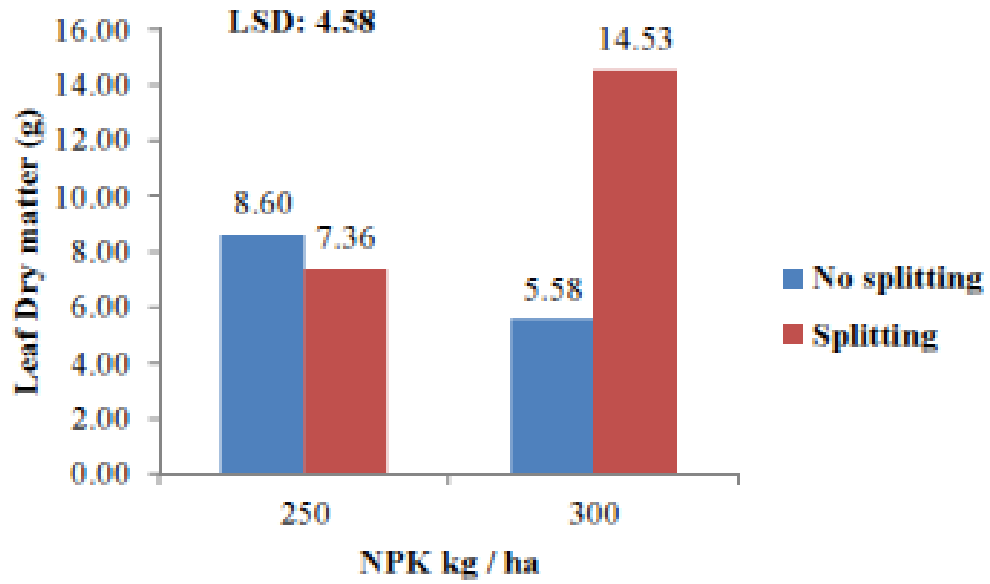


Figure 4.12: The interaction effect of NPK by Number of Application on leaf dry matter



CHAPTER FIVE

EXPERIMENT 2

5.8. DISCUSSION

5.9. Plant Height (cm)

The differences that existed in the NPK by Number of application interaction indicated that, since NPK is a fast released nutrient fertilizer it dissolves into the soil when there is moisture immediately it is applied for the plants root to absorb for growth and development. According to the results, 300 kg / ha NPK interacting with split application recorded statistically the highest plant height. This could be because, 300 kg / ha NPK gave enough quantity of nutrients when split applied at different stages of the plants growth. This gave the plants the opportunity to have access to nutrients in the application stages; therefore the problem of nutrient leaching was reduced. The significant difference that existed in the NPK main effect as indicated by the results could be the nature of NPK nutrients release into the soil provided moisture was sufficient and its impact was immediate in the plants as indicated in the plants height. Since *Amaranthus* is a short lived plant its impact is seen as compared to the manure rates. It could also be that, the NPK fertilizer had increase the nutrient composition of the soil as the base soil was low in nitrogen as indicated in the soil analysis that could have led to the increase in the plant height. Palada and Chang, (2003) reported that, *Amaranthus* is known to be a low management crop that can grow in poor soils but also stated that yield can be improved by fertilizer. Myers (1998) and Schippers (2000) reported that *Amaranthus* responds well to good soil fertility and organic matter. The results also indicated that,





significant differences existed in the Number of applications between split application and single application. This could be that, the single application may lose most nutrients due to leaching because the fertilizer was applied once at the early stage of the plant and watering was frequently done but splitting it at different stages of the plant life could help the plants to have access to nutrients at the different stages of the fertilizer's application, hence leaching could not have affected the plants nutrient used in the split compare to single application.

5.10. Number of Leaves

There were no significant differences in the 3 – way and 2 – way interactions. The results also revealed that, significant difference existed in only NPK main effect between no NPK and 300 kg / ha NPK even though, both treatments had not shown any significant difference to 250 kg / ha NPK as far as the number of leaves was concern. This could be that, 300 kg / ha NPK nutrient was sufficient for the production of number of leaves higher than no NPK which statistically recorded the same number of leaves as 250 kg / ha NPK even when singly applied because, the soil was deficient in nitrogen and 300 kg / ha NPK was the highest quantity applied. Elbehri *et al.*, (1993) noted that application of NPK fertilizer (at recommended rates) and irrigation during *Amaranthus* production could increase grain yield from 700 kg / ha to 3000 kg / ha.

5.11. Leaf Area (cm²)

Statistical difference only showed in the Manure by NPK application interaction. In the absence of NPK, there existed significant difference between no manure and the manure



treatments but as NPK was added and increased from 250 kg / ha to 300 kg / ha, there was no significant change in the leaf area. According to Rai and Yadav, (2005) *Amaranthus* does not do well on heavy, poorly drained or on sandy soils, which is very poor in water holding capacity and poor in fertility. With the NPK main effect, the application of NPK had helped to broaden the leaves. This could help the plant to trap more sun energy for photosynthesis for better growth in the subsequent stages of the plants life. Even though the nutrient release of manure is slow yet, its effect was shown.

5.12. Canopy Spread (cm)

The result indicated that, canopy spread was not significantly different from each other in the 3 - way interaction. The differences that existed in the NPK by Number of application interaction indicated that, since NPK is a fast released nutrient fertilizer it dissolves into the soil in the presence of moisture. According to the results, 300 kg / ha NPK with split application recorded the highest canopy spread. This could be due to the fact that, 300 kg / ha NPK provided the plants high quantities of plant nutrients in each application at the different growing stage of the plants life, though the plants have no difference in the nutrient uptake but the quantities applied could be a factor if leaching was low. The significant difference that was shown in the Chicken Manure by NPK application interaction could be that, the chicken manure had some positive impact in the canopy at the growing stage of the plant either by adding some nutrients to the soil or by binding the soil particles together so as to reduce leaching of the nutrients released which could have led to the wider canopy spread of the plant. This agreed with Ogunbile and Olukosi (1990) vegetable producers mostly apply poultry manure in addition to nitrogen-based



fertilizers because poultry manure alone is believed to dissolve slowly and may not meet up the yield of vegetable. Pagliai and Vignozzi (1998) stated that, the use of manure improves the structural and chemical compositions of the soil. Yet, the manure does not release nutrients to the soil immediately because it is a slow release fertilizer. As the NPK was increased from 250 kg / ha to 300 kg / ha in the presence of manure, there was no significant change in the canopy spread. In the absence of NPK there existed significant difference, this could probably be due to the effect of only chicken manure which could have improved the soil structure for better water retention compared to no manure. This might help broaden the canopy spread. The significant difference that existed in the NPK main effect could be that, NPK releases its nutrients faster provided there is moisture in the soil and its impact was immediate in the plants as indicated in the canopy spread. Since *Amaranthus* is a short lived plant NPK application impact was seen as compared to the chicken manure rates. It could also be that, the NPK fertilizer had increase the nutrient composition of the soil that could have led to the increase in the canopy spread. Palada and Chang, (2003) reported that, *Amaranthus* is known to be a low management crop that can grow in poor soils but also stated that yield can be improved by fertilizer. Myers (1998) and Schippers (2000) reported that *Amaranthus* response well to good soil fertility and organic matter. The results also indicated that, significant differences existed in the Number of applications between split application and single application. This could be that, the single application may lose most nutrients due to leaching because the fertilizer was applied once at the early stage of the plants and that, frequent watering can lead to nutrient lost through leaching, when split applied, could help the plant to have nutrients at different stages of the plants life.



5.13. Fresh Leaf Weight (g)

The results indicated that, the fresh leaf weight showed no significant differences among the treatments in the interactions and the main effects. This could be that, the amount of moisture in the plants at harvest was enormous compared to the dry component. The factor that led to the insignificant differences in the fresh leaf weight was largely water.

5.14. Leaf Dry Matter (g)

Significant difference existed in the NPK by Number of application interaction. The NPK split applied at 300 kg / ha produced significantly higher leaf dry matter compared to 250 kg / ha. This might suggest that, split application offers the plants enough nutrients in each application at the different stages of the growing life of the plants to overcome nutrient lost this led to the increase of roughage. It could also be that, NPK fertilizer is a fast release fertilizer and gave the plant its nutrients needed for better output at the fertilizer application stages of the plants growth as nutrient lost (especially leaching) was reduced to minimum.

This is supported by the statement that NPK fertilizer has the ease of dissolution of nutrients in the inorganic fertilizer and it is being in a more soluble form and that poultry manure contains useful soil nutrients that are needed for the growth of plants (Ayeni *et al.*, 2012). The composition of poultry manure is in the crude form that is released slowly to the soil (Nyankanga *et al.*, 2012). The significant difference that was observed between the Number of application in the main effects in the results showed the positive effect of the split application on the dry matter. Again the results revealed that, the dry matter was significantly higher in 300 kg / ha NPK split application because leaching was reduce to the minimum due to the splitting of the NPK fertilizer that made

the nutrients available to the plants at each stage it was applied. This made the plants to have access to the nutrients at the different stages of the plants' life. Hence the dry matter of the plants was increase due to the impact of the NPK applied at different stages of the plant. The chicken manure main effect showed significant difference in the yield parameter but not in any of the growth parameters. This may be due to the fact that, by the time the plants were harvested the chicken manure might have release some of its nutrients to the soil which probably help increase the roughage content of the plants given that treatment. This could have led to the increase in the dry matter of the plants.



CHAPTER SIX

EXPERIMENT 2

6.3. CONCLUSION AND RECOMMENDATIONS

6.4. Conclusion

From the study, application of 300 kg / ha NPK to *Amaranthus hybridus* can result in relatively high yield, however split applying 300 kg / ha NPK to *Amaranthus hybridus* have significantly higher mean values for almost all the parameters measured such as plant height, leaf area, number of leaves, fresh leaf weight and leaf dry matter of the crop produced from the experiment 2. Although *Amaranthus* is a short lived crop, yet split application has shown better performance than single application.

This study can be used as a guide by farmers for selecting the amount of NPK fertilizer and the way it should be applied (split application) to minimize nutrient lost for the crop studied. It is again evident from the results that *Amaranthus* is a valuable and low-input crop whose price is affordable, though fertilization increases output. It is therefore important to promote its growth throughout the year under recommended NPK fertilizer application and its use by many more people.

Finally, the results revealed that incorporating NPK with Manure on the field could be beneficial to short lived plants like *Amaranthus* but not immediate. It should have a long term benefit if the cultivation will be continuous on the same field.



6.5. Recommendations

- ☐ With reference to the findings from this study, it is recommended that farmers should split apply 300 kg / h NPK to *Amaranthus* for satisfactory plant responses pertaining to the growth and yield parameters measured.
- ☐ It is also recommended that an experiment of this nature should be conducted on farm with full participation of the farmers themselves to observe and see the outcome of the study.
- ☐ Several experiments of this nature should be repeated within the study district on the field to ascertain the results obtained.
- ☐ Subsequent experiments should include analyzing the nutritional composition of the crop produced.
- ☐ Chicken manure experiment should be conducted and it's residual benefit on the *Amaranthus*.



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Appendix I

Tables for Residual Maximum Likelihood (REML) Variance Components Analysis for
experiment 1

Appendix 1: REML Variance Components Analysis on Plants Height

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	47.72	3	15.91	<0.001
NPK	11.09	2	5.55	0.004
Manure.NPK	4.33	6	0.72	0.632

Appendix 2: REML Variance Components Analysis on Number of Leaves

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	12.43	3	4.14	0.006
NPK	5.70	2	2.85	0.058
Manure.NPK	11.16	6	1.86	0.084

Appendix 3: REML Variance Components Analysis on Leaf Area

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	46.45	3	15.48	<0.001
NPK	8.17	2	4.08	0.017
Manure.NPK	10.19	6	1.70	0.117

Appendix 4: REML Variance Components Analysis on Canopy Spread

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	32.87	3	10.96	<0.001
NPK	24.51	2	12.25	<0.001
Manure.NPK	6.44	6	1.07	0.376

Appendix 5: REML Variance Components Analysis on Chlorophyll Level



Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	0.92	3	0.31	0.821
NPK	0.19	2	0.09	0.910
Manure.NPK	1.36	6	0.23	0.969



Appendix 6: REML Variance Components Analysis on Fresh Weight

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	35.34	3	11.78	<0.001
NPK	65.83	2	32.91	<0.001
Manure.NPK	6.91	6	1.15	0.329

Appendix 7: REML Variance Components Analysis on Dry Matter

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	5.12	3	1.71	0.163
NPK	30.26	2	15.13	<0.001



Manure.NPK	8.79	6	1.47	0.186
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Appendix II

Tables for Residual Maximum Likelihood (REML) Variance Components Analysis for

experiment 2

Appendix 8: REML Variance Components Analysis on Plants Height



Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	2.87	1	2.87	0.090
NPK	28.30	2	14.15	<0.001
App	5.05	1	5.05	0.025
Manure.NPK	3.65	2	1.82	0.161
Manure.App	0.13	1	0.13	0.720
NPK.Application	7.07	1	7.07	0.008
Manure.NPK.Application	0.07	1	0.07	0.785

Appendix 9: REML Variance Components Analysis on Number of Leaves

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	2.46	1	2.46	0.117
NPK	6.47	2	3.24	0.039
Application	0.17	1	0.17	0.679
Manure. NPK	4.20	2	2.10	0.122
Manure.Application	0.60	1	0.60	0.440
NPK.Application	2.27	1	2.27	0.132
Manure.NPK.Application	0.63	1	0.63	0.426

Appendix 10: REML Variance Components Analysis on Leaf Area

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
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Manure	3.33	1	3.33	0.068
NPK	12.85	2	6.42	0.002
Application	0.30	1	0.30	0.583
Manure.NPK	7.76	2	3.88	0.021
Manure.Application	0.47	1	0.47	0.492
NPK.Application	2.25	1	2.25	0.134
Manure.NPK.Application	0.25	1	0.25	0.620



Appendix 11: REML Variance Components Analysis on Canopy Spread

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure	3.41	1	3.41	0.065
NPK	20.90	2	10.45	<0.001
Application	5.95	1	5.95	0.015
Manure.NPK	10.00	2	5.00	0.007
Manure.Application	0.57	1	0.57	0.449





Appendix 13: REML Variance Components Analysis on Dry Matter

Fixed term	Wald statistic	d.f.	Wald / d.f.	Chi-sq prob
Manure1	5.55	1	5.55	0.018

NPK	11.02	2	5.51	0.004
Application	5.67	1	5.67	0.017
Manure. NPK	1.64	2	0.82	0.440
Manure.Application	0.01	1	0.01	0.934
NPK.Application	9.89	1	9.89	0.002
Manure.NPK.Application	1.13	1	1.13	0.287

