EFFECTS OF DIFFERENT TYPES OF ORGANIC FERTILIZERS ON GROWTH PERFORMANCE, NUTRIENTS AND TOXICOLOGICAL COMPOSITION OF *AMARANTHUS CAUDATUS* AND *AMARANTHUS CRUENTUS*

BY

JERRY CHECHET KAHU

DEPARTMENT OF BIOCHEMISTRY,

FACULTY OF LIFE SCIENCES

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

JUNE, 2017

EFFECTS OF DIFFERENT TYPES OF ORGANIC FERTILIZERS ON GROWTH PERFORMANCE, NUTRIENTS AND TOXICOLOGICAL COMPOSITION OF *AMARANTHUS CAUDATUS* AND *AMARANTHUS CRUENTUS*

BY

KAHU CHECHET JERRY, B.Sc (ABU) 2010

MSc/SCI/44499/2012-2013

A THESIS SUBMITTED TO THE POSTGRADUATE SCHOOL, AHMADUBELLO UNIVERSITY, ZARIA, NIGERIA

IN PARTIAL FULFILLMENT FOR THE AWARD OF DEGREE OF MASTERS OF SCIENCE IN NUTRITION

DEPARTMENT OF BIOCHEMISTRY,

FACULTY OF LIFE SCIENCES

AHMADU BELLO UNIVERSITY,

ZARIA, NIGERIA

JUNE, 2017

Declaration

I declare that the work in this Dissertation entitled 'EFFECTS OF DIFFERENT TYPES OF ORGANIC FERTILIZERS ON GROWTH PERFORMANCE, NUTRIENTS AND TOXICOLOGICAL COMPOSITION OF *AMARANTHUS CAUDATUS* AND *AMARANTHUS CRUENTUS*' has been carried out by me in the Department of Biochemistry. The information derived from the literature has been duly acknowledged in the text and a list of references provided. No part of this dissertation was previously presented for another degree or diploma at this or any other institution.

Mr. Kahu Jerry Chechet …… ……..

Name of Student Signature Date

Certification

This Dissertation entitled 'EFFECTS OF DIFFERENT TYPES OF ORGANIC FERTILIZERS ON GROWTH PERFORMANCE, NUTRIENTS AND TOXICOLOGICAL COMPOSITION OF *AMARANTHUS CAUDATUS* AND *AMARANTHUS CRUENTUS'* by Jerry Chechet KAHU, meets the regulations governing the award of the degree of masters of Science in Nutrition of the Ahmadu Bello University, and is approved for its contribution to knowledge and literary presentation.

Prof. S. Ibrahim (Signature)……..…… Date……
Chairman, Supervisory Committee

Prof. E. Onyike (Signature)…… Date.....

Member, Supervisory committee

Prof. M.N. Shuaibu (Signature)…… Date……

Head of Department

Prof. S.Z. Abubakar (Signature)…… Date…….

Dean, School of Postgraduate

Acknowledgements

All praise and glory to God Almighty for his grace, mercy, and gifts of wisdom upon me.

Special gratitude goes to all those who contributed to the success of this work. Firstly, I will extend my sincere appreciations to my supervisors, Prof. S.I. Ibrahim and Prof. E. Onyike for guiding me through the entire work and their inputs towards making this work a success. Special thanks also to the staff of the Department of Biochemistry, Ahmadu Bello University, Zaria. Many thanks to the staff of the Institute of Agricultural Research, Ahmadu Bello University, Zaria, especially the Department of Soil science, Department of Horticulture and Department of Agronomy. A special thanks to Prof. C. Daudu for his support and intellectual contributions to this work. I also want to appreciate the staff of National Agency for Food and Drug Administration and Control (NAFDAC) for their support especially Mrs. Ijeoma Muoka, Mr. Moore Njoku, Mrs. Martina Mapis and Mr. Abubakar Umar

I appreciate the contributions of my Lecturers, Mr. O.A Owolabi, Prof. D.B. James and Dr. Gloria Chechet

Finally, to my entire family and loved ones who stood by me throughout the research period especially Mrs. Juliana Kahu, Mr. Gideon Kahu, Mrs. Linda Mande, Mrs. Nancy Akinlaja, Miss Patience Kahu, Mr. Seth Kahu, Miss Lag-ayan Chinyio, Miss Kuzangka Zakka and Mr. Chisom Umeh

God bless you all.

Dedication

This work is dedicated to my parents, (Late) Mr. Paul Y. Kahu and Mrs. Juliana P. Kahu

Table of Contents

Title Page……....ii

Declaration…….....iii

Certification…….....iv

Acknowledgement…….....v

Dedication…….....vi

Table of Contents……....vii

List of Tables…….....xii

List of Figures…….....xiii

Abstract.....xv

1.0 INTRODUCTION …….……1

1.1 Background…….……....1

1.2 Statement of Problem…….……...3

1.3 Justification…….....4

1.4 Null Hypothesis……..…….....5

1.5 General Aim……..…..5

1.6 Specific Objectives…….……..5

2.0 LITERATURE REVIEW ……...6

2.1 Amaranth ……...……...6

2.1.1 Taxonomy and origin…….....7

2.1.2 Uses of Amaranth…….....8

2.1.3 Environmental Response of Amaranth……..12

2.1.4 Cultivation of Amaranth……...12

2.1.5 Adaptability of Amaranth……..13

2.1.6 Pest and Disease Management of Amaranth……..13

2.2 Nutritional value of Amaranth……...……14

2.2.1 Carbohydrates in Amaranth……...15

2.2.2 Proteins in Amaranth…….....16

2.2.3 Lipids in Amaranth……..…..18

2.2.4 Micronutrients in Amaranth……...……19

2.3 Toxic aspects of amaranth……...21

2.3.1 Anti-nutrients…….21

2.3.2 Total Aflatoxins…….25

2.3.3 Heavy metals……..26

2.4 Fertilizers……...28

2.4.1 Inorganic Fertilizers……29

2.4.2 Organic Fertilizers……..31

2.4.3 Effect of fertilizers during germination, emergence and growth……...33

2.4.4 Frequency and timing of application of fertilizers…….35

2.4.5 Influence of fertilizers on yield and quality……...35

2.5 Soil ……36

2.5.1 Application of organic compost to improve soil quality……...36

3.0 MATERIALS AND METHODS……..38

3.1 Materials……....38

3.1.1 Chemicals……...38

3.1.2 Seeds……..38

3.1.3 Study area……...…...38

3.1.4 Soil sampling.……39

3.1.5 Fertilizers……39

3.2 Methods…….40

3.2.1 Soil analysis……40

3.2.2 Experimental design and fertilizer treatment…….46

3.2.3 Planting and nursery management……...…..46

3.2.4 Data collection for growth performance……47

3.2.5 Harvesting of the vegetable……49

3.2.6 Preparation of plant for analysis…….49

3.2.7 Estimation for proximate composition…..……...……...50

3.2.8 Estimation of micronutrients…….……...……..54

3.2.9 Estimation of toxicological properties……...58

3.2.10 Statistical analysis……..61

4.0 RESULTS……...62

4.1 Physical and Chemical Properties of Soil and Organic Fertilizers……..62

4.1.1 Physical and Chemical Properties of the Soil used in this Experiment…….……62

4.1.2 Chemical Properties of Organic Fertilizers used in this Experiment…….62

4.2 Effect of Different Organic Fertilizers and Different Concentrations on Growth Performance of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)…….……...….....65

4.2.1 Effect of Organic Fertilizers on Plant Height of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)……...……..65

4.2.2 Effect of Organic Fertilizers on Number of Leaves of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)……69

4.2.3 Effect of Organic Fertilizers on Leaf Length of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)…….……72

4.2.4 Effect of Organic Fertilizers on Leaf Width of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)…….……75

4.2.5 Effect of Organic Fertilizers on Leaf Area of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)…….……78

4.2.6 Effect of Organic Fertilizer on Leaf Area Index of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)……...….81

4.3 Effect of Different Organic Fertilizers and Different Concentrations on Nutrient Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)…….....84

4.3.1 Effect of Organic Fertilizers on Macronutrient Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)…….....84

4.3.2 Effect of Organic Fertilizers on Micronutrient Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)……...…….....88

4.4 Effect of Different Organic Fertilizers and Different Concentrations on Toxicological Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)……..……...……..92

4.4.1 Effect of Organic Fertilizer on Anti-nutrient Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)……..…….....92

4.4.2 Effect of Organic Fertilizer on Total Aflatoxins of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)……...…….95

4.4.3 Effect of Organic Fertilizer on Heavy Metals of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)…….....……95

5.0 DISCUSSION…….…...98

6.0 CONCLUSION AND RECOMMENDATIONS.....110

6.1 Conclusion…….…….110

6.2 Recommendations ……..111

REFERENCES……...112

APPENDICES……....134

LIST OF TABLES

Table 4.1.1: Physical and Chemical Properties of Soil used in this Experiment……...63

Table 4.1.2: Chemical Properties of Organic Fertilizers used in this Experiment……64

Table 4.3.1 Effect of Organic Fertilizers on Proximate Composition of *Amaranthus caudatus* (Samaru local variety)…….....86

Table 4.3.2 Effect of Organic Fertilizers on Proximate Composition of *Amaranthus cruentus* (NH84/452)…….....87

Table 4.3.3 Effect of Organic Fertilizers on Micronutrient Composition of *Amaranthus caudatus* (Samaru local variety)…….....90

Table 4.3.4 Effect of Organic Fertilizers on Micronutrient Composition of *Amaranthus cruentus* (NH84/452)…….....91

Table 4.4.1 Effect of Organic Fertilizers on Anti-nutrient Composition of *Amaranthus caudatus* (Samaru local variety)…….....93

Table 4.4.2 Effect of Organic Fertilizers on Anti-nutrient Composition of *Amaranthus cruentus* (NH84/452)…….....94

Table 4.4.3 Effect of Organic Fertilizers on Total Aflatoxins of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)…….....96

Table 4.4.4 Effect of Organic Fertilizers on Heavy Metals of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)……..97

LIST OF FIGURES

Fig 2.1 *Amaranthus cruentus* (NH84/452)……...10

Fig 2.2 *Amaranthus caudatus* (Samaru local variety)……..……..11

Fig 4.2.1: Effect of Organic Fertilizers on Plant Height of *Amaranthus caudatus* (Samaru local variety)……...67

Fig 4.2.2: Effect of Organic Fertilizers on Plant Height of *Amaranthus cruentus* (NH84/452)……..……..68

Fig 4.2.3: Effect of Organic Fertilizers on Number of Leaves of *Amaranthus caudatus* (Samaru local variety)……70

Fig 4.2.4: Effect of Organic Fertilizers on Number of Leaves of *Amaranthus cruentus* (NH84/452)……..……...71

Fig 4.2.5: Effect of Organic Fertilizers on Leaf Length of *Amaranthus caudatus* (Samaru local variety)……...73

Fig 4.2.6: Effect of Organic Fertilizers on Leaf Length of *Amaranthus cruentus* (NH84/452)……..……...74

Fig 4.2.7: Effect of Organic Fertilizers on Leaf Width of *Amaranthus caudatus* (Samaru local variety)……..**.....**76

Fig 4.2.8: Effect of Organic Fertilizers on Leaf Width of *Amaranthus cruentus* (NH84/452)……..……**...**77

Fig 4.2.9: Effect of Organic Fertilizers on Leaf Area of *Amaranthus caudatus* (Samaru local variety)……..**.....**79

Fig 4.2.10: Effect of Organic Fertilizers on Leaf Area of *Amaranthus cruentus* (NH84/452)……..……...80

Fig 4.2.11: Effect of Organic Fertilizers on Leaf Area Index of *Amaranthus caudatus* (Samaru local variety)……82

Fig 4.2.12: Effect of Organic Fertilizers on Leaf Area Index of *Amaranthus cruentus* (NH84/452)…….……...83

Abstract

The objective of this study is to evaluate the effect of different types organic fertilizers on growth performance, nutrient and toxicological composition of two varieties of amaranth (*Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)).The study consists of seven treatments which includes control (no fertilizer), poultry manure of 5 tons/ha and 10 tons/ha, sewage sludge of 5 tons/ha and 10 tons/ha, NPK compound fertilizer of 35 kg/ha and 70 kg/ha; with two varieties of amaranth (*Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)) in factorial arrangement fitted into a randomized complete block design (RCBD) and replicated three times. Growth performance data were collected on plant height, number of leaves, leaf length, leaf width, leaf area and leaf area index from 2 weeks after transplanting (WAT) to 6 weeks after transplanting (WAT) using measuring tape and ruler. At 6WAT, poultry manure of 10 tons/ha recorded the highest value for all the growth parameters for both varieties except for leaf length, leaf width and leaf area of *Amaranthus caudatus* (Samaru local variety), where 10 tons/ha sewage sludge and 70kg/ha NPK compound fertilizer were highest. All the treatments showed increased effect on proximate composition (ash, moisture, fat, crude protein, crude fibre, available carbohydrate and energy) for the two varieties but there was no significant ($p<0.05$) difference except for protein which was significantly ($p<0.05$) highest at 9.67 ± 0.16% for the 70kg/ha NPK compound fertilizer in *Amaranthus caudatus* (Samaru local variety), proximate composition was determined according to A.O.A.C. (1999). Water soluble vitamins were analyzed using High Performance Liquid Chromatography (HPLC) while the metals were analyzed using Atomic Absorption Spectroscopy (AAS) For *Amaranthus caudatus* (Samaru local variety). β-carotene, zinc, riboflavin, iron, niacin and vitamin C levels were highest for 10 tons/ha sewage sludge, poultry manure of 10 tons/ha, NPK compound fertilizer of 70 kg/ha, poultry manure of 10 tons/ha, NPK compound fertilizer of 70 kg/ha, and 10 tons

poultry manure respectively while for *Amaranthus cruentus* (NH84/452), β-carotene, zinc, niacin, iron, vitamin C and riboflavin were highest for 10 tons/ha sewage sludge, poultry manure of 10 tons/ha, 70kg/ha NPK compound fertilizer, sewage sludge of 10 tons/ha, NPK compound fertilizer of 70kg/ha and 10 tons/ha sewage sludge respectively. The 10 tons/ha poultry manure gave the highest value of tannins for both varieties but there was no significant ($p<0.05$) difference among the treatments. The 70 kg/ha NPK compound fertilizer recorded the highest level of phytate while the 10 tons/ha sewage sludge had the highest level of saponins, oxalate, and lead for both varieties of amaranth. Total aflatoxins and cadmium were not detected in any of the treatments including the control. The experimental results of this study have shown that poultry manure had higher growth performance and nutrients on the two varieties of Amaranth when compared with sewage sludge and NPK compound fertilizer, while sewage sludge resulted in the plants having higher anti-nutrients and heavy metals. The application of poultry manures at 10 tons/ha is therefore recommended for farmers to use to obtain higher yields of Amaranth.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Increasing population of the world has doubled the food demands and inundated the available land resources. Alongside other food alternatives, vegetables are considered cheap source of energy (Hussain *et al*., 2009). Vegetables are rich sources of essential biochemicals and nutrients such as carbohydrates, carotene, protein, vitamins, calcium, iron, ascorbic acid and palpable concentration of trace minerals (Salunkhe and Kadam, 1998). Plants also contain compounds which can potentially compromise health. These are termed 'anti-nutritive' compounds such as oxalates, tannins, nitrates which are present in spinach. Amaranth is one of important vegetables of Amaranthaceae family. Amaranth has been naturalized in central parts of Asia and possibly Iran (Kawazu *et al*., 2003) and has cultivation history of more than 2000 years (Daneshvar, 2000), but it is also widely grown in Nigeria and many part of the North including Kaduna state. Amaranth is eaten as a vegetable across various states in Nigeria.

Organic and inorganic fertilizers are essential for plant growth. Both fertilizers supply plants with the nutrients needed for optimum performance (Erisman *et al*., 2008). Organic fertilizers have been used for many centuries whereas chemically synthesized inorganic fertilizers were only widely developed during the industrial revolution. Inorganic fertilizer has significantly supported global population growth, it has been estimated that almost half the people on the earth are currently fed as a result of artificial nitrogen fertilizer use (Erisman *et al*., 2008). Commercial and subsistence farming has been and is still relying on the use of inorganic fertilizers for growing crops (Masarirambi *et al*., 2010). This is because they are easy to use, quickly absorbed

and utilized by crops. The continued dependence of developing countries on inorganic fertilizers has made prices of man agricultural commodities to skyrock (Makinde *et al*., 2010). Most vegetable farmers in tropical Africa are small holders who cannot afford cost of inorganic fertilizers, although soil fertility limits yield of vegetables especially in urban centres (Makinde *et al*., 2010). In Nigeria, fertilizer being costly and sometimes scare can make farmers not apply enough for good growth (Alonge *et al*., 2007). Fertilizer application rates in intensive agricultural systems have increased drastically during recent years in Nigeria. Farmers depend largely on locally sourced organic fertilizers (Makinde *et al*., 2010). In Nigeria, huge amount of organic wastes such as poultry waste, animal excreta, sewage sludge, refuse soil and palm oil mill effluent are generated and heaped on damp sites, posing potential environmental hazard (Agboola and Omueti, 1982). Incorporating these wastes materials into the soil for crop production is expected to be beneficial to the buildup of organic matter layer that is needed for a steady supply of nutrients by tropical soils (Agboola and Omueti, 1982). However, due to high quantity needed, adequate quantity of an organic and inorganic waste may be obtained, hence the farmers often apply organic and inorganic fertilizer combined. Also, getting the appropriate application protocol or rates is important in obtaining good yield (Agboola and Omueti, 1982).

Oyedeji *et al.* (2014) reported that NPK and poultry manure improve the growth and yield of three different species of amaranth (*Amaranthus hybridus, Amaranthus deflexus* and *Amaranthus cruentus*) but influenced proximate composition differently where NPK had the highest crude fibre, protein and fat while poultry manure showed the highest fat content. Emede *et al.* (2012) reported that poultry manure influenced the plant growth and yield of *Amaranthus cruentus* L. positively. Makinde *et al*. (2010) reported that organic material alone or in combination with NPK significantly increased protein and ash while fibre was reduced; NPK gave least values of

protein, fibre and ash compared with organic material. Funda *et al*. (2011) studied the effect of organic and inorganic fertilizers on yield and mineral content of onion and reported that the treatments influenced K content, but did not influence N, P, Ca, Na, Mg, Fe, Zn, Cu and Mn contents of the onion bulb. In the second year, the treatments influenced Na content, but did not influence the others. Coolong *et al*. (2005) reported that N, P, Mn, Fe and Zn content of bulb were increased by N treatments but the content of N was decreased by N doses but K, Cu and Mo contents were not affected by the treatments. Abdelrazzag (2002) found that increasing the rate of sheep and chicken manure increased N content of onion significantly, while P and K contents had low level. Mixture of chicken manure and biofertilizer increases the yield of onion and enriched nutrient content in tuber (Fatma *et al*., 2007). Application of organic manures significantly increased levels of organic C and N and the formation of water stable aggregates, as compared with application of chemical fertilizers (N'Dayegamiye, 2006). Several studies have centered on the effect of organic, inorganic fertilizer or used in combination on soil properties, nutrients uptake, growth, yield and some minerals contents. However, there is scarce research information on the effect of organic and inorganic fertilizer on nutritional and toxicological composition of *Amaranthus caudatus* and *Amaranthus cruentus*.

1.2 Statement of Research Problem

According to the Food and Agricultural Organization (FAO), there are about 795 million undernourished people in 2015 (FAO, 2015). To apprehend the situation, interests have been centralized on the exploitation, quantification and utilization of food plants, especially vegetables (Dini *et al*., 2005). In spite of the integrated use of various soil fertility amendment input aimed at alleviating nutrient deficiency and improving their availability in soil reserves, crop and nutrient yield still fall short of their potential because of inadequate nutrient and chemical inputs,

inappropriate quality of the organic materials and insufficient combination (Palmer *et al*., 1997). Various studies has been done on how fertilizer use affect the yield on different plants but fewer research is carried on their effects on growth performance, nutrient and toxicological composition in leafy vegetables especially spinach which is commonly consumed in this part of world.

Furthermore, there are various fertilizers that have been shown to have effect on the yield of spinach in terms of growth. Therefore, it is necessary to investigate the exact effect different sources of organic fertilizers will have on the growth performance, nutrients and toxicological composition *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452).

1.3 Justification

Vegetables are cheaper sources of many nutrients, biochemicals and phytochemicals which are responsible for normal physiological functions and also help in reducing the risk of chronic diseases. To enhance the optimal production of this nutrients and phytochemicals, appropriate use of fertilizers has to be employed. Many organic materials are produced around the home, or can be obtained at little or no cost from livestock operations, municipal green waste collection centers, and local landfills. Virtually any organic material can be used as a fertilizer; however, materials vary considerably in the concentration of plant nutrients they contain and the rate at which these nutrients are released for plant use. Therefore, some organic fertilizers are better for certain situations than others, and different materials need to be applied at different rates to supply the correct amount of plant nutrients (Koenig and Johnson, 1999).

A common misconception is that organic fertilizers are safer for plants and the environment than inorganic (chemical) products. Improper *organic* fertilizer application can also contribute to

surface and ground water pollution, may induce a plant nutrient deficiency or toxicity. If properly used, both organic and inorganic fertilizers are safe for plants and the environment (Koenig and Johnson, 1999). Hence, it is necessary to evaluate the effect organic fertilizers will have on growth performance, nutrients and toxicological composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452).

1.4 Null Hypotheses

Application of different organic fertilizers does not have any effect on growth performance, nutrients and toxicological composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452).

1.5 General Aim

The general aim and objective of this study is to evaluate the effect of different types of organic fertilizers on growth performance, nutrients and toxicological composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452).

1.6 Specific Objectives

The specific objectives of this study are to determine:

i. The effect of different types of organic fertilizer application on growth performance of Amaranth varieties leaves.
ii. The effect of different types of organic fertilizer application on nutrient composition of Amaranth varieties leaves.
iii. The effect of different types of organic fertilizer application on toxicological composition of Amaranth varieties leaves.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Amaranth

In Nigeria, as in most other tropical countries of Africa where the daily diet is dominated by starchy staple foods, vegetables are the cheapest and most readily available sources of important proteins, vitamins minerals, and essential amino acids (Onwordi *et al*., 2009). African leafy vegetables are increasingly recognized as possible contributors of both micronutrients and bioactive compounds to the diets of populations in Africa (Smith and Eyzaguirre, 2007). The continent is rich of vegetable species including amaranths which are among the most popular leafy vegetables on the continent (Maundu *et al*., 2009).

Amaranth is a genus of annual herbs belonging to the family *Amaranthaceae* (Stephens, 2009). Amaranths consist of 60–70 species (Xu and Sun, 2001) and include at least 17 species with edible leaves and three grain amaranths grown for their seeds (Grubben and Denton, 2004). Although, several species are often considered weeds, people around the world value amaranths as leafy vegetables, cereals and ornamentals (Trucco and Tranel, 2011). Originating from Central and South America, amaranth has been cultivated for more than 8,000 years dating back to Mayan, Incan and Aztec civilizations (Svirskis, 2003; Yarger, 2008). Four types of amaranth are presently recognized: grain, vegetable, ornamental and weed but many fall into more than one category (Kauffman and Weber, 1988; Price and Berkelaar, 2006). Grain amaranth is represented by *A. hypochondriacus* (prince's feather), *A. cruentus* (purple amaranth) and *A. caudatus* (love-lies-bleeding) (Yarger, 2008), grain amaranth is not commonly cultivated in Africa (Grubben and Denton, 2004). More recently however, a few farmers have taken the growing of grain amaranth

more seriously and are supplying millers and supermarkets in Zimbabwe, Kenya, Uganda and Ethiopia. Vegetable amaranths grow very well in the hot and humid regions of Africa, Southeast Asia, China and India and are represented by *A. hybridus*, *A. tricolor* (tambala), *A. viridus*, A. *dubius*, *A. cruentus*, *A. edulis* and *A. blitum* (Muyonga *et al*., 2008; Yarger, 2008). Although, *A. caudatus* is a grain type it is often grown more as an ornamental leaf (Ofitserov, 2001; Yarger, 2008). Weedy species are represented by *A. retroflexus* (redroot pigweed), *A. albus* (tumbleweed) and *A. spinosus* (spiny amaranth) (Yarger, 2008).

There is no distinct separation between all the types of amaranth since the leaves of their young plants can be eaten as both human and animal food (Muyonga *et al*., 2008; Yarger, 2008). They are very good sources of vitamins, protein and dietary minerals including calcium, iron, magnesium, phosphorus, potassium, zinc, copper and manganese (Ofitserov, 2001). Since about 1980, Amaranth has been rediscovered as a promising food crop mainly due to its resistance to heat, drought, diseases and pests, and the high nutritional value of both seeds and leaves (Wu *et al*., 2000). According to Onyango (2010), improvement of amaranths through research and development could produce an easy and cost-effective way of eliminating malnutrition and promoting people's health as well as achieving food security. *Amaranthus hybridus* is a nutritious and leafy vegetable from the family of amaranthaceae family and it has a variety of uses (Omoson *et al*., 2008). The local names in Nigeria are *alayyafoo* in Hausa, *efoo* in Yoruba and *imine olu* in Igbo.

2.1.1 Taxonomy and Origin

Amaranthus caudatus belongs to the family Amaranthaceae, it tolerates varying soil and climatic conditions but altitudes of over 1500ft are unsuitable. *Amaranthus caudatus* is widely grown in

West Africa, Indonesia and Malaysia (Iheanacho and Udebuani, 2009). *Amaranthus caudatus* is an annual herbaceous plant of 1- 6 feet high. The leaves are alternate petioled, 3 – 6 inches long, dull green, and rough, hairy, ovate or rhombic with wavy margins (Oke, 1983).

Amaranthus cruentus also belongs to the family Amaranthaceae. *Amaranthus cruentus* is an annual herb that grows up to 2m tall; it is often reddish tinted throughout with stout and branched stems. The leaves are long with petioles arranged spirally without stipules, they are deeply lobed and oval shaped with a sub-acute apex that ends abruptly in a sharp point. Seeds are egg-shaped with an arrow end at the base, whitish to yellowish or blackish in colour (Grubben, 2004). *Amaranthus cruentus* was domesticated as a grain amaranth in Central America from the weed *Amaranthus hybridus* L. from around 6000 years ago. It is a widespread traditional vegetable in all countries of tropical Africa and very important in many lowland areas e.g. in southern Nigeria, DR Congo, Kenya and Tanzania. It is also an important vegetable in many tropical areas outside Africa (Grubben, 2004). The main use of *Amaranthus cruentus* in the past was for its grain, however presently, its leaves are consumed as a vegetable dish or used in sauces; the leaves and tender stems are cut and fried and eaten with cereals and tubers (Grubben, 2004).

2.1.2 Uses of Amaranth

Amaranth is essentially grown for human consumption. In Nigeria, Amaranth leaves combined with condiments are used to prepare soup (Oke, 1983; Mepha *et al*., 2007). In Congo, their leaves are eaten as spinach or green vegetables (Dhellot *et al*., 2006). These leaves boiled and mixed with a groundnut sauce are eaten as salad in Mozambique and in West Africa (Oliveria and DeCarvalho, 1975; Martin and Telek, 1979). Amaranth has been shown to contain large amount of squalene, a compound that has both health and industrial benefits (Rao and Newmark, 1998; Smith, 2000; He *et al.*, 2003). The plant has been used in treating dysentery, ulcers and

hemorrhage of the bowel due to its astringent property. Leaves possess antibacterial effect, cleansing effect and also help to reduce tissue swelling. The basis for the traditional use of this herb in the management of painful related conditions is yet to be scientifically verified (Sumitra and Sandeep, 2011). Amaranth is also used in the treatment of intestinal bleeding, diarrhea and excessive menstruation. A tea made from the leaves is astringent (Omosun *et al*., 2008). Vegetable amaranth has received significantly less research attention than grain amaranth. However, it has been rated considerably higher in minerals, such as calcium, iron, phosphorous and carotenoids (Alegbejo, 2013) than most vegetables. Pharmacological properties of different amaranth species also have been investigated. It was determined that *Amaranthus paniculatus* and *Amaranthus cruentus* are good sources of flavanoids, especially for rutin, which are mostly produced in the stage of blossoming (Martirosyan, 2001).

Usage of amaranth as livestock feed indicated relatively high protein qualities (Sleugha *et al*., 2001). The leaves, shoots and tender stems are eaten as a potherb in sauces or soups, cooked with other vegetables or with a main dish. Chopped plants have been used as forage for livestock. It was reported through the Environment, Community, Health and Observatory (ECHO) network that goats fed amaranth forage consistently bore twins! And, the flowers are nice ornamentals, fresh or dried. Amaranth is not in the grass family, therefore is not considered a cereal grain. However, since it is used much like cereal grains, it's often called a pseudo cereal. Like other small grains, amaranth may be processed in popped, flaked, extruded and ground forms (Sleugha *et al*., 2001).



Fig 2.1 *Amaranthus cruentus* (NH84/452)



Fig 2.2 *Amaranthus caudatus* (Samaru local variety)

2.1.3 Environmental Response of Amaranth

According to Fafunso and Bassir (1975) Amaranth is grown during both wet and dry seasons, though irrigation is normally required for dry season crops since the rate of transpiration by the leaves is fairly high, frequent applications of water are required, related to the stage of growth of the crop and moisture- retaining capacity of the soil. Amaranth is a C4 plant and this characteristic is believed to have contributed to the plants wide geographic adaptability to diverse environmental conditions. However, in cultivation every aspect of production requires special attention and consideration. Amaranth prefers soils with pH above 6 and soil temperature above 15^0C for establishment. Seeding rates of 1.2 to 3.5 kg seed/ hectare planted to an average depth of 1.3cm is recommended. The most accurate commercial seeding rates have been achieved by using vegetables seeders which use seed plates of appropriate size to meter the seed. The most commonly advised fertility guide for amaranth has been 112 to 135 kg/hectare of total available N, P and K.

2.1.4 Cultivation of Amaranth

The crop is adapted to a wide range of soil conditions. Sandy soil with slight acidity is best suited. A temperature range of 20-30^0C is required for better vegetative growth. The land should be ploughed or dug followed by leveling then shallow trenches of width 30 - 35cm well rotten farm yard manure is mixed with soil in the trenches. (Costea and Demason, 2001). Amaranth is planted either by direct seeding or transplanting. The choice of planting method depends on availability of seed and labor and may also vary with growing season. Direct seeding is appropriate when plenty of seeds is available, labor is limited and during the dry season when frequency of watering is less. Transplanting is preferred when there is limited amount of seed,

plenty of labor and during the wet season when heavy rains and flooding are most likely to wash out the seeds. When direct seeding is used, seeds are either broadcast or sown in rows on well-prepared seedbeds. Broadcast seeds uniformly at the rate of 0.5 to 1.0g/m^2 bed; there are about 1000 amaranth seeds per gram. Since amaranth seeds are very small, mix seeds with sand at a ratio of 1g seed to 100g sand to make it easier to sow the seed and obtain a uniform stand, cover seed lightly with a layer of compost or rice hulls immediately after broadcast (Costea and Demason, 2001).

2.1.5 Adaptability of Amaranth

It is highly adapted under lowland condition. Grow well at day temperatures above 25^0C and night temperatures not lower than 15^0C. Amaranths are quantitative short day plants. It consumes high amount of water and uses 6 mm/day. Amaranth prefers fertile, well drained soils with a loose structure. (Aletor and Adeogun, 1995).

2.1.6 Pest and Disease Management of Amaranth

Insect pests and diseases must be controlled to ensure good yield and marketable quality. Amaranth is susceptible to damage by foliar insects such as leaf miners, leaf rollers, cutworms, aphids, flea beetles, and mites. An effective method of controlling insect pests is to cover the bed with a fine screen or nylon mesh netting (32-mesh or finer) (Palada and Chang, 2003). Traditional methods of spreading wood ash to dispel insects have been replaced by spraying regularly up to twice a week with insecticides. Chemical pesticides should be used mainly as a corrective measure. Choose a pesticide that targets the specific insect that is causing the damage, and try to avoid pesticides that kill or inhibit the development of beneficial organisms. Choose pesticides that have short persistence, i.e., the effects last only a few days. Pesticides should be

applied in the evening, and workers should not be allowed into the field until the recommended waiting period (usually 12 to 24 hours) has passed.

2.2 Nutritional Value of Amaranth

Amaranth plants (*Amaranthaceae*) are spread throughout the world, growing under a wide range of climatic conditions and they are known to infest or to produce useful feed and food products (Rastrelli *et al*., 1995). The leaves of amaranth constitute an inexpensive and rich source of protein, carotenoids, vitamin C and dietary fibre (Shukla *et al*., 2006), minerals like calcium, iron, zinc, magnesium (Kadoshnikov *et al*., 2008; Shukla *et al*., 2006), and phosphorus (Ozbucak *et al*., 2007). Grain amaranth leaves are highly nutritious. They are especially rich in vitamin C, β-carotene, folic acid, iron, calcium and proteins (Yarger, 2008). Amaranth grain contains high protein of ranging from 13% to 21% for plant sources (Zheleznov *et al.,* 1997; Yarger, 2008). It is also very high in lysine, an essential amino acid that is low in other grains. Compared with many grains, amaranth grain is high in calcium, phosphorus, iron, potassium, zinc, vitamin E, and vitamin B-complex (Ofitserov, 2001). Both the grain amaranth and leaves are utilized for human as well as for animal food (Tucker, 1986). The nutritional value of amaranth has been extensively studied. It has been shown that amaranth leaves are excellent sources of protein, with its maximal accumulation in the blossoming phase (Kadoshnikov *et al.,* 2005) (17.2–32.6% from dry weight for various samples). Grain amaranth has higher protein than other cereal grains and has significantly higher lysine content (Bressani, 1989).

Amaranth grain consists of 6 to 10% of oil, which is higher than most other cereals. Amaranth oil contains approximately 77% polyunsaturated fatty acids which are mostly within the germ (Whelton, 1997). Amaranth oil is predominantly unsaturated oil which is high in linoleic acid (about 50%), which is necessary for human nutrition. Yanez *et al.,* (1994) showed that oil

extracted from *Amaranthus cruentus* contained 19% palmitic acid, 3.4% stearic acid, 34% oleic acid and 33% linoleic acid. Docosaenoic acid (C22: 1) was present at the level of 9%. The ratio of saturated to unsaturated fatty acids was approximately 1:3. The lipid fraction is unique due to such high biologically active compounds, such as: squalene (up to 8%), tocopherols (to 2%), phospholipids (to 10%), and phytosterols (to 2%). The use of cooked or autoclaved amaranth grain for use as chicken feed, gave production results comparable to those from feeding corn/soybean ration. Processed amaranth (*A.hypochondriacus*) grain is a potentially useful energy supplement for broiler diets and can be incorporated at levels up to 400 g per kg without adverse effects (Ravindran *et al.,* 1996)

2.2.1 Carbohydrates in Amaranth

Polysaccharides constitute the main compositional part of amaranth and its seeds, starch being the main component in this fraction. Starch of various *Amaranthus* species was studied mainly in the 1980s and these studies were reviewed by Teutonico and Knorr (1985). In general, amaranth seeds contain 65% to 75% starch and 4% to 5% dietary fibers in comparison to wheat grain, and nonstarch polysaccharide components (Burisová *et al.,* 2001). Sucrose was the major sugar followed by raffinose, whereas inositol, stachyose, and maltose were found in small amounts in most of the analyzed amaranth seed samples (Becker *et al.,* 1981). However, these figures reported in various articles on different *Amaranthus* species may be in a wider range (Teutonico and Knorr, 1985). Later, the contents of low-molecular-weight carbohydrates in *A. cruentus* and *A. caudatus* were reported in the following ranges (g/100 g): sucrose (0.58 to 0.75), glucose (0.34 to 0.42), fructose (012 to 017), maltose (0.24 to 0.28), raffinose (0.39 to 0.48), stachyose (0.15 to 0.130, and inositol (0.02 to 0.04) (Gamel *et al.,* 2006).

The physicochemical and digestibility characteristics of starch present in diverse food crops, including *A. hypochondriacus,* were reviewed by emphasizing the starch after cooking, the storage of starchy products, and the potential of starch isolated from unconventional sources to produce resistant starch-rich products using different treatments (Bello-Pérez and Paredes-López, 2009). Some studies on the effects of agrotechnological practices and treatments on amaranth composition were also carried out. Presowing stimulation by He–Ne laser light and magnetic field of amaranth seeds resulted in a decrease in the level of carbohydrates (Sujak *et al.,* 2009). The optimum crop density of adapted grain amaranth genotypes "Neuer Typ" and "Mittlerer Typ" (*A. hypochondriacus*) and "Amar" (*A. cruentus*) in eastern Austria was studied and it was found that the contents of crude fiber and carbohydrates were in the ranges of 3.5% to 4.2% and 66.7% to 72.7%, respectively; however, crop density affected neither grain yield nor grain quality (Gimplinger *et al.,* 2007).

2.2.2 Proteins in Amaranth

The contents of proteins and their derivatives have been widely studied and these studies revealed the variations in protein content between different plant species and varieties, for example, as it was shown in the case of 25 *Amaranthus caudatus* cultivars (Imeri *et al.,* 1987). Protein content in 14 selections of 4 amaranth species (*A. caudatus, A. hybridus, A. cruentus,* and *A. hypochondriacus*) varied from 12.5% to 16.0% (Bressani *et al.,* 1987), a 13% to 21% variation was observed in wild and cultivated forms of amaranth; besides albumins and globulins, the proteins were also composed of 20.8% alkali-soluble glutelins with similar nutritive value and 12% alcohol-soluble prolamins that are lacking in essential amino acids (Zheleznov *et al.,* 1997). The analysis of 48 *Amaranthus hypochondriacus* and 11 *Amaranthus*

caudatus lines revealed that *A. caudatus* lines had higher protein content than *A. hypochondriacus* lines (Kaur *et al.,* 2010). Eight groups of *A. cruentus* and *A. hypochondriacus* grain samples grown in Hungary and Austria were studied and it was found that a difference between the lowest (14.23%) and highest (17.40%) protein content was relatively large, suggesting that breeding might be a potential mean for increasing the protein content (Tömösközi *et al.,* 2009). Proteins of amaranth leafy parts were not studied so intensively, although their nutritional value was shown to be also quite high: the chemical score of the essential amino acids from proteins of the leaves of *A. dubius* flour consisting of albumins (73.42%), globulins (6.60%), prolamins (6.47%), and glutelins (6.41%) was 92.83% (Rodríguez *et al.,* 2011). Protein contents were evaluated in the foliage of 61 accessions of grain and vegetable types *Amaranthus* (10 species in total): variation for leaf protein was 14 to 30 and 15 to 43 g/kg (fresh weight) in vegetable and grain types, respectively. Leaf protein of some high-carotenoid lines had a well-balanced amino acid composition with high content of Lys (40 to 56 g/kg) (Prakash and Pal, 1991).

The application of NPK fertilizers increased protein content in *A. caudatus* (Peru) from 12.35% to 14.50% but not in other tested amaranth species. The fertilizers did not affect protein quality either in raw or processed grain (Bressani *et al.,* 1987). With increasing N fertilization rate (120, 180, and 240 kg N/ha), crude protein and true protein increased in *A. hypochondriacus* forage (Abbasi *et al.,* 2012). The Pacesetter Grade B organic fertilizer and organic manures kola pod husk, alone or combined with reduced level of NPK, generally increased crude protein significantly on immediate and residual basis; however, the organic fertilizers had more residual effect than NPK. For instance, the organic manures kola pod husk applied with NPK at the ratio

of 75:25 resulted in higher crude protein content by 19.8% and 14.9% in *Amaranthus cruentus* grown on 2 soil types in Lagos, Nigeria (Makinde *et al.,* 2010).

2.2.3 Lipids in amaranth

Lipids are very important nutritive constituents of Amaranth and its seeds, with triacylglycerols (TAGs), phospholipids, squalene, and lipid-soluble vitamins such as tocopherols being the main components in the lipophilic fraction. Various minor components, such as phytosterols, waxes, and terpene alcohols have also been reported in different *Amaranthus* species. The content of all these components in amaranth seeds primarily depends on plant species and cultivar, whereas the extractable amount of lipids also depends on their isolation procedure and the applied solvent. Some earlier performed studies reported the content of lipids in amaranth seeds between 4.8% and 8.1% (Saunders and Becker, 1984). However, later investigations showed that it varies in a wider range depending on the species, cultivar, agrotechnological practices, and growing location and may be present at remarkably higher concentrations. For instance, crude fat percentages in 21 accessions of 8 amaranth species varied from 5.2% to 7.7% on the dry basis of the seeds (Budin *et al.,* 1996), whereas in another study, which analyzed 14 selections from 4 species (*A. caudatus, A. hybridus, A. cruentus,* and *A. hypochondriacus*), it was from 7.7% to 12.8% (Bressani *et al.,* 1987) and from 10.6% to 16.7% (12 accessions) (Kraujalis and Venskutonis, 2013). Comparison of 48 *A. hypochondriacus* and 11 *A. caudatus* lines demonstrated that the *A. caudatus* lines had a higher fat content as compared to *A. hypochondriacus* lines (Kaur *et al.,* 2010). Crude fat content in adapted grain amaranth genotypes “Neuer Typ” and “Mittlerer Typ” (*A. hypochondriacus*) and “Amar” (*A. cruentus*) in

the Pannonian region of eastern Austria was 5.4% to 8.6%; however, crop density affected neither grain yield nor grain quality (Gimplinger *et al.,* 2007).

The accumulation of oil in "Rawa" and "Aztek" *A. cruentus* varieties was affected by fertilization; the highest content was determined when the plants were treated with the highest level of nitrogen/phosphorus/potassium (NPK) fertilizer. In addition, Aztec variety had a higher content of fat than "Rawa" (Skwaryło-Bednarz, 2012). Some effects of NPK fertilizers on the content of fat were also observed earlier in 4 *Amaranthus* samples of 3 species, although the increasing NPK application level did not have any clear effect, since for both *A. cruentus* samples, a decrease was observed, while for *A. caudatus*, there was an increase (Bressani *et al.*, 1987).

2.2.4 Micronutrients in Amaranth

Amaranths have excellent nutritional value because of their high content of essential micronutrients such as beta-carotene, iron, calcium, vitamin C and folic acid (Priya *et al.*, 2007). *Amaranthus hybridus* has higher content of minerals than *Vernonia amygdalina* Delile, *Telfairia occidentalis* (Aletor *et al.*, 2002). Schonfeldt and Pretorius (2011) found that raw leaves of *Amaranthus tricolor*, *Cleome gynandra* L., and *Corchorus olitorius* L. contained the highest concentration of iron, zinc as well as phosphorus and calcium, respectively, and compared with *Vigna unguiculata* L. and *Cucurbita maxima*. Cooked *Cucurbita maxima* and cooked *Amaranthus tricolor* had higher magnesium levels than other three cooked vegetables. One cup of amaranth leaves that are cooked, boiled, and drained contains 90 % vitamin C daily value requirement, 73 % vitamin A, 28 % calcium and 17 % iron. The vitamin composition of the plant is higher than those reported for *Aspilia Africana* (Pers.), *Bryophyllum pinnatum* (Lam.) Oken,

Vernonia amygdalina, *Eucalyptus globules* L. and *Ocimum gratissimum* L. (Alabi *et al.*, 2005). The leaves of vegetable amaranth are also a good source of vitamin C and folate (Onyango *et al.*,, 2008). When compared to spinach, *Amaranthus spp* contains 3 times more vitamin C, calcium, iron and niacin (Mnkeni *et al.*, 2007). It contains 18 times more vitamin A, 20 times more calcium and 7 times more iron when compared to lettuce. Amaranthus leaves have high levels of carotene and micronutrients such as sodium, copper, manganese, chloride (Mnkeni *et al.*, 2007).

The contents of P, Na, K, Mg, Ca, Cu, Fe, Mn, and Zn were similar among 14 selections of *A. caudatus, A. hybridus, A. cruentus*, and *A. hypochondriacus* (Bressani *et al.*, 1987). Later, it was reported that the concentrations of minerals in seeds of 8 groups of *Amaranthus cruentus* and *Amaranthus hypochondriacus* grain samples grown in Hungary and Austria varied through a relatively wide range; the microcomponents, like Fe, Zn, and Cu, were present in higher concentrations in amaranth seeds compared to the average values determined in wheat. The contents of some minerals (Fe, Cu, and Na) in *A. cruentus* were affected by plant heading, while the concentrations of others (Mg, Zn, Ca, and K) did not change significantly (Musa *et al.*, 2011). Pre-sowing electromagnetic stimulation of amaranth seeds with laser light or/and magnetic field significantly decreased the levels of K, Ca, Mg, Na, Cu, and Mn, while stimulation with both electromagnetic methods significantly increased the level of Zn and Fe. Air classification increased the content of minerals by more than 35%; thermal treatments did not have effect, whereas germination increased the contents of Ca and Zn in *A. caudatus* and *A. cruentus* seeds (Gamel *et al.*, 2006). NPK fertilization was shown to affect the contents of Cu, Zn, and Fe levels in *A. cruentus* leaves, and Cu and Mn in seeds (Skwaryło-Bednarz *et al.*, 2011).

2.3 Toxic Aspects of Amaranth

Lehmann (1992), in a review article, identifies some of these reported anti-nutritional factors in amaranth to be phenolics, saponins, tannins, phytic acid, oxalates, protease inhibitors, nitrates, polyphenols and phytohemagglutinins. Of these, oxalates and nitrates are of more concern when amaranth grain is used in foraging applications. Heavy metals contamination in crops has been a recent issue on toxicity; plants have been contaminated by various heavy metals like cadmium, lead, mercury, arsenic and so on. Some studies suggest thermal processing of amaranth, particularly in moist environment, prior to its preparation in food and human consumption may be a promising way to reduce the adverse effects of amaranth's anti-nutritional and toxic factors.

2.3.1 Anti-nutrients in Amaranth

Anti-nutritional factors are a chemical compounds synthesized in natural food and / or feedstuffs by the normal metabolism of species and by different mechanisms (for example inactivation of some nutrients, diminution of the digestive process or metabolic utilization of food/feed) which exerts effect contrary to optimum nutrition (Soetan and Oyewol, 2009). Such chemical compounds, are frequently, but not exclusively associated with foods and feeding stuffs of plant origin. These anti-nutritional factors are also known as ‘secondary metabolites’ in plants and they have been shown to be highly biologically active. These secondary metabolites are secondary compound produced as side products of processes leading to the synthesis of primary metabolites. One major factor limiting the wider food utilization of many tropical plants is the ubiquitous occurrence in them of a diverse range of natural compounds capable of precipitating deleterious effects in man, and animals compound which act to reduce nutrient utilization and/or food intake are often referred to as anti-nutritional factors (Shanthakumari, *et al.,* 2008).

Antinutrients are chemicals which have been evolved by plants for their own defense, among other biological functions and reduce the maximum utilization of nutrients especially proteins, vitamins, and minerals, thus preventing optimal exploitation of the nutrients present in a food and decreasing the nutritive value. Some of these plant chemicals have been shown to be deleterious to health or evidently advantageous to human and animal health if consumed at appropriate amounts (Ugwu, and Oranye, 2006)

2.3.1.1 *Tannins*

These are water-soluble and complex polyphenolic secondary metabolites manufactured by plants for protection against herbivores, microbes and potential frugivores (Masette *et al.,* 2015). Tannins greatly affect the nutritive value of foods eaten by humans and feedstuffs eaten by animals (Mueller-Harvey, 2001). The content of tannins reported in various *Amaranthus* cultivars was in a very wide range, from 0.4 to 5.2 mg/g; however, these fluctuations might be due to the differences between plant species and cultivars and due to the differences in measurement method. The condensed tannin extracts of raw, cooked, and roasted grains, as well as raw, cooked, and blanched vegetables, showed antidiabetic effects by inhibiting α-amylase and α-glucosidase activity up to 50% and 78%, respectively. Roasting of grains and cooking of vegetables better preserved the tannins and their functional properties than soaking plus cooking and blanching (Kunyanga *et al.,* 2011).

2.3.1.2 *Saponnins*

Saponins are high-molecular-weight glycosides, consisting of a sugar unit(s) linked to a triterpene or a steroid aglycone (Murthy *et al*., 2010). Saponins were found to reduce the bioavailability of nutrients and decrease enzyme activity and it affects protein digestibility by

inhibit various digestive enzymes such as trypsin and chymotrypsin (Gemede and Ratta, 2014). Saponins were not detected in the Peruvian ecotype of *Amaranthus caudatus* by fast atom bombardment-MS of the saponin extracts and GC analysis of the sapogenols after acid hydrolysis of the extract (Cuadrado *et al.,* 1995). However later, four different forms of saponins were identified in *Amaranthus cruentus* (Junkuszew *et al.,* 1998); their total concentration was 0.09% to 0.1% dry weight, which increased during 4 days of germination to 0.18%, remained stable for 3 days, and afterward dropped to 0.09% (Oleszek *et al.,* 1999). It was concluded that amaranth saponins due to their low content and relatively low toxicity do not create a significant hazard for the consumer. Saponins, phytic acid, and trypsin inhibitors were present in the *Amaranthus cruentus* concentrate obtained by extraction at pH 11 and precipitation at pH 4.5; it was suggested that consumption of the APC might reduce the risk of heart disease by favoring lipid metabolism (Escudero *et al.,* 2004).

2.3.1.3 *Oxalate*

A salt formed from oxalic acid is known as an oxalate, strong bonds are formed between oxalic acid, and various other minerals, such as Calcium, Magnesium, Sodium, and Potassium. Some oxalate salts such as calcium oxalate has the tendency to precipitate (or solidify) in the Kidney or in the Urinary tract leading to formation of Kidney stones (Gemede and Ratta, 2014). Oxalic acid forms water soluble salts with metals rendering these minerals unavailable to animals (Liener, 2005). Amaranths in addition to their high nutritional value also accumulate high levels of anti-nutritional factors such as oxalates. Research indicates that oxalate plays various functional roles in plants, including calcium regulation, plant protection and detoxification of certain metals. It is well established from the studies carried out by many workers on animals that oxalates present in foods interfere with the assimilation of calcium (Gupta *et al.,* 2005).

The distribution of oxalates in plants is also very variable. Some green leafy vegetables such as spinach, purple and green amaranth and colocasia contain very high oxalate levels (Brogren and Savage, 2003). There is high levels of between 8% and 10% dry weight basis in *Amaranthus cruentus* and *Amaranthus viridis* respectively, while *Amaranthus spp*. contained 1.1% to 7.9% oxalic acid contents in the dry weight (Radek and Savage, 2008; Ricardo, 1993). Oxalate accumulation in the leaves is affected by different factors such as soil conditions, climate, species or cultivar, and maturity hence the need to document the levels of oxalate in vegetable amaranth grown with effluent water.

2.3.1.4 *Phytate*

Phytate (is also known as Inositol hexakisphosphate (InsP6)) is the salt form of phytic acid, are found in plants, animals and soil. It is primarily present as a salt of the mono- and divalent cations and accumulates in the seeds during the ripening period. Phytate works in a broad pH-region as a highly negatively charged ion, and therefore its presence in the diet has a negative impact on the bioavailability of divalent, and trivalent mineral ions such as Zn^{2+}, Fe^{2+}, Ca^{2+}, Mg^{2+}, Mn^{2+}, and Cu^{2+} (Gemede and Ratta, 2014). Whole grains of amaranth contain comparatively high concentrations of phytic acid, an inhibitor of intestinal absorption of Fe and other minerals; therefore, it was measured in several studies, mainly in association with the Fe uptake studies when amaranth is used in food formulations. In earlier studies, the presence of phytates in amaranth grain was reported as between 4.8 and 34.0 μmol/g, while recently the measured amount of phytates in the amaranth seed was 21.1 μmol/g (Sanz-Penella *et al.*, 2012). The content of phytates may be reduced by germination of the seeds (Gamel *et al.*, 2006). Several groups have studied antinutritional factors of amaranth seeds. The phytic acid and phenol contents in *A. cruentus*, *A. hybridus*, and *A. hypochondriacus* ranged from 5.2 to 6.1 g/kg, and as

phytate is present throughout, kernels dehulling did not reduce its content, whereas the tannin content in dehulled seeds decreased by 80% (Lorenz and Wright, 1984). The content of phytate in *A. cruentus* and *A. hypochondriacus* seeds was reported as 5.0 to 5.8 and 5.4 to 6.2 g/kg, respectively (Teutonico and Knorr, 1985), while in the other study, the levels of phytic acid in *A. caudatus* and *A. cruentus* seeds were 4.4 and 3.2 g/kg, respectively, which decreased on germination (Colmenares de Ruiz and Bressani, 1990).

2.3.2 Total Aflatoxins

Aspergillus flavus is a fungus that was first recognized to cause aflatoxicosis in domestic animals and is the most important aflatoxin-producing species in food on a global basis. It produces aflatoxin B_1 (AFB_1) and aflatoxin B_2 (AFB_2) and affects many commodities, but most human exposure comes from contaminated corn (also referred to as maize), peanuts (also referred to as groundnuts) and rice. Another important producer of aflatoxin, *Aspergillus parasiticus*, produces AFB_1, AFB_2, aflatoxin G_1 (AFG_1) and aflatoxin G_2 (AFG_2) and is primarily associated with peanuts in the Americas, but can also occur on corn, figs and pistachios. Of these four aflatoxins, AFB_1 is most frequently present in contaminated samples; AFB_2, AFG_1 and AFG_2 are generally not reported in the absence of AFB_1. Aflatoxin M_1 (AFM_1) is the hydroxylated metabolite of AFB_1; in areas of high aflatoxin exposure, humans are exposed to AFM_1 more or less exclusively through milk and milk products, including breast milk (Joint FAO/WHO Expert Committee on Food Additive, JECFA 2016).

Aflatoxins appear when a producing strain of *Aspergillus flavus* or *Aspergillus parasiticus* grows in a substrate, where environmental conditions favor their development. The genotype of each species, some biological, environmental and chemical factors determine the amount of aflatoxin produced by aflatoxicogenic strains in the substrate. The fungi *Aspergillus spp*. is stimulated by

physical factors such as temperature, relative humidity of the atmosphere and substrate, or by biological, biochemical and environmental factors. The principal factors for aflatoxin production are: the aflatoxicogenic fungus, the substrate, environmental and substrate humidity (an environmental relative humidity of 85% corresponds to a wetness content of 16.5-18% of the grain), temperature, oxygen of the storage atmosphere and time of storage.

The aflatoxin production in the substrate can happen in the field and in storage conditions between 20 and 40°C with a 10-20% of humidity, and 70-90% of relative humidity in the air. Aflatoxins can be formed in storage conditions or in the cereal fields before harvest. These fungi grow at temperatures from 8 to 55 °C being 36 to 38 °C the optimal ones, and 25 a 35 °C for aflatoxin production; beginning at 11 to 14 °C and stopping aflatoxin production below 10 °C or more than 45°C. *A. parasiticus* grows mainly in tropical or subtropical areas; *A. flavus* develops in a wide range of temperatures in substrates with high hydrocarbon content, nevertheless many non aflatoxicogenic strains do the same, therefore the fungi presence do not indicate the existence of aflatoxins (Joint FAO/WHO Expert Committee on Food Additive, JECFA 2016).

2.3.3 Heavy metals

The pollution of agricultural soils by heavy metals is widespread. Long-term sewage irrigation may lead to the accumulation of heavy metals in agricultural soils. Improper treatment and disposal of industrial wastewaters are major causes of soil contamination by heavy metals (Nordberg *et al.*, 2011). Heavy metal toxicity is one of the oldest environmental problems and remains a serious health concern today. Cadmium (Cd) is common toxic heavy metals in the environment. The general public is exposed to Cd and Pb through the ambient air, drinking water, food, industrial materials and consumer products (Zhai *et al.*, 2015). The application of

soil amendments to immobilize heavy metals is a promising technology to meet the requirements for environmentally sound and cost-effective remediation (Gupta *et al.,* 2007).

Vegetables are important edible crops and are an essential part of the human diet. They are rich in nutrients required for human health, and are an important source of carbohydrates, vitamins, minerals, and fibers (Hu *et al.,* 2013). Heavy metals can be readily taken up by vegetable roots, and can be accumulated at high levels in the edible parts of vegetables, even heavy metal in soil at low levels (Yang *et al.,* 2016). Vegetable species differ widely in their ability to take up and accumulate heavy metals, even among cultivars and varieties within the same species (Säumel *et al.,* 2012). Alexander *et al.* (2006) reported that Pb significantly accumulated in lettuce and onion, while Cd accumulated to the greatest extents in spinach and lettuce. Yang *et al.* (2016) found that Chinese leek, pak choi, and carrot had higher Cd concentrations in their edible parts than radish, cucumber, and tomato. Säumel *et al.* (2012) reported that Zn concentrations in green beans, tomato, potato, kahlrabi, and carrots were significantly lower than the concentrations in leafy vegetables. It has been reported that vegetable amaranths has a way of concentrating metals in their tissues and or that aerial deposition may be a major source of contamination (Atayese *et al.,* 2009.) Heavy metal concentrations in Amaranthus cultivated on soils characterized by heavy traffic were significantly higher ($P \leq 0.05$) than those cultivated on the reference soil which had been collected from the rural communities (Atayese *et al.,* 2009). (Othman, 2001) collaborated this finding and studied five varieties of green vegetables namely amaranth, Chinese cabbage, cowpeas, leafy cabbage and pumpkin leaves. He found out that Amaranth and pumpkin leaves had more than 60% higher content of heavy metals especially copper, chromium and lead than the other vegetables. It has been reported that the lead content of vegetable amaranth collected

from twenty one supermarkets in Kenya averaged 1.03 mg/100g dry weight (Onyango *et al.*, 2008).

The Joint FAO/ World Health Organization Expert Committee on Food Additives (JECFA) established a provisional tolerable weekly intake (PTWI) for lead as 0.025 mg/kg body weight (JECFA, 2004). The WHO provisional guideline of 0.01 mg/L has been adopted as the standard for drinking water (WHO, 2004a). The Joint FAO/WHO has recommended the PTWI as 0.007 mg/kg body weight for cadmium (JEFCA, 2004). The EPA maximum contaminant level for cadmium in drinking water is 0.005 mg/L whereas the WHO adopted the provisional guideline of 0.003 mg/L (WHO, 2004a).

2.4 Fertilizers

A fertilizer material is a fertilizer which either contains important quantities of no more than one of the primary plant nutrients: nitrogen (N), phosphorus (P) and potassium (K), or has 85% or more of its plant nutrient content present in the form of a single chemical compound, or is derived from a plant or animal residue or by-product or natural material deposit which has been processed in such a way that its content of plant nutrients has not been materially changed except by purification and concentration." (AAPFCO, 1997). There is only limited information available on the fertility requirements of amaranth but nitrogen is reported to be the primary limiting factor in amaranth production (Pospisil *et al.,* 2006). Various studies have shown that yield differences of amaranth cultivars were due to nitrogen availability (Pospisil *et al.,* 2006) and individual cultivar traits (Nyankanga *et al.,* 2012).

2.4.1 Inorganic Fertilizers

Artificial fertilizers are inorganic fertilizers formulated in appropriate concentrations and the combinations supply three main nutrients: nitrogen, phosphorus and potassium (N, P and K) for various crops and growing conditions. N (nitrogen) promotes leaf growth and forms proteins and chlorophyll. P (phosphorus) contributes to root, flower and fruit development. K (potassium) contributes to stem and root growth and the synthesis of proteins (Corradini *et al*., 2010). 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. According to Stalknecht and Schultz-Schaeffer (1993) a general suggested fertilization guide for Amaranthus is 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. 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 (N-P-K).

Plants grown with poultry manure had better yields when compared to those grown with kraal manure (Spreeth *et al.*, 2004). There are a number of studies examining the effects of fertilization on grain amaranth yield and protein content (Bressani *et al.*, 1987; Elbehri *et al.*, 1993; Myers, 1998; Olaniyi, 2007). Most studies found a significantly positive correlation between increasing fertilizer application, typically N, and yield with applications of up to 90 kg N/ ha (Myers, 1998). Myers (1998) observed the effect of N-fertilizer on Amaranthus species grain yield, yield components and growth and development investigated in three Missouri environments with 5-levels of N-fertilizer and 3 cultivars. Averaged across cultivars and environments, N fertilizer act and top rate of 180 kg/ha produced a yield increase of 42% relative to plots receiving no

fertilizer. Although amaranth yield is responsive to N-application, high rates of N fertilizer can negatively affect grain harvest in terms of excessive plant height, increased lodging and delayed crop maturity. Optimum nutrient amounts reported for maximum amaranth growth by different researchers are substantially different. Apart from the use of inorganic fertilizers, the level of organic compost in the soil is very essential in promoting crop growth. The complementary use of organic compost and mineral fertilizer has been recommended for sustenance of long term cropping in the tropics (Palm *et al.,* 1997). Akambi and Togun (2002) reported that optimum N and P uptake by amaranth was obtained when 30 tons/ha compost was applied along with 30 N Kg/ha fertilizer while the best K uptake was obtained with plants treated with 1.5 tons/ha compost plus 60 N kg/ha.

Another study conducted in Croatia by Pospisil *et al.* (2006) examined the effects of chemical N fertilizer on grain amaranth yield and protein content, finding a yield response in dry years, but no effect on protein content. On this basis, the authors concluded that organic production of grain amaranth was a possibility in soils where moisture is adequate for provision of plant available N. This shows how environmental conditions greatly affect plant density and soil fertility management on grain amaranth. It also shows that nitrogen is major nutrient affecting grain amaranth (Olaniyi *et al.,* 2008). Lucas (1988) recommended application of 50-100 kg N, 20-60 P_2O_5 and 40-60 K_2O kg/ha after two weeks of planting. Babatola and Olaniyi (1999) revealed that 120 kg and 160 N kg/ha have the best yield of *Amaranthus caudatus.*

On evaluation of nitrogen fertilization rates between 0 and 180 kg/ha in Missouri, by Myers in 1998, grain amaranth yields increased with nitrogen fertilization up to 90 kg, while Elbehri *et al.* (1993), in Minnesota obtained yield response with nitrogen fertilization up to 180 kg/ha, with no response to phosphorus and potassium. Yields increased from 1094 kg/ha with nitrogen

application to 1428 kg/ha with nitrogen applied at 180 Kg/ha. Therefore most studies examining the effects of fertilization on grain amaranth yield (Bressani *et al.,* 1987; Elbehri *et al.,* 1993; Myers, 1998; Olaniyi, 2007) have shown a significantly positive correlation flanked by increasing fertilizer application, typically N, and yield of grain amaranth. The N needed for the growth of a crop will vary depending on the N status of the soil and potential for mineralization. Therefore, optimum N amount reported for maximum amaranth growth by different researchers are substantially different. The reported range varies from 50-200 N kg/ha (Keskar *et al.*, 1981). All studies agree that supplemental N is required for optimum amaranth yield. However, few of these studies did not explore organic soil amendments as a nutrient source, nor did they test amaranth responses in nutrient-poor soils. Additionally, most studies did not report initial plant available nutrient levels prior to fertilizer application.

2.4.2 Organic Fertilizers

Organic fertilizers are usually known as manures. Manure such as cattle and chicken waste, and other bulky, natural substances that are applied to the soil with the intention of increasing the productivity of crops. Nutrient content of manure varies depending on source, moisture content, storage, and handling methods (Van Averbeke and Yoganathan, 2003). Manures are a source of almost all the essential nutrients (Ogunlela *et al*., 2005). Adding manure to compacted soil helps loosen the soil. Manure produces increased soil carbon, which is an important source of energy that makes nutrients available to plants. Other benefits of manure include reduced runoff and leaching of nitrates in the soil. Organic matter in soil improves moisture and nutrient retention. The added organic matter increases the moisture holding capacity of the soil, lowers soil bulk density, and improves overall soil structure, thus increasing the efficiency of crop production and irrigation. Manure is quickly decomposed under warm, moist soil conditions (Haynes, 2008).

Manure is considered a slow-release plant fertilizer; it provides small amounts of nutrients over an extended period. This makes it an acceptable form of mulch for plants (Hamilton, 2009).

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

Premsekhar and Rajashree (2009) performed an experiment to determine the influence of different organic manures on growth, yield and quality of okra. The organic manures they used were farm yard manure, poultry manure, vermicompost and neemcake. Results revealed that all the organic manure treatments showed positive effect on growth and yield characters. Akparobi (2009) studied the effect of different level of farmyard manures on the growth and yield of *Amaranthus cruentus*. The amaranthus treated with the highest level of manure attained the highest plant height than those that received no manure. Emede *et al.* (2012) reported that 15 tons/ha and 20 tons/ha poultry manure influenced higher herbage yield on *Amaranthus cruentus*

L. Dahdoh and Hassan (1997) reported that, the effect of adding sewage sludge rates to calcareous loam and loamy soils, irrigated with waters of differing salinity using broad bean plants. The results shows a significant increase of broad bean yield when using sewage sludge up to 2% in calcareous loam irrigated by tap water or saline water but the yield under tap water irrigation is always higher.

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. Apaza-Gutierrez *et al.* (2002), who tested yield response of *A.caudatus* and *A. hypochondriacus* to application of dried organic sheep manure (7.5 and 15 ton/ha) in Bolivian soils with moderate levels of organic matter and low levels of NPK. Both species showed a linear yield response to organic and chemical fertilizers and a quadratic response to a mixture of the two. Yield response to fertilization by chemical fertilizer was 29% greater than for the manure treatment.

2.4.3 Effect of Fertilizers during Germination, Emergence and Growth

Seed germination and early seedling growth are regulated by distinct physiological processes following water imbibition by the seed that are almost certainly not fully understood. Of these the respiration process is probably the most important initial physiological activity (Hurro and Cees, 1991). The process is crucial simply because it fulfils two essential, but competitive, key roles namely the breakdown of substrates to supply energy and the alteration of substrates to intermediates required for biosynthesis (Botha *et al.*, 1992). In essence respiration is an energy supplying process and entails a series of events, including glycolysis, the Krebs cycle and the oxidative pentose phosphate (OPP) pathway, depending on the availability of oxygen (Oryokot

et al., 1997). Initially a germinating seed experiences a lack of oxygen, due to the impermeability of the seed coat, and anaerobic respiration proceeds where only glycolysis is involved and energy supply is rather limited (Bewley and Black, 1994). However, the availability of O_2 appears to be a critical factor for germination and successful seedling establishment (Crawford, 1978).

The overall respiration process involves a series of oxidation-reduction reactions whereby compounds are completely broken down to CO_2 and water while energy is released in the form of ATP and NADH (Pinheiro and Chaves, 2011). Especially carbohydrates such as starch, sucrose, glucose and fructose, but also lipids and protein can serve as respiratory substrate. However, the respiration rate in plant tissues is related to both substrate supply and energy demand (Dwivedi, 2000).

When seed is sown to a stand, very high amounts of organic fertilizer can kill some seedlings, slow emergence of others and decrease the number of plants which establish. Initially, various forms of placement were tested but these involved the use of more sophisticated and expensive equipment than that which was already present on most farms. Later work showed that an initial broadcast application permits full establishment and gives optimum early growth. Once the crop is established, the required balance of organic fertilizer can be applied with impunity at the 2-4 true leaf stage (Amstrong *et al.*, 1983). In addition to improving the colour of the leaves, nitrogen in fertilizers noticeably increases their size and number. Early in the season, therefore, nitrogen increases dry matter production per unit area, mostly from leaves and petioles (Amstrong *et al.*, 1983). Later in the season, nitrogen maintains this increase in leaf and petiole dry matter. In practical terms, nitrogen fertilizer applications need to be planned to boost the early growth of

the leaf canopy, to maintain it throughout the period until harvest but to avoid excessive vegetative growth which inevitably depresses root quality (Goodlass *et al*., 1997).

2.4.4 Frequency and Timing of Application of Fertilizers

Crop, soil and nutrient type influence the time of fertilizer application. The development pattern of vegetable crops differs, and therefore nutrient needs vary. Rainfall and temperature influence the availability of nutrients to plants, from the time they are applied, until when they are used by the plant. Fertilizer should be applied when plants need it, when it will be most effective, and when plants can readily take it up. The best way to ensure that added nutrients are used efficiently by plants and to reduce the risk of nutrient loss to the environment is to match nutrient availability to plant demand over time. Annual crops, perennial crops and pastures all have different patterns of nutrient demand over time, and respond differently according to soil moisture status and temperature (Rantae, 2013).

2.4.5 Influence of Fertilizers on Yield and Quality

Optimum use of fertilizer results in higher yield and better crop quality. For example, the protein content of cereals can be increased by proper management of nitrogen, in particular by providing adequate nitrogen for full growth. Similarly, a proper supply of phosphorus and potassium increases the sugar and starch contents of crops, while secondary and micronutrients also play important roles in improving crop quality (Lairon *et al*., 1984). The quality of crop products depends on inherited genetic makeup and on environmental (external) factors. The inherited factors determine the basic quality specific to the crop and variety while the environmental factors affect the realization of the inherited potential, by regulating it in different ways. Balance use of plant nutrients plays a vital role in determining the quality of the produce. Frequently,

quality is improved by fertilizer application up to an optimum level, while applications well in excess of this may lead to lower quality, either because of a straightforward nutrient excess or because of imbalance between nutrients (Marschner, 1986).

2.5 Soil

Throughout the 1990's interest in soil quality and understanding its importance has come to the forefront of environmental sustainability (Wallace and Terry, 1998). The terms soil quality; soil degradation, soil health, and soil resilience are being used more frequently and with greater urgency in connection with strategies to protect our global environment. The needs to improve our quality of life and protect many scarce natural resources are forcing society to recognize the importance of their soil resource. However, soil quality and land management both have a direct influence on water and atmospheric quality and, by extension, to human and animal health (Doran and Parkin, 1994; Kennedy and Papendick, 1995). Soil is a vital resource for producing the food and fiber needed to support an increasing world population (Pappendick and Parr, 1992).

2.5.1 Application of Organic Compost to Improve Soil Quality

The increased demand for animal production for food has significantly increased the amount of manure produced. In addition, with the increase of urban sprawl and the human population the amount of sewage sludge and solid waste will also continue to grow (Zhu, 1998). Agricultural by-products have the potential to be recycled and used to help improve soil quality. Animal manures have long been used to help recycle nutrients and improve soil tilts on agricultural fields (Edwards *et al*., 1995). They are an excellent source of nutrients such as N, P, K, Ca, and Mg and have a high content of organic carbon (Zhu, 1998). Recently use of land-applied, composted

animal waste has become a more attractive option for enhancing soil quality in turf management, the forestry industry and the reclamation of soils contaminated by mining (Zhu, 1998).

Organic composts such as dairy and swine manures are land-applied because they can improve soil quality by modifying various physical, chemical and biological soil properties. The main benefit of organic amendments is the addition of organic carbon and organic matter. Organic matter, in turn, influences many soil properties including aggregation, pH, nutrient retention and microbial diversity. Organic amendments improve physical properties by mainly increasing soil organic matter and increasing biological activity (Stewart *et al*., 2000). A reduction in bulk density and increased soil porosity and infiltration are very common when organic amendments are used (Herrick and Lal, 1995). Miller *et al.*, (1985) reported changes to soil chemical properties following applications of swine manure, namely an increase in soil pH from 5.2 up to 8.0 and a decrease in redox potential (Eh).

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Materials

3.1.1 Chemicals

Chemicals and reagents used were purchased from (Sigma chemical Company St. Louis, U.S.A) and were of analytical grade.

3.1.2 Seeds

The seeds of *Amaranthus caudatus* (Samaru local variety) were obtained from local farmers in Samaru Zaria while the seeds of *Amaranthus cruentus* (NH84/452) were obtained from National Horticultural Research Institute (NIHORT) Ibadan. *Amaranthus caudatus* sample collected was authenticated at the herbarium unit of Biological Sciences Department, Ahmadu Bello University Zaria, Nigeria and a voucher specimen was deposited. The voucher number was as follows;

- *Amaranthus caudatus* (Samaru local variety) – (Voucher No: 585)

3.1.3 Study Area

The field experiment was carried out in the nursery of a homestead garden at No 20 Isaiah Balat Street, Sabo GRA Sabo Tasha, Kaduna state.

Kaduna metropolis has a tropical savanna climate with dry winters characterized by maritime air and rainfall is between April and October with an annual raining days ranging from 81 to 103 during the reference period, the annual mean rainfall values range from 145.37mm to 318.67mm. From the figures above, ample rains are available for the production of many agricultural crops. During harmattan, dry desert wind blows between December and mid February while night

temperature is very low. The geographical location of Kaduna metropolis is Latitude $9^{0}03^{1}$N and $11^{0}32^{1}$N north of the equator and Longitudes $6^{0}05^{1}$ E and $8^{0}38^{1}$ E East of the Greenwich meridian. Kaduna metropolis has a sub-humid semi arid tropical climate with maximum annualmean temperature ranging from 25.30^{0}C to 36.20^{0}C while the minimum annual mean temperature range of 28.45^{0}C to 34.38^{0}C. (Abdullahi *et al*., 2009).

3.1.4 Soil Sampling

Surface soil sample was taken from the experimental site at a depth of 0 – 15cm at land preparation (after ploughing and harrowing) using the zigzag method (Brady and Weil, 2008). The sample was collected from twenty points and bulked to form a composite sample. The composite sample was air-dried, crushed and sieved through a 2mm mesh sieve and stored for chemical analysis.

3.1.5 Fertilizers

3.1.5.1 *Poultry manure*

The poultry manure was collected at Ishaya"s poultry farm in Sabo GRA, Sabo Tasha Kaduna state.

3.1.5.2 *Sewage sludge*

The dried packed sewage sludge was collected at the sewage site of Ahmadu Bello University Zaria.

3.1.5.3 *NPK compound fertilizer*

NPK compound fertilizer (15:15:15) was bought at Kawo market Kaduna State.

3.2 Methods

3.2.1 Soil Analysis

The sampled soil was analyzed at the Soil Science Department of the Institute of Agricultural Research, Ahmadu Bello University Zaria, Nigeria. The following parameters were analyzed in the sampled soil; particle size, pH (in water), organic carbon, available phosphorus, total nitrogen, cation exchange capacity (CEC) and exchangeable bases (Burt, 2014).

3.2.1.1 *Determination of soil particle size*

Fifty grams of 2mm sieved soil was weighed into a 250mL plastic beaker. Then 100ml of 50% calgon was added into the beaker and stirred with a glass rod. Distilled water of 100ml was also added and stirred. It was left to stand for about 30mins with occasional stirring. The sample was transferred into a mixing cup and the content of the beaker was washed into the cup and stirred for 5mins. The mixture was then transferred completely into a 1000cm3 measuring cylinder and made up to 1000cm^3 marks with water. The suspension was thoroughly mixed using a long-handle plunger to ensure that the sediment at the bottom of the cylinder is completely disturbed. Hydrometer readings were taken at 40sec and 2hrs. Before reading is due, the hydrometer was lowered gently into the suspension. Readings were taken at the top of the meniscus. A blank cylinder was prepared by making 100mL of 50% calgon solution up to 1ltr mark with water. Hydrometer readings were also taken for the blank at 40sec and 2hrs. Temperatures of both the

suspension and the blank were taken. After the last reading, the suspension was poured through a 0.2mm mesh sieve. Sand grains retained on the sieve were washed with water into a beaker and dried in an oven at 105^0C (Burt, 2014).

Calculations:

The corrected hydrometer readings C(g/L) were obtained by subtracting the blank reading RL(g/L) from the hydrometer readings in the soil suspension R(g/L) and adding 0.36g/L for every degree above 20^oC

C=R - RL + (0.36T)

Where T=Room temperature minus 20

The percentages by weight of the Silt, Clay and Sand are given by:

$$\%\text{clay} = \frac{corrected\ 2hrs\ reading\ -Blank\ x\ 100}{weight\ of\ soil\ taken}$$

$$\%\text{silt} = \frac{corected\ 40\ \text{sec}\ reading - Blank\ x\ 100 - \%clay}{weight\ of\ soil\ taken}$$

%sand = 100 – (% clay + % silt)

The sample was then classified according to the USDA or International Systems of Textural Classification

3.2.1.2 *Determination of soil pH (in Water)*

Twenty grams of air-dry soil (passed 2nm sieve) was weighed into a 50ml beaker and 20ml of distilled water was added. The suspension was stirred several times during the next 30 minutes

with a glass rod. The soil suspension was allowed to stand for about 30 minutes to allow most of the suspended clay to settle out of the suspension. The electrodes of the pH meter were inserted into the partly settled suspension and the pH was measured (Burt, 2014).

3.2.1.3 *Determination of soil organic carbon (Walkley-Black method)*

A representative sample was taken and ground to pass through a 0.5nm sieve. One gram of the sample was weighed and placed in the 250ml flask. Then 10ml of 1N $K_2Cr_2O_7$ solution was pipette accurately into each flask and the flasks were swirled gently to disperse the soil. Then 20ml conc. H_2SO_4 was rapidly added from a measuring cylinder. The flask was immediately swirled gently until the soil and reagents were mixed and then swirled more vigorously for one minute. The flask was rotated again and allowed to stand on a sheet of asbestos for about 30 minutes. After that 100ml of distilled water was added and was allowed to cool again. Then 5ml of phosphoric acid was added to sharpen the colour change at the end point. Before titration, 3 drops of indicator were added and the solution was titrated with 0.5N ferrous sulphate solution on a white background. As the end point was approached, ferrous sulphate was added in drops until the colour changed sharply from blue to red in reflected light against a white background. The blank solution was prepared in the same way but without soil to standardize the dichromate (Burt, 2014).

Calculation:

$$\% \text{ Organic Carbon in soil} = \frac{(\text{Blank titre} - \text{actual titre}) \times 0.003 \times m \times f}{\text{g of air dry soil}}$$

Where:

f = Correction factor = 1.33

m = Concentration of $FeSO_4$

3.2.1.4 *Determination of soil available phosphorus (Extractable Phosphate - Bray and Kurtz – Method)*

One gram of soil was weighed into a 25ml bottle with screw cap. Then 7ml of the extraction solution was added (with pipette). The container was shaken for exactly 1 minute and the suspension was filtered into a dry bottle or beaker. After which 2ml of the filtrate (pipette) was transferred to a dry 25ml beaker. Then 5ml of ammonium molybdate reagent and 1ml stannous chloride dilute solute were added to the filtrate in the beaker and mixed. It was then made up to the $10cm^3$ mark. The colour development was measured after 10 minutes at 890nm on a Spectronic 20. The absorption was read. The standards were measured in the same way (Burt, 2014).

3.2.1.5 *Determination of soil total nitrogen (Kjeldahl Method)*

One gram of fine mesh soil was weighed into 500ml Kjeldahl flask or a digestion tube. Some few drops of water were added and allowed to stand for about 30mins. Five gram of Kjeldahl catalyst and 20ml of concentrated sulphuric acid were added. The flask was heated cautiously on a sand bath until frothing ceased. The temperature was then increased until digest cleared and for another 2hrs. The flask was cooled and little water was added with care before the content was washed into a 100ml volumetric flask. The content was allowed to cool completely and was then made up to mark. Then 10ml of the digest was pipetted into a distillation flask. After that 20ml 2% Boric acid was measured into a 100ml conical flask and the flask was introduced to the bottom of the condenser (3 drops of mixed indicator were added). Then 10ml of 10N NaOH was added to the 10ml digest in the distillation flask. The distillating unit was immediately

introduced and the digest was distilled-off. About 50ml of the distillate was then collected. The distillate was titrated with 0.01N H_2SO_4 from green to purple end point (Burt, 2014).

Calculation:

$$\%\text{Nitrogen} = \frac{0.014 \times (T - 1) \times NA \times \text{Vol. of digest} \times 100}{\text{Weight of soil} \times \text{Aliquot distilled}}$$

3.2.1.6 *Determination cation exchange capacity (CEC) (Ammonium saturation method)*

Ten grams of air-dried (2mm) soil was weighed into a 500ml Erlenmeyer flask and 40ml NH_4OAc was added. The flask was shaken thoroughly and allowed to stand overnight. The soil was filtered with light suction using a 55-mm Buchner funnel (Corning size No. 40). The soil was not allowed to become dry and cracked. The soil was leached with the neutral 1N NH_4OAc reagent until no tests for calcium could be obtained in the effluent solution. (For the Ca test, a few drops of 1N NH_4Cl, 10% ammonium oxalate, and dilute NH_4OH of the leachate were added to a test tube, and the solution was heated close to its boiling point. The presence of Ca was indicated by a white precipitate). The leachate for the determination of exchangeable cations was preserved. The soil was leached about four times with neutral 1N NH_4Cl and once with 0.25N NH_4Cl (25ml of each was used). The electrolyte was washed out with 200ml of 99% isopropyl alcohol. The soil was transferred and filtered to 500ml Kjedahl flask. After that 200ml of distilled water, few drops of liquid paraffin, pumice beads to prevent fuming and bumping and 10ml of 1N NaOH were added. About 60ml of the solution was distilled into 50ml of 2% Boric acid solution measured into a 250ml Erlenmeyer flask. Ten drops of bromocresol green-methyl red mixed indicator was added and the NH_4-borate produced with standard 0.02N H_2SO_4,

filtered. Blanks were run on the reagents. The titre was corrected with the blank results. The colour change was from bluish green through bluish purple to pink at the end point (Burt, 2014).

Calculation:

$$CEC\ (\frac{meq}{100g}) = (T - B)x\ N\ x\frac{100}{}W$$

Where:
T = Vol of acid used in titration
B = Titre value for blank
N = Normality of acid used
W = Weight of soil used

3.2.1.7 *Determination of exchangeable bases (Ca, Mg, K and Na)*

The leachates preserved from the CEC determination (i.e after dilution) were used for the determination of Ca, Mg, K and Na with AAS Perkin Elmer AAnalyst 400. The standard readings for the different concentrations of each cation were used to plot a graph of Absorbance vs Concentration (ppm) (Burt, 2014). The operational conditions for the metals are:

i. Wavelengths at 422.7nm, 285.2nm, 766.5nm and 589.0nm for Ca, Mg, K and Na respectively.
ii. Slit of 0.7nm, 0.7nm, 0.7nm and 0.2nm for Ca, Mg, K and Na respectively.
iii. Relative noise at 1.0, 1.0, 1.0 and 1.0 for Ca, Mg, K and Na respectively.
iv. Linear range of 5.0 mg/L, 0.5 mg/L, 2.0 mg/L and 1.0 mg/L for Ca, Mg, K and Na respectively.

Calculation:

$$\text{Excahangeables bases (meq/100g)} = \frac{\text{ppm graph x V.E. x DF x 100}}{\text{1000 x W x Eq Wt. of element}}$$

Where:
V.E. = Volume of extractant
DF = Dilution factor
W = Wt of soil used

3.2.2 Experimental Design and Fertilizer Treatment

The experiment included seven (7) fertilizer treatments for each of the two (2) varieties of Amaranth which are in factorial arrangement fitted into a randomized complete block design (RCBD) and replicated three times. Hence, the experiment had a total of 42 experimental plots. The treatments are as follows;

i. Control (no fertilizer)
ii. 5 tons/ha poultry manure
iii. 10 tons/ha poultry manure
iv. 5 tons/ha sewage sludge
v. 10 tons/ha sewage sludge
vi. 35kg/ha NPK compound fertilizer
vii. 70kg/ha NPK compound fertilizer

3.2.3 Planting and Nursery Management

Prior to planting, the amaranth seeds were soaked in water for about 24 hours in order to enhance germination. The soaked seeds were first sown in the nursery of about 1.9 cm deep and were

watered twice daily. Appropriate nursery management practices were carried out as at when needed to obtain healthy and uniform seedlings.

The experimental site was ploughed, harrowed and prepared into slightly raised beds (plots) of 25cm width × 80cm length dimension preparatory to transplanting the crop seedlings. During land preparation, poultry manure and sewage sludge were incorporated according to treatment level to specific plots, and thoroughly mixed with the soil and then left for two weeks to allow for mineralization. Half of the NPK Compound fertilizer was applied at day of transplanting while the balance was applied one week later as shown in Appendix 1.

After two weeks in the nursery, randomly picked seedlings were transplanted to the well prepare beds (plots). The seedlings were watered twice daily using watering can and the surrounding areas were weeded regularly. The experimental area and the surroundings were kept clean to prevent harbouring of pest. Insects were controlled by using "Dime Force Insecticide" with concentration of 1.5 L/ha.

3.2.4 Data Collection for Growth Performance

Data were first collected two weeks after transplanting (WAT) and subsequently at one week interval for up to six weeks after transplanting. Two randomly selected plants were tagged and used in each plot for data collection. Data collected included: plant height, number of leaves, leaf length and leaf width, while the leaf area and leaf area index were computed as shown in Appendix 2. Chemical analysis for nutrient and toxicological compositions were determined after harvesting.

3.2.4.1 *Determination of plant height*

Plant height is the length of the plant from the base of the stem (surface of the soil) to the apex of the leaves. Plant height was measured using a measuring tape for the two tagged plants per plot and the average computed (Masarirambi *et al*., 2012).

3.2.4.2 *Determination of number of leaves*

The number of leaves was counted from the two tagged plants and the average computed (Masarirambi *et al*., 2012).

3.2.4.3 *Determination of leaf length and leaf width*

The leaf length and leaf width were determined by measuring the length and width of the two tagged leaves using a ruler and the average was computed. The leaf length was measured from the leaf base to the tip whereas the leaf width was measured at the broadest part of the leaf blade (Masarirambi *et al*., 2012).

3.2.4.4 *Determination of leaf area*

The Leaf Area (LA) was computed by multiplying the Leaf Length (LL) by the Leaf Width (LW) and the product multiplied by the correction factor (Masarirambi *et al*., 2012).

Calculation;

Leaf Area = (Leaf Length × Leaf Width) 0.578.

3.2.4.5 *Determination of leaf area index*

The leaf area index (LAI) was computed using this formula (Msibi *et al.*, 2014)

$LAI = Y \times N \times LA \times (AP)^{-1}$

Where:

Y = Population of plants per plot (5 plants)

N = Average number of leaves

LA = Leaf area

AP = Area of plot (25cm width * 80cm length = 2000cm^2)

3.2.5 Harvesting of the Vegetable

The leaves of the spinach grown in field experiment in control and treated soil were harvested at vegetative phase (market maturity) of plant development and were used for analysis.

3.2.6 Preparation of Plant for Analysis

The leaves of each treatment were uniformly mixed before sampling and prepared for appropriate analysis as below.

3.2.6.1 *Preparation of plant for chemical analysis*

Upon arrival at the laboratory, the fresh and healthy vegetable were immediately washed under tap water and excessive water dripped off. Edible portions of the vegetables were cut into small pieces and homogenized using a Commercial Blender for two minutes. The homogenized sample was used for analysis immediately, but otherwise were transferred into an air-tight container and kept at -20°C before analysis (Abuye *et al.*, 2003)

3.2.6.2 *Preparation of plant for mineral and heavy metals analysis*

Upon arrival at the laboratory, the fresh and healthy vegetables were immediately washed under tap water to remove all soil particles and then spread on newspaper for drying. After sun drying, the plants were weighed and oven dried at 70^0C for 72 hrs. The herbage was grounded. The powdered form was kept for mineral and heavy metals analysis (Abuye *et al.*, 2003). The

minerals that were analyzed are Iron (Fe), Zinc (Zn), while heavy metals were Lead (Pb) and Cadmium (Cd).

3.2.7 Estimation for Proximate Composition

The macronutrient compositions of each treatment were determined using the procedures of A.O.A.C. (1999). The macronutrient composition consist of ash content, moisture content, crude protein, total fat, crude fibre, available carbohydrate and total energy.

3.2.7.1 *Determination of moisture*

A washed and dried platinum dish was weighed as W_1 with an analytical balance, and then 3g of the sample was added and weighed as W_2. The dish and its content was then transferred into a desiccator, then to an oven and left for three hours at 105^0C until the water completely dried. The platinum dish was transferred and cooled in the desiccator and weighed as W_3.

Calculation;

$$\% \text{ Moisture content} = \frac{(W_2 - W_3)}{(W_2 - W_1)} \times 100\%$$

3.2.7.2 *Determination of ash content*

A cool dry platinum dish was weighed as (W_1) using an analytical balance and 3g of the sample was added and weighed (W_2). Then it was pre-ash on open flame and then transferred using a tong into a muffle furnace at 550^0C until it fully ashes (the colour changes to grey) and then weighed as (W_3).

Calculation;

$$\% \text{ Ash content} = \frac{(W_3 - W_1)}{(W_2 - W_1)} \times 100\%$$

3.2.7.3 *Determination of total fat*

Two grams of the sample was weighed into a clean dry test tube. Then 10ml of distilled water and 10ml of conc. HCl were added and placed in a boiling water bath for 30 minutes for hydrolysis. The hydrolysed sample was cooled and transferred to the separating funnel. The test tube was rinsed with 10ml ethanol and added to the experimental separating funnel. Then to the experimental separating funnel, 30ml 0f diethyl ether was added and shaken then allowed to settle for separation to occur. A clean dry empty conical flask was weighed as W_1. The ether layer was collected in a pre-weighed conical flask. The ethanol layer was re-extracted twice with 25ml diethyl ether and the ether layer was added to the pre-weighed flask and the combined ether extract was evaporated over a boiling water bath. After the evaporation, the evaporated conical flask was placed in an oven maintained at 105^{o}C for 2hrs after which it was cooled in the desiccator and weighed again as W_2.

Calculation:

$$\% \text{ Fat} = \frac{W_2 - W_1}{W} \times 100\%$$

3.2.7.4 *Determination of crude protein using Kjeldahl method*

Digestion:

One gram of the sample was weighed into a distillation flask, 25ml of conc. H_2SO_4 was added and a pinch of $CuSO_4$ and anti-bumps were added. The resulting mixture was digested till the mixture becomes colourless. Then removed from heating and allowed to cool.

Distillation:

Exactly 200ml of distilled water was poured into the mixture followed by 85 ml of 50% NaOH and then rinsed with another 50ml of distilled water for neutralization. Then it was distilled in the upper layer of the Kjeldahl apparatus, where 50ml of 2% boric acid with 3 drops of screened methyl red in a 250ml conical flask was used to collect the released ammonia gas.

Titration:

About 200ml of the distillate was collected in the conical flask and titrated using 0.05M of H_2SO_4 till colour changes from blue light red. The titre value was recorded as (V).

Calculation:

$$\% N = \frac{V \times 0.0014 \times 100}{\text{Weight of sample (W)}}$$

W is the weight of sample taken

% Protein = %N X F

F is factor equal to 6.25

3.2.7.5 *Determination of crude fibre*

Two grams of the sample was put into a round bottom flask, 100ml of (0.23M) sulfuric acid solution was added and the mixture boiled under reflux for 30 minutes. The hot solution was quickly filtered under suction. The insoluble matter was washed several times with hot water until it was acid free. This was quantitatively transferred into the flask and 100ml of hot (0.312M) sodium hydroxide solution was added and the mixture boiled again under reflux for 30 minutes and quickly filtered under suction. The insoluble residue was washed with boiling water until it was alkaline free. It was dried to constant weight in the oven set at 105^0C, cooled in a desiccator and weighed (C_2). The weighed residue was then incinerated in a muffle furnace at 550^0C for 30 minutes, cooled in the desiccators and reweighed (C_3).

Calculation:

$$\% \text{ Crude Fibre} = \frac{C_2 - C_3}{W} \times 100$$

W = Weight of original sample.

C_2-C_3 = the loss in weight on ashing (incineration).

3.2.7.6 *Determination of available carbohydrate*

Available carbohydrate was determined by calculation

Available Carbohydrate (%) = 100 – (Ash + Moisture + Protein + Fat + Crude fibre)

3.2.7.7 *Estimation of total energy*

Total energy will be estimated as follows:

Total energy (Kcal) = (Total carbohydrate x 3.57) + (crude protein x 2.44) + (total fat x 8.37)

Total Carbohydrate = available carbohydrate + crude fibre

3.2.8 Estimation of micronutrients

3.2.8.1 *Estimation of water soluble vitamins using HPLC*

For the purpose of this research, the water soluble vitamins that were estimated were Vitamin C (Ascorbic acid), Vitamin B2 (Riboflavin) and Vitamin B3 (Niacin). These water soluble vitamins were determined using a procedure of A.O.A.C (1999).

3.2.8.1.1 Buffer preparation

Sodium hexane sulphonic acid salt of 1.8822g was weighed into a 2L volumetric flask. Then 1500ml of de-ionized water was added and shaken to dissolve, then 20ml of glacial acetic acid was added and the resulting solution was made up to mark with de-ionized water and sonnicated. The concentration of the buffer prepared was 0.1M sodium hexane sulphonic at pH 4.9.

3.2.8.1.2 Analytical Standards

Ascorbic acid (VIT C) (Reagent grade), Riboflavin (B2) (Reagent grade) , Niacinamide/Nicotinamide (B3) (Reagent grade)

3.2.8.1.3 Chromatography

Hitachi Elite LaChrome Auto sampler HPLC L-2200, Hitachi pump L-2130, Hitachi UV-VIS detector L-2420, Hitachi Column Oven L-2350, Chimei monitor and laser Jet 1320 printer, Chromatographic analysis was carried out isocratically using the following:

i. Wavelength: 275nm
ii. Column: Waters Spherisorb / Restek Allure C18, 5µm ODS2, 4
iii. Flow rate: 1.0 ml/minute
iv. Mobile phase: 30% Methanol: 70% Buffer (300ml Methanol: 700ml Buffer)

3.2.8.1.4 Preparation of mobile phase

Methanol (HPLC grade) of 300ml was measured using a class A 500ml measuring cylinder and was poured into a 1L class A amber volumetric flask. The 1L volumetric flask was made up to mark with hexane suphonic acid solution and then transferred into an instrument solvent reservoir bottle and sonnicated for 30 minutes.

3.2.8.1.5 Preparation of standards

The preparation of individual stock standard solution, intermediate mixed stock standard solution and mixed working standard solution was done appropriately.

3.2.8.1.6 Calibrants

The Calibrant of each standard was prepared at five different levels. Calibration curve was plotted using calibrant versus absorbance.

3.2.8.1.7 Preparation of sample for HPLC analysis

Two grams of the blended sample was taken into a 25ml amber volumetric flask and 5ml of the sodium hexane sulphonic acid buffer solution was added. The resulting solution was mixed for 5 minutes using a Vortex mixer and made up to mark with sodium hexane sulphonic acid buffer solution. The solution was filtered with Whatman filter paper (2) and the filtrate was transferred into the auto sampler vials, corked and was loaded into the auto-sampler tray. One (1µl) micro liter of the sample was injected twice in HPLC using the auto-sampler for analysis.

3.2.8.2 *Determination of β-carotene*

β-carotene content was determined by ethanol and petroleum ether extraction method (Musa *et al.*, 2010). Two grams of Na_2SO_4 was added to 10g of vegetable leaves and ground in mortar.

The ground vegetable was extracted with 100ml of hot 95% ethanol for 30 min in hot water bath. The extract obtained was filtered and measured. Water was added to the extract to bring the percentage of the ethanol extract to 85%. The 85% ethanol extract was cooled in a cold water bath for some minutes. After cooling, the ethanol extract was put inside separating funnel and 30ml of petroleum ether was added and the mixture shaken. The separating funnel was clamped to the retort stand for some time to allow the solution to settle down into layers. The bottom layer containing ethanol was collected into the beaker while the top layer of the petroleum ether was stored in 250ml conical flask. The ethanol layer in the beaker was re-extracted twice with 10ml of petroleum ether. The ether layers of re-extraction was added to the original petroleum extract in the conical flask and re-extracted with 50ml of 85% ethanol in order to remove any xanthophylls which may be present. The top petroleum ether layer which contained β-carotene was collected, measured and the volume noted.

Lastly, the optical density (OD) of the final petroleum ether extract was determined at the wave length of 450 nm with spectrophotometer using petroleum ether as blank.

Calculation:

The concentration of β-carotene (µg/100g) was calculated thus:

$$\mathbf{C = \frac{A \times E^{\%}}{L}}$$

Where:

A = Absorbance of the sample
$E^{\%}$ = Extinction coefficient of β-carotene in petroleum ether (2592)
L = Path length (usually 1.0 cm)

3.2.8.3 *Estimation of mineral content using AAS*

For the purpose of this research, the minerals that were estimated are Iron (Fe) and Zinc (Zn). The minerals were determined using a Perkin Elmer AAnalyst 400 AAS.

3.2.8.3.1 Preparation of Ash sample

The ash sample was prepared using a procedure by Association of Analytical Chemist (A.O.A.C., 1999). A platinum plate was weighed as (W_1) using a Mettler weighing balance and then 3g of the dried grinded sample was weighed into the empty platinum dish as (W_2), the sample was pre-ashed on a Bursen burner and transferred into a furnace with temperature set at 550^0C for ashing to occur. After completion of ashing, the resulting dish was weighed as (W_3). The exact weight of the test sample measured was gotten from $W_2 - W_1$

3.2.8.3.2 Preparation of sample for AAS analysis

The resulting ash in the dish was dissolved with 1% Nitric acid and transferred into an 100ml volumetric flask, and made up to mark with 1% Nitric acid. The resulting solution was filtered using Whatman (1) filter paper and the filtrate was taken for analysis using AAS.

3.2.8.3.3 Estimation of Iron and Zinc using AAS

The filtrate gotten from the ash was used to determine the concentration of Iron (Fe) and Zinc (Zn) using a PerkinElmer AAnalyst 400 ASS. The operational conditions for the metals are:

i. Wavelengths at 213.9nm and 248.3nm for Zn and Fe respectively.
ii. Slit of 0.7nm and 0.2nm for Zn and Fe respectively.
iii. Relative noise at 1.0 and 1.0 for Zn and Fe respectively.
iv. Linear range of 1.0 mg/L and 6.0 mg/L for for Zn and Fe respectively.

3.2.9 Estimation of Toxicological Properties

The toxicological properties that were analyzed are tannins, saponin, phytate, oxalate, heavy metals (lead and cadmium) and total aflatoxins.

3.2.9.1 *Determination of tannins*

The analysis of tannins content was performed according to the International Pharmacopoeia (2003) and AOAC (1965) method, after some modifications. Three grams of the sample was extracted with distilled water into 250ml volumetric flask for 4 hours at room temperature and then the sample was filtered. Then 25ml of the infusion was measured into 1L conical flask, 25ml of indigo solution and 750ml distilled water was added. Aqueous solution of $KMnO_4$ (0.1N) was used for titration until the blue coloured solution becomes green colour. Then few drops were added at a time until solution becomes golden yellow. Standard solution of Indigo carmine was prepared as following: Six grams Indigo carmine was dissolved in 500ml of distilled water by heating, after cooling 50ml of 97% H_2SO_4 was added; the solution was diluted to 1L and filtered. The blank test was carried out by titration of the mixture of 25ml Indigo carmine solution and 750ml distilled water.

Calculation:

$$\text{Tannins content (\%)} = \frac{(V-V0) \times 0.004157 \times 250 \times 100}{g \times 25}$$

Where V is the volume of 0.1N aqueous solution of $KMnO_4$for the titration of the sample (ml); volume of 0.1N aqueous of $KMnO_4$for the titration of the blank sample (ml): 004157 – tannins

equivalent in 1ml of 0.1N aqueous solution of $KMnO_4$: g – mass of the sample taken for the analysis; 250 – volume of the volumetric flask, ml; 100 – percent, %.

3.2.9.2 *Determination of saponins (Hudson and El-Difrawi, 1979)*

Ten grams of sample was taken into a 100ml 0f 20% aqueous ethanol in water and agitated with a magnetic stirrer for 30minutes. The solution was filtered using whatman No 1 filter paper and the residue was re-extracted with 300ml of 20% aqueous ethanol. The extracts was combined and reduced to about 40ml under vacuum using a rotary evaporator. The extract and 20ml diethyl ether was transferred into a 250ml separatory funnel and shaken vigorously. The aqueous layer was discarded. The process of purification was continued until a colourless aqueous extract was obtained. The pH of the remaining aqueous solution was adjusted to 4.5 by adding 4g of sodium chloride and the solution then shaken successively with butanol. The butanolic extract was washed twice with 10ml of 5% (W/V) NaCl and evaporated to dryness in a fume cupboard, to give the saponin, which was weighed and expressed as a percentage.

Calculation:

$$\% \text{ Saponin} = \frac{\text{Weight of saponin}}{\text{Weight of original sample}} \times 100\%$$

3.2.9.3 *Determination of phytate*

Phytic acid was determined by the procedure of Lucas and Markakas (1975). Two grams of the sample was weighed into a 250 mL conical flask. Then 100ml 2% HCl was used to soak sample for 3hr and then filtered with a Whatman No1 filter paper. After that 50ml of the filtrate and 10ml of distilled water was added in each case to give proper acidity. Then 10ml 0.3% ammonium thiocyanate solution was added into the solution as indicated and titrated with

standard Iron II Chloride solution containing 0.00195g Iron/ml to get a persistent yellow end point.

Calculation:

% Phytic acid = y × 1.19 × 100

Where,

y = titre value × 0.00195 g

3.2.9.4 *Determination of oxalate*

Oxalate was determined by using the method of Sanchez-Alonso and Lachica (1987). One gram of the sample was placed in 250ml volumetric flask, 190 ml of distilled water and 10ml of 6M HCl were added. The mixture was then warmed in a water bath at 90°C for 4hr and the digested sample centrifuged at 2,000 rpm for 5 min. The supernatant was then diluted to 250ml. Three 50ml aliquots of the supernatant was evaporated to 25ml, the brown precipitate was filtered and washed. The combined solution and washings were then titrated with concentrated ammonia solution in drops until the pink colour of methyl orange changed to yellow. The solution was then heated in a water bath to 90°C and the oxalate was precipitated with 5% $CaCl_2$ solution was allowed to stand overnight and then centrifuged, precipitate was washed with hot 25% H_2SO_4, diluted to 125 ml with distilled water and titrated against 0.05 M $KMnO_4$.

Calculation:

1 mL 0.05 M KMnO4 = 2.2 mg Oxalate

3.2.9.5 *Determination of heavy metals*

Lead (Pb) and Cadmium (Cd) were determined using atomic absorption spectroscopy as described for the method of determination of mineral content. A Perkin Elmer AAnalyst 400 was used. The operational conditions for the metals are:

i. Wavelengths at 228.8nm and 283.3nm for Cd and Pb respectively.

ii. Slit of 0.7nm and 0.7nm for Cd and Pb respectively.

iii. Relative noise at 1.0 and 0.43 for Cd and Pb respectively.

iv. Linear range of 2.0 mg/L and 20.0 mg/L for Cd and Pb respectively.

3.2.9.6 *Determination of total aflatoxins*

Five grams of the sample was weighed in a sample bottle and 25ml of acetonitrile water (84:16) was added to the sample. The sample was shook for 3mins at 250 rpm using an orbital shaker, the resulting mixture was filtered using a filter paper with the aid of a funnel into a centrifuge tube and cleaned up the filtrate using a mycosep clean up column. Then 500 µl of the cleaned filtrate was pour into a vial and heated using a heating block, it was then reconstituted with NaOH:H_2O (70:30) and 200 µl of the conjugate was added. After that 100µl of the standard was added into the first 6 wells and 100µl of the samples were added into the other wells and incubated for 15mins at room temperature. It was then washed and dried; 100µl of the substrate was added into each well and incubated for 5mins, after which a stop solution was added. The total aflatoxins was read (ppb) using an ELISA Reader (Stat fax 303/Plus)

3.2.11 Statistical analysis

Data was analyzed using the Statistical Package for Social Sciences (SPSS) version 21.0 computer package. Descriptive statistics was used to determine the measures of central tendency. Means were separated using Duncan Multiple Range test. Values with different superscripts down the column are significantly different at $p<0.05$.

CHAPTER FOUR

4.0 RESULTS

4.1 Physical and Chemical Properties of Soil and Organic Fertilizers.

4.1.1 Physical and Chemical Properties of the Soil used in this Experiment

Results of analyses of the soil used for this experiment are shown in Table 4.1.1. The texture class of the soil is sandy clay loam in which sand was highest with value of 66 ± 2.0%, followed by clay with 24 ± 3.0% and silt was the lowest with value of 10 ± 1.0%. The soil organic carbon, total nitrogen and available phosphorus were 0.46 ± 0.02%, 0.32 ± 0.01% and 7.4 ± 0.30ppm respectively. The exchangeable bases of Sodium, magnesium, calcium, potassium and cation exchange capacity (CEC) contents were 0.34 ± 0.02Cmol/Kg, 0.84 ± 0.02Cmol/Kg, 3.26 ± 0.05Cmol/Kg, 0.65 ± 0.03Cmol/Kg and 5.7 ± 0.20Cmol/Kg respectively. Soil pH value was 7.7 ± 0.2.

4.1.2 Chemical Properties of Organic Fertilizers used in this Experiment

Results of analyses of the organic fertilizers used for this experiment are shown in Table 4.1.2. Poultry manure showed a pH of 7.62 ± 0.04, while the concentrations for total nitrogen, available phosphorus and potassium were found to be 3.53 ± 0.02%, 0.71 ± 0.05% and 1.61 ± 0.03% respectively. Sewage sludge pH was found to be 8.25 ± 0.09; the concentrations of total nitrogen, available nitrogen and potassium were gotten as 2.44 ± 0.03%, 0.97 ± 0.02% and 1.33 ± 0.05% respectively.

Table 4.1.1: Physical and Chemical Properties of Soil used in this Experiment.

Physical and Chemical Properties of Soil used in Experiment	
Particle size	
• **Clay**	24 ± 3.0 %
• **Silt**	10 ± 1.0 %
• **Sand**	66 ± 2.0 %
Texture Class	Sandy Clay Loam
pH (in Water)	7.70 ± 0.20
Organic Carbon	0.46 ± 0.02 %
Available Phosphorus	7.40 ± 0.30 ppm
Total Nitrogen	0.32 ± 0.01 %
Exchangeable bases	
• **Calcium (Ca)**	3.26 ± 0.05 Cmol/Kg
• **Magnesium (Mg)**	0.84 ± 0.02 Cmol/Kg
• **Potassium (K)**	0.65 ± 0.03 Cmol/Kg
• **Sodium (Na)**	0.34 ± 0.02 Cmol/Kg
• **Cation Exchange Capacity (CEC)**	5.70 ± 0.20 Cmol/Kg

Values are mean ± standard deviation of triplicate analysis.

Table 4.1.2: Chemical Properties of Organic Fertilizers used in this Experiment

Chemical Properties of the Organic Fertilizers used in the Experiment				
	pH (in H_2O)	Total Nitrogen (%)	Available Phosphorus (%)	Potassium (%)
Poultry manure	7.62 ± 0.04	3.53 ± 0.02	0.71 ± 0.05	1.61 ± 0.03
Sewage sludge	8.25 ± 0.09	2.44 ± 0.03	0.97 ± 0.02	1.33 ± 0.05

Values are mean ± standard deviation of triplicate analysis.

4.2 Effect of Different Organic Fertilizers and Different Concentrations on Growth Performance of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

4.2.1 Effect of Organic Fertilizers on Plant Height of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

Plant height was significantly ($p<0.05$) higher in plants derived from poultry manure treated plots applied at 10 tons/ha treatment and lowest in plants derived from no fertilizer treatment plots for both *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) as shown in Fig 4.2.1, Fig 4.2.2, Appendix 2 and 3.

At 2 Weeks After Transplanting (WAT), the plant height was highest at 26.28±1.07cm and 45.97±0.88cm from poultry manure applied at 10 tons/ha treatment for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively as shown in Fig 4.2.1, Fig 4.2.2, Appendix 2 and 3.

At 3WAT, plots with 10tons/ha poultry manure showed the highest plant height for *Amaranthus caudatus* (Samaru local variety) with value of 58.33±2.39cm while for *Amaranthus cruentus* (NH84/452) NPK compound fertilizer applied at 70Kg/ha had the highest plant height of 77.43±3.52cm.

At 4WAT, poultry manure applied at 5tons/ha had the highest plant height of 89.48±2.57cm for *Amaranthus caudatus* (Samaru local variety) but was not significantly different from 10tons/ha poultry manure, 35Kg/ha and 70Kg/ha NPK compound fertilizer, while *Amaranthus cruentus* (NH84/452) showed the highest plant height of 110.57±5.38cm for 10tons/ha poultry manure.

At 5WAT, poultry manure applied at 10tons/ha had the highest plant height of 106.73±1.26cm for *Amaranthus caudatus* (Samaru local variety) but was significantly different from the other

treatments except the 5tons/ha poultry manure, while *Amaranthus cruentus* (NH84/452) showed the highest plant height of 122.87±1.41cm for 10tons/ha poultry manure.

At 6WAT, poultry manure applied at 10tons/ha had the highest plant height of 118.10±1.32cm and 135.67±2.92cm for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively, and was lowest for treatments with no fertilizer at 98.73±2.30cm and 110.02±2.77cm for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively. Plant height for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively was 112.83±1.94cm and 132.52±4.24cm, 107.65±0.95cm and122.53±4.02cm, 109.58±1.78 and125.87±3.60cm, 105.30±1.77cm and 119.98±1.89cm, and 108.80±0.69cm and 125.55±1.43cm at fertilizer treatments of 5tons/ha poultry manure, 5tons/ha sewage sludge, 10tons/ha sewage sludge, 35Kg/ha NPK Compound fertilizer and 70Kg/ha NPK Compound fertilizer respectively as shown in Fig 4.2.1, Fig 4.2.2, Appendix 2 and 3.

Amaranthus cruentus (NH84/452) consistently had higher plant heights than *Amaranthus caudatus* (Samaru local variety) independent of the treatments. Poultry manure elicited higher plant height than NPK compound fertilizer, sewage sludge and control in decreasing order in both varieties of amaranth used. Increase in plant height in all treatments were dose and time dependent, there was a consistent increase in plant height across the weeks after transplanting to maturity of the plants.

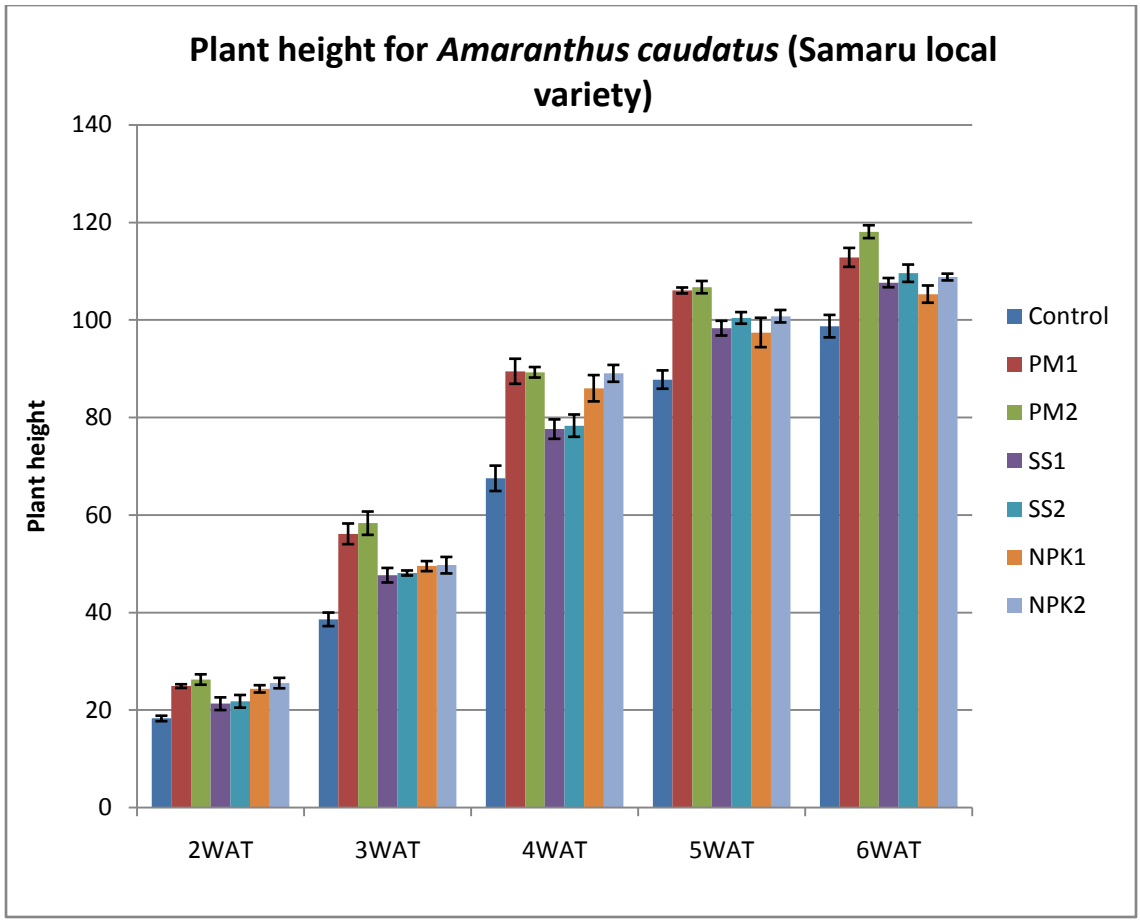


Fig 4.2.1: Effect of Organic Fertilizers on Plant Height of *Amaranthus caudatus* (Samaru local variety)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

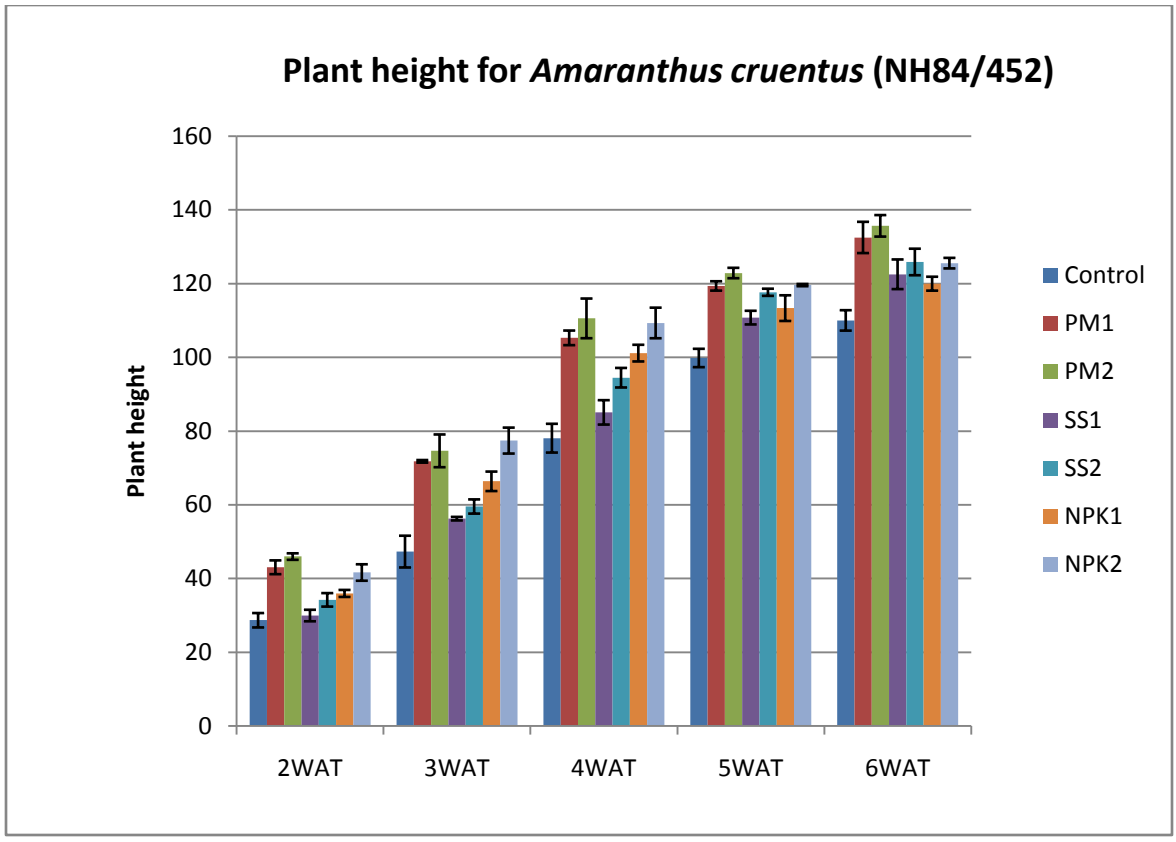


Fig 4.2.2: Effect of Organic Fertilizers on Plant Height of *Amaranthus cruentus* (NH84/452)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

4.2.2 Effect of Organic Fertilizers on Number of Leaves of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

The number leaves were highest for plants treated with 10tons/ha poultry manure for both varieties of amaranth and were not significantly ($p<0.05$) different among the treatments except for the plants in the control group as shown in Fig 4.2.3, Fig 4.2.4, Appendix 4 and 5.

At 2WAT, the average number of leaves for *Amaranthus caudatus* (Samaru local variety) was significantly ($P<0.05$) higher in plants derived from poultry manure treated plots at 10 tons/ha with average number of leaves at 23.83±1.44, while for *Amaranthus cruentus* (NH84/452) NPK compound fertilizer applied at 70Kg/ha recorded the highest average number of leaves with value of 16.67±0.29 as shown in Fig 4.2.3, Fig 4.2.4, Appendix 4 and 5.

Amaranthus caudatus (Samaru local variety) recorded highest number of leaves at 3WAT and 4WAT for plants treated with 10 tons/ha sewage sludge, while 10 tons/ha poultry manure gave the highest values at 5WAT. Although for *Amaranthus cruentus* (NH84/452) NPK compound fertilizer applied at 35Kg/ha had the highest average number of leaves at 3WAT, 4WAT and 5WAT as shown in Fig 4.2.3, Fig 4.2.4, Appendix 4 and 5.

At 6WAT, poultry manure applied at 10 tons/ha had the highest average number of leaves of 76.33±5.03 and 64.50±3.50 for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively but were only significantly different from the control as shown in Fig 4.2.3, Fig 4.2.4, Appendix 4 and 5.

Amaranthus caudatus (Samaru local variety) consistently had higher number of leaves than the *Amaranthus cruentus* (NH84/452) independent of treatment. Poultry manure gave higher number of leaves than sewage sludge, NPK fertilizer and control in decreasing order in both varieties. Increase in average number of leaves was dose and time dependent.

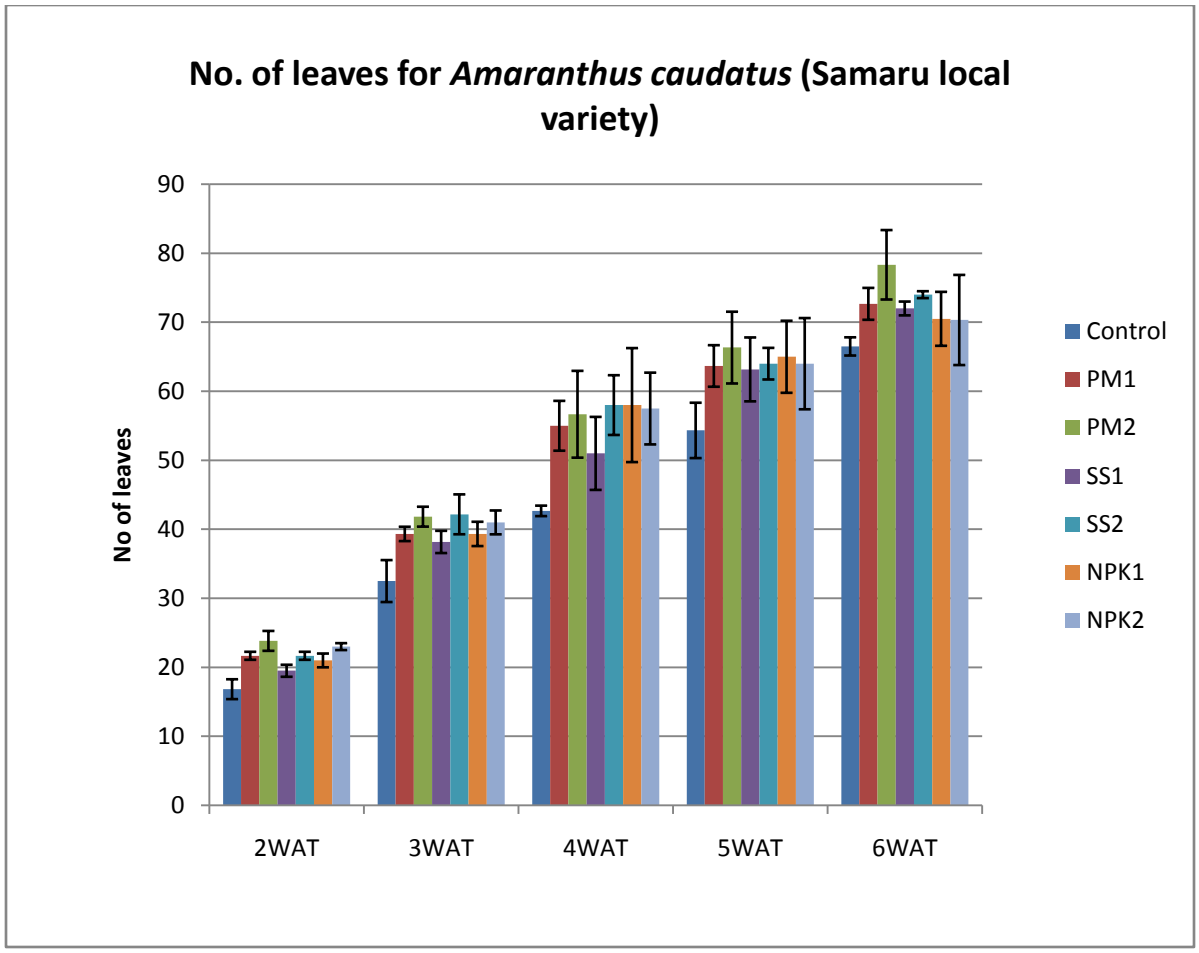


Fig 4.2.3: Effect of Organic Fertilizers on Number of Leaves of *Amaranthus caudatus* (Samaru local variety)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

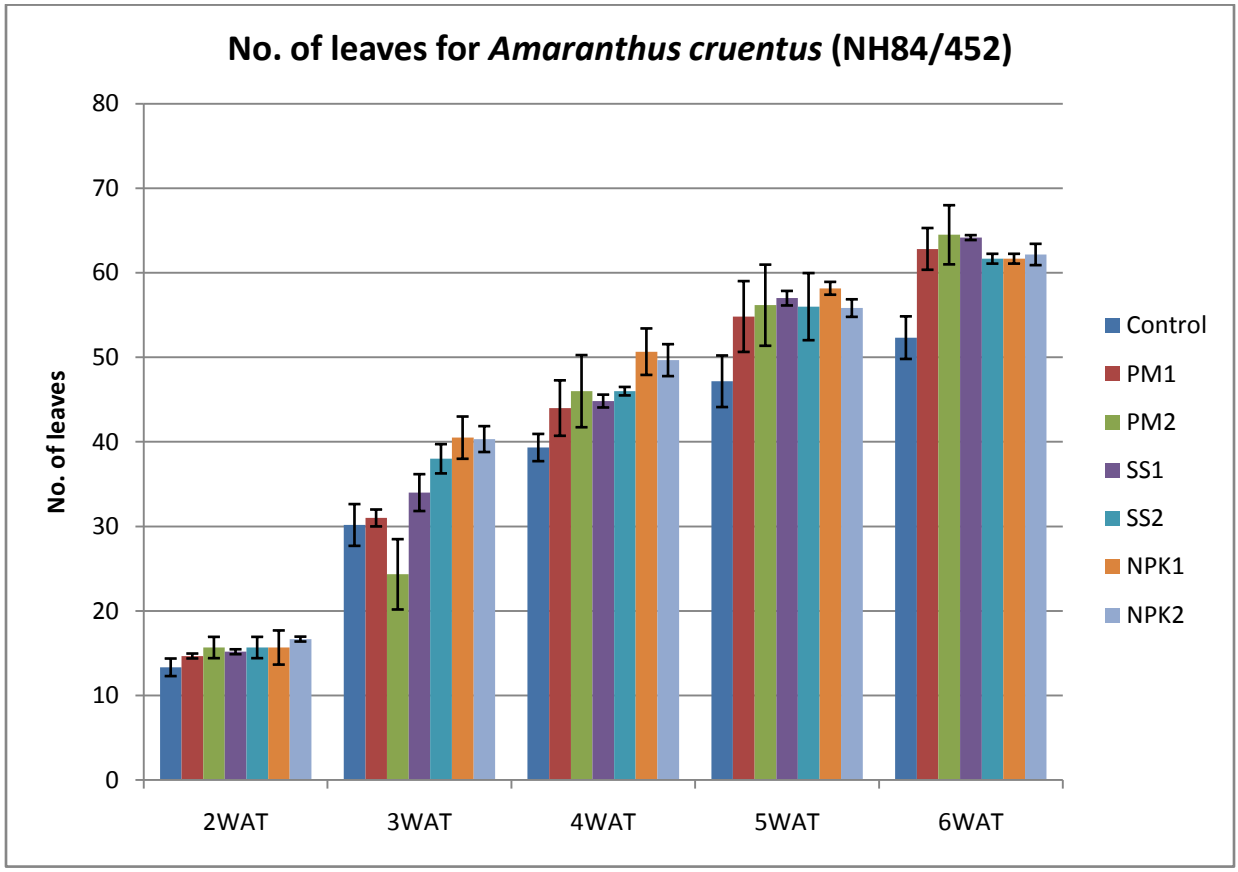


Fig 4.2.4: Effect of Organic Fertilizers on Number of Leaves of *Amaranthus cruentus* (NH84/452)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

4.2.3 Effect of Organic Fertilizers on Leaf Length of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

At maturity, leaf length was significantly ($p<0.05$) higher in plants derived from plots treated with 10 tons/ha sewage sludge and 10 tons/ha poultry manure for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively as shown in Fig 4.2.5, Fig 4.2.6, Appendix 6 and 7.

For *Amaranthus caudatus* (Samaru local variety) poultry manure applied at 10 tons/ha had the highest leaf length of 14.78±0.08cm and 19.82±0.13cm at 2WAT and 3WAT respectively but there was no significant ($p<0.05$) difference between the treatment except for the control treatment, while sewage sludge applied at 10 tons/ha recorded the highest leaf length at 4WAT, 5WAT and 6WAT with values of 22.62±0.75cm, 22.77±0.18cm and 2357±0.21cm respectively as shown in Fig 4.2.5 and Appendix 6

While for *Amaranthus cruentus* (NH84/452), the leaf length of plants derived from 10 tons/ha poultry manure treated plots was significantly higher at 2WAT, 3WAT, 4WAT, 5WAT and 6WAT with values of 18.67±0.61cm, 25.68±1.66cm, 31.98±0.42cm, 32.72±0.43cm and 33.20±0.53cm respectively and showed significant difference among the various treatments as shown in Fig 4.2.6 and Appendix 7.

Amaranthus cruentus (NH84/452) consistently had higher leaf length than *Amaranthus caudatus* (Samaru local variety) independent of the treatments. Sewage sludge elicited higher leaf length than NPK compound fertilizer, poultry manure and control in decreasing order in *Amaranthus caudatus* (Samaru local variety) while for *Amaranthus cruentus* (NH84/452), poultry manure gave higher leaf length than sewage sludge, NPK fertilizer and control in decreasing order. Increase in leaf length in all treatments was dose and time dependent.

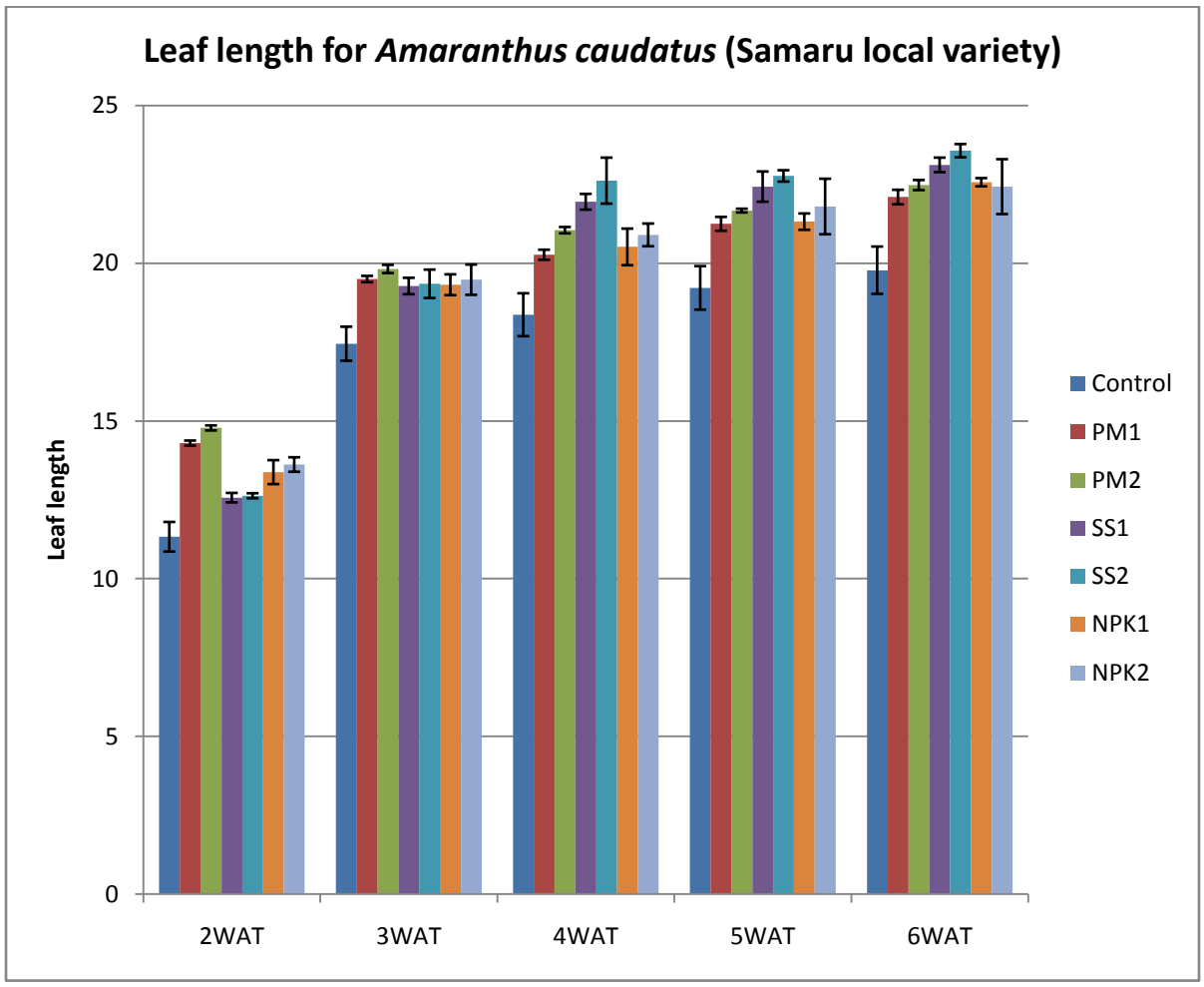


Fig 4.2.5: Effect of Organic Fertilizers on Leaf Length of *Amaranthus caudatus* (Samaru local variety)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

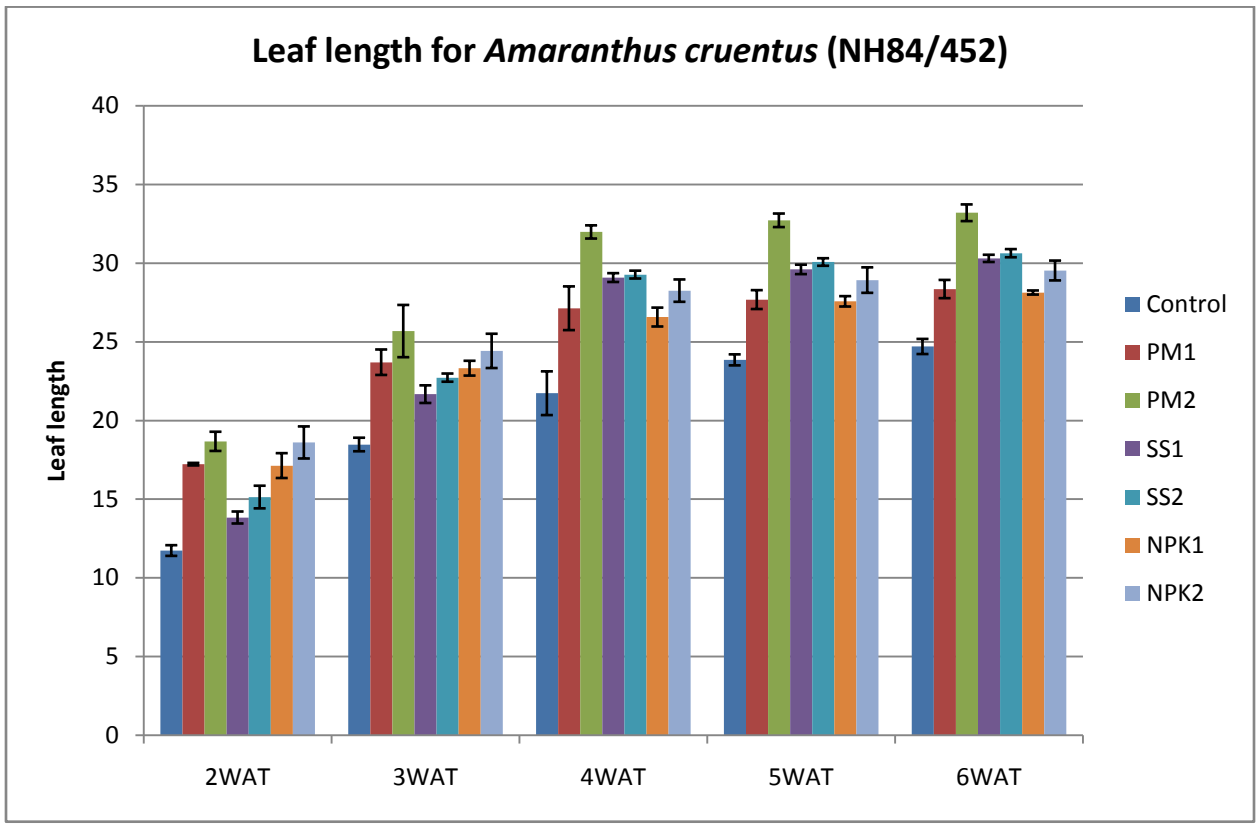


Fig 4.2.6: Effect of Organic Fertilizers on Leaf Length of *Amaranthus cruentus* (NH84/452)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

4.2.4 Effect of Organic Fertilizers on Leaf Width of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

At maturity, Leaf width was highest in plants derived from plots treated with 70 kg/ha NPK compound fertilizer and 10 tons/ha poultry manure for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively but not significantly ($p<0.05$) different from other treatments and was lowest in plants derived from plots with no fertilizer added as shown in Fig 4.2.7, Fig 4.2.8, Appendix 8 and 9.

For *Amaranthus caudatus* (Samaru local variety), at 2WAT, 4WAT, 5WAT and 6WAT leaf width was highest in plants derived from plots treated with 70kg/ha NPK compound fertilizer at 7.72±0.54cm, 9.17±0.51cm, 9.62±0.43cm and 9.70±0.46cm respectively and there was no significant ($p<0.05$) difference between the other treatments. While at 3WAT, 35kg/ha NPK compound fertilizer plants recorded the highest leaf width at 8.60±0.23cm, while plants in plots having no fertilizer had the lowest leaf widths across the weeks after transplanting as shown in Fig 4.2.7 and Appendix 8.

For *Amaranthus cruentus* (NH84/452), plants treated with 10 tons/ha poultry manure had the highest leaf width at 10.17±0.35cm for 2WAT, 13.17±0.34cm for 4WAT, 13.67±0.39cm for 5WAT and 13.93±0.43cm for 6WAT and at 3WAT 70kg/ha NPK compound fertilizer had the highest leaf width of 12.35±0.88cm while plants from plots having no fertilizer had the lowest leaf widths across the weeks after transplanting as shown in Fig 4.2.8 and Appendix 9.

NPK compound fertilizer gave the highest leaf width than poultry manure, sewage sludge and control in decreasing order in *Amaranthus caudatus* (Samaru local variety), while in *Amaranthus cruentus* (NH84/452) poultry manure elicited the highest leaf width. *Amaranthus cruentus* (NH84/452) recorded higher leaf width than *Amaranthus caudatus* (Samaru local variety).

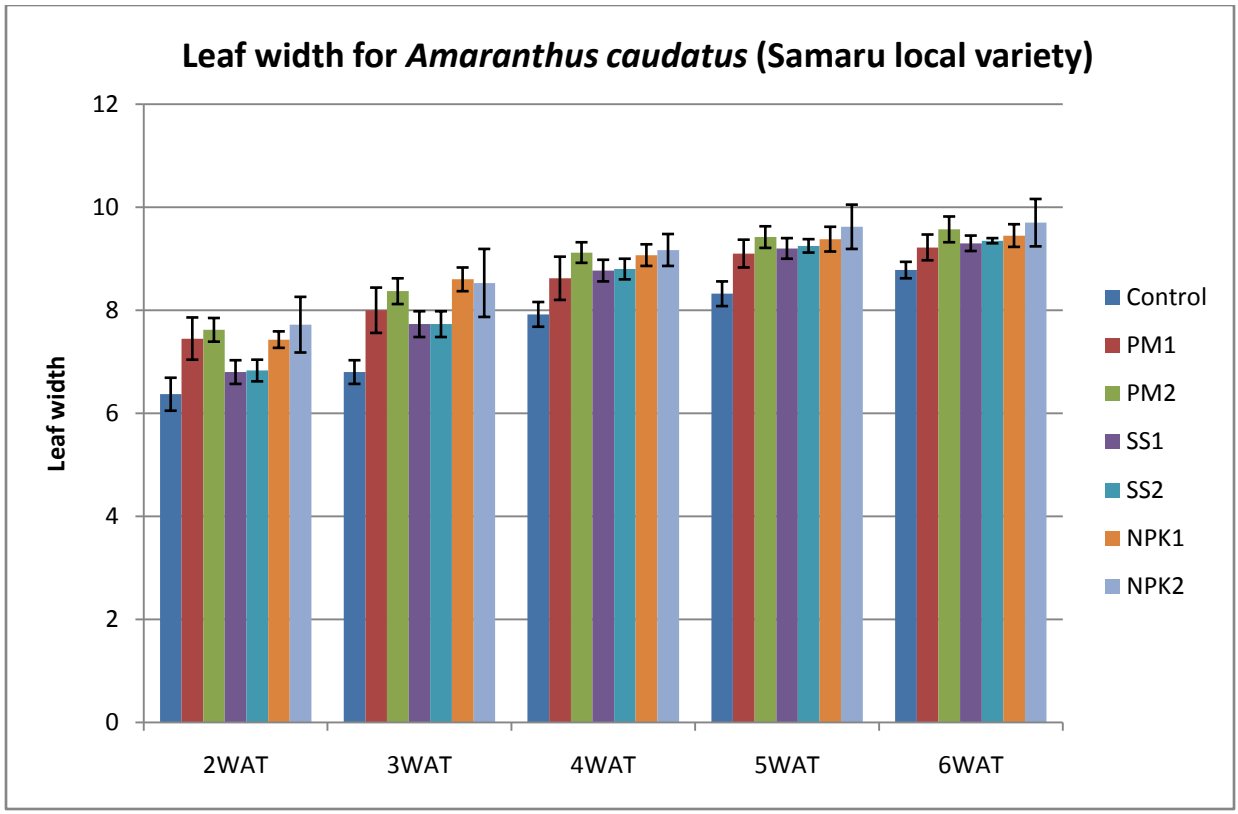


Fig 4.2.7: Effect of Organic Fertilizers on Leaf Width of *Amaranthus caudatus* (Samaru local variety)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

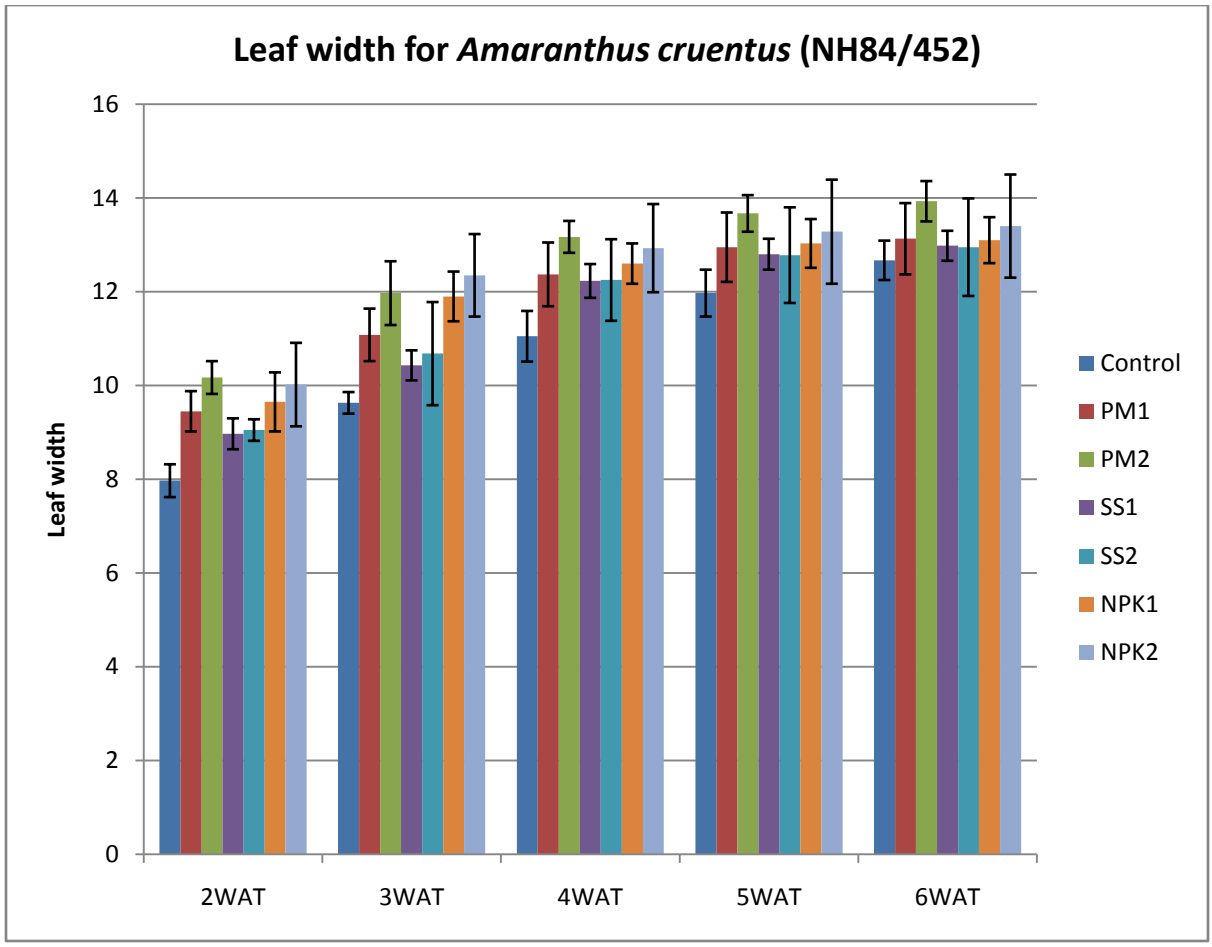


Fig 4.2.8: Effect of Organic Fertilizers on Leaf Width of *Amaranthus cruentus* (NH84/452)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

4.2.5 Effect of Organic Fertilizers on Leaf Area of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

At maturity, leaf area which is a measure from the leaf length and leaf width was significantly ($p<0.05$) higher in plants derived from plots treated with 10 tons/ha sewage sludge and 10 tons/ha poultry manure for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively and was lowest in plants derived from plots with no fertilizer (control treatment) as shown in Fig 4.2.9, Fig 4.2.10, Appendix 10 and 11.

For *Amaranthus caudatus* (Samaru local variety), 10 tons/ha poultry manure had the highest leaf area of 65.08±2.14cm^2 at 2WAT, 70kg/ha NPK compound fertilizer had the highest leaf area of 99.66±5.44cm^2 at 3WAT, 10 tons/ha sewage sludge recorded the highest leaf area of 115.05±4.95cm^2, 121.93±0.13cm^2 and 127.36±0.79cm^2 at 4WAT, 5WAT and 6WAT respectively and control treatments had the lowest leaf area across the weeks after transplanting as shown in Fig 4.2.9 and Appendix 10.

For *Amaranthus cruentus* (NH84/452), plants from plots treated with 10 tons/ha poultry manure had the highest leaf area at 109.74±6.41cm^2 for 2WAT, 178.03±21.79cm^2 for 3WAT, 243.45±9.29cm^2 for 4WAT, 258.50±10.54cm^2 for 5WAT and 258.29±23.96cm^2 for 6WAT and the 10tons/ha poultry manure treatment was significantly ($p<0.05$) different from the other treatments as shown in Fig 4.2.10 and Appendix 11

Amaranthus cruentus (NH84/452) consistently recorded higher leaf area than *Amaranthus caudatus* (Samaru local variety). Sewage sludge elicited higher leaf area than NPK compound fertilizer, poultry manure and control for *Amaranthus caudatus* (Samaru local variety) in decreasing order, while for *Amaranthus cruentus* (NH84/452) poultry manure gave higher leaf area than sewage sludge, NPK compound fertilizer and control in decreasing order.

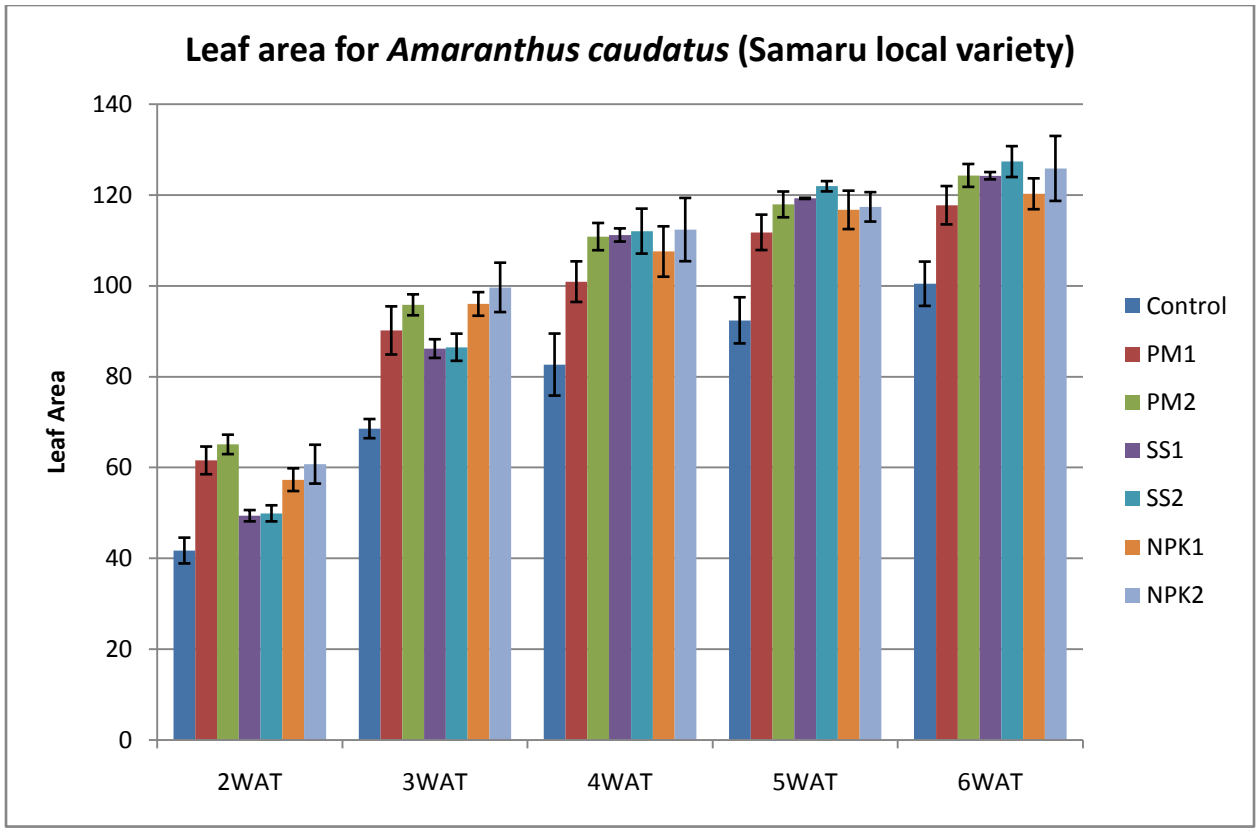


Fig 4.2.9: Effect of Organic Fertilizers on Leaf Area of *Amaranthus caudatus* (Samaru local variety)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

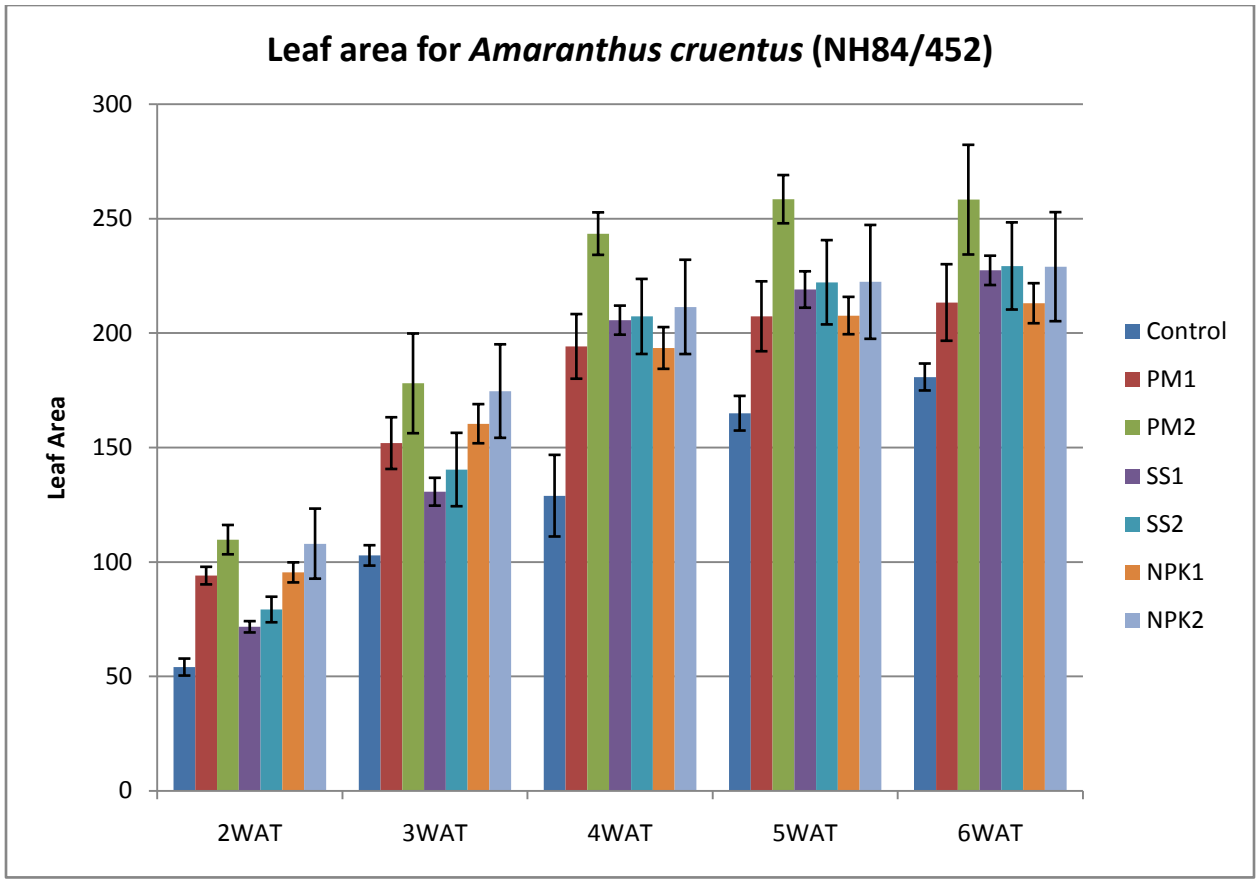


Fig 4.2.10: Effect of Organic Fertilizers on Leaf Area of *Amaranthus cruentus* (NH84/452)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

4.2.6 Effect of Organic Fertilizer on Leaf Area Index of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

Leaf area index which indicates the photosynthetic ability of the plants was significantly ($p<0.05$) higher in plants derived from plots treated with 10 tons/ha for both *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) and was lowest for plants derived from plots with no fertilizer added for both varieties as shown in Fig 4.2.11, Fig 4.2.12, Appendix 12 and 13.

For *Amaranthus caudatus* (Samaru local variety), at 2WAT plants derived from plots treated with 10 tons/ha poultry manure had the highest leaf area index of 3.88±0.05, at 3WAT and 4WAT 70kg/ha NPK compound fertilizer had the highest leaf area index of 10.21±0.56 and 16.17±1.95 respectively, at 5WAT and 6WAT plants derived from plots treated with 10 tons/ha poultry manure recorded the highest leaf area index of 19.57±1.82 and 23.74±1.96 respectively while plants from the control treatment recorded the lowest leaf area index as shown in Fig 4.2.11 and Appendix 12.

For *Amaranthus cruentus* (NH84/452), plants derived from plots treated with 70kg/ha NPK compound fertilizer had the highest leaf area index of 4.51±0.73 and 17.57±1.50 at 2WAT and 3WAT respectively, poultry manure applied at 10 tons/ha recorded the highest leaf area index of 28.05±3.58, 36.40±4.45 and 41.72±5.48 at 4WAT, 5WAT and 6WAT respectively, while control treatments had the lowest leaf area index as shown in Fig 4.2.12 and Appendix 13.

Increase in leaf area index was time and dose dependent, but *Amaranthus cruentus* (NH84/452) consistently had higher leaf area index than *Amaranthus caudatus* (Samaru local variety). Poultry manure recorded higher leaf area index than sewage sludge, NPK compound fertilizer and control in decreasing order in both varieties of amaranth.

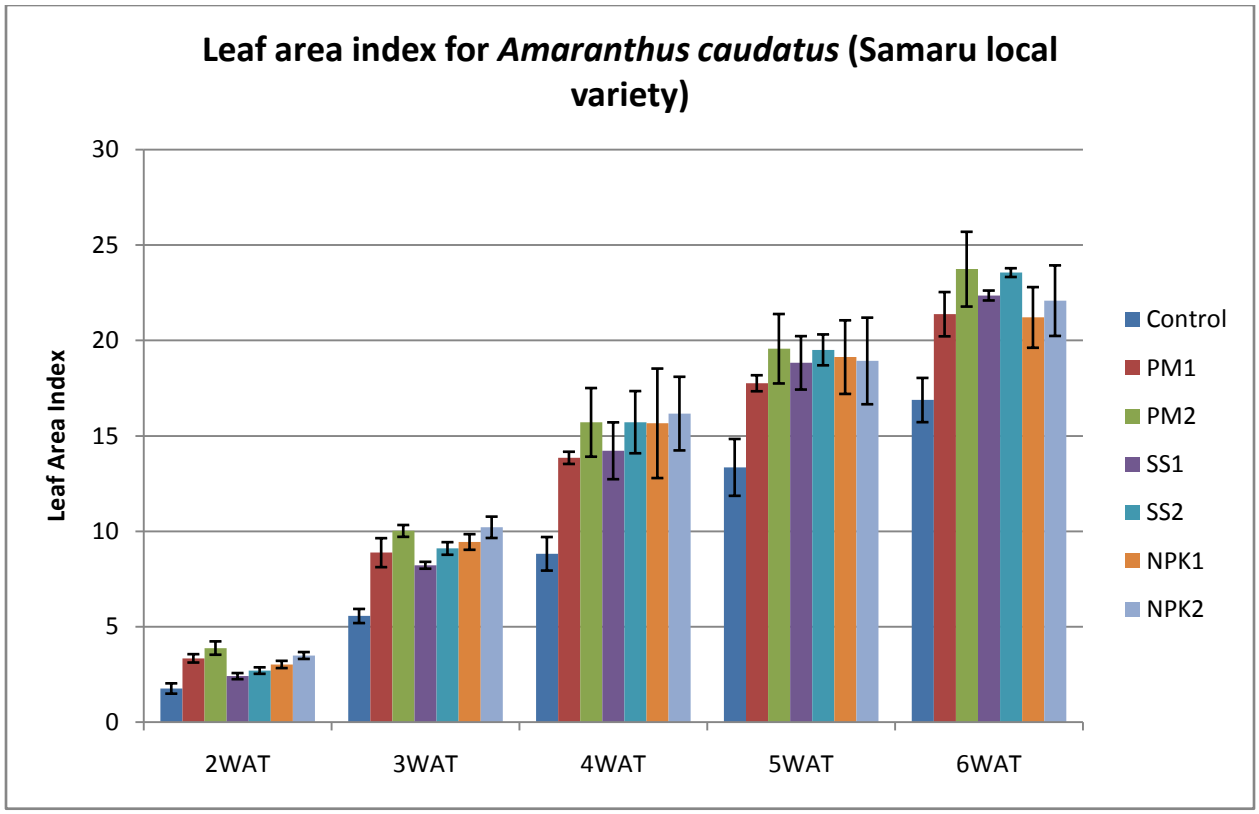


Fig 4.2.11: Effect of Organic Fertilizers on Leaf Area Index of *Amaranthus caudatus* (Samaru local variety)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

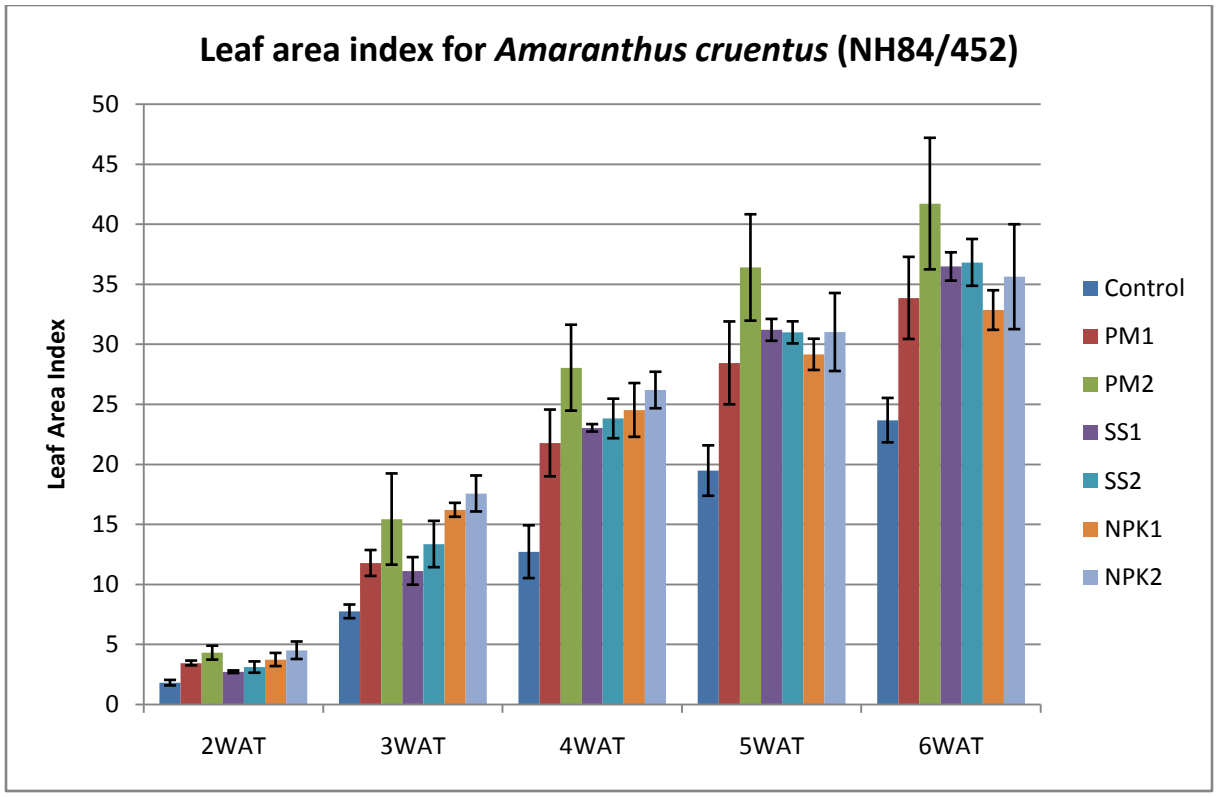


Fig 4.2.12: Effect of Organic Fertilizers on Leaf Area Index of *Amaranthus cruentus* (NH84/452)

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

4.3 Effect of Different Organic Fertilizers and Different Concentrations on Nutrient Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

4.3.1 Effect of Organic Fertilizers on Proximate Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

For *Amaranthus caudatus* (Samaru local variety), the result on the effect of fertilizers on ash content showed that the fertilizers had a significant ($p<0.05$) difference from the control on ash content with plants derived from plots treated with 10 tons/ha poultry manure having the highest ash content of 3.06±0.13% and the control treatment showed the lowest at 2.58±0.06%, while the moisture content was highest on plants derived from plots treated with 5 tons/ha with value of 80.19±0.62% and lowest at 79.21±1.21% on plants from 35kg/ha NPK compound fertilizer treated plots but there was no significant ($p<0.05$) difference among the treatments as shown in Table 4.3.1. The fat content showed no significant ($p<0.05$) difference from the control but the 10 tons/ha poultry manure treatment had the highest value at 1.49±0.16% and was lowest for plants derived from plots treated with the 70kg/ha NPK compound fertilizer at 1.22±0.05% as shown in Table 4.3.1

The fertilizers had significant ($p<0.05$) difference from the control for crude protein, the 70kg/ha NPK compound fertilizer was significantly highest with value of 9.67±0.16% and lowest at 7.49±0.16% for the control as shown in Table 4.3.1. Crude fibre was highest for plants derived from the 10 tons/ha poultry manure treated plots with value of 2.71±0.20% and lowest at 2.41±0.27% for the 70kg/ha NPK compound fertilizer but there was no significant ($p<0.05$) difference among the treatments as shown in Table 4.3.1. Available carbohydrate was significantly highest at 6.46±0.88% for the control treatment and lowest at 4.00±0.12% for the

10 tons/ha sewage sludge treatments. The was no significant ($p<0.05$) difference among the treatments for energy but the control treatment showed the highest at 61.52±2.81Kcal/g and lowest at 57.62±2.24Kcal/g for the 10 tons/ha sewage sludge treatment as shown in Table 4.3.1.

For *Amaranthus cruentus* (NH84/452), there was no significantly ($p<0.05$) difference among the treatments for ash content but the 10 tons/ha sewage sludge had the highest value at 2.99±0.19% and the control had the lowest value at 2.80±0.12% as shown in Table 4.3.2. Moisture content was highest at 80.69±1.01% for the 10 tons/ha poultry manure and lowest at 79.24±0.79% for the NPK compound fertilizer and there was no significant ($p<0.05$) difference among the treatments. The 10 tons/ha poultry manure was significantly highest at 1.31±0.07% for fat content and lowest at 1.04±0.07% for the control treatment as shown in Table 4.3.2.

The fertilizers showed significant ($p<0.05$) difference from the control for crude protein and the 70kg/ha NPK compound fertilizer had the highest value at 9.17±0.17% and the control had the lowest at 8.14±0.21%. Crude fibre was highest at 3.28±0.16% for the 10 tons/ha poultry manure and the 35kg/ha NPK compound fertilizer had the lowest value at 2.90±0.20% as shown in Table 4.3.2. Available carbohydrate and total energy were highest at 5.67±0.44% and 59.33±2.75Kcal/g respectively for plants from the control treatment, the 10 tons/ha poultry manure had the lowest value at 3.02±0.38% and 54.72±3.01Kcal/g for available carbohydrate and energy respectively but there was no significant ($p<0.05$) difference among the treatments for both available carbohydrate and energy as shown in Table 4.3.2

Amaranthus caudatus (Samaru local variety) recorded higher levels of ash, fat, protein, available carbohydrate and energy than *Amaranthus cruentus* (NH84/452). Moisture and crude fibre were higher in *Amaranthus cruentus* (NH84/452) than *Amaranthus caudatus* (Samaru local variety).

Table 4.3.1 Effect of Organic Fertilizers on Proximate Composition of *Amaranthus caudatus* (Samaru local variety)

Proximate composition of *Amaranthus caudatus* (Samaru local variety)

Treatments	Ash (%)	Moisture (%)	Fat (%)	Crude Protein (%)	Crude Fibre (%)	Available Carbohydrate (%)	Total Energy (Kcal/g)
Control	2.58 ± 0.06^{a}	79.57 ± 0.97^{a}	1.30 ± 0.08^{ab}	7.49 ± 0.16^{a}	2.61 ± 0.08^{a}	6.46 ± 0.88^{b}	61.52 ± 2.81^{a}
PM1	2.88 ± 0.15^{ab}	79.42 ± 2.12^{a}	1.36 ± 0.09^{ab}	8.94 ± 0.50^{b}	2.67 ± 0.13^{a}	4.73 ± 1.29^{ab}	59.64 ± 6.99^{a}
PM2	3.06 ± 0.13^{b}	79.63 ± 0.61^{a}	1.49 ± 0.16^{b}	9.09 ± 0.31^{b}	2.71 ± 0.20^{a}	4.01 ± 0.63^{a}	58.69 ± 1.49^{a}
SS1	2.74 ± 0.11^{ab}	80.19 ± 0.62^{a}	1.35 ± 0.14^{ab}	8.93 ± 0.22^{b}	2.62 ± 0.10^{a}	4.24 ± 0.75^{a}	57.62 ± 2.24^{a}
SS2	2.87 ± 0.26^{ab}	80.09 ± 0.48^{a}	1.41 ± 0.18^{ab}	8.99 ± 0.24^{b}	2.64 ± 0.17^{a}	4.00 ± 0.12^{a}	57.42 ± 1.08^{a}
NPK1	2.78 ± 0.22^{ab}	79.21 ± 1.21^{a}	1.31 ± 0.18^{ab}	9.48 ± 0.34^{bc}	2.54 ± 0.07^{a}	4.49 ± 1.76^{ab}	59.19 ± 4.42^{a}
NPK2	2.94 ± 0.23^{b}	79.65 ± 1.04^{a}	1.22 ± 0.05^{a}	9.67 ± 0.16^{c}	2.41 ± 0.27^{a}	4.53 ± 1.41^{ab}	58.47 ± 4.64^{a}

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Table 4.3.2 Effect of Organic Fertilizers on Proximate Composition of *Amaranthus cruentus* (NH84/452)

Proximate composition of *Amaranthus cruentus* (NH84/452)

Treatments	Ash (%)	Moisture (%)	Fat (%)	Crude Protein (%)	Crude Fibre (%)	Available Carbohydrate (%)	Total Energy (Kcal/g)
Control	2.80 ± 0.12^{a}	79.40 ± 0.63^{a}	1.04 ± 0.07^{a}	8.14 ± 0.21^{a}	2.96 ± 0.31^{ab}	5.67 ± 0.44^{b}	59.33 ± 2.75^{a}
PM1	2.96 ± 0.09^{a}	79.78 ± 0.75^{a}	1.22 ± 0.08^{ab}	8.67 ± 0.40^{ab}	3.21 ± 0.13^{ab}	4.16 ± 0.87^{ab}	57.65 ± 2.55^{a}
PM2	2.98 ± 0.12^{a}	80.69 ± 1.01^{a}	1.31 ± 0.07^{b}	8.72 ± 0.35^{b}	3.28 ± 0.16^{b}	3.02 ± 0.38^{a}	54.72 ± 3.01^{a}
SS1	2.89 ± 0.30^{a}	78.78 ± 2.23^{a}	1.19 ± 0.12^{ab}	8.88 ± 0.31^{b}	3.23 ± 0.19^{ab}	5.03 ± 1.90^{ab}	57.48 ± 4.09^{a}
SS2	2.99 ± 0.19^{a}	79.36 ± 1.11^{a}	1.18 ± 0.24^{ab}	8.98 ± 0.38^{b}	3.29 ± 0.10^{b}	4.20 ± 0.69^{b}	57.71 ± 2.64^{a}
NPK1	2.86 ± 0.24^{a}	79.24 ± 0.79^{a}	1.15 ± 0.15^{ab}	9.05 ± 0.25^{b}	2.90 ± 0.12^{a}	3.80 ± 1.55^{ab}	55.62 ± 4.50^{a}
NPK2	2.86 ± 0.28^{a}	79.28 ± 1.25^{a}	1.28 ± 0.06^{a}	9.17 ± 0.17^{b}	2.90 ± 0.20^{a}	4.50 ± 1.35^{ab}	59.57 ± 4.85^{a}

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

Control = No fertilizer, PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

4.3.2 Effect of Organic Fertilizers on Micronutrient Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

For *Amaranthus caudatus* (Samaru local variety), the effect of the fertilizers on the level of vitamin C revealed significant ($p<0.05$) difference from the control treatment with plants derived from the 10 tons/ha poultry manure treated plots having the highest level of vitamin C at 40.36±1.84mg/100g and the control treatment having the lowest level at 32.63±0.48mg/100g as shown in Table 4.3.3.

β-carotene was significantly highest from plants derived from plots treated with the 10 tons/ha sewage sludge with value of 6.68±0.55mg/100g and control treatment had the lowest level at 4.79±0.08mg/100g. The fertilizers effect on level of Niacin was significantly ($p<0.05$) different from the control with the 70kg/ha NPK compound fertilizer having the highest level of niacin at 22.15±0.83mg/100g and lowest at 17.36±0.29mg/100g for the control treatment as shown in Table 4.3.3. Riboflavin content showed the highest value at 10.82±0.77mg/100g for plants from the 70kg/ha NPK compound fertilizer treatment while plants derived from plots with no fertilizer application (control treatment) had showed the lowest level at 8.37±1.02mg/100g. But statistically, the fertilizer treatments of poultry manure, sewage sludge and N.P.K compound fertilizer were significantly ($p<0.05$) different from the control treatments (no fertilizer application) as shown in Table 4.3.3.

The effect of the fertilizers on the level of iron and zinc showed significant ($p<0.05$) difference from the control treatment, plants derived from plots treated with poultry manure applied at 10 tons/ha had the highest level of iron and zinc at 13.40±0.23mg/100g and 9.10±0.09mg/100g respectively and were lowest at 10.33±0.04mg/100g and 5.11±0.11mg/100g for iron and zinc

respectively from plants derived from plots which had no fertilizer application (control treatment) as shown in Table 4.3.3.

For *Amaranthus cruentus* (NH84/452), plants derived from plots treated with 70kg/ha NPK compound fertilizer had the highest level of vitamin C at 25.08±3.70mg/100g and the control treatment had the lowest at 14.37±0.64mg/100g and the fertilizer treatments were significantly ($p<0.05$) different from the control, while the β-carotene content was significantly higher for plants from the 10 tons/ha sewage sludge treatment plots with value of 6.57±0.22mg/100g and plants from the control treatment showed the lowest level at 5.58±0.44mg/100g as shown in Table 4.3.4

The effect of the fertilizers on the level of niacin and riboflavin were significantly ($p<0.05$) different from the control treatment, plants derived from plots treated with 70kg/ha NPK compound fertilizer had the highest level of niacin at 11.89±0.82mg/100g and plants derived from plots which had no fertilizer (control) had the lowest level of niacin at 5.97±0.61mg/100g while plants derived from the 10 tons/ha sewage sludge treatment had the highest level of riboflavin at 27.99±1.06mg/100g and the control treatment showed the lowest level of riboflavin at 16.25±1.89 as shown in Table 4.3.4. Iron content was significantly highest at 13.25±0.26mg/100g for the 10 tons/ha sewage sludge treatment and the control treatment had the lowest level of iron at 10.03±0.46mg/100g, while zinc content was significantly highest for plants from the 10 tons/ha poultry manure with level at 9.41±0.66mg/100g and lowest at 5.80±0.00mg/100g for the control treatment as shown in Table 4.3.4.

Amaranthus caudatus (Samaru local variety) gave higher levels of beta-carotene, vitamin C, niacin and iron than *Amaranthus cruentus* (NH84/452). Riboflavin and zinc were higher in *Amaranthus cruentus* (NH84/452) than *Amaranthus caudatus* (Samaru local variety).

Table 4.3.3 Effect of Organic Fertilizers on Micronutrient Composition of *Amaranthus caudatus* (Samaru local variety)

Micronutrient composition of *Amaranthus caudatus* (Samaru local variety)

Treatments	β-Carotene (mg/100g)	Vitamin C (mg/100g)	Niacin (mg/100g)	Riboflavin (mg/100g)	Iron (mg/100g)	Zinc (mg/100g)
Control	4.79 ± 0.08^{a}	32.63 ± 0.48^{a}	17.36 ± 0.29^{a}	8.37 ± 1.02^{a}	10.33 ± 0.04^{a}	5.11 ± 0.11^{a}
PM1	5.54 ± 0.56^{a}	38.63 ± 2.14^{cd}	18.30 ± 0.37^{ab}	10.04 ± 0.10^{bc}	12.45 ± 0.39^{cd}	8.76 ± 0.00^{e}
PM2	5.46 ± 0.60^{a}	40.36 ± 1.84^{d}	20.83 ± 0.77^{d}	10.68 ± 0.32^{bc}	13.40 ± 0.23^{e}	9.10 ± 0.09^{e}
SS1	6.39 ± 0.23^{b}	35.38 ± 1.50^{b}	17.81 ± 0.10^{a}	9.64 ± 0.57^{b}	12.12 ± 0.23^{c}	6.62 ± 0.21^{c}
SS2	6.68 ± 0.55^{b}	38.11 ± 1.92^{bcd}	19.95 ± 0.24^{cd}	10.45 ± 0.34^{bc}	12.83 ± 0.06^{d}	7.42 ± 0.45^{d}
NPK1	5.15 ± 0.23^{a}	37.73 ± 0.50^{bcd}	19.36 ± 1.07^{bc}	10.60 ± 0.45^{bc}	10.80 ± 0.21^{b}	5.68 ± 0.16^{b}
NPK2	5.33 ± 0.45^{a}	36.85 ± 1.04^{bc}	22.15 ± 0.83^{e}	10.82 ± 0.77^{c}	10.94 ± 0.19^{b}	5.55 ± 0.29^{b}

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Table 4.3.4 Effect of Organic Fertilizers on Micronutrient Composition of *Amaranthus cruentus* (NH84/452)

Micronutrient composition of *Amaranthus cruentus* (NH84/452)

Treatments	β-Carotene (mg/100g)	Vitamin C (mg/100g)	Niacin (mg/100g)	Riboflavin (mg/100g)	Iron (mg/100g)	Zinc (mg/100g)
Control	5.58 ± 0.44^{a}	14.37 ± 0.64^{a}	5.97 ± 0.61^{a}	16.25 ± 1.89^{a}	10.03 ± 0.46^{a}	5.80 ± 0.00^{a}
PM1	5.73 ± 0.37^{ab}	17.65 ± 0.53^{ab}	7.56 ± 0.50^{b}	25.97 ± 0.99^{cd}	11.35 ± 0.40^{b}	8.17 ± 0.05^{b}
PM2	5.97 ± 0.23^{abc}	21.26 ± 1.90^{bc}	8.20 ± 0.20^{bc}	25.60 ± 1.52^{c}	12.66 ± 0.29^{cd}	9.41 ± 0.66^{c}
SS1	6.31 ± 0.26^{bc}	20.94 ± 1.63^{bc}	8.81 ± 0.18^{c}	23.47 ± 0.31^{b}	12.20 ± 0.22^{c}	8.18 ± 0.00^{b}
SS2	6.57 ± 0.22^{c}	22.87 ± 3.48^{c}	8.20 ± 0.20^{bc}	27.99 ± 1.06^{d}	13.25 ± 0.26^{d}	8.29 ± 0.00^{b}
NPK1	6.04 ± 0.32^{abc}	17.75 ± 2.54^{ab}	8.93 ± 0.28^{c}	24.41 ± 0.49^{bc}	10.51 ± 0.41^{a}	5.93 ± 0.18^{a}
NPK2	6.02 ± 0.38^{abc}	25.08 ± 3.70^{c}	11.89 ± 0.82^{d}	26.24 ± 0.44^{cd}	10.61 ± 0.34a	6.14 ± 0.12^{a}

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

Control = No fertilizer, PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

4.4 Effect of Different Organic Fertilizers and Different Concentrations on Toxicological Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

4.4.1 Effect of Organic Fertilizer on Anti-nutrient Composition of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

For *Amaranthus caudatus* (Samaru local variety), 10 tons/ha poultry manure treatment had the highest level of tannins at 0.64±0.08% and the control treatment had the lowest tannins content at 0.33±0.08% while the phytate level was significantly ($p<0.05$) different from the control with the 70kg/ha NPK compound fertilizer having the highest level at 0.94±0.05% and the lowest level at 0.40±0.07 for the control treatment as shown in Table 4.4.1. Saponins level was significantly highest in the 10 tons/ha sewage sludge with value of 2.30±0.18% and the control treatment had the lowest level at 1.36±0.11%. The 10 tons/ha poultry manure and 5 tons/ha sewage sludge treatments had the highest level of oxalate at 0.96±0.11% and 0.96±0.05% respectively while the control treatment had the lowest level at 0.61±0.06% as shown in Table 4.4.1.

For *Amaranthus cruentus* (NH84/452), plants derived from poultry manure applied at 10 tons/ha had the highest level of tannins with value of 0.69±0.14% but there was no significant ($p<0.05$) difference among the treatments. Phytate level was significantly different from the control with plants from the 35kg/ha and 70kg/ha NPK compound fertilizer having the highest levels at 0.90±0.04% each.. The 10 tons/ha sewage sludge treatment had the highest levels of saponins and oxalate with values of 2.09±0.23% and 1.01±0.06% respectively, the levels of saponins and oxalate were significantly ($p<0.05$) different from the control treatment as shown in Table 4.4.2

Table 4.4.1 Effect of Organic Fertilizers on Anti-nutrient Composition of *Amaranthus caudatus* (Samaru local variety)

Anti-nutrients content on *Amaranthus caudatus* (Samaru local variety)

Treatments	Tannins (%)	Phytate (%)	Saponins (%)	Oxalate (%)
Control	0.33 ± 0.08^{a}	0.40 ± 0.07^{a}	1.36 ± 0.11^{a}	0.61 ± 0.06^{a}
PM1	0.60 ± 0.16^{ab}	0.58 ± 0.05^{b}	1.71 ± 0.13^{ab}	0.81 ± 0.05^{b}
PM2	0.64 ± 0.08^{b}	0.66 ± 0.06^{bc}	2.04 ± 0.26^{bc}	0.96 ± 0.11^{c}
SS1	0.51 ± 0.16^{ab}	0.63 ± 0.04^{bc}	2.06 ± 0.36^{bc}	0.96 ± 0.05^{c}
SS2	0.60 ± 0.08^{ab}	0.68 ± 0.02^{c}	2.30 ± 0.18^{c}	0.92 ± 0.05^{c}
NPK1	0.51 ± 0.29^{ab}	0.82 ± 0.06^{d}	1.35 ± 0.07^{a}	0.70 ± 0.03^{ab}
NPK2	0.60 ± 0.16^{ab}	0.94 ± 0.05^{e}	1.55 ± 0.47^{a}	0.72 ± 0.06^{ab}

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

Control = No fertilizer, PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Table 4.4.2 Effect of Organic Fertilizers on Anti-nutrient Composition of *Amaranthus cruentus* (NH84/452)

Anti-nutrients content on *Amaranthus cruentus* (NH84/452)

Treatments	Tannins (%)	Phytate (%)	Saponins (%)	Oxalate (%)
Control	0.37 ± 0.16^{a}	0.43 ± 0.03^{a}	1.29 ± 0.09^{a}	0.53 ± 0.04^{a}
PM1	0.60 ± 0.08^{a}	0.58 ± 0.08^{b}	1.67 ± 0.24^{bc}	0.85 ± 0.05^{bc}
PM2	0.69 ± 0.14^{a}	0.60 ± 0.12^{bc}	1.46 ± 0.30^{ab}	0.95 ± 0.07^{cd}
SS1	0.64 ± 0.21^{a}	0.70 ± 0.03^{cd}	1.89 ± 0.16^{cd}	1.00 ± 0.04^{d}
SS2	0.64 ± 0.21^{a}	0.72 ± 0.06^{d}	2.09 ± 0.23^{d}	1.01 ± 0.06^{d}
NPK1	0.55 ± 0.28^{a}	0.90 ± 0.04^{e}	1.52 ± 0.11^{ab}	0.75 ± 0.08^{b}
NPK2	0.65 ± 0.21^{a}	0.90 ± 0.04^{e}	1.47 ± 0.05^{ab}	0.76 ± 0.13^{b}

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

Control = No fertilizer, PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

4.4.2 Effect of Organic Fertilizer on Total Aflatoxins of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

Total aflatoxins was not detected in all the treatments of poultry manure, sewage sludge and N.P.K compound fertilizer including the control for both *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452), which shows that the fertilizers used had no effect on the level of total aflatoxins in both *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) as shown in Table 4.4.3. The reason for not having total aflatoxins in amaranth is due to low lipid content as compared to grains especially nuts which serve as a substrate for the synthesis of aflatoxins.

4.4.3 Effect of Organic Fertilizer on Heavy Metals of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

For *Amaranthus caudatus* (Samaru local variety), plants derived from plots treated with the 10 tons/ha sewage sludge were significantly highest among the treatments for lead with value of 0.08 ±0.01mg/kg while the control had the lowest level of lead at 0.05 ±0.01mg/kg, but cadmium was not detected in any of the treatments of poultry manure, sewage sludge and N.P.K compound fertilizer as shown in Table 4.4.4.

For *Amaranthus cruentus* (NH84/452), lead was found to be significantly highest in plants derived from plots treated with 5 tons/ha and 10 tons/ha sewage sludge with values of 0.08 ±0.01mg/kg and 0.08 ±0.00mg/kg respectively and the plants derived from plots with no fertilizer application (control treatment) was the lowest at 0.05 ±0.02mg/kg, while cadmium was not detected in any of the treatments of poultry manure, sewage sludge and N.P.K compound fertilizer with varying concentrations as shown in Table 4.4.4.

Table 4.4.3 Effect of Organic Fertilizers on Total Aflatoxins of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

Total Aflatoxins (ppb)		
Treatments	*Amaranthus caudatus* (Samaru local variety)	*Amaranthus cruentus* (NH84/452)
Control	ND	ND
PM1	ND	ND
PM2	ND	ND
SS1	ND	ND
SS2	ND	ND
NPK1	ND	ND
NPK2	ND	ND

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

ND = Not detected

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Table 4.4.4 Effect of Organic Fertilizers on Heavy Metals of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452)

Heavy metals (mg/kg)

	***Amaranthus caudatus* (Samaru local variety)**		***Amaranthus cruentus* (NH84/452)**	
Treatments	**Lead**	**Cadmium**	**Lead**	**Cadmium**
Control	0.05 ± 0.01^{a}	ND	0.05 ± 0.02^{a}	ND
PM1	0.06 ± 0.01^{ab}	ND	0.06 ± 0.01^{ab}	ND
PM2	0.07 ± 0.01^{bc}	ND	0.07 ± 0.01^{bc}	ND
SS1	0.06 ± 0.01^{abc}	ND	0.08 ± 0.01^{cd}	ND
SS2	0.08 ± 0.01^{c}	ND	0.08 ± 0.00^{d}	ND
NPK1	0.06 ± 0.01^{abc}	ND	0.06 ± 0.01^{abc}	ND
NPK2	0.06 ± 0.00^{abc}	ND	0.06 ± 0.01^{ab}	ND

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

ND = Not detected

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

CHAPTER FIVE

5.0 DISCUSSION

The increasing population of many tropical countries led to awareness of the importance of vegetables as a source of essential nutrients and various chemicals which may not be available in other food sources (Ihekoronye and Ngoddy, 1985). Fertilizers play an important role in improving soil fertility by adding essential nutrients to soil which aid in adequate growth and yield of plants, hence the two varieties of Amaranth grown under poultry manure, sewage sludge and NPK compound fertilizer had significant increased growth and nutrient levels compared to the control treatment. This effect can be associated to the vital nutrients contained in the fertilizers which are deposited in the soil and thereby absorbed by the plants. In this current study, the two varieties of amaranth exhibited better response to poultry manure than sewage sludge and NPK compound fertilizer; this implies that the mineralization of poultry manure was faster than sewage sludge and sustained longer in soil than NPK compound fertilizer. Similar report was given by Ogedegbe *et al.* (2013). *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) exhibited significant differences for measured parameters, where *Amaranthus cruentus* (NH84/452) had higher values for plant height, leaf length, leaf width, leaf area and leaf area index than *Amaranthus caudatus* (Samaru local variety), while the number of leaves was higher for *Amaranthus caudatus* (Samaru local variety) than *Amaranthus cruentus* (NH84/452). These differences between the varieties may be due to genetic differences, similar occurrence observed among amaranth varieties by Henderson *et al.* (2000) was attributed to genotypic variation.

Dosage of the fertilizers (concentration levels) had an increment effect on the plant height, average number of leaves, leaf length, leaf width, leaf area and leaf area index, this implies the

higher the dosage the higher the growth performance which can be attributed to the increased amount of nutrients in higher dosage of fertilizers. Hence, the higher nutrients in higher dosage were used for the development of important parts of the plants such as higher foliage and longer shoot. Similar effect was reported for *Amaranthus caudatus* by Abayomi and Adebayo (2014). Dosage of fertilizers also had an increment effect on nutrients and antinutrients in both varieties of amaranth used. The reason behind this increment is because in higher dosage of fertilizers, there are more nutrients for the synthesis of various other nutrients, chemicals and antinutrients in the amaranth. Time of growth also show a consistent or progressive increment of growth parameters in the two varieties of amaranth. The effect of time on the increment of growth parameters may be due to the continuous supply of nutrients to the plants and hence consequent and continual increase in growth of the plants.

The soil used is typically sandy clay loam which indicates that the water holding capacity of the soil is good. The essentials nutrients such as organic carbon, nitrogen, phosphorus, sodium, magnesium and potassium in soil used are very low which shows the low fertility status of the soil which is in agreement with work by Ogedegbe *et al.* (2013). This observation confirmed Akanbi and Togon (2002) who reported that most agricultural soils were impoverish due to weathering, leaching, erosion and intensive cultivation. A good soil has an organic matter value above 3% (Alam *et al.,* 2007), this implies that the variable response of amaranth varieties to applied fertilizers observed in this study was expected and also application of organic fertilizers to increase soil fertility for amaranth production was justified which was also reported by Law-Ogbomo and Ajayi (2009).

The poultry manure used for this experiment had higher nitrogen and potassium content compared to the sewage sludge; this could be attributed to the high nutrient dense feed chickens

consume and concentrate over a short period of time while the sewage sludge waste had to undergo series of pre-treatment at the sewage sites where some of the nutrients are leached into the ground or loss during certain processes during pre-treatment. Sewage sludge had higher phosphorus and pH than poultry manure; the higher pH in the sludge can be due to higher levels of ammonia and urea in the sewage sludge coming from human excreta.

The highest plant height for the two varieties of amaranth at maturity were both observed in plants treated with 10 tons/ha poultry manure which was significantly ($p<0.05$) different from the other treatments, this position was earlier reported by Egharevba and Ogbe (2002) and Okokoh and Bisong (2011). The highest plant height exhibited by plants treated with 10 tons/ha poultry manure might have been due to the presence of the primary nutrients plus other minerals found in inorganic manure, and also it may be probably due to favourable nutrient mineralization of poultry manure as a result of the influence of the mineral component on the organic content of the manure (Abayomi and Adebayo, 2014). The control plants had the lowest height as they had to depend mainly on the intrinsic soil fertility as exhibited by the soil chemical analysis to be low. A similar effect for control was reported for *Amaranthus caudatus* by Abayomi and Adebayo (2014) and on radish stems amaranth-indian spinach by Islam *et al.* (2011). The height of the plant is an important growth character directly linked with it productive potential of plants. An optimum plant height is claimed to be positively corrected with productivity of plants (Saeed *et al.,* 2007).

At the start of the experiment the average number of leaves was highest for poultry manure and NPK compound fertilizers for both varieties of Amaranth. However, between 2WAT and 4WAT, the highest development of new leaves was observed in 70 kg/ha NPK compound fertilizer. Relatively high content of nitrogen in the NPK compound fertilizer increase the growth and

development of new leaves. Normally inorganic fertilizer nutrients are soluble, so the nitrogen was quickly released into the soil leading to fast leaf growth and development. Although, during maturity leaf development declined because the nutrients were probably exhausted in the soil; However, the reason for the high number of leaves for plants treated with poultry manure compared to the sewage sludge at the early stages was attributed to the high amount of nitrogen in the poultry manure than sewage sludge from chemical analysis, and also due to faster mineralization and release of nutrients from the poultry manure than sewage sludge. At maturity, the 10 tons/ha poultry manure showed the highest average number of leaves for both varieties of Amaranth, which was also reported by Law-Ogbomo and Ajayi (2009) for *Amaranthus cruentus*. This also agrees with reports by previous workers such as Sanwal *et al.* (2007) in turmeric (*Curcuma longa*); Premesekhar and Rajashree (2009) in Okra (*Abelmuchus esculentus*) who separately attributed higher leaf yield to released nutrients from organic manure application which improved chemical, physical and biological properties of soil. This high leaves development in the poultry manure compared to the sludge is due to the higher amount of nitrogen in poultry manure and continuous release of the nutrients. However, the reason behind the higher number of leaves for plants treated with organic fertilizers than the NPK compound fertilizer may be due to availability of nutrients as affected by the water holding capacity of the soil (Jacobs *et al.,* 2003). Most probably because as the manure quantities increased the water holding capacity of the soil and subsequent nutrient release increases, while the NPK compound fertilizer nutrients have been exhausted as the early stages due to the solubility of the nutrients.

At maturity, the 10tons/ha sewage sludge and poultry manure gave the highest leaf length for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively and were significantly ($p<0.05$) different from the other treatments. Leaf length increases with

increasing rate of organic fertilizers and this was in harmony with those of *Amaranthus cruentus* L. reported by Emede *et al.* (2012) and Mshelia and Degri (2014) for *Amaranthus caudatus* L. The elevated leaf length for the organic fertilizers over NPK compound fertilizer was due to slow release of nutrients from the organic fertilizers and its bioavailability to the plants over a longer period of time. Although, the reason behind sewage sludge having the highest leaf length on *Amaranthus caudatus* (Samaru local variety) and poultry manure having the highest on *Amaranthus cruentus* (NH84/452) is attributed to genotypic variations between the two varieties.

Leaf width and leaf area were found to be highest in plants from the 70 kg/ha NPK compound fertilizer for green type and the 10tons/ha poultry manure recorded the highest for *Amaranthus cruentus* (NH84/452) but there no significant ($p<0.05$) difference among the treatments except for the control treatment. Similar work also reported by Mshelia and Degri (2014) on effect of different levels of poultry manure on performance of *Amaranthus caudatus* L. Okokoh and Bisong (2011) reported similarly in a research in Calabar that application of poultry manure significantly influence performance of amaranth. The increase in leaf area had been claimed to be directly influence by nitrogen supply in fertilizer applied (Ehigiator, 1990). The insignificant difference among the treatments suggests that5 the nutrients in both the organic and inorganic fertilizers increases leaf width but higher amount of nutrients in individual fertilizers may not necessary influence noticeable difference in the width of the plants.

The 10tons/ha poultry manure treatment resulted in the highest leaf area index for both varieties of amaranth which is consistent with report on red lettuce (Masarirambi *et al.*, 2010). The positive effect of poultry manure increasing leaf area index of amaranth was earlier reported by Egharevha and Ogbe (2002). Law-Ogbomo and Ajayi (2009) also reported similar results on *Amaranthus cruentus*. Leaf area index and number of leaves follow the same pattern as both are

directly related. The higher leaf area index in poultry manure was caused by the relatively higher nutrient availability which increased the leaf length, number of leaves and leaf width per unit area of the plot. Normally, inorganic chemical fertilizer nutrients are soluble, so the nitrogen was quickly released into the soil thus leading to fast leaf growth and development. However, during maturity, leaf development declined because the nutrients were probably exhausted in the soil. This resulted in the leveling of the leaf growth and development between NPK compound fertilizer, sewage sludge and poultry manure at maturity as sewage sludge and poultry manure was continuously releasing nitrogen. Organic manures like cattle manure and poultry manure have been reported to release both micro and macro nutrients slowly resulting in subsequent promotion of vegetable growth (Van-Averbeke and Yoganathan, (2003); Ogunlela *et al*., (2005); Pimentel *et al*., (2005); Kuntashula *et al*., (2006)).

Plants treated with 10 tons/ha poultry manure and 10 tons/ha sewage sludge showed the highest ash content in the *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively but were not significantly ($p<0.05$) different among the treatments. Oyedeji *et al.* (2014) reported similar results for *Amaranthus hybridus, Amaranthus deflexus* and *Amaranthus cruentus*. The ash content in the organic fertilizers were significantly higher and may be due to the balanced nutrients in the manures which contains a lot of minerals and trace elements unlike the NPK compound fertilizer with only proportionate content of nitrogen, phosphorus and potassium.

The moisture content for both *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) gave highest values for plants treated with 5 tons/ha sewage sludge and 10 tons/ha poultry manure respectively, and there was no significant ($p<0.05$) difference among the treatments. Similar result was reported by Mofunanya *et al.* (2014) on the effect of organic and

inorganic fertilizers on the nutritional composition of *Amaranthus spinosus* L. The reason for a bit higher moisture content in both poultry manure and sewage sludge can be attributed to the dense organic matter in the organic fertilizers which improves the water holding capacity of the soil. Hence, the plants will be able to absorb more water for use and in turn the amount of moisture on the leaves might be higher.

Plants derived from plots treated with 10 tons/ha poultry manure recorded the highest amount of fat for both varieties but there was no significant ($p<0.05$) difference among the treatments. The result of this study does not agree with previous work of Oyedeji *et al.* (2014) and Aluko *et al.* (2014) who reported that NPK fertilizer gave higher values of fat for amaranth and Jute mallow respectively. But Mofunanya *et al.* (2014) had similar findings with this study, that plants grown with organic fertilizer gave the highest value for fat. The reason for having higher fat for plants grown with organic fertilizers is attributed to the high organic content of the poultry manure and sewage sludge, thereby having high level of carbon containing compounds which are attacked by bacteria, actinomycetes and fungi under aerobic conditions and the carbon is primarily mineralized into CO_2 and some lost as methane. The CO_2 is absorbed by the plants and used to produce fatty acids.

NPK compound fertilizer applied at 70 kg/ha gave the highest level of crude protein for both varieties and was significantly ($p<0.05$) different among the treatments. This work was similar with works of Oyedeji *et al.* (2014) on *Amarnthus hybridus*, *Amaranthus cruentus* and *Amaranthus deflexus*. NPK fertilizer contains very high amount of nitrogen, so when applied to the soil the nitrogen is converted into ammonia by the process of nitrogen fixation by some bacteria such as azotobacter, clostridium, rhizobium and azospirillum. Also, the ammonia can be further converted to nitrate by nitrifying bacteria, the ammonia in the form of ammonium and

nitrate are taken by the plants and used for synthesis of nucleotides and protein. The lower level of protein in poultry manure and sewage sludge treated plants as compared to plants from NPK compound fertilizer may be due to the presence of sawdust or other bedding or large amount of residue deposited in the soil surface, thereby making the available nitrogen in the soil or manure to be immobilized by bacteria decomposing the carbonaceous material leaving plants with less nitrogen than they need for protein synthesis.

Crude fibre was found to be highest for the 10 tons/ha poultry manure for both varieties but there was no significant ($p<0.05$) difference among treatments. Mofunanya *et al.* (2014) reported similar results for *Amaranthus spinosus* L. The high crude fibre may be due to the high levels of carbon containing compounds in the poultry manure which are easily converted to CO_2 and absorbed by the plants which readily synthesize fibre.

The control treatment recorded the highest available carbohydrate for both varieties but there was no significant ($p<0.05$) difference among the treatments. The untreated plants produced high carbohydrate because the plants gotten from the treated plots had more available nutrients and hence produced more nutrients like mineral elements, fat and protein, thereby having less carbohydrate than the untreated plants which couldn't produce many nutrients. Energy was highest for the control for both varieties but was not significantly ($p<0.05$) different. This may be due to the fact the control plants have high levels of carbohydrate couple with a bit elevated levels of fat and protein which are sources of energy.

The 10 tons/ha poultry manure gave the highest level of vitamin C for *Amaranthus caudatus* (Samaru local variety) which was significantly ($p<0.05$) different among the treatments while the 70 kg/ha NPK compound fertilizer was found to be highest for the *Amaranthus cruentus*

(NH84/452) but there was no significant difference among the treatments. Similar findings were reported by Mofunanya *et al.* (2014) on *Amaranthus spinosus* L. and Adekayode and Ogunloya (2011) on amaranth in southwest Nigeria. Virtually, vitamin C was high in plants treated with organic matter content which leads to an increase in soil microbial population, while high microbial population had been reported to improve the antioxidant capacity of the soil which could lead to availability of the substrates for vitamin C biosynthesis. The high levels of vitamin C for NPK in *Amaranthus cruentus* (NH84/452) may be due to genetic variation.

Beta-Carotene was observed to be highest in plants derived from 10 tons/ha sewage sludge treatments for both varieties and were significantly different from the other treatments. The results of this study are in agreement with Arisha *et al.* (2003) on pepper cultivars, Abdelrazzag (2004) on onion and Mofunanya *et al.* (2014) on *Amaranthus spinosus* L. The high level of beta-carotene on plants treated with sewage sludge over the poultry manure may be attributed to the higher phosphorus content in the sewage sludge than the poultry manure from the organic fertilizer analysis. Since the precursor of carotenoids is phytoene which is synthesized from small precursor molecules called geranyl geranyl pyrophosphate, indicating that the phosphorus is used to synthesize geranyl geranyl pyrophosphate. The higher beta-carotene on sewage sludge treated plants over NPK may be due to possible leaching of the nutrients in NPK due to their solubility.

Niacin was highest for the 70 kg/ha NPK compound fertilizer treated plants for both varieties and were significantly different among the treatments. This may be due attributed to high amounts of nitrogen in NPK fertilizer compared to the organic fertilizers. Nitrogen is required in the synthesis of tryptophan which is an amino acid having an indole side chain containing nitrogen, tryptophan serves as the precursor of niacin.

Riboflavin content was found to be highest for plants treated with 70 kg/ha NPK compound fertilizer and 10 tons/ha sewage sludge for *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) respectively but there were no significant difference aon the treatments. The reason behind the high riboflavin content in plants from NPK compound fertilizer and sewage sludge over poultry manure may be due to the higher amounts of phosphorus in NPK and sewage sludge over poultry manure. Since riboflavin is synthesized from one molecule of guanosine triphosphate and two molecules of ribulose-5-phosphate, both substrates containing phosphate backbone produced from phosphorus.

In all treatments, fertilization resulted in significant effects in mineral composition of the leaves of *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452). There were relatively higher zinc and iron contents in plants produce from poultry manure and sewage sludge, there were significant ($p<0.05$) different from the plants treated with NPK compound fertilizer. Similar results were reported by Masarirambi *et al.* (2010) on effect of organic fertilizers on growth, yield, quality and sensory evaluation of red lettuce (*Lactica sativa* L.) "Veneza Roxa". The higher level of zinc and iron from the organic fertilizers compared to the NPK fertilizer can be attributed to the balance quantity of nutrients in the poultry manure and sewage sludge. Maghos *et al.* (2003) reported that although a small number of studies have been published, slightly higher contents of minerals such as iron and zinc have been obtained in organic vegetables.

Poultry manure applied at the rate of 10 tons/ha revealed the highest level of tannins for both varieties but no significant ($p<0.05$) difference among the treatments for both varieties except for the control. Similar results were reported by Mofunanya *et al.* (2014) on *Amaranthus spinosus* L. Tannins are synthesized from gallic acid with a carbohydrate usually glucose, whereas gallic acid

is derived from 3-dehydoshikimic acid which comes from glyceraldehydes-3-phospahte via the Calvin cycle. The insignificant difference observed for tannins among the fertilizers may be due to moderate contribution of phosphorus to its synthesis including other biomolecules like carbohydrate.

The plants from plots treated with 70 kg/ha NPK compound fertilizer shown the highest values for phytate for both varieties and were significantly ($p<0.05$) different among the treatments. This may be due to higher amount of phosphorus in the NPK compound fertilizers which are soluble and readily available to the plants. Phosphorus is a key component of phytate which is also known as inositol hexakisphosphate. Phytate was observed to be higher in plants treated with sewage sludge than poultry manure; this is evident in the higher phosphorus content of sewage sludge over poultry manure during fertilizer analysis.

Saponins and oxalate contents were higher in plants derived from plots treated with sewage sludge compared to the other fertilizers. This may be as a result of presence of considerable high levels of glycosides, triterpene and some other sugar units in the sewage sludge which are responsible for the synthesis of saponins and oxalate.

Total aflatoxins were not found in plants derived from any of the treatments including the control for both varieties. The reason behind this may be due to the nature of plants being vegetables, which do not contain high amount of the appropriate substrate (fatty acids) for the production of aflatoxins. Also, other factors such as temperature, relative humidity, biochemical and environmental factors may have been involved in the production of aflatoxins,

Lead was found to be higher in plants treated with sewage sludge for both varieties and were significantly ($p<0.05$) different among the treatments. The reason for this may be due to the fact

that lead contamination occurs through food, air, drinking water and even lead containing vessels that sometimes humans use for cooking and this may be translated to the sewage and subsequently absorbed by the plants. Cadmium was not detected in any of the treatments for both varieties and it may be as a result of heavy metals absorption being governed by soil characteristics such as pH and organic matter content. The extent of accumulation and toxic level depend on plant and heavy metal species. Hence, cadmium may have not been present in the soil and fertilizers, and if present might not be readily available for uptake by the varieties of amaranth used.

CHAPTER SIX

6.0 CONCLUSION AND RECOMMENDATIONS

6.1 Conclusion

The rapidly rising cost of chemical fertilizers has forced small scale vegetative farmers to look for alternatives such as organic fertilizers; the result of this present study justifies the use of some organic fertilizers over chemical fertilizer due to high vegetative growth and plant development and increased level of nutrients but fails to justify based on elevated level of anti-nutrients and heavy metals seen in the organic fertilizer treatments. Although, plants treated with organic and chemical fertilizer both showed improve growth and development, increased amounts of nutrients and elevated levels of toxicological parameters over plants with no fertilization for both *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452).

The present study revealed that application of poultry manure at 10 tons/ha on average effected the highest growth and development of *Amaranthus Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) with highest values for plant height, number of leaves , leaf length, leaf width, leaf area and leaf area index. This effect can be as a result of the slow decomposition and release of nutrients from the organic fertilizers.

Organic and chemical fertilizers increased the proximate composition of both *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) with poultry manure and sewage sludge showing the highest values, although the treatments were not significantly different. Proximate compositions were increased by all the fertilizers used in this experiment.

Sewage sludge revealed on an average to have the greater effect on levels of anti-nutrients and heavy metals on *Amaranthus caudatus* (Samaru local variety) and *Amaranthus cruentus* (NH84/452) but total aflatoxins and cadmium were not detected in all treatments.

6.2 Recommendations

i. Beyond the common application of organic manures as fertilizers, this research has demonstrated the efficacy of 10 tons/ha poultry manure to enhance vegetative growth and development, and also improve the levels of many nutrients in Amaranth. Hence it's recommended for farmers to use to obtain relatively higher yields.

ii. *Amaranthus cruentus* (NH84/452) gave a better growth performance in terms of plant height, number of leaves, leaf length, leaf width, leaf area and leaf area index than *Amaranthus caudatus* (Samaru local variety), and with higher leaf area index the better it's photosynthetic ability and hence improved nutrients as also seen in this study. Hence, it is recommended for farmers to use *Amaranthus cruentus* (NH84/452) for higher yields.

iii. Since both the organic and chemical fertilizers showed improved growth and nutrient content, it is recommended that further research should be made by mixing these fertilizers in varying rates so as to further reveal their effects.

iv. It is recommended that more research be conducted across different locations with varied ecology to validate the recommendations.

REFERENCES

Abayomi, O.A. and Adebayo, O.J. (2014). Effect of fertilizer types on the growth and yield of *Amaranthus caudatus* in Ilorin, Sothern Guinea, Savanna Zone of Nigeria. *Advances in Agriculture.* **14**:5

Abbasi, D., Rouzbehan, Y., Rezaei, J. (2012). Effect of harvest date and nitrogen fertilization rate on the nutritive value of amaranth forage (*Amaranthus hypochondriacus*). *Anim Feed Sci Technol*. **171**:6–13.

Abdelrazzag, A., (2002). Effect of chicken manure, sheep manure and inorganic fertilizer on yield and nutrients uptake by onion. *Pak. J. Biol. Sci.*, **5**: 266-268.

Abdelrazzag, A., (2004). Effect of Chicken manure, sheep manure and inorganic fertilizer on yield and nutrients uptake by onion. *Pakistan Journal of Biological Science,* **5**(3):266-268.

Abdullahi, J., Shaibu-Imodagbe, E.M., Mohammed, F., Said, A. and Idris, U.D. (2009). Rural – Urban migration of the Nigerian work populace and climate change effects on food supply. A case study of Kaduna city in northern Nigeria. In *Presented on Fifth Urban Symposium* (Vol. 29).

Abuye, C., Urga, K., Knapp, H., Selmar, D., Omwega, A.M., Imungi J.K. and Winterhalter, P. (2003). A compositional study of *Moringa stenopetala* leaves. *J. East Afr. Med.,* **80**: 247–252.

Adekayode, F.O. and Ogunkoya, M.O. (2011). Comparative effects of organic compost and NPK fertilizer on soil fertility, yield and quality of amaranth in Southwest Nigeria. *Int. J. Biol. Chem. Sci.* **5**(2):490-499

Agbaire, P.O. (2011). Nutritional and Anti-nutritional Levels of Some Local Vegetables(*Vernomia anydalira, Manihot esculenta, Teiferia occidentalis, Talinum triangulare, Amaranthus spinosus)* from Delta State, Nigeria. *J. Appl. Sci. Environ. Manage*. **15** (4): 625 – 628.

Agboola, A. A., and Omueti, J. (1982). Soil fertility problem and its management in tropical Africa. *International Institute of Tropical Agriculture Ibadan, Nigeria*. **2**: 215.

Ainika, J.N., Auwalu, B.M. and Yusuf, A.U. (2011). Response of grain amaranth to Nitrogen and Farm yard Manure. *World Journal of Engineering and Pure and Applied Sciences.* **1**(2): 46- 49.

Ainika, J.N., Amans, E.B., Olonitola, C.O., Okutu, P.C. and Dodo, E.Y. (2012). Effect of organic and inorganic fertilizer on growth and yield of Amaranthus caudatus L. in Northern Guinea Savanna of Nigeria. *World Journal of Engineering and Pure and Applied Sci*. **2(**2):26.

Akanbi, W. B. and Togun, A. O. 2002. The influence of maize Stover compost and nitrogen fertilizer on growth, yield and nutrient uptake of Amaranth. *Scientia Horticulturae* 93: 1-9.

Akparobi, S.O. (2009). Effect of farm yard manures on the growth and yield of *Amaranthus cruentus*. *Agricultura Tropicaet Subtropica*. **42** (1): 1-4.

Alabi, D., Onibudo, M. and Amusa, N. (2005) Chemicals and nutritional composition of four botanicals with fungitoxic properties. *World J Agric Sci.* **1**(1):84–88

Alam, M. N., Jahan, M. S., Ali, M. K., Islam, M. S., Khandaker, S. M. and Khandaker, A.T. 2007. Effect of vermocompost and NPKS fertilizers on growth, yield and yield components of red amaranth. *Australian Journal of Basic and Applied Sciences* **1**(4):706-716.

Alegbejo, J.O. (2013). Nutritional value and utilization of Amaranthus (Amaranthus spp) – A review. *Bajopas* **6**(1): 135 -143.

Aletor, M.V.A and Adeogun, O.A. (1995). Nutrient and antinutrient component of some Tropical vegetable. *Fd. Chem*. **53**:375-379

Aletor, O., Oshodi, A. and Ipinmoroti, K. (2002) Chemical composition of common leafy vegetables and functional properties of their leaf protein concentrates. *Food Chem*,**78**(1):63–68

Alexander, P.D., Alloway, B.J. and Dourado, A.M. (2006). Genotypic variations in the accumulation of Cd, Cu, Pb and Zn exhibited by six commonly grown vegetables. *Environ. Pollut*. **144**:736–745.

Alonge, S.O., Alonge, F.O., Bako, S.P., Olarewaju, J.D. and Adeniji, O.B. (2007). Effects of rates and split application of compound NPK fertilizer on the growth and yield of three *Amaranthus* species in Nigeria guinea savanna. *Asian J. Plant Sci.*, **6**: 906-912.

Aluko, O.A., Olanipekun, T.O., Olasoji, J.O., Abiola, I.O., Adeniya, O.N., Olanipekun, S.O., Omenna, E.C., Kareem, K.O. and Douglas, A.I. (2014). Effect of organic and inorganic fertilizers on the yield and nutrient composition of Jute mallow. *Global journal of agriculture research*. **2**(3):1-9

Amstrong, M.J., Milford, G.F.J., Biscoe, P.V. and Last, P.J. (1983). Influences of nitrogen on physiological aspects of sugar beet productivity. p. 53-55. In: B. Tinkler & H. Laucli (eds). Symposium 'Nitrogen and sugar beet'. International Institute for Sugar Beet Research. 22-27 February 1983, New York.

Apaza-Gutierrez, V., Romeo-Saravia, A., Guillen-Portal, F.R. and Baltens perger, D.D. (2002). Response of grain amaranth to density and fertilization in Tarija, Bolivia. In:Trends in New Crops and New Uses, pp. 107-109.

Arisha, A.M.E., Gad, A.A. and Younes, S.E. (2003). Response of some pepper cultivars to organic and mineral nitrogen fertilizer under sandy soil conditions. *Zagazig Journal of Agricultural Research,* **30**: 1875-1899.

Association of American Plant Food Control Officials (AAPFCO), (1997): Official Publication, No. 50. AAPFCO, West Lafayette, Indiana.

Association of Official Analytical Chemist (AOAC) (1999). Methods of Analysis of Association of official Analytical chemists (16^{th} ed). Washington, D.C.**1**: 600-792.

Association of Official Analytical Chemist (AOAC). (1965). Official Methods of Analysis of the Association of Official Analytical Chemists, (10^{th}ed). Washington, D.C

Atayese, M.O., Eigbadon, A.I., Oluwa, K.A and Adesodun, J.K. (2009): Heavy metal contamination of amaranthus grown along major highways in Lagos, Nigeria. *African Crop Science Journal*, **16**:225 – 235.

Babatola, L.A and Olaniyi, J.O. (1999). Performance of Amaranthus caudatus at different levels of NPK fertilization and under different storage methods. Proceedings of the 16th Annual Conference of Horticultural Society of Nigeria, UNAAB, Abeokuta. Pp 36-40.

Becker, R., Wheeler, E.L., Lorenz, K., Stafford, A.E., Grosjean, O.K., Betschart, A.A. and Saunders, R.M. (1981). A compositional study of amaranth grain. *J Food Sci*. **46**:1175–1180.

Bello-Pérez, L.A. and Paredes-López, O. (2009). Starches of some food crops, changes during processing and their nutraceutical potential. *Food Eng Rev*. **1**:50–65.

Bewley, J.D. and Black, M. (1994). Seeds: Physiology of Developments and Germination. Prenum Press, New York, USA. Pp.147-153.

Bok, I., Madisa, M., Machacha, D., Moamogwe, M. and More, K. (2003). Manual for vegetable production in Botswana. Ministry of Agriculture. Botswana. Pp 52.

Botha, F.C., Potgieter, G.P. and Botha, A.M. (1992). Respiratory metabolism and gene expression during seed germination. *Plant Growth Regulation.* **11**: 211-224.

Brady N.C. and Weil R.R. (2008). The Nature and Properties of Soils, 14th ed. Pearson Education, Inc., Upper Saddle River, NJ.965 pp.

Bressani, R. (1989). The proteins of grain amaranth. *Food Review International* **5**:13-38.

Bressani, R., Gonzales, J.M., Elias, L.G. and Melgar, M. (1987). Effect of fertilizer application on the yield, protein and fat content, and protein quality of raw and cooked grain of three amaranth species. *Plant Food Hum Nutr*. **37**:59–67.

Bressani, R., Gonzalez, J.M., Elias, L.G. and Melgar, M. (1987). Effect of fertilizer application on yield, protein and fat content, and protein quality of raw and cooked grain of three amaranth species. *Plant Foods for Human Nutrition.* **37**:59-67.

Bressani, R., González, J.M., Zúñiga, J., Breuner, M. and Elías, L.G.(1987). Yield, selected chemical composition and nutritive value of 14 selections of amaranth grain representing four species. *J Sci Food Agric*. **38**:347–356.

Bressani, R., Kalinowski, L.S., Ortiz, M.A., Elias, L.G. (1987). Nutritional evaluation of roasted, flaked and popped *A. caudatus*. Arch Latioam Nutr. **37**:525–231.

Brogren, M. and Savage, G.P. (2003). "Bioavailability of Soluble Oxalate from Spinach Eaten with and without Milk Products," *Asia Pacific Journal of Clinical Nutrition*. **12**(2): 219-224.

Budin, J.T., Breene, W.M. and Putnam, D.H. (1996). Some compositional properties of seeds and oils of eight *Amaranthus* species. *J Am Oil Chem Soc*. **73**:475–481.

Burisová, A., Dodok, L., Skrovankova, S. and Serulova, D. (2001). The influence of substitution of wheat flour by amaranth flour on fermentative gas production and quality of bread. *Rostlinna Vyroba*. **47**:276–279.

Burisová, A., Tomášková, B., Sasinková, V. and Ebringerová, A. (2001). Isolation and characterization of the non-starch polysaccharides of amaranth seeds. *Chem Pap.* **55**:254–260.

Burt R. (2014). Soil survey field and laboratory methods manual. *Soil survey investigations report*. **2**(51): 181-387.

Colmenares de Ruiz, A.S. and Bressani, R. (1990). Effect of germination on the chemical composition and nutrition value of amaranth grain. *Cereal Chem.* **67**:519–522.

Coolong, T.W., Kopsell, D.A., Kopsell, D.E. and Randle, W.M. (2005). Nitrogen and sulfur influence nutrient usage and accumulation in onion. *J. Plant Nutr.* **27**: 1667-1686.

Corradini, E., de Moura, M.R. and Mattoso, L.H.C. (2010). A preliminary study of the incorporation of N.P.K. fertilizer into chitosan nonoparticles. *Express polymer letters.* **4**(8): 509-515.

Costea, M. and DeMason, D. A. (2001). Stem morphology and anatomy in Amaranthus L. (Amaranthaceae), taxonomic significance. *Journal of the Torrey Botanical Society*, 254-281.

Crawford, R.M.M. (1978). Metabolic adaptations to anoxia. In: Plant life in anaerobic environments. Ann Arbor Science Publishers, Michigan. Pp. 119-136.

Cuadrado, C., Ayet, G., Burbano, C., Muzquiz, M., Camacho, L., Cavieres, E., Lovon, M., Osagie, A. and Price, K.R. (1995). Occurrence of saponins and sapogenols in Andean crops. *J Sci Food Agric*. **67**:169–172.

Dahdoh, M.S.A. and Hassan F.A. (1997):Combined effect of sewage sludge and saline water irrigation on growth and elements composition of broad bean. *Egyptain Journal of soil science*. **37** (2):189-204.

Daneshvar, H. (2000). Vegetable Farming. *Chamran University Press Martyr*, **190**: 461.

Dhellot, J.R., Matouba, E., Maloumbi, M.G., Nzikou, J.M., Safou-Ngoma, D.G., Linder, M., Desobry, S. and Parmentier, M. (2006). Extraction, chemical composition and nutritional characterization of vegetable oils: Case of *Amaranthus hybridus* (Var 1 and 2) of Congo Brazzaville. *Afr. J. Biotechnol*. **5**(11): 1095-1101.

Dini, I., Tenore, G.C. and Dini, A. (2005). Nutritional and antinutritional composition of Kancolla seeds: an interesting and underexploited andine food plant. *Food Chemistry*, **92**(1): 125-132.

Doran, J.W. and T.B. Parkin. (1994). Defining and assessing soil quality. *Defining soil quality for a sustainable environment (Definingsoilqua)*. Pp. 1-22

Dwivedi, P. (2000). Regulation of root respiration and sugar mediated gene expression in plants. *Current Science*. **78**(10): 1196-1202.

Edwards, J. H., Burt, E. C., Raper, R. L., and Walker, R. H. (1995). Issues affecting application of noncomposted organic waste to agricultural land. *Agricultural utilization of urban and industrial by-products, (agriculturaluti).* Pp 225-249.

Egharevba, R.K.A. and Ogbe, F.M. (2002). The effects of different levels of organic and mineral fertilizers on the yield performance of two Amaranthus (*A. cruentus*) cultivars. *The Plant Scientists*. **3**:62-72.

Ehigiator, J. O. (1990). Farm yard manure: Need for its adoption as an alternative to chemical fertilizer uses in Nigeria. *Nigerian Journal of Horticultural Science* **3**: 1– 9.

Elbehri, A., Putnam, D.H. and Schmitt, M. (1993). Nitrogen fertilizer and cultivar effects on yield and nitrogen-use efficiency in grain amaranth. *Agronomy Journal*. **85**:120-128.

Emede, T.O., Law-Ogbomo, K.E. and Osaigbovo, A.U. (2012). Effects of poultry manure on the growth and herbage yield of amaranth (*amaranthus cruentus* l.). *Nigerian Journal of Agriculture, Food and Environment*. **8**(4):26-31.

Erisman, J.W., Sutton, M.A., Galloway, J., Klimont, Z. and Winiwarter, W. (2008). How a century of ammonia synthesis changed the world. *Nat. Geosci.,* **1**: 636-639.

Escudero, N.L., De Arellano, M.L., Luco, J.M., Gimenez, M.S. and Mucciarelli, S.I. (2004). Comparison of the chemical composition and nutritional value of Amaranthus cruentus flour and its protein concentrate. *Plant Food Hum Nutr.* **59**:15–21.

Fafunso, M. and Bassir, O. (1975). Variations in the protein, carbohydrate, lipid and ash content of six tropical vegetables. *Plant foods for man*. **6**:10-15

Food and Agriculture Organization, International Fund for Agricultural Development, World Food Program. 2015. "The State of Food Insecurity in the World 2015. Strengthening the enabling environment for food security and nutrition." FAO.

Funda, Y., Safak, C. Nilgun, M. and Bihter, C.E. (2011). Effect of organic and in fertilizer on yield and mineral content of onion (*Allium cerpa* L.). *Afr. J. Biotechnol.,* **10**: 11488-11492.

Gamel, T.H., Linssen, J.P., Mesallam, A.S., Damir, A.A. and Shekib, L.A. (2006). Effect of seed treatments on the chemical composition of two amaranth species: oil, sugars, fibres, minerals and vitamins. *J Sci Food Agric*. **86**:82–89.

Gamel, T.H., Linssen, J.P., Mesallam, A.S., Damir, A.A. and Shekib, L.A. (2006). Seed treatments affect functional and antinutritional properties of amaranth flours. *J Sci Food Agric*. **86**:1095–1102.

Gemede, H.F. and Ratta, N. (2014). Anitnutritional Factors in Plant Foods: Potential Health Benefits and Adverse Effects. *International Journal of Nutrition and Food Sciences*. **3**(4):284-289.

Gimplinger, D.M., Dobos, G., Schoenlechner, R. and Kaul, H.P. (2007). Yield and quality of grain amaranth (*Amaranthus* sp.) in Eastern Austria. *Plant Soil Environ*. **53**:105–112.

Goodlass, G., Rahn, C., Shepherd, M.A., Chalmers, A.G. and Seeney, F.M. (1997). The nitrogen requirement of vegetables: Comparisons of yield response models and recommendation system. *J. Hort. Sci.* **72**: 239-254.

Grubben, G. J.H. (2004). *Amaranthus cruentus* L. *PROTA*. **2**: 71-72

Grubben, G.J.H. and Denton, O.A. (2004) Plant resources of tropical Africa 2. Vegetables. PROTA Foundation, Wageningen. Netherlands/Backhuys Publishers, Leiden. Pp. 668.

Gupta, A.K., Dwivedi, S., Sinha, S. and Tripathi, R.D. (2007). Metal accumulation and growth performance of Phaseolus vulgaris grown in fl y ash amended soil. *Bioresour Technol*, **17**:3404– 3407

Gupta, S., Jyothi Lakshmi, A., Manjunath, M. N., and Prakash, J. (2005). Analysis of nutrient and antinutrient content of underutilized green leafy vegetables. *Food Science and Technology*, **38**(4): 339–345

Hamilton, R. (2009). Agriculture's sustainable future: Breeding better crops. *Sci. American*, **19**: 16-17.

Haynes, C. (2008). The Organic Green Revolution. Retrieved from: http://www.rodaleinstitute.org/ files/ GreenRevUP.pdf. (Accessed on: June 12, 2008).

He, H.P., Corke, H. and Cai, J.G. (2003). Supercritical Carbon dioxide Extraction of oil and squalene from Amaranthus Grain. *J. Agric. Food chem*. **51**(27): 7921-7925.

Henderson, T., Johnson, B. and Schneiter, A. (2000). Row spacing, plant population and cultivar effects on grain amaranth in the Northern Great Plains. *Agronomy Journal*, **92**:329-336.

Herrick, J.E. and Lal, R. (1995). Soil physical property changes during dung decomposition in a tropical pasture. *Soil Sci. Soc. Am. J.* **59**:908-912.

Hudson, B.J.F. and El-Difrawi, E.A. (1979). The sapogenins of the seeds of 4 Lupin sp. *J.plant Foods*, **3**:181

Hurro, J.B. and Cees, M.K. (1991). The dual role of temperature in the regulation of the seasonal changes in dormancy and germination of seeds of Polygonum. *Oecologia.* **90**: 88-94.

Hussain, J., Khan, A.L., Rehman, N., Hamayun, M., Shah, T., Nisar, M. and Lee, I. (2009). Proximate and nutrient analysis of selected vegetable species: A case study of Karak region, Pakistan. *African Journal of Biotechnology*, **8**(12).

Hussein, K.A., Hassan, A.F. and Abdul-Hady, E.S. (2010). Study of sewage sludge use in agriculture and its effect on plant and soil. *Agric. Biol. J. N. Am*., 2010, **1**(5): 1044-1049.

Ibude, M.A., Unambra, R.P.A. and Udealor, A. (1988). Soil management strategies in relation to farming system development in the South Eastern Agricultural Zone of Nigeria. Paper presented at the National Farming system Research Workshop, Jos, Plateau State, Nigeria, 26-29 p.

Iheanacho, K.M.E. and Udebuani, A.C. (2009). Nutritional composition of some leafy vegetables consumed in Imo state, *Nigeria. J. Appl. Sci. Environ. Manage*. **13**(3) 35-38.

Imeri, A., Gonzalez, J.M., Flores, R., Elias, L.G. and Bressani, R. (1987). Genetic variability and correlations among yield, grain size, chemical composition and protein quality of 25 varieties of amaranth (*Amaranthus caudatus*). *Arch Latinoam Nutr*. **37**:132–146.

Islam, M.M., Karim, A.J.M., Jahiruddin, M., Majid, N.M., Miah, M.G., Ahmed, M.M. and Hakim M.A. (2011). Effects of organic manure and chemical fertilizers on crops in the radish-stem amaranth-indian spinach cropping pattern in homestead area. *Australian journal of crop science*. **5**(11):1370-1378.

Jacobs, R.D., Loan, D. and Jacob, J. (2003). Cage Layer Manure: An Important Resource for Land use. Retrieved from: http://edis.ifas.ufl.edu/PS005, (Accessed on: May 19, 2009).

Joint FAO/WHO Expert Committee on Food Additives (JECFA),. (2004). Safety evaluation of certain food additives and contaminants. WHO Food Additives Series No 52..

Junkuszew, M., Oleszek, W., Jurzysta, M., Piancente, S. and Pizza, C. (1998). Triterpenoid saponins from the seeds of *Amaranthus cruentus*. *Phytochemistry*. **49**:195–198.

Kadoshnikov, S.I., Kadoshnikova, I.G., Kulikov, Y.A. and Martirosyan, D.M. (2008). Researches of fractional composition of protein of amaranth. Curr. *Nutr. Food Sci.,* **4**: 196-205.

Kadoshnikov, S.I., Serge, I., Kadoshnikova, I.G. and Martirosyan D.M. (2005). Investigation of Fractional Composition of the Protein in Amaranth. In Book "Non-Traditional Natural Resources, Innovation Technologies and Products" Issue 12 Moscow. Russian Academy of Natural Sciences, Moscow; 81- 104.

Kauffmann, C. S. and Weber, L.E. (1988). Grain amaranth: Advances in new crops: Proceedings of the First National Symposium of New Crops: Research, Development and Economics. Timber Press, Oregon. Pp 127-139.

Kaur, S., Singh, N. and Rana, J.C. (2010). *Amaranthus hypochondriacus* and *Amaranthus caudatus* germplasm: characteristics of plants, grain and flours. *Food Chem*. **123**:1227–1234.

Kawazu, Y., Okimura, M., Ishii, T. and Yui, S. (2003). Varietal and seasonal differences in oxalate content of spinach. *Scientia Horticulturae*, **97**(3), 203-210.

Kennedy, A.C., and Papendick, R.I. (1995). Microbial characteristics of soil quality. J. Soil and Water Cons. May-June. 243-248

Keskar, B.G., Bhore, D.P., Patil, A.V., Sonone, H.N. and Maslekar, S.R. (1981). Comparative defficiency of soil and foliar application of nitrogen through urea on yield of leafy vegetable-Chaulai (*Amaranthus blitum* L.) at various seed rates. *J. Maharashtra Agr. Univ.* **6**:68-69.

Koenig, R. and Johnson, M. (1999). “Selecting and using Organic Fertilizers”.

Kraujalis, P. and Venskutonis, P.R. (2013). Optimisation of supercritical carbon dioxide extraction of amaranth seeds by response surface methodology and characterization of extracts isolated from different plant cultivars. *J Supercrit Fluid.* **73**:80–86.

Kraujalis, P. and Venskutonis, P.R. (2013). Supercritical carbon dioxide extraction of squalene and tocopherols from amaranth and assessment of extracts antioxidant activity. *J Supercrit Fluid*. **80**:78–85.

Krinsky, N. I. (1993). Actions of carotenoids in biological systems. *Annual Review of Nutrition*. **13**: 561-587.

Kuntashula, E., Shileshi, G., Mafongoya, P.L. and Banda, J. (2006). Farmer participatory evaluation of the potential for organic vegetable production in the wetlands of Zambia. *Outlook Agr.*, **35**(4): 299-305.

Kunyanga, C.N., Imungi, J.K., Okoth, M., Momanyi, C., Biesalski, H.K. and Vadivel, V. (2011). Antioxidant and antidiabetic properties of condensed tannins in acetonic extract of selected raw and processed indigenous food ingredients from Kenya. *J Food Sci.* **76**:560–567.

Lairon, D., Splitz, N., Termine, E., Ribaud, P., Lafont, H. and Hauton, J. (1984). Effect of organic and mineral nitrogen fertilisation on yield and nutritive value of butter head lettuce. *J. Sci. Food Agric.* **34**: 97-108.

Law-Ogbomo, K. A. and Ajayi, S. O. 2009. Growth and yield performance of Amaranthus cruentus influenced by planting density and poultry manure application. *Natulae Botanicae Horti Agrobotanici Cluj-Napoca* **37**(1): 195-199.

Lehman, J. (1992). The Official Newsletter of Amaranth Institute; Amaranth Institute. *Legacy*, **9**: 6-9.

Liener, I.E. (2005). Implications of antinutritional components in soybean foods. *Food Sci.* **34**:31.

Lorenz, K. and Wright, B. (1984). Phytate and tannin content of amaranth. *Food Chem*. **14**:27–34.

Lucas, B.O. (1988). The potential of leafy vegetables in Nigeria. *Outlook on Agriculture*. **17** (4): 163-168.

Lucas, G.M. and Markakas, P. (1975). Phytic acid and other phosphorus compounds of bean (Phaseolus vulgaris). *J. Agric. Educ. Chem*, **23**: 13 -15.

Macrae, R., Robinson, R.K. and Sadler, M.J. (1993). Encyclopedia of Food science , Food technology and nutrition. Academic press, London. Pp 4816-4820; 4822-4826.

Magkos, F., Arvaniti, F. and Zampelas, A. (2003). Organic food: Nutritious food or food for thought? A review of evidence. *Int. J. of Food Sci. Nutri.,* **54**: 357-371.

Makinde, E.A., Ayeni, L.S., Ojeniyi, S.O. and Odedina, J.N. (2010). Effect of organic, organomineral and NPK fertilizer on nutritional quality of *Amaranthus* in Lagos, Nigeria. *Researcher*, **2**: 91-96.

Marschner, H. (1986). Mineral nutrition of higher plants. Academic Press, Harcourt Brace Jovanovich Publishers, London. Pp. 674.

Martin, F.W. and Telek, L. (1979). Vegetables for the hot humid. Part 6: Amaranth and Celosia. U.S. Dept of Agric., New Orleans, LA, pp. 156-163.

Martirosyan, D.M. (2001). Amaranth as a Nutritional Supplement for the Modern Diet. Amaranth Legacy, USA, **14**:2-4.

Masarirambi, M.T., Hlawe, M.M., Oseni, O.T. and Sibiya, T.E. (2010). Effects of organic fertilizers on growth, yield, quality and sensory evaluation of red lettuce (*Lactuca sativa* L.) 'Veneza Roxa'. *Agric. Biol. J. North America*, **1**(6): 1319-1324.

Masarirambi, M.T., Mbokazi, M.B., Wahame, P.K. and Oseni, T.O. (2012). Effect of kraal manure, chicken manure and inorganic fertilizer on growth and yield of lettuce (*Lactuca sativa* L. var Commander) in a semi-arid environment. *Asian Journal of Agricultural Sciences* **4**(1): 56-64.

Masette, M., Isabirye,G., Baranga, D. and Chemurot, M .(2015). Levels of tannins in fruit diet of grey-cheeked mangabeys in Lake Victoria basin forest reserves. *Journal of Ecology and Natural Environment,* **7**(5): 146 - 157.

Maundu, P., Achigan-Dako, E.G. and Morimoto, Y. (2009) Biodiversity of African vegetables. In: Shackleton CM, Pasquini MW, DrescherAW(eds) African indigenous vegetables in urban agriculture. Earthscan, London, pp 65–104.

Mepha, H.D., Eboh, L. and Banigbo, D.E.B. (2007). Effects of processing treatments on the Nutritive Composition and consumer acceptance of some Nigerian edible leafy vegetables. *Afr. J. Food Agric. Nutr. Dev.* **7**(1): 1-18.

Mhlontlo, S., Muchaonyerwa, P. and Mnkeni, P.N.S. (2007). Effects of sheep kraal manure on growth, dry matter yield and leaf nutrient composition of a local Amaranthus accession in the Central Region of the Eastern Cape Province, South Africa. *Water SA.* **33(**3): 363-368.

Miller, W.P., Martens, D.C. and Zelazny, L.W. (1985). Effects of manure amendment on soil chemical properties and hydrous oxides. *Soil ScL Soc. Am. J.* **49**:856-861

Mnkeni, A. P., Masika, P., and Maphaha, M. (2007). Nutritional quality of vegetable and seed from different accessions of Amaranthus in South Africa. *African journal online*. **33**:(3).

Mofunanya, A.A.J., Ebigwai, J.K., Bello, O.S. and Egbe, A.O. (2014). Comparative study of the effects of organic and inorganic fertilizer on nutritional composition of *Amaranthus spinosus* L. *American-Eurasian J. Agric. & Environ. Sci.* **14**(9):824-830

Mshelia, J.S. and Degri, M.M. (2014). Effect of different levels of poultry manure on the performance of *Amaranthus caudatus* L. in Bama, Nigeria. *International journal of science and nature.* **5**(1):121-125

Msibi, B.M., Mukabwe, W.O., Manyatsi, A.M., Mhazo, N. and Masarirambi, M.T. (2014). Effect of liquid manure on growth and yield of spinach (*Beta vulgaris* var Cicla) in a sub-tropical environment in Swaziland. *Asian Journal of Agricultural Sciences* **6**(2): 40-47.

Mueller-Harvey, I. (2001). Analysis of hydrolysable tannins. *Animal Feed Science and Technology*, **91**: 3-20.

Murthy, E., Pattanaik, C., Reddy, C. and Sudhakar, R. (2010). Piscicidal plants used by Goud tribe of kawal wildlife sanctuary, Andhrapresh. *Indian Journal of Traditional Knowledge*, **1**(1): 97 - 101.

Musa, A. and Ogbadoyi, E.O. (2012). Effect of Nitrogen Fertilizer on the levels of some nutrients, anti-nutrients and toxic substances in Hibiscus sabdariffa. *Asian Journal of Crop Science*, **4**: 103-112.

Musa, A., Ezenwa, M.I., Oladiran, J.A., Akanya, H.O. and Ogbadoyi, E.O. (2010). Effect of soil nitrogen levels on some micronutrients, antinutrients and toxic substances in Corchorus olitorius grown in Minna, Nigeria. *African Journal of Agricultural Research*, **5**(22): 3075-3081.

Muyonga, J.H., Nabakabya, D., Nakimbudgwe, D.N. and Masinde, D. (2008). Efforts to promote Amaranth production and consumption in Uganda to fight malnutrition. Department of Food Science and Technology, Makerere University, Kampala. Pp 1-9.

Myers, R.L. (1996). Amaranth: New crop opportunity. In: *Progress in New Crops. ASHS Press, Alexandria, VA*. Pp. 207-220.

Myers, R.L. (1998). Nitrogen fertilizer effect on grain amaranth. *Agronomy Journal*. **90**(5):597-602.

N'Dayegamiye, A. (2006). Mixed paper mill sludge effects on corn yield, nitrogen efficiency and soil properties. *Agron. J.*, **98**: 1471-1478.

Nordberg, G.F., Nogawa, K., Nordberg, M. and Friberg, L.T. (2011). Metals- A new old environmental problem: Cadmium. In Handbook on the Toxicology of Metals. Academic Press: Burlington, MA, USA. pp. vii, 446–451, 463–470, 600–609.

Nyankanga, R., Onwonga, O., Wekesa, F.S., Nakimbungwe, D., Masinde D. and Mugisha, J. (2012). Effect of inorganic and organic fertilizers on the performance and profitability of grain amaranth *(Amaranthus caudatus* L.) in Western Kenya. *Journal of agricultural science*. **4**(1): 1-6.

Ofitserov, N.E. (2001). Amaranth: Perspective raw material for Food-processing and Pharmaceutical Industry. Chemistry and computational simulation, Tatarstan. Pp 1-4.

Ogedegbe, S.A., Ajala, B.A. and Ogah, J.J. (2013) Effect of organic fertilizers on leaf and seed yields of amaranth (*Amaranthus specie* L.) varieties in Vom, Nigeria. *Nigerian journal of agriculture, food and environment.* **9**(4):13-18

Oke, O.L. (1983). Amaranth. In: Handbook of Tropical Foods. Chan HT (ed). Marcel-Dekker, Inc., New York, pp 1-14.

Okokoh, S.J. and Bisong, B.W. (2011) Effect of Poultry Manure and Urea- N on Flowering Occurrence and Leaf Productivity of *Amranthus cruentus* in Calabar. *Journ.of Apl. Sic. Environmental Management.* **15**(1):13-15.

Olaniyi, J.O. (2007). Evaluation of yield and quality performance of grain amaranth varieties in the southwestern Nigeria. *Research Journal of Agronomy*. **1**(2): 42-45.

Olaniyi, J.O., Adelasoye, K.A. and Jegede, C.O. (2008).Influence of nitrogen fertilizer on the growth, yield and quality of grain amaranth varieties. *World J. Agric Sciences*. **4**:506-513.

Oleszek W, Junkuszew M, Stochmal A. 1999. Determination and toxicity of saponins from *Amaranthus cruentus* seeds. *J Agric Food Chem*. **47**:3685–3687.

Oliveria, J.S. and DeCarvalho, M.F. (1975). Nutritional Value of some edible leaves in Mozambique. *Econ. Bot.* **29**: 255-259.

Omosun, G., Markson, A.A. and Mbanasor, O. (2008). Growth and anatomy of Amaranthus hybridus as affected by different crude oil concentrations. *Ametrican-Eurasian Journal of Scientific research* **3**(1): 70-74.

Onwordi, C.T., Ogungbade, A.M. and Wusu, A.D. (2009). "The proximate and mineral composition of three leafy vegetables commonly consumed in Lagos,Nigeria,"*African Journal of Pure and Applied Chemistry*, **3**(6): 102–107.

Onyango, C. M., Shibairo, S. I., Imungi, J. K. and Harbinson, J. (2008). The physico-chemical characteristics and some nutritional values of vegetable amaranth sold in Nairobi-Kenya. *Ecology of food and nutrition*, ***47***(4), 382-398.

Onyango, C.M. (2010). Preharvest and postharvest factors affecting yield and nutrient contents of vegetable amaranth (Var. Amaranthus hypochondriacus). Ph.D. Thesis, Wageningen University.

Onyango, M.C., Shibairo, S.I., Imungi, J.K. and Harbinson, J. (2008). The physico-chemical characteristics and some nutritional values of vegetable amaranth sold in Nairobi-Kenya. *Ecology of Food Nutrition*. **47**: 382-398.

Oryokot, J.O.E., Murphy, S.D., Thomas, A.G. and Swanton, C.J. (1997). Temperature and moisture dependent models of seed germination and shoot elongation in green and redroot pigweed (*Amaranthus powellii* and *Amaranthus retroflexus*). *Weed Science.* **45**: 488-496.

Othman, O.C. (2001). Heavy metals in green vegetables and soils from vegetable gardens in Dar ES Salaam-Tanzania. *Tanz.J.Sci*. **27**:1-6.

Oyedeji, S., Animasaun, D.A., Bello, A.A. and Agboola, O.O. (2014). Effect of NPK and Poultry Manure on Growth, Yield, and Proximate Composition of Three Amaranths. Hindawi Publishing Corporation *Journal of Botany*. **10**: 11 – 55.

Ozbucak, T.B., ErgenAkcin, O. and Yalcin, S. (2007). Nutrition contents of the somewild edible plants in Central Black Sea Reagion of Turkey. *Inter. J. Natural Engineering Sci.,* **1**: 11-13.

Palada, M.C. and Chang, L.C. (2003). AVRDC International Cooperators' Guide.

Palm, C.A., Myers, R.K.J. and Nandwa, S.M. (1997). Combined use of Organic and inorganic nutrient sources for Soil fertility maintenance and replenishing. Special Publication Madison, WI. *Soil Sciences Society of America*. **151**:193-217.

Palmer, M.A., Ambrose, R.F. and Poff, N.L. (1997). Ecological theory and community restoration ecology. *Restoration ecology*, **5**(4): 291-300.

Papendick, R.I. and Parr, J.F. (1992). Soil quality: The key to sustainable agriculture. *Am. J. Altern. Agric.* **7**:2-3

Pimentel, D., Hepperly, P., Hanson, J., Douds, D. and Sidel, R. (2005). Environmental, energetic and economic comparisons of organic and conventional farming systems. *BioSci.*, **55**(**7**): 573-582.

Pinheiro, C. and Chaves, M.M. (2011). Photosynthesis and drought: Can we make metabolic connections from available data? *Experimental Botany*. **62**(3): 869–882.

Pospisil, A., Pospisil, M., Varga, B. and Svecnjak, Z. (2006). Grain yield and protein concentration of two amaranth species (Amaranthus spp.) as influenced by the nitrogen fertilization. *European Journal of Agronomy*. **25**: 250–253.

Prakash, D. and Pal, M. (1991). Nutritional and antinutritional composition of vegetable and grain amaranth leaves. *J Sci Food Agric*. **57**:573–583.

Premsekhar, M. and Rajashree, V. 2009. Influence of organic manures on growth, yield and quality of okra. *American-Eurasian Journal of sustainable Agriculture*, **3**(1): 6-8.

Price, M. and Berkelaar, D. (2006). Grain Amaranth. ECHO Development Notes, Florida. Pp 1-8.

Priya, V.P., Celine, V.A., Gokulapalan, C. and Rajamony, L. (2007) Screening amaranth genotypes (Amaranthus spp.) for yield and resistance to leaf blight caused by Rhizoctonia solani Kuhn. *Plant Genet Res Newsl.* **147**:1–4

Radek, M. and Savage, G.P. (2008). Oxalates in some Indian green leafy vegetables. *International Journal of Food Sciences and Nutrition*, **59**(3): 246– 260.

Rantae, G. (2013). Growth, yield and quality response of beet (Beta vulgaris L.) to nitrogen. Fertilizer and plant nutrition guide, (1984). FAO fertilizer and plant nutrition bulletin, 9th edn. Rome, Italy.

Rao, C.V. and Newmark, H.L. (1998). Chemo-preventive effect of Squalene on colon cancer. *Carcinogenesis*. **19**: 287-290.

Rastrelli, L., Pizza, C., Saturnino, P., Schettino, O. and Dini, A. (1995). Studies on the constituents of *Amaranthus caudatus* (Kiwicha) seeds. Isolation and characterization of seven new triterpenesaponins. *J. Agricultural Food Chem.,* **43**: 904-909.

Ravindran, V., Hood, R.L., Gill, R.J., Kneale C.R. and Bryden, W.L. (1996). Nutritional evaluation of grain amaranth (*Amaranthus hypochondriacus*) in broiler diets. *Animal Feed Science and Technology* **1**(4): 323- 331.

Rodríguez, P., Pérez, E., Romel, R. and Dufour, D. (2011). Characterization of the protein fractions extracted from leaves of *Amaranthus dubius* (*Amaranthus* spp.). *Afr J Food Sci*. **5**:417–424.

Saeed, I.N., Abbasi, K. and Kazim, M. (2001). Response of maize (Zea nmays) to nitrogen and phosphorus fertilization under agro-climatic condition of Rawalokot Azad Jammu and Kashmir. *Pak. J. Biol. Sci.* **4**:53-55.

Salunkhe, D.K. and Kadam, S.S. (1998). Handbook of Vegetable Science and Technology: Production, Composition, Storage and Processing. Marcel Dekker, INC, pp: 721.

Salunkhe, D.K., Bilon, H.R. and Reddy, N.R. (1991). Storage, Processing and Nutritional Quality of Fruits and Vegetables. CRC press. *Fresh fruits and vegetables*. **1**(2): 285.

Sanchez-Alonso, F., and Lachica, M. (1988). Oxalate salts in the leaves of plum (Prunus salicina L.) and cherry (P. avium L.). *New phytologist*, **108**(4): 505-508

Sanwal, S. K., Lakminaragana, K., Yadav, R. K., Yadav, D. S. and Mousumi, B. (2007). Effect of organic manures on soil fertility, growth, physiology, yield and quality of turmeric. *Indian Journal of Horticulture,* **64** (4): 444-449.

Sanz-Penella, J.M., Wronkowska, M., Soral-Smietana, M. and Haros, M. (2013). Effect of whole amaranth flour on bread properties and nutritive value. *LWT-Food Sci Technol*. **50**:679–685.

Säumel, I., Kotsyuk, I., Hölscher, M., Lenkereit, C., Weber, F. and Kowarik, I. (2012). How healthy is urban horticulture in high traffic areas? Trace metal concentrations in vegetable

crops from plantings within inner city neighbourhoods in Berlin, Germany. *Environ. Pollut*. **165**:124–132.

Saunders, R.M. and Becker, R. (1984). Amaranthus: a potential food and feed resource. In: Pomeranz Y, editor. Advances in cereal science and technology. *St. Paul, MN*: American Association of Cereal Chemists. pp 357–397.

Schippers, R. R. (2000). African Indigenous Vegetables: An Overview of the cultivated species. Chatham UK. Natural Resource Institute/ACP-EU Technical Centre for Agricultural Resources and Rural Cooperation.

Schonfeldt, H. and Pretorius, B. (2011) The nutrient content of five traditional South African dark green leafy vegetables—a preliminary study. *J Food Compos Anal.* **24**(8):1141–1146

Shukla, S., Bhargava, A., Chatterjee, A., Srivastava, J., Singh, N. and Singh, S.P. (2006). Mineral proWle and variability in vegetable amaranth (*Amaranthus tricolor*). *Plant Food. Hum. Nutr.*, **61**: 23-28.

Skwaryło-Bednarz, B. (2012). Assesment of content of fat and tocopherols in seeds of Amaranthus in relation to diversified fertilization with macroelements. *Ecol Chem Eng*. **19**:273–279.

Skwaryło-Bednarz, B., Brodowska, M.S. and Brodowski, R. (2011). Evaluating the influence of varied NPK fertilization on yielding and microelements contents at amaranth (*Amaranthus cruentus* L.) depending on its cultivar and plant spacing. *Acta Sci Pol Hortorum Cultus.* **10**:245–261.

Sleugha, B.B., Mooreb, K.J., Brummerb, E.C., Knappb, A.D., Russellb, J. and Gibsonb, L. (2001). Forage Nutritive Value of Various Amaranth Species at Different Harvest Dates. *Crop Science* **41**:466-472.

Smith, F.I. and Eyzaguirre, P. (2007) African leafy vegetables: their role in the World Health Organization and Apos. *S Global fruit and vegetables initiative*, pp 1-8.

Smith, T.J. (2000). Squalene: Potential Chemo preventive agent. *Expert Opin. Invest. Drugs.* **9**: 1841-1848.

Soetan, K. and Oyewol, O. (2009). The need for adequate processing to reduce the antinutritional factors in plants used as human foods and animal feeds: A review. *African Journal of Food Science.* **3**(9): 223-232.

Spreeth, M. H., Slabbert, M. M., De ronde, J. A. and Van den heever, E. (2004). Screening of cowpea, Bambara groundnut and Amaranthus germplasm for drought tolerance and testing of selected plant material in participation with targeted communities. WRC Report No. 944/1/04.

Stallknecht, G. F. and Schulz-Schaeffer, J. R. (1993). Amaranth rediscovered. *New crops. Wiley, New York*, Pp. 211-218.

Stephens, J.M. (2009). Amaranth- *Amaranthus* spp., University of Florida, Florida. *IFAS.* Pp 1-2.

Stewart, B.A., Robinson, C.A. and Parker, D.B. (2000). Examples and case studies of beneficial reuse of beef cattle by-products. p. 387-407. *In* D.L. Karlen et ale (ed.) Agricultural utilization of urban and industrial by-products. ASA Spec. Publ. 58. ASA, CSSA, and SSSA, Madison, WI.

Sujak, A., Dziwulska-Hunek, A. and Kornarzynski, K. (2009). Compositional and nutritional values of amaranth seeds after pre-sowing He-Ne laser light and alternating magnetic field treatment. *Intl Agrophys*. **23**:81–86.

Sumitra, S. and Sandeep, S.S. (2011). Evaluation of the nutinociceptive activity of Amaranthus hybridus Linn root extracts. Acta polaniae pharmceutica- Drug Research, **68**(2):255-259.

Svirskis, A. (2003). Investigation of amaranth cultivation and utilisation in Luthuania. *Agronomy Research.* **1**(2): 253-264.

Teutonico, R.A. and Knorr, D. (1985). Amaranth: composition, properties and applications of a rediscovered food crop. *Food Technol*. **39**:49–61.

The International Pharmacopoeia,. (2003). World Health Organization Geneva, Vol. 3.

Trucco, F. and Tranel, P.J. (2011). Amaranthus. In: Kole C (ed) Wild crop relatives: genomic and breeding resources vegetables, *Springer-Verlag, Berlin Heidelberg*, **26**:11–21

Tucker, J. B. (1986). Amaranth: the once and future crop. *Bioscience* **36**: 9-13, 59 – 60.

Ugwu, F.M. and Oranye, N.A. (2006). Effects of some processing methods on the toxic components of African breadfruit (Treculia qfricana). *African Journal of Biotechnology* **5**: 2329-2333.

Van-Averbeke, W. and Yoganathan, S. (2003). Using Kraal Manure as Fertilizer. Department of Agriculture Cape Town, University of Fort Hare, Republic of South Africa. Retrieved form: http://www.daff.gov.za/docs/Infopaks/KraalManure.pdf. (Accessed on: May 28, 2016)

Venskutonis, P. R., and Kraujalis, P. (2013). Nutritional components of amaranth seeds and vegetables: a review on composition, properties, and uses. *Comprehensive Reviews in Food Science and Food Safety*, **12**(4), 381-412.

Wallace, A. and Terry, R.E. (1998). Soil conditioners p. 1-42 *In* A. Wallace and R. Terry (ed.) Handbook of soil conditions: Substances that enhance the physical properties of soil. Marcel Dekker, New York.

Whelton, P.K. (1997). Effects of oral potassium on blood pressure. *Journal of the American Medical Association*. **277**:1624-1632.

WHO. (2004a). Guidelines for drinking-water quality. Sixty-first meeting, Rome, 10-19 June 2003. Joint FAO/WHO Expert Committee on Food Additives, Available from http://ftp.fao.org/es/esn/jecfa/jecfa61sc.pdf

Worthington, V. (2001). Nutritional quality of organic versus conventional fruits, vegetables andgrains. *J. Altern. Complem. Med.*, **7**(2): 342-353.

Wu, H., Sun, M., Yue, S., Sun, H., Cai, Y., Huang, R., Brenner, D. and Corke, H. (2000) Field evaluation of an Amaranthus genetic resource collection in China. *Genet Resour Crop Evol*. **47**(1):43–53.

Xu, F. and Sun, M. (2001) Comparative analysis of phylogenetic relationships of grain amaranths and their wild relatives (Amaranthus; Amaranthaceae) using internal transcribed

spacer, amplified fragment length polymorphism, and double-primer fluorescent intersimple sequence repeat markers. *Mol Phylogenet Evol*. **21**(3):372–387

Yanez, E., Zacarias, I., Granger, D., Vasquez, M. and Estevez, A.M. (1994). Chemical and nutritional characterization of amaranthus (Amaranthus cruentus). *Arch Latinoam Nutr*, **44**(1):57-62.

Yang, Y., Zhang, F.S., Li, H.F. and Jiang, R.F. (2009). Accumulation of cadmium in the edible parts of six vegetable species grown in Cd-contaminated soils. *J. Environ. Manag*. **90**:1117–1122.

Yarger, L. (2008). Amaranth: Grain and Vegetable Types. Echo Technical Note, Florida. Pp 1-14.

Zhai, Q., Narbad, A. and Chen, W. (2015). Dietary Strategies for the treatment of cadmium and lead toxicity. *Nutrients*, **7**:552-571

Zhang, M., Garlak, R., Mitchell, A., and Sparrow, S. (2006). Soil and liquid cattle manure application in subarctic soil. *Agronomy Journal*, **98**(6): 1551-1558.

Zheleznov, A.V., Solonenko, L.P. and Zheleznova, N.B. (1997). Seed proteins of the wild and the cultivated *Amaranthus* species. *Euphytica*. **97**:177–182.

Zhu, D. (1998). Heavy metal transport in soils as influenced by plants, organic amendments and organic compounds. Ph.D Thesis. Kansas State University, Manhattan, Kansas.

APPENDICES



Appendix 1: Pictures during land preparation, fertilizer application, transplanting and nursery management and data collection.

Plant Height (cm)					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	18.30 ± 0.56^{a}	38.62 ± 1.39^{a}	67.53 ± 2.60^{a}	87.78 ± 1.88^{a}	98.73 ± 2.30^{a}
PM1	24.93 ± 0.38^{cd}	56.15 ± 2.12^{c}	89.48 ± 2.57^{c}	106.05 ± 0.61^{d}	112.83 ± 1.94^{d}
PM2	26.28 ± 1.07^{d}	58.33 ± 2.39^{c}	89.27 ± 1.08^{c}	106.73 ± 1.26^{d}	118.10 ± 1.32^{e}
SS1	21.32 ± 0.08^{b}	47.67 ± 1.49^{b}	77.62 ± 1.99^{b}	98.32 ± 1.51^{bc}	107.65 ± 0.95^{bc}
SS2	21.81 ± 1.30^{b}	48.12 ± 0.52^{b}	78.33 ± 2.29^{b}	100.42 ± 1.19^{bc}	109.58 ± 1.78^{c}
NPK1	24.37 ± 0.75^{c}	49.53 ± 1.03^{b}	86.00 ± 2.70^{c}	97.43 ± 3.01^{b}	105.30 ± 1.77^{b}
NPK2	25.55 ± 1.07^{cd}	49.72 ± 1.69^{b}	89.05 ± 1.73^{c}	100.77 ± 1.28^{c}	108.80 ± 0.69^{c}

Appendix 2: Effect of Organic Fertilizers on Plant Height of *Amaranthus caudatus* (Samaru local variety)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Plant Height (cm)					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	28.70 ± 1.95^{a}	47.32 ± 4.31^{a}	78.08 ± 3.90^{a}	99.83 ± 2.49^{a}	110.02 ± 2.77^{a}
PM1	43.07 ± 1.87^{cd}	71.80 ± 0.35^{d}	105.28 ± 1.98^{de}	119.37 ± 1.27^{cd}	132.52 ± 4.24^{c}
PM2	45.97 ± 0.88^{d}	74.65 ± 4.44^{d}	110.57 ± 5.38^{e}	122.87 ± 1.41^{d}	135.67 ± 2.92^{c}
SS1	29.98 ± 1.56^{a}	56.25 ± 0.48^{b}	85.08 ± 3.31^{b}	110.78 ± 1.85^{b}	122.53 ± 4.02^{b}
SS2	34.23 ± 1.83^{b}	59.55 ± 1.93^{b}	94.48 ± 2.65^{c}	117.65 ± 0.97^{c}	125.87 ± 3.60^{b}
NPK1	35.97 ± 0.95^{b}	66.38 ± 2.64^{c}	101.15 ± 2.26^{d}	113.35 ± 3.84^{b}	119.98 ± 1.89^{b}
NPK2	41.65 ± 2.23^{c}	77.43 ± 3.52^{d}	109.33 ± 4.15^{e}	119.60 ± 0.30^{cd}	125.55 ± 1.43^{b}

Appendix 3: Effect of Organic Fertilizers on Plant Height of *Amaranthus cruentus* (NH84/452)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Number of leaves					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	16.83 ± 1.44^{a}	32.50 ± 3.04^{a}	42.67 ± 0.76^{a}	54.33 ± 4.01^{a}	66.50 ± 1.32^{a}
PM1	21.67 ± 0.58^{cd}	39.33 ± 1.04^{bc}	55.00 ± 3.61^{b}	63.67 ± 3.01^{b}	72.67 ± 2.31^{ab}
PM2	23.83 ± 1.44^{e}	41.83 ± 1.44^{bc}	56.67 ± 6.29^{b}	66.33 ± 5.20^{b}	78.33 ± 5.03^{b}
SS1	19.50 ± 0.87^{b}	38.17 ± 1.61^{b}	51.00 ± 5.29^{ab}	63.17 ± 4.63^{b}	72.00 ± 1.00^{ab}
SS2	21.67 ± 0.58^{cd}	42.17 ± 2.89^{c}	58.00 ± 4.33^{b}	64.00 ± 2.29^{b}	74.00 ± 0.50^{b}
NPK1	21.00 ± 1.00^{bc}	39.33 ± 1.76^{bc}	58.00 ± 8.26^{b}	65.00 ± 5.22^{b}	70.50 ± 3.91^{ab}
NPK2	23.00 ± 0.50^{de}	41.00 ± 1.73^{bc}	57.50 ± 5.20^{b}	64.00 ± 6.61^{b}	70.33 ± 6.53^{ab}

Appendix 4: Effect of Organic Fertilizers on Number of Leaves of *Amaranthus caudatus* (Samaru local variety)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Number of leaves					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	13.33 ± 1.04^{a}	30.17 ± 2.47^{a}	39.33 ± 1.61^{a}	47.17 ± 3.05^{a}	52.33 ± 2.52^{a}
PM1	14.67 ± 0.29^{ab}	31.00 ± 1.00^{a}	44.00 ± 3.28^{b}	54.83 ± 4.19^{b}	62.83 ± 2.47^{b}
PM2	15.67 ± 1.26^{b}	34.33 ± 4.16^{ab}	46.00 ± 4.27^{bc}	56.17 ± 4.80^{b}	64.50 ± 3.50^{b}
SS1	15.17 ± 0.29^{ab}	34.00 ± 2.18^{ab}	44.83 ± 0.76^{b}	57.00 ± 0.86^{b}	64.17 ± 0.29^{b}
SS2	15.67 ± 1.26^{b}	38.00 ± 1.73^{bc}	46.00 ± 0.50^{bc}	56.00 ± 3.97^{b}	61.67 ± 0.58^{b}
NPK1	15.67 ± 2.02^{b}	40.50 ± 2.50^{c}	50.67 ± 2.75^{c}	58.17 ± 0.76^{b}	61.67 ± 0.58^{b}
NPK2	16.67 ± 0.29^{b}	40.33 ± 1.53^{c}	49.67 ± 1.89^{c}	55.83 ± 1.04^{b}	62.17 ± 1.26^{b}

Appendix 5: Effect of Organic Fertilizers on Number of Leaves of *Amaranthus cruentus* (NH84/452)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Leaf Length (cm)					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	11.33 ± 0.47^{a}	17.45 ± 0.54^{a}	18.37 ± 0.68^{a}	19.22 ± 0.69^{a}	19.78 ± 0.75^{a}
PM1	14.30 ± 0.08^{d}	19.50 ± 0.10^{b}	20.27 ± 0.16^{b}	21.25 ± 0.22^{b}	22.10 ± 0.23^{b}
PM2	14.78 ± 0.08^{e}	19.82 ± 0.13^{b}	21.05 ± 0.10^{b}	21.67 ± 0.06^{bc}	$22.48 \pm 0\text{-}16^{bc}$
SS1	12.57 ± 0.15^{b}	19.28 ± 0.26^{b}	21.95 ± 0.25^{c}	22.43 ± 0.48^{cd}	$23.12 \pm 0\text{-}23^{cd}$
SS2	12.63 ± 0.08^{b}	19.35 ± 0.45^{b}	22.62 ± 0.73^{c}	22.77 ± 0.18^{d}	23.57 ± 0.21^{d}
NPK1	13.38 ± 0.38^{c}	19.32 ± 0.33^{b}	20.52 ± 0.58^{b}	21.32 ± 0.26^{b}	22.57 ± 0.13^{b}
NPK2	13.62 ± 0.23^{c}	19.48 ± 0.48^{b}	20.90 ± 0.36^{b}	21.80 ± 0.88^{bc}	22.43 ± 0.87^{bc}

Appendix 6: Effect of Organic Fertilizers on Leaf Length of *Amaranthus caudatus* (Samaru local variety)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Leaf Length (cm)					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	11.73 ± 0.34^{a}	18.47 ± 0.43^{a}	21.73 ± 1.39^{a}	23.85 ± 0.35^{a}	24.70 ± 0.48^{a}
PM1	17.22 ± 0.08^{d}	23.70 ± 0.81^{cd}	27.13 ± 1.39^{bc}	27.68 ± 0.60^{b}	28.35 ± 0.58^{b}
PM2	18.67 ± 0.61^{e}	25.68 ± 1.66^{e}	31.98 ± 0.42^{e}	32.72 ± 0.43^{e}	33.20 ± 0.53^{e}
SS1	13.83 ± 0.38^{b}	21.67 ± 0.56^{b}	29.08 ± 0.28^{d}	29.60 ± 0.30^{cd}	30.30 ± 0.23^{cd}
SS2	15.13 ± 0.72^{c}	22.72 ± 0.26^{bc}	29.27 ± 0.25^{d}	30.07 ± 0.24^{d}	30.63 ± 0.26^{d}
NPK1	17.13 ± 0.79^{d}	23.32 ± 0.47^{cd}	26.57 ± 0.60^{b}	27.57 ± 0.33^{b}	28.13 ± 0.13^{b}
NPK2	18.60 ± 1.02^{e}	24.42 ± 1.09^{de}	28.25 ± 0.71^{cd}	28.92 ± 0.81^{c}	29.53 ± 0.63^{c}

Appendix 7: Effect of Organic Fertilizers on Leaf Length of *Amaranthus cruentus* (NH84/452)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Leaf Width (cm)

Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	6.37 ± 0.32^{a}	6.80 ± 0.23^{a}	7.92 ± 0.24^{a}	8.32 ± 0.24^{a}	8.78 ± 0.16^{a}
PM1	7.45 ± 0.41^{b}	8.00 ± 0.44^{bc}	8.62 ± 0.42^{b}	9.10 ± 0.27^{b}	9.22 ± 0.25^{ab}
PM2	7.62 ± 0.23^{b}	8.37 ± 0.25^{bc}	9.12 ± 0.20^{b}	9.42 ± 0.21^{bc}	9.57 ± 0.25^{b}
SS1	6.80 ± 0.23^{a}	7.73 ± 0.25^{b}	8.77 ± 0.21^{b}	9.20 ± 0.20^{bc}	9.30 ± 0.15^{b}
SS2	6.83 ± 0.21^{a}	7.73 ± 0.25^{b}	8.80 ± 0.20^{b}	9.25 ± 0.13^{bc}	9.35 ± 0.05^{b}
NPK1	7.43 ± 0.16^{b}	8.60 ± 0.23^{c}	9.07 ± 0.21^{b}	9.38 ± 0.24^{bc}	9.45 ± 0.22^{b}
NPK2	7.72 ± 0.54^{b}	8.53 ± 0.66^{c}	9.17 ± 0.31^{b}	9.62 ± 0.43^{c}	9.70 ± 0.46^{b}

Appendix 8: Effect of Organic Fertilizers on Leaf Width of *Amaranthus caudatus* (Samaru local variety)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Leaf Width (cm)

Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	7.97 ± 0.35^{a}	9.63 ± 0.23^{a}	11.05 ± 0.54^{a}	11.97 ± 0.50^{a}	12.67 ± 0.42^{a}
PM1	9.45 ± 0.43^{bc}	11.08 ± 0.56^{bcd}	12.37 ± 0.68^{b}	12.95 ± 0.74^{ab}	13.13 ± 0.76^{a}
PM2	10.17 ± 0.35^{c}	11.97 ± 0.68^{d}	13.17 ± 0.34^{b}	13.67 ± 0.39^{b}	13.93 ± 0.43^{a}
SS1	8.97 ± 0.33^{b}	10.43 ± 0.32^{ab}	12.23 ± 0.36^{b}	12.80 ± 0.33^{ab}	12.98 ± 0.32^{a}
SS2	9.05 ± 0.23^{b}	10.68 ± 1.10^{abc}	12.25 ± 0.87^{b}	12.78 ± 1.02^{ab}	12.95 ± 1.04^{a}
NPK1	9.65 ± 0.63^{bc}	11.90 ± 0.53^{cd}	12.60 ± 0.43^{b}	13.03 ± 0.52^{ab}	13.10 ± 0.49^{a}
NPK2	10.02 ± 0.89^{c}	12.35 ± 0.88^{d}	12.93 ± 0.94^{b}	13.28 ± 1.11^{ab}	13.40 ± 1.10^{a}

Appendix 9: Effect of Organic Fertilizers on Leaf Width of *Amaranthus cruentus* (NH84/452)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Leaf Area (cm^2)					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	41.71 ± 2.84^{a}	68.56 ± 2.11^{a}	82.66 ± 6.83^{a}	92.40 ± 5.08^{a}	100.46 ± 4.88^{a}
PM1	61.56 ± 3.05^{cd}	90.18 ± 5.30^{bc}	100.92 ± 4.47^{b}	111.78 ± 3.90^{b}	117.75 ± 4.22^{b}
PM2	65.08 ± 2.14^{d}	95.82 ± 2.31^{cd}	110.84 ± 3.00^{c}	117.93 ± 2.84^{bc}	124.31 ± 2.52^{bc}
SS1	49.38 ± 1.24^{b}	86.18 ± 2.06^{b}	111.20 ± 1.45^{c}	119.26 ± 0.13^{c}	124.25 ± 0.80^{bc}
SS2	49.90 ± 1.77^{b}	86.48 ± 2.99^{b}	113.05 ± 4.95^{c}	121.93 ± 1.13^{c}	127.36 ± 3.40^{c}
NPK1	57.31 ± 2.50^{c}	96.01 ± 2.60^{cd}	107.56 ± 5.55^{bc}	116.72 ± 4.23^{bc}	120.27 ± 3.40^{bc}
NPK2	60.73 ± 4.28^{cd}	99.66 ± 5.44^{d}	112.39 ± 6.97^{c}	117.39 ± 3.24^{bc}	125.85 ± 7.15^{c}

Appendix 10: Effect of Organic Fertilizers on Leaf Area of *Amaranthus caudatus* (Samaru local variety)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Leaf Area (cm^2)					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	54.07 ± 3.71^{a}	102.85 ± 4.45^{a}	128.95 ± 17.83^{a}	164.97 ± 7.57^{a}	180.81 ± 5.89^{a}
PM1	94.03 ± 3.84^{c}	151.92 ± 11.30^{bcd}	194.18 ± 14.12^{b}	207.33 ± 15.28^{b}	213.36 ± 16.73^{b}
PM2	109.74 ± 6.41^{e}	178.03 ± 21.79^{d}	243.45 ± 9.29^{c}	258.50 ± 10.54^{c}	258.29 ± 23.96^{c}
SS1	71.67 ± 2.47^{b}	130.68 ± 6.08^{b}	205.64 ± 6.35^{b}	219.03 ± 7.96^{b}	227.39 ± 6.41^{bc}
SS2	79.22 ± 5.59^{b}	140.37 ± 16.03^{bc}	207.25 ± 16.40^{b}	222.19 ± 18.41^{b}	229.32 ± 19.04^{bc}
NPK1	95.43 ± 4.38^{cd}	160.40 ± 8.55^{cd}	193.49 ± 9.12^{b}	207.65 ± 8.16^{b}	213.04 ± 8.75^{b}
NPK2	107.99 ± 15.31^{de}	174.66 ± 20.43^{d}	211.43 ± 20.60^{b}	222.36 ± 24.88^{b}	229.01 ± 23.82^{bc}

Appendix 11: Effect of Organic Fertilizers on Leaf Area of *Amaranthus cruentus* (NH84/452)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Leaf Area Index					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	1.76 ± 0.27^{a}	5.56 ± 0.37^{a}	8.82 ± 0.88^{a}	13.35 ± 1.49^{a}	16.88 ± 1.16^{a}
PM1	3.34 ± 0.22^{de}	8.88 ± 0.76^{bc}	13.85 ± 0.32^{b}	17.76 ± 0.42^{b}	21.38 ± 1.16^{bc}
PM2	3.88 ± 0.35^{f}	10.02 ± 0.31^{d}	15.71 ± 1.80^{b}	19.57 ± 1.82^{b}	23.74 ± 1.96^{c}
SS1	2.41 ± 0.16^{b}	8.22 ± 0.18^{b}	14.22 ± 1.49^{b}	18.83 ± 1.40^{b}	22.36 ± 0.26^{bc}
SS2	2.70 ± 0.17^{bc}	9.10 ± 0.33^{c}	15.72 ± 1.63^{b}	19.51 ± 0.81^{b}	23.56 ± 0.23^{bc}
NPK1	3.02 ± 0.19^{cd}	9.44 ± 0.41^{cd}	15.66 ± 2.87^{b}	19.13 ± 1.93^{b}	21.21 ± 1.59^{b}
NPK2	3.49 ± 0.18^{ef}	10.21 ± 0.56^{d}	16.17 ± 1.93^{b}	18.93 ± 2.27^{b}	22.09 ± 1.85^{bc}

Appendix 12: Effect of Organic Fertilizers on Leaf Area Index of *Amaranthus caudatus* (Samaru local variety)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha

Leaf Area Index					
Treatments	2 WAT	3 WAT	4 WAT	5 WAT	6 WAT
Control	1.81 ± 0.23^{a}	7.75 ± 0.57^{a}	12.72 ± 2.20^{a}	19.48 ± 2.10^{a}	23.68 ± 1.85^{a}
PM1	3.45 ± 0.20^{bc}	11.78 ± 1.08^{b}	21.78 ± 2.78^{b}	28.45 ± 3.45^{b}	33.86 ± 3.42^{b}
PM2	4.31 ± 0.58^{d}	15.44 ± 3.80^{cd}	28.05 ± 3.58^{d}	36.40 ± 4.43^{c}	41.72 ± 5.48^{c}
SS1	2.72 ± 0.11^{b}	11.12 ± 1.15^{b}	23.04 ± 0.31^{bc}	31.20 ± 0.91^{b}	36.48 ± 1.18^{bc}
SS2	3.11 ± 0.47^{bc}	13.36 ± 1.93^{bc}	23.82 ± 1.65^{bcd}	30.99 ± 0.92^{b}	36.82 ± 1.95^{bc}
NPK1	3.74 ± 0.55^{cd}	16.21 ± 0.58^{cd}	24.53 ± 2.24^{bcd}	29.16 ± 1.30^{b}	32.85 ± 1.65^{b}
NPK2	4.51 ± 0.73^{d}	17.57 ± 1.50^{d}	26.19 ± 1.52^{cd}	31.02 ± 3.25^{b}	35.63 ± 4.37^{b}

Appendix 13: Effect of Organic Fertilizers on Leaf Area Index of *Amaranthus cruentus* (NH84/452)

Values are mean ± standard deviation of triplicate analysis.

Values with different superscripts down the column are significant ($P<0.05$) different.

WAT = Week after transplanting

Control = No fertilizer

PM1 = Poultry manure at 5 tons/ha

PM2 = Poultry manure at 10 tons/ha

SS1 = Sewage sludge at 5 tons/ha

SS2 = Sewage sludge at 10 tons/ha

NPK1 = NPK compound fertilizer at 35Kg/ha

NPK2 = NPK compound fertilizer at 70 Kg/ha