UNIVERSITY OF CAPE COAST

ASSESSING THE EFFICACY OF A RECYCLED ABATTOIR WASTES FERTILIZER (THALLO^{TM}) AS AN ALTERNATIVE PHOSPHORUS (P) SOURCE ON SOIL FERTILITY, CROP YIELD AND N-FIXATION IN LOW NUTRIENT TROPICAL SOILS IN TWO AGRO ECOLOGICAL ZONES OF GHANA

ABDUL RAZAK MENSAH IDDRISS

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UNIVERSITY OF CAPE COAST

ASSESSING SOIL FERTILITY AND YIELD RESPONSES OF CROPS IN LOW NUTRIENT SOILS AMENDED WITH RECYCLED ABATTOIR WASTES FERTILIZER (THALLO) IN TWO AGRO ECOLOGICAL ZONES OF GHANA

BY

ABDUL RAZAK MENSAH IDDRISS

Thesis submitted to the Department of Soil Science of the School of Agriculture, College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfilment of the requirements for the award of Doctor of Philosophy degree in Land Use and Environmental Science

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DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my own original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature:... Date:...........................

Name: Abdul Razak Mensah Iddriss

Supervisor's Declaration

We hereby declare that the preparation and presentation of the thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature:..................................Date:...........................

Name: Prof. Kwame Agyei Frimpong

Co-Supervisor's Signature: .... Date:.........................

Name: Dr. Kofi Atiah

ABSTRACT

Inorganic fertilizer application has successfully improved crop yields in Ghana, but they are often expensive and not readily available to smallholder farmers and has been reported to induce soil acidity, greenhouse gases emission and eutrophicaton. This study examined the effect of Thallo (a novel multi-element fertilizer produced from abattoir wastes by Elemental Digest, UK.) on soil pH, OC, total N, available P and exchangeable K contents, crop N, P, and K uptakes and use efficiencies, as well as the growth, yield, and nutritional quality of maize, cabbage, cowpea, and sweet potato across Semi Deciduous forest and Coastal Savannah agro ecological zones of Ghana. The study comprised three treatments namely recycled abattoir waste fertilizer (Thallo), conventional NPK and control with four replications laid in a Randomized Complete Block Design (RCBD). The result showed that Thallo improved significantly ($P<0.05$) soil pH, organic matter content, total nitrogen, available phosphorus and exchangeable potassium in both experimental sites compared with the NPK treated soil. Also, relative to the conventional NPK treatments, Thallo increased maize grain yield by 13.5% (Jukwa) and 18% (UCC), cabbage head yield by 13% (Jukwa) and 23% (UCC) for the two zones respectively, cowpea seed yield (109%) and sweet potato tuber yield (72%) at coastal savannah. Thallo increased crop N, P and K uptakes and their use efficiencies by all the crops in both agroecological zones. In conclusion, the application of Thallo improved soil fertility, increased crop yield, crop N, P and K uptake and use efficiency by all crops under field conditions. Coastal Savannah zone recorded higher yields than the Semi Deciduous forest.

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DEDICATION

Dedicated to my dear wife Millicent Baidoo and my daughters Ewuresi Rabi Mensah Iddriss and Kukua Shellinat Nyankomagow Mensah Iddriss

TABLE OF CONTENTS

Page
DECLARATION ii
ABSTRACT iii
ACKNOWLEDGMENTS iv
DEDICATION v
TABLE OF CONTENTS vi
LISTS OF TABLES xvi
LIST OF FIGURES xx
LISTS OF ABBREVATION xxiii

CHAPTER ONE: INTRODUCTION

Background Information 1
Problem Statement 3
Justification 3
Hypothesis 4
Objectives of the Study 4
Specific Objectives 4

CHAPTER TWO: LITERATURE REVIEW

Overview 6
Soil Degradation and Soil Quality Decline 6
Classes of Soil Degradation 7
Water Erosion 7
Chemical Deterioration 9
Physical Deterioration 9
Causes of Soil Degradation 10

Soil Quality or Health 10

Soil Quality Index 11

Effects of Soil Degradation on Soil Quality and Agricultural Production 12

Sources of Plant Nutrients 17

Inorganic Sources 17

Straight Fertilizers 19

Organic Nutrient Inputs or Organic Fertilizers 19

Biological Nitrogen Fixation (BNF) 20

Recycled Organic-Mineral Fertilizers 21

Production and Properties of Organo-Mineral Fertilizers 22

Meat and Bone Meal Fertilizers (MBM) 23

Production and use of MBM 24

MBM as a Phosphorus Fertilizer 29

Recycled Abattoir Fertilizers 31

Impact of Recycled Abattoir Fertilizer on Soil Quality, Crop Quality and Crop Yield Improvement 32

Fertilizer Type Effect 33

Nitrogen Level Effect 35

MBM and Potassium Content of Fertilizer 35

Soil Fertility and Nutrient Uptake Efficiencies in Recycled Abattoir Waste Fertilizer Amended Soils 36

Changes in Soil Quality 39

MBM use as Organic Source of Nutrients 39

Potential of Thallo to Improve Yields and Nutritional Composition of Crop 42

Potential Adoption Opportunities and Challenges of Thallo 43

Research Gaps 44

CHAPTER THREE: RESEARCH METHODOLOGY

Study Area 46
School of Agriculture Teaching and Research Farm 46
Jukwa 47
Production of Recycled Abattoir Waste Fertilizer (Thallo) 47
Tests Crops Used and their Varieties. 48
Experimental Design 49
Field Experiment 50
Soil Sampling for Pre Planting Analysis 50
Land Preparation, Site Demarcation and Plotting 50
Seed Bed Preparation 51
Nursing of Cabbage Seeds and Seedling Transplanting 51
Maize Planting 52
Planting Sweet Potatoes 52
Planting of Cowpea 52
Cultural and Maintenance Practices 53
Watering/Irrigation and Weeding 53
Pest Control 53
Fertilizer Application 53
Post-Harvest Soil Sampling 54
Field Data Collection 54
Screening for Disease and Pest Attack in Maize 57
Cowpea 57
Determination of Leaf Area of Maize and Cabbage 58

Laboratory Analyses 58

Total Nitrogen Determination 59

Soil Available Phosphorus (P) Determination 60

Determination of Exchangeable Potassium 61

Plant Biomass Analyses 61

Determination of Mineral Elements Concentrations in the Edible Biomas 62

Preparing Sample Solutions for N, K, Na, Ca, Mg, and P Determination 62

Digestion of Sulphuric Acid-Hydrogen Peroxide 62

Colorimetric Determination of P using the Ascorbic Acid Method 62

Determination of Potassium and Sodium 63

Determining Calcium and Magnesium using EDTA Titration 64

Nutritional Analyses 65

Determining the Dry Matter 65

Determination of Ash 65

Oil/ Fat Determination 65

Protein Determination 66

Crude Fibre Determination 66

Carbohydrate Determination 67

Determination of Yield and some Agronomic Indices 68

Total Yield per Hectare 68

Harvest index 68

N_2 Fixation 68

Nutrient Uptake 69

Nutrient use Efficiency 69

Recovery Efficiency 69

Physiological Efficiency 69

Agronomic Efficiency(AE) 69

Analysis of Data 69

CHAPTER FOUR: RESULTS

Some Chemical Properties of the Soil and Thallo used 71

Soil Chemical Properties, Growth and Yield Responses Following the Application of Recycled Abattoir Waste Thallo and Inorganic NPK Fertilizer on Maize 71

NPK and Recycled Thallo Fertilizer Effect on Soil Chemical Properties 71

Effect of Thallo and NPK on the Agronomic Indices of Maize 73

Effect of Thallo and NPK on Maize Grain Yield Indices 78

Effect of Thallo and NPK on Grain Yield of Maize 80

Effect of Thallo and NPK on the Proximate Quality of Maize 85

Effect of NPK and Thallo on The Mineral Concentrations in the Maize Grain 85

Effect of Thallo and NPK on the Nutrient uptake and Nutrient use Efficiency of Maize 89

Effect of Recycled Abattoir Waste (Thallo) and Inorganic NPK Fertilizer on Soil Fertility, Cabbage Growth, Yield and Nutritional Quality 92

NPK and Thallo on Soil Chemical Properties after Cabbage Harvesting 92

Effect of NPK and Thallo on Agronomic Indices of Cabbage 96

Effect of NPK and Recycled Thallo Fertilizer on the Mean Head Circumference and Mean Head Fresh Weight of Cabbage in two agro zones 102

Effect of NPK and Thallo fertilizer on the Mean Number of Leaves, Harvest Index and Root Shoot Ratio of Cabbage in two agro ecological zones 103

Effect of NPK and Recycled Thallo Fertilizer on the Mean Head Yield of Cabbage in two agro ecological zones 105

Effect of Thallo and NPK on the Proximate Components of Cabbage 107

Effect of Thallo and NPK on the Mineral Compositions of Cabbage 108

Effect on Thallo and NPK Nutrient Uptake and Nutrient use Efficiency of Cabbage 113

Effect Of NPK and Thallo on Nutrients Use Efficiency Indices in Cabbage 116

Growth, Yield and Nutritional Quality of Sweet Potato in Thallo Amended Soil. 117

Effect of Thallo and NPK on Some Soil Chemical Properties after planting Sweet Potato 117

NPK and Thallo on Agronomic Performance of Sweet Potato at Harvesting. 121

Tuber yield and Marketability of Sweet Potato Following the Application of NPK and Thallo 123

Impact of NPK and Thallo Nutrients Uptake and Efficiency of Sweet Potato 128

Effect of Thallo and NPK on the Nutritional Quality of Sweet Potato 129

N-Fixation, Nutritional Quality, Growth and Yield of Cowpea (Vigna Unguiculata L. Walp) in Thallo Amended Soils 132

Agronomic Performance of Cowpea at Harvesting Following the Application Of NPK and Thallo Fertilizers. 138

Effect of NPK and Thallo on the Number of Branches, Leaves Number, Shoot Root Ratio and Harvest Index at Harvesting of Cowpea 140
Yield and Yield Indices of Cowpea Following the Application of NPK and Thallo Fertilizers 142
Effects of Thallo and NPK on nutritional quality of Cowpea 144
Effect of NPK and Thallo on N, P, and K uptake and use efficiency of cowpea 146
Effect of NPK and Thallo on N, P, and K uptake and use efficiency of cowpea 146

CHAPTER FIVE: DISCUSSION

Response of Soil Chemical Properties, Maize Growth, Yield, Nutritional Quality and Nutrient Use Efficiency following the Application of Thallo and NPK 154
Response of Some Soil Chemical Properties to NPK and Thallo Application 154
Effect on Agronomic Performance of Maize 156
Effects of NPK and Thallo on the Mean Yield and Yield Attributes of Maize 157
Impact of NPK and Thallo on Maize Response to Pest and Disease Attack 158
Effect on Height At Maturity, Above Ground Dry Matter and Harvest Index of Maize 159
Effects of NPK and Thallo on Proximate Components of Maize 159
Effect of Thallo and NPK on Soil Chemical Properties, Cabbage Growth, Yield, Nutritional Quality and Nutrient Use Efficiency 162
Effect of NPK and Thallo on Soil Nutrient Status after Harvesting 162

Effect on Agronomic Performance of Cabbage 164

Effect of NPK and Thallo on head Circumference (cm) and head weight (g) of Cabbage 164

Effect of NPK and Thallo on Harvest index (%), Shoot Root Ratio and number of leaves at maturity 166

Cabbage Head Yield (t ha^{-1}) 166

Effects of NPK and Thallo on Proximate Components of Cabbage Head 167

Effects of NPK and Thallo on the Mineral Concentrations in Cabbage Head 168

Effects of NPK and Thallo on The Nutrient Uptake and use Efficiency by Cabbage 169

Effects of NPK and Thallo on the Nutrient use Efficiency Indices of Cabbage 170

The Impact of Recycled Abattoir Waste Thallo Fertilizer on the growth, yield, nutritional Quality and Nutrient Use Efficiency on Sweet Potato. 172

Effect of Thallo and NPK Addition on Soil Chemical Properties after Harvesting of Sweet Potato 172

Effect of Thallo and NPK Fertilizers Application on Growth Parameters of Sweet Potato 173

Effects of NPK and Thallo on Yield Components of Sweet Potato 174

Tuber Length and Circumference 174

Number of Tubers Per Plant and Marketable Number of Tubers Per Plant 175

Tuber Weight Per Plant and Marketable Weight Per Plant 176

Total Yield Per Hectare, Marketable Yield Per Hactare and Percent Marketability 177

Effect NPK and Thallo on Proximate Components of Sweet Potato 179

Effects of NPK and Thallo on the Mineral Concentrations of Sweet Potato Tuber 180

NPK and Thallo Fertilizers Effect on Nutrient Uptake and Nutrient use Efficiency 181

Effects of NPK And Thallo on the Nutrient use Efficiency Indices 182

Response of growth, yield, N-Fixation and Nutrient Use Efficiency of Cowpea Following the Application of Thallo and Conventional NPK 184

Effect Of NPK and Thallo on Some Selected Soil Chemical Properties After Harvesting Cowpea 184

Agronomic Performance of Cowpea at Harvesting Following the Application of NPK and Thallo Fertilizers. 185

Effect of NPK and Thallo on Cowpea Nodulation 186

Cowpea Yield and Yield Indices as Influenced by Application of Thallo and NPK 188

Yield 188

Effects of NPK and Thallo on Nutritional Quality of Cowpea Seed 190

NPK and Thallo Fertilizers Effect on Nutrient Uptake and Nutrient use Efficiency 191

Effects of NPK and Thallo on the Nutrient use Efficiency Indices 192

CHAPTER SIX: GENERAL SUMMARY, CONCLUSION AND RECOMMENDATION

Summary 195

General Conclusions 196

Recommendations 197

REFERENCES 198

APPENDICES 239

Appendix A: Pictorial display of abattoir waste Thallo fertilizer 239

Appendix B: Pictorial dispaly of maize ears as affected by the ammendments 240

Appendix C: Pictorial display of sweet potato tubers as affected by the ammendments 242

Appendix D: Cowpea grains as influenced by the ammendments 244

LISTS OF TABLES

Table Page

1 Chemical Composition of Thallo 48

2 Chemical Properties of the soils used before planting 48

3 Test crops used and their varieties 49

5 Soil Chemical Properties After Maize Harvesting at Two Agro ecological Zones 72

6 Effect of NPK and Recycled Thallo fertilizer on the mean ear length, ear weight and ear circumference of maize in two agro zones 79

7 Impact of NPK and Recycled Thallo fertilizer on 1000 seed weight and seed yield of maize in two agro zones 81

8 Susceptibility of maize to pest and maize streak mossaic attack following the application of NPK and recycled Thallo fertilizer in two agro zones 83

9 Mean plant height, above ground biomass and harvest index of maize at harvesting following the application of NPK and Thallo in two agro ecological zones 84

10 Effect of NPK and Thallo on proximate parameters in maize 86

11 Effect of NPK and Thallo on concentrations of mineral elements in maize 87

12 NPK and Thallo on nutrient uptake and use efficiencies 90

13 Correlation matrix between yield and yield indicators of maize and soil chemical properties after harvesting at jukwa site 93

14 Correlation matrix between NPK Uptake and their Use parameters 94

15 Effect of NPK and Thallo on chemical properties after harvesting 96

16 The impact of NPK and Recycled Thallo fertilizer on the mean head circumference and mean head fresh weight of cabbage in two agro ecological zones 102

17 NPK and Recycled Thallo fertilizer influence on the mean number of leaves, harvest index and Root Shoot ratio of cabbage in two agro zones 104

18 The Influence of NPK and Thallo fertilizer on the mean head yield of cabbage in two agro ecological zones 106

19 Effect of NPK and Thallo on proximate parameters in cabbage head 109

20 Influence of NPK and Thallo on concentrations of mineral composition in the cabbage head 112

21 Impact on Thallo and NPK nutrient uptake and nutrient use efficiency of cabbage 114

22 Correlation matrix between yield and yield indicators of cabbage head and soil chemical properties after harvesting 118

23 Effect of NPK and Thallo on Agronomic, Physiological and Recovery efficiencies of NPK in cabbage 119

24 Correlation matrix between NPK Uptake and their Use parameters of cabbage 120

25 Some soil chemical properties after harvesting sweet potatoat UCC 117

26 Tuber Circumference and Length and Numbers of Leaves at Maturity as Influenced by the Application of NPK and Thallo 124

27 Effects of NPK and Thallo on number of tubers and marketable tubers of sweet potato 124

28 Effects of NPK and Thallo on total tuber yield (t ha^{-1}), Marketable yield (t ha^{-1}) and percent marketability (%) of sweet potato 126

29 Effects of NPK and Thallo on above and below ground dry biomass of sweet potato 127

30 Soil nutrient uptake and nutrient use efficiency following the application of NPK and Thallo fertilizers. 128

31 Effect of NPK and Thallo on Agronomic, Physiological and Recovery efficiencies of NPK in sweet potato 130

32 Effect of NPK and Thallo on proximate parameters in sweet potato 133

33 Effect of NPK and Thallo on mineral concentrations in sweet potato 134

34 Correlation matrix between yield and yield indicators of sweet potato and soil chemical properties after harvesting 135

35 Correlation matrix between NPK Uptake and their Use parameters 136

36 Effect of Thallo and NPK on soil properties after harvesting cowpea 132

37 Effect of NPK and Thallo on Number of Branches, Number of Leaves, Shoot Root Ratio and Harvest Index of Cowpea at Harvesting 140

38 NPK and Thallo application on number of nodules, active nodules, percent activity and N-Fixation 141

39 Effect of NPK and Thallo on number of seed per pod and pod weight 143

40 Effect of NPK and Thallo on 100 seed weight and seed yield 143

41 Effect of NPK and Thallo on proximate components of cowpea 147

42 Effect of NPK and Thallo on mineral concentrations of cowpea 148

43 NPK and Thallo effect on nutrient uptake and nutrient use efficiency of cowpea 149

44 NPK and Thallo application on nutrient use efficiency indices 150

45 Correlation Matrix Between Yield and Yield Indicators of Cowpea and Soil Chemical 152

46 Correlation matrix between NPK Uptake and their Use parameters 153

LIST OF FIGURES

Figure Page

1 Effects of NPK and Thallo on maize plant height from 4th to 7th week 73

2 Effect of NPK and thallo on chlorophyll index from 4th week to 7th week after planting 74

3 Effect of NPK and Thallo on leaf area of maize from week 4 to week 7. 76

4 NPK and Thallo effect on the number of tassells of maize from 6th to 9th weeks after planting 77

5 Effect of NPK and Thallo on the rate of fruiting 7th to 10th weeks after planting. 78

6 Effect of PK and Recycled Thallo fertilizer on cabbage height from 4th to 7th week after transplanting 97

7 Effect of NPK and Recycled Thallo fertilizer on the chlorophyll content of cabbage from 4th week to 7th week after transplanting 98

8 Impact of NPK and Thallo on the leaf area of cabbage from 4th week to 7th week after transplanting. 99

9 Impact of NPK and Thallo on the rate of bulbing of cabbage from 7th week to 10th week after transplanting. 100

10 Effect of NPK and Thallo on sweet potato vine length at maturity 122

11 Effect of NPK and Thallo on sweet potato vine girth at harvesting 123

12 Effects of NPK and Thallo on the leaf number of sweet potato at harvesting 123

13 Plant height influenced by NPK and Thallo on cowpea at harvesting 138

14 Effect of NPK and Thallo on pod length of cowpea at harvesting 139

15 Effects of Thallo and NPK on the number of pods of cowpea at harvesting 139

LISTS OF ABBREVATION

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
DTMA	Drought Tolerant Maize for Afria
FAO	Food and Agriculture Organisation
HMG	Her Majesty's Government
IPCC	Intergovernmental Panel on Climate Change
MBC	Microbial Biomass Carbon
MBM	Meat and Bone Meal
MiDA	Millennium Development Authority
MOFA	Ministry of Food and Agriculture
PAP	Processed Animal Proteins
PAWC	Plant-Available Water Capacity
RAWTF	Recycled Abattoir Waste Thallo Fertilizer
RMAA	Red Meat Abattoir Association
ROTAP	Review of Transboundary Air Pollution
SOC	Soil Organic Carbon
SOM	Soil Organic Matter
SP	Sampling Period
SP	Superphosphate
SSA	Sub-Saharan Africa
SSSA	Soil Science Society of America

CHAPTER ONE

INTRODUCTION

Background Information

Soil fertility management is a key prerequisite for sustainable crop intensification in Ghana. There is a continuous soil fertility decline in most agroecological zones in Ghana as farmers undertake continuous cropping without adequate nutrient replenishment. Available options for soil fertility improvement include application of inorganic and or organic resources such as crop residue, manures, compost and recycled waste materials such as abbatoir waste. Abattoir wastes management has become a major concern in the cities all over the world. The threat posed by improper control of abattoir wastes can therefore be the exertion of oxygen demand on the surrounding environment or be a breeding ground for large number of decomposers (microorganism) of which, some may be pathogens (Gauri et al, 2006).

Previous research works done in some developing countries revealed that abbatoir waste can be recycled or processed into beneficial products including soil amendments for crop production, feeds for fish, and poultry or livestock production (Chaudhry et al, 1993, , Konopka et al, 2012 and Stępień and Wojtkowiak 2013).

Soil fertility decline is a major problem in confronting most countries especially in the tropics. This is largely as a result of growing quest to achieve food security for the rapidly increasing population, which has resulted in over utilization of farmland resources (Sanyelou & Adepoju, 2018). Consequently, this has led to the degradation of soil available resources in tropical Africa, with its attendant ecological issues of soil erosion and nutrients leaching. Continuous cultivation without adequate nutrient replenishment of the soil has contributed to decreased crop yield in tropical Africa (Bationo et al, 2006) as a result of physical, chemical and biological deteriotation of the soil resources (Bationo et al., 2006).

Moreover, the population of the world is increasing and the United Nations (2015) anticipates that by 2050 the world population will be 8.9 billion people. The developing countries are likely to host a large number of this population, even though about 20% of the people are already underfed or malnourished (FAO, 2015). There will be increase in the demand for sbubsequently the need to increase food production even on the declining farm lands. (Lal, 2009). Consequently this will lead to pressure on soils and exacerbate the already depleted soil fertility. To increase crop production on such marginal lands requires the application of external nutrient sources, primarily chemical and organic fertilizers. Sridhar and Adeoye (2003) notted that improving the fertility status of the soil have basically been the reliance on the traditional application of plant and animal manures and the use of chemical fertilizers. However, these amendments come with theirr attendant constraints in procurement and application. In developing countries, farmers are unable to rely on chemical fertilizers because they are expensive, resulting in a nutrient imbalance of the soil (Bationo et al., 2006).

Moreover, the continuous use of inorganic fertilizers is reported to cause eutrophication, enhance greenhouse gases emission including oxides of carbon and nitrogen implicated in global climate change and environmental deterioration (Karnal, 2009).

Problem Statement

The inherent fertility of Ghanaian soils is fast declining under continuous cropping and there is, therefore, the need to improve upon the fertility status of the soils. Farmers in the past were improving soil fertility through bush fallowing, shifting cultivation, mulching, cover cropping, rotational cropping among others as means of regenerating soil fertility (Karnal, 2009). The use of chemical fertilizers has now taken the centre stage and remains one sure way of improving soil fertility. The inorganic fertilizers that are used by farmers in tropical African region are costly and not available and they also cause soil acidity, greenhouse gases emission and eutrophicaton (Karnal, 2009).

One largely underutilized resource available for the improvement of the soil‘s fertility is the use of waste from the abattoir processing industry, whose improvement management has become a major concern in the cities all over the world (Awafo and Amenorfe, 2021). The use of organic soil conditioner such as recycled abattoir waste fertilizer (Thallo) from abattoir waste would be a better alternative to improve soil fertility and increase crop yield.

Justification

Ghana is saddled by the challenge of producing more to meet her over growing population due to low inherent soil fertility of farming lands coupled with the use of farming lands for human habitats (Beah et al, 2015). What is more, Ghana is battling with waste (solid, liquid and gaseous) management problems. Issues of abattoir waste control and management are important aspect of the waste control plans in the nation (Awafo and Amenorfe, 2021). Therefore, these abatoir wastes, which often pose threats to the environment can be recycled or converted to soil amendments to improve the fertility of soils. As a soil amendment it could serve as a sustainable and effective alternative to expensive and rarely accessible inorganic fertilizers for improved crop yields and nutritional quality in Ghana. Additionally, the conversion of these wastes to a soil amendment will help to control pollution.

Elemental Digest Systems Ltd (EDS) UK, has manufactured Thallo fertilizer from abattoir wastes and supplemented with trace nutrients from industrial by-products to serve as a soil amendement and also help control pollution that might have been caused by these wastes.

In Ghana, however, the use of abattoir waste fertilizers as soil amendments for fertility improvement is yet to gain patronage. It is for this reason that this work was designed to test the efficacy of this novel recycled abattoir waste fertilizer (Thallo).

Hypothesis

Thallo fertilizer application to the soil improves soil fertility, crop yield and nutrient use efficiency.

Objectives of the Study

The general objective of this work was to assess the effect of Thallo fertilizer application on selected soil fertility indicators, yields and improving nutritive values of diferent crops in two agroecological zones.

Specific Objectives

This study specifically sought to :

1. Assess the effect of application of recycled abattoir waste fertilizer (Thallo) and Inorganic NPK fertilizer on selected soil chemical

properties (N, P, K, OC and pH) in two agro ecological zones in Ghana

2. Investigate the impact of recycled abattoir waste fertilizer (Thallo) and Inorganic NPK fertilizer application on the growth and yield of maize, cabbage, sweet potato and cowpea in two agroecological zones in Ghana.
3. Examine the the influence of the application of Recycled abattoir waste fertilizer (Thallo) and Inorganic NPK fertilizer N-fixation and nutrient use efficiency in two agro ecological zones in Ghana

CHAPTER TWO

LITERATURE REVIEW

Overview

This chapter sought to review recent and earlier works or studies related to the research topic. It mainly encompasses soil degradation and soil quality decline issues, soil fertility and its decline. It also elaborates the potential of recycled abattoir waste fertilizer (Thallo) as soil amendment interventions in improving crop growth and yield and soil chemical properties. This chapter also reviews the research gaps pertaining to the use of recycled abattoir waste fertilizers.

Soil Degradation and Soil Quality Decline

With regards to lands used for agricultural and forestry purposes, soil is a critical factor or component. Constant and growing pressure on the soil causes its deterioration and contamination, which can lead to a partial or complete loss of its crop production capability. With limited resources and limited access to inputs, soil quality management is critical for strengthening and sustaining ecosystem services.

Soil degradation is the loss of soil productivity due to changes in nutritional status, soil organic matter, structural characteristics, and electrolyte and toxic chemical concentrations (Lamb et al, 2005). Soil degradation is a process that reduces a soil's current and/or future ability to produce crops or services (Lamb et al. 2005).

According to the (UNEP, 1999), soil degradation is described as the rate at which soil attributes deteriorate, resulting in a decrease in land productivity due to processes mostly caused by human activity. As a result, soil degagdration breeds a decrease in soil productivity, a loss in vegetation cover, a qualitative decline in water resources, and air pollution. Soil degradation is severe in the tropics and subtropics, particularly in the dry zones of tropical Africa (Bini 2009). According Leon and Osorio (2014), soil degradation reduced soil ecosystem services by 60% between 1950 and 2010. Accelerated soil degradation is reported to affect as much as 500 Mha of land in the tropics (Lamb et al, 2005), and about 33 percent of the world's land surface (Bini, 2009). Soil degradation can also have severe impact on agronomic production as well as economic growth, especially in nations where agriculture is the main source of income and economic dvelopment (Scherr 2001). In addition to the environmental and economic consequences, soil degradation has health risks (Guerra et al, 2005 and Lal, 2009). likewise other degrading processes pose health hazards Soil degradation implies a decrease in soil quality, as well as a reduction in ecosystem activities and services (Lal 2009).

Classes of Soil Degradation

Water erosion, wind erosion, chemical degradation, and physical degradation are the four basic types of soil degradation.

Water Erosion

Water erosion, according to Ballayan (2000) and Infonet-Biovision (2010), occurs when soil particles are detached and transported either by raindrops or running water. Water erosion is caused by four factors, according to Infonet-Biovision (2010): rainfall, soil type, slope/gradient, and soil use/vegetation cover.

Rainfall: Raindrops on the soil surface have the potential to dissolve soil aggregates and spread aggregate material throughout the surface. The less dense aggregate components, such as very fine sand, silt, clay, and organic matter, are quickly washed away by rain splash and runoff water. Denser aggregates, such as sand and gravel particles, will require more energy to move from raindrops or runoff volumes.

Soil type: Smooth and fine particles as well as loose soil particles are easily washed away by rain splashes and runing water. Compacted soils are noteasilywashed away.

***Slope gradient*:** The field with a steeper gradient tends to have the greater amount of soil washed away through erosion by water.

***Soil use*:** When the field is covered with plants and residues, the impact of raindrops and splashes is modest. As the movement of surface runoff is slowed or impeded, this tends to promote infiltration of excess surface water.

Wind erosion

According to Shelton (2003), the following factors are considered to influence the rate and volume of wind soil erosion:

***Erodibility of soil*:** Very fine particles are easily suspended and transported over great distances by the wind. Course particles can be transported along the surface, whereas light and intermediate size particles can be elevated and dumped (in a process called the saltation effect).

***Soil surface roughness*:** Wind is least opposed by soil surfaces that are not coarse or uneven. However, the uneven surfaces can be filled in over time, and the coarseness can be leveled by abrasion to form a finer, wind-resistant surface.

***Vegetative cover*:** In some regions, the lack of stable and consistent vegetative cover has resulted in severe wind erosion. The most disposed soils are those that are loose, dry, and bare. A good system of living windbreaks, in combination with appropriate tillage, residue reduction, and crop selection, must provide the highest effective vegetative cover for safeguard.

Chemical Deterioration

Chemical deterioration, according to FAO/AGL (2000) rationalizations, is a type of soil degradation that includes nutrient loss, organic matter loss, salinization, acidification, soil pollution, and fertility decline. The nutrients removal decreases the capability of soils to promote plant growth and cultivation of crop and causes acidification. In dry and semi-arid locations problems can emanate as a result of collection or buildup of salts, which inhibits the entrance of water into the roots of plants. Toxic soils can be created by a variety of factors, including municipal and industrial wastes, oil spills, excessive fertilizer, pesticide, and herbicides use, compounds released from radioactive activities, and acidification by airborne pollutants.

Soils chemical degradation is sometimes induced by agricultural over-exploitation, where there is sole reliance on replenishing lost nutrient through harvesting by only synthetic fertilisers. Chemical fertilizers are frequently unable to stabilize all nutrients in the soil, resulting in nutrient disparity. They also can not replenish the organic matter that has been lost, which is crucial for nutrients absorption. Furthermore, chemical fertilizers may be contaminate (phosphate rock can be polluted by radioactively processes).

Physical Deterioration

According to FAO/AGL (2000), physical deterioration includes soil crusting, sealing, and compaction, which can be caused by a variety of factors such as compaction by heavy machinery or animals. This conundrum occurs on practically every continent, in almost all temperatures and soil physical characteristics, but it has become more pronounced with the use of heavy machinery. Soil crusting and compaction increase runoff, decrease water infiltration, stifle plant growth, and leave the soil surface exposed and vulnerable to other kinds of degradation. Severe crusting of the soil surface caused by the disintegration of soil aggregates might obstruct water penetration into the soil and prevent seedling emergence.

Causes of Soil Degradation

Soil deterioration can occur as a result of natural disasters, inappropriate land usage, or ineffective land management techniques. The major factors causing soil degradation are improper management of cultivable lands by farmers, tillage methods that are unsuitable to local environments and overgrazing by livestocks FAO/AGL (2000).

Globally, environmental pressures will be minimized if cultivation and management soils are done in a more sustainable way. This can be acheived when crops are harvested, the organic materials are left on the fields. When artificial fertilizers are employed to restore nutrient losses, they are unable to compensate for the loss of organic matter. Soil quality deteriorates over time, leaving the soils with lesser water holding capacity, less air, and nutrients.

Soil Quality or Health

Soil health, also called soil quality, is described as "the ability of soil to function within ecosystem boundaries to sustain biological activity, preserve environmental quality, and promote plant and animal health" (Doran and Zeiss 2000). Soil quality can also be defined as ‘the capacity of a certain types of soil to function within natural or managed ecosystem boundaries to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation (Karlen et al., 1997).

Soil health concepts are frequently used to measure changes, compare soils, and evaluate the effectiveness of land-use management. From Gong et al, (2015), soil quality is a basic parameter determing whether the land is able to do what you want it to do or being managed. According to the Soil Science Society of America (SSSA 1997) sustainability is defined as managing soil and crop cultural practices so as not to degrade or impair environmental quality on or off site, and without eventually reducing yield potential as a result of the chosen practice through exhaustion or either on-site resources or non-renewable inputs.

Soil Quality Index

Soil quality indicators are measurable soil attributes that reveals soil productivity response or soil environment functionality, and are used to determine soil quality improvement rate (Ghaemi et al, 2014).

Soil quality indicators vary by soil type, climate, and land use. The distribution depth, quality features (physical, chemical, biological), and the turnover rate or mean residence time (MRT) are all indicators or parameters used to measure SOC, in addition to its amount. The important pointers of soil physical quality consist of the aggregates amount and stability; vulnerability to crusting and compaction; porosity (pore geometry and continuity); colour of the soil; transmission or percolation of water and plant-available water capacity (PAWC); aeration and gaseous exchange; effective rooting depth; soil heat capacity and the temperature regime. Equally, suitable pointers of soil chemical quality include pH, CEC, availability of nutrient; and beneficial elemental balance and absence of any toxicity or deficiency. Microbial biomass C (MBC), activity and diversity of soil fauna and flora, and the lack of diseases and pests as indicated by a soil's disease-suppressive qualities are all used to assess soil biological quality. According to Andrews et al. (2002), the appropriate optimum blend or combination of these characteristics affects agronomic productivity, water use efficiency, nutrients and other inputs, and management practice sustainability.

Effects of Soil Degradation on Soil Quality and Agricultural Production

The possible effects of variations in soil properties as a result of degradation dangers on essential soil tasks have been revealed through a number of studies. Food and fiber production, water and carbon storage, water and air purification, infrastructure support, and biodiversity sustenance, habitat maintenance, preservation of cultural and archaeological heritage are all functions that soil is expected to do (HMG, 2011).

Although natural threats can cause soil erosion, current concerns or anxieties are related to quicker erosion, where the scale has increased dramatically as a result of anthropogenic action and greatly exceeds existing estimates of soil formation (Verheijen et al, 2009). Water is widely known to be the chief cause of erosion, with fine-textured particles being the most vulnerable (Quinton and Catt, 2004), however, erosion by wind occurs on cultivable soils, though it is very problematic to quantify. The removal of topsoil has an effect on agricultural yield. Acoording to Bilotta et al., 2010, lowland grasslands erosion, varying between 0.5 and 1.2 Mgha^{-1}, can be crucial for silage growth and quality. Erosion gets rid of soil habitat space, which has an impact on biodiversity and water storage functions.

Porosity deficiency according to Dexter (1997), Whitmore et al, (2004) and Pilgrim et al (2010), worsens soil tasks including storage of water and regulation of flood. As reported by van den Akker (1997), compaction-imposed loss of porosity can cause decline in plant growth especially when there is the development of a thick plough pan. Furthermore, compaction impairs the ability of plant roots to penetrate and develop (Batey, 2009; Whalley et al, 1995). In the United Kingdom, Douglas et al, 1992; and Gregory et al, 2007, recorded precise reduction in agricultural yields reaching 3 Mgha^{-1} for each 0.1 Mgm^{-1} rise in bulk density (Whalley et al, 1995) or each 1 MPa rise in strength (Whalley et al, 2006, 2008). According to Gregory et al, (2007) decline in yields of about 3 Mgha^{-1} in a severely compacted loamy soil was recorded. Batey (2009), reported that a crops‵ susceptibility to soilborne diseases and fungi might also increase due to compaction. Nonetheless, in arable systems, certain compaction can be helpful in attaining excellent seed-to-soil contact (Dexter, 1988) and according to Scott et al. (2005) reducing the danger of stem or seedling falling.

Even though very few studies have critically investigated into the loss of N and P in detail, these nutrients could be lost in degraded top soil (Quinton et al, 2001; Palmer and Smith, 2013).

A deterioration in physical quality of the soil has consequences on support for biodiversity. Different plant species have different abilities to germinate and develop in hardened soils (Godefroid and Koedam, 2004), and uncompacted soils will have more biodiversity compared to compcted soils (Roovers et al, 2004). There is a proof of a relationship between soil compaction and a decline in Lepidoptera soil pupating larvae (butterflies and moths) (Roach and Campbell, 1983). According to Gilroy et al (2008), in the eastern part of England, soil strength and *Motacilla flava* (yellow wagtail) abundance were found to be negatively linked, possibly due to the effect on soil dwelling prey. *Sturnus vulgaris, Turdus philomelos* and several species are among the British grassland species that may be affected (Clarke et al, 2007). Compaction and trafficking are believed to hinder the quality of soil-turf systems used as amenity (Marjamaki and Pietola 2007; Han et al, 2008), however, in some cases, especially in cricket pitches compaction may be desired (Baker et al, 1998). Conservation of artefacts of cultural and archaeological importance in the soil may be influenced by compaction (Blum, 1993).

Even though there is slight numerical proof for crucial levels (Korschens et al, 1998; Loveland and Webb, 2003; Reynolds et al, 2007), it is believed that with the absence of an appreciable amount of SOM, soil will not be able to function optimally (van Camp et al, 2004). Mostly, soil structure development and decrease in SOM are difficult to distinguish. In farming soils in southern England, Robinson and Woodun (2008) discovered that surface runoff due to crusting and SOM content are inversely related. Fullen (1991) and Watts and Dexter (1998) reported that when SOM derceases, erosion and clay scattering increase.

Other tasks may be compromised as well. Soil Organic Matter, Diptera (flies) number and aerially Coleoptera (beetles) in England agricultural soils have been linked (Gilroy et al., 2008). A relationship has also been shown between the loss of SOM and the release of hazardous substances in soils (ROTAP, 2009).

Many functions are affected by changes in soil chemical characteristics, particularly pH caused by agricultural inputs or pollutants. Metals and metalloids may collect in topsoil as a result of atmospheric pollution or the utilization of agricultural inputs (inorganic fertilizers, agro-chemicals, organic manures, or waste products) on land, and when released in dangerous proportions, especially in acidic crcumstance, may significantly affect crop development and quality of food (Blake and Goulding, 2002; Degryse et al, 2007 and Atkinson et al, 2012). When some metals and metalloids are highly concentrated, they become phytotoxic and lower yields whereas 'passage poisons' injure animals and people who eat food but have no influence on crop output (McGrath and Zhao, 2015). Imbalances of plant nutrients (Phoenix et al, 2004), lifted the risk leaching of nutrient (Jefferies and Maron 1997; Degryse et al, 2007), and greater vulnerability to stressors such as diseases and pests have all been linked to acidification (Power et al, 1998; Carroll et al, 1999). Grazing on acidic grassland becomes dangerous. Because of the proximity of pollutant sources, aboveground biomass may be considerably reduced near urban areas (Ander et al, 2013). Although excessive amount of salt are hazardous to several species of plants, the halophytic habitats that arise are typically rich in biodiversity (Watts et al, 2003). Undoubtedly, one of the most important regulators of biodiversity of plant is soil pH (Bunemann et al, 2006; Cookson et al, 2006; Rousk et al, 2009). At a primary content, when there is breakage in soil sealing the relationship between soils and the rest of the 'spheres,' services including promoting vegetation development, carbon sequestration, water and air filtration and support of biodiversity are considerably and irreparably harmed (Huber et al, 2008; Scalenghe and Marsan, 2009).

Furthermore, the degradation of soil qualities caused by development of brownfield complicates the re-creation of functional soils. Intervention may be required to restore a desirable post-operation land use, such as species-rich grassland (Carrington and Diaz, 2011). Modern restoration approaches, on the other hand, can successfully reproduce ecosystems of greater nature preservation value (Tarrant et al, 2013), and poor structured soils or nutrient deficiency soils may even assist this course (HMG, 1996).

As a result, it is clear that if predicted dangers from degradation of soil are achieved, changes on measured soil parameters may have an impact on a variety of key soil functions. The studies discussed above mostly focused on addressing pressing economic issues (e.g agricultural output and management of water reserve), and were frequently practical clarifications instead of routine reports associated to soil qualities. As a result, extrapolating knowledge about soil properties and functions is difficult (HMG, 2011), even though similar processes may be at action. A related problem is whether or not soils have the ability to be really multifunctional. There are apparent tradeoffs: agricultural monoculture, for example, may be incompatible with biodiversity support. With time, a better spontaneous knowledge of how soil functions respond to processes of degradation via observed variations in features of soil will be beneficial.

It is worth noting that degradation processes don't always have irreversible consequences for soil functions. To improve soil qualities and functions, management of land practices may be updated to lessen or better eliminate the possibility of deterioration. In agriculture, examples are lowering crusting through tilling soil in a brittle instead of sticky condition, reducing pressures of tyre on machines (Batey 2009), and reducing soil erosion through perpendicular tilling against the slope instead of than along the slope (Quinton and Catt, 2004). Growers can use residues or organic resources to compensate for SOM loss. Degradation issues comprising pollution, sealing, and development of brownfield site may likely be only alleviated by legislation on non-agricultural land.

Sources of Plant Nutrients

Essential plant nutrients can be supplied as inorganic / synthetic / artificial sources mainly as inorganic fertilizers or as organic sources consisting crop residues, compost, farm yard manure, poultry manure, and cow dung among others.

Inorganic Sources

Fertilizer comes from the Latin word fertilis, meaning 'fruit yielding.' Fertilizer is described to be a processed, mined, or manufactured product that contains single or sveral required plant nutrients in commercially valuable levels in available or potentially available forms, without having any dangerous substance over legal limits (Stewart, 2022). Inorganic fertilizers are materials that are mined, refined, or synthesized, according (Stewart 2022). They comprise one or more chemical versions of important plant nutrients that are readily available or possibly commercially lucrative. Inorganic fertilizers that are acceptable should not contain any dangerous substances in excess of authorized amounts. Prefixes like, chemical, artificial mineral, synthetic, or inorganic are frequently employed interchangeably to designate inorganic fertilizers.

For this study, the term fertilizer is employed in a restrictive sense, in that there are organic inputs which qualify to be termed organic fertilizers, but they are not usually covered by the term fertilizer. This is mainly due to convention and their generally much lower nutrient content (Singh, 2012). For example, urea, the most widely used nitrogen fertilizer, is an organic molecule that, after transformation in the soil, releases plant-available nitrogen. In extension and the fertilizer trade, the legal guarantee of available plant nutrients represented as a percentage by weight in a fertilizer is referred to as fertilizer grade. For example, a grade 12–32–16 NPK compound fertilizer contains 12 percent nitrogen (N), 32 percent phosphorous pentoxide (P_2O_5), and 16 percent potassium (K_2O). The NPK content of a fertilizer bag is normally shown in the following order: N, P_2O_5, and K_2O. Inorganic fertilizers are occasionally called chemical or artificial fertilizers, meaning that they are of less quality natural (often organic) fertilizers. Fertilizers, on the other hand, are neither unnatural nor inferior items. Lots of fertilizers are completed inputs obtained from natural residues, either enhanced for plant use (e.g., phosphate fertilizer) or purified of unwanted or hazardous elements (e.g. K fertilizer). Though several N fertilizers are manufactured synthetically, in chemical industries, and get their nitrogen from air, and its constituents, such as nitrate, ammonia, and urea, are same as those found naturally in soils and plants. Phosphorus Rock, is a naturally occurring mineral which must be extracted, processed, and dissolved before it can be used in fertilizers, is the primary source of all P in fertilizers. Inorganic fertilizers have typically been divided into two categories: simple and complex fertilizers.

Straight Fertilizers

One of the three primary nutrients, N, P, or K, can be found in these. In contrast to multinutrient fertilizers, this is a classic term for fertilizers made up of and utilized for a single main nutrient. Products containing elemental S, magnesium sulphate, calcium oxide, and others are examples of secondary nutrients. Straight fertilizers for micronutrients include borax, Zn and Fe chelates, and sulphate salts of micronutrients. Micronutrient carriers, on the other hand, are rarely referred to as single fertilizers. Due to the fact several simple fertilizers have in addition other critical plant elements, such as sulphur in sulphate of ammonium, this is not a really accurate term. These are also known as single-nutrient.

Organic Nutrient Inputs or Organic Fertilizers

Most organic nutrition inputs, comprising waste materials, have a wide range of compositions and typically just a small concentration of nutrients that vary in availability (Green, 2015; Hitha et al., 2021; Mora et al., 2019). Organic inputs including cereal straw decay slowly and gradually deposit nutrients (because of a high C:N ratio), whereas N-rich leguminous green manures and oilcakes decay swiftly with quick release of nutrients (Paul et al, 2019; Chandra, 2005; Timsina, 2018). A wide range of materials derived from agriculture, animal, anthropogenic, and factory wastes recycling may serve as plant nutrient sink (Sadh et al, 2018; Modupe et al., 2020; Goulding et al, 2008). Nutrient inputs derived from plant or animal-based processed products are becoming more important as nutrient sources. (Paul et al, 2019; Yang et al, 2021; Timsina, 2018; Jayathilakan, 2012). Every plant (forage crops inclusive), needs comparatively higher quantities of nitrogen (N) for optimum growth and development. Organic fertilizers are fertilizers derived from animal matter, human execrate or vegetable matter (e.g. compost, manure). Organic fertilizers application can enrich the soil and make it suitable for crop production (Assefa and Tadesse, 2019).

Biological Nitrogen Fixation (BNF)

A large amount of nitrogen is produced through BNF by a variety of soil microorganisms, either by itself or in association with particular plants. The inocula of these micro-organisms are widely called to as biofertilizers, that are meant to increase the amount of nitrogen available to crops. Organic manures are thought to contribute a considerable but minor amount of nutrients, notwithstanding their positive effects on soil physico-chemical and biological qualities (Assefa and Tadesse, 2019).

According to Haynes 2005, organic matter content is regarded as an important indication of soil quality and fertility. It is one of the three soil composition that are critical for its physicochemical features, such as its supportive and buffer capabilities as well as its biodiversity and biological functions.

Lin et al. (2019) discovered that minor-aggregates with recalcitrant Soil Organic Matter had less conducive habitat circumstances because of higher collaboration and rivalry within microbial groups, and that the Gaiellales and Pezizales classes were common in micro-aggregates. Microaggregates with reduced SOM favored Actinobacteria using the k-selection technique, but macroaggregates with high labile SOM favored Proteobacteria (Davinic et al, 2012). Furthermore, Ma et al, (2018) found that a labile SOM shortage increased both corraboration and competition among soil bacteria. The type of natural fertilizers used and the existence of local microbial communities in arable soil, however, had a significant impact on the degree of aggregation. Guo et al. (2018) used manure from straw to enhance the stability of soil's structure, while cattle dung showed to elevate the proportion of major-aggregates (Hurisso et al., 2013). Lin et al. (2019) found that soils amended with manure from pig rather than plant waste or synthetic NPK had resulted in active soil aggregation, with about 30.6 percent sperior aggregate formation, whilst Babalola et al. (2012) found about 15.7 percent rise in stability of soil aggregation following the addition of compost from green manure. Furthermore, when compared to chemical fertilizer treatment, poultry manure utilization decreased the micro-aggregates formation by 34% and increased glomalin production (Bertagnoli et al., 2020). Animal dung with a high salt concentration, on the other hand, was found to degrade soil structure to some amount (Li-Xian et al, 2007). For the fact that organic matter exerts a favorable influence on the functionality of soil, it is important that its resources be preserved or improved (Lin et al, 2019).

Recycled Organic-Mineral Fertilizers

Organo-mineral fertilizers are a mixture of organic and mineral fertilizers with a texture suited for crop application. These fertilizers are made up of natural components derived from animals or plants and enriched with chemical (mineral or synthetic) materials (Olaniyi et al 2009. These fertilisers include at least 25% organic matter and work faster (but for a shorter period of time) than fully organic fertilisers. The organic components in these types of fertilizers promote humus formation in the soil (Olaniyi et al 2009)

As a new concept in animal waste management, the combination of animal dung and mineral fertilisers have been widely utilized for decades to supply macro- and micronutrients for crop productivity. Organomineral fertilizers contain a higher nutrient concentration than animal dung, allowing for lower application rates. Among the numerous benefits of using organomineral fertilizers are their potential to help increase soils nutrient retention capacity (cation exchange capacity) (Chowdhury et al, 2021), soils water and air retention capacity (Kominko et al, 2017), soils trace mineral levels, soils pH level (Crusciol et al, 2020) and soils beneficial micro-organism populations (Bargaz et al, 2018).

Production and Properties of Organo-Mineral Fertilizers

Organo-mineral fertilizers, according to Osumah and Tijani (2010), have two key constituents: a chemical part that is rapidly available to plants and an organic part that is gradually released from decomposition for plant use. With the ever increasing population of the Ghanaian populace and its associated pressure on land for other purposes other than farming such as road and buildings constructions plus other infrastructural development, the fallow period – a traditional method of soil fertility replenishment has been further reduced. The use of synthetic and organo-mineral fertilizers has been found to improve the growth and development of crops leading rise in production of food. However, there is limited information about minimum guarantees of nutrients that will enable optimization of quantities to apply and best management practices for organo-mineral fertilizer application. Examples of organo-mineral fertilizers are sewerage sludge, blood meal, MBM.

The quality of sewerage sludge can be improved through fortification with inorganic fertilizer nutrients. For instance, sewerage sludge granules can be coated with molten urea (46% N) and grinded potash (60% K_2O) to increase the concentrations of nitrogen and potassium, respectively (Eifediyi et al., 2017). The final product from this process is a compound NPK organo-mineral fertilizer.

Meat and Bone Meal Fertilizers (MBM)

Plant nutrients can be obtained from a variety of wastes generated from the bodies of domestic animals. Various types of animal meals, especially bonemeal, are important among these, as it is a long-established supply of phosphate for crop productivity. The term "animal meal" refers to a variety of organic manures made from the wastes of animals other than dung and urine. MBM has a protein of around fifty percent, ash of thirty five percent, fat of about 8-12 percent, and moisturecontent of 4-7 percent, with crop nutrients averaging 8 percent Nitrogen, 6 percent Phosphorus, and 0.5 percent potasium (Ylivainio et al, 2008). MBM also is made up of 11 to 15 percent calcium, 0.19 to 0.25 percent magnesium, and 0.2 to 0.4 percent sulfur, as well as mineral compounds, chiefly include Se and B (0.28 $mgkg^{-1}$ and 0.25-0.27 $mgkg^{-1}$ dry matter respectively). The mean percentage of organic materials is 50 percent. Nonetheless, the nutritious content of M.B.M. ranges greatly depending on the raw material used (Nogalska 2016).

According to Ylivainio et al, (2008) bone meal is end product of processing meat during abattor activities which employed as a natural fertilizer. Rendering is a set of activities of transforming discarded animal waste tissues to form secired, high-valued commodities such as MBM. MBM production differs in terms of procedures and raw materials, but the overall concept is that watses from animal are chopped, taken through sterilization, extraction of fat, and then the remaning bulk rich in protein is pulverized into acceptable product.

Production and use of MBM

According to literature, the usage of animal waste as fertilizer dates back thousands of years (Lowrison, 1993). Significant volumes of bone meal were supposed to have been utilized as a source of fertilizer in England commencing in the latter part of the 18th century. United Kingdom needed to import prized phosphorus fertilizer yearly from all over Europe and South-America to meet the their fertilizer demand (Simonen, 1948). Initially, the efficiency of the fertilizers was rather on the low side due to untreated milled bones used on fields compared to the latter method of production which gave better results. The fat and proteins extraction from fresh bone material was used in the latter procedure, which improved the efficacy of bone meal fertilizers (Simonen, 1948). The rendering industry grew rapidly as a result of the social and industrial change and steam technology development in the 18th and 19th centuries, leading to superior quantities of its products such as tallow, grease, and meat meals. In the 1920s, a dry batch rendering technique had been developed in a way to achieve greater energy efficiency and a higher protein yield than the traditional wet method. Several rendering plants employed the dry technique by the end of World War Two, paving the way for meat and bone meal to be widely used for protein supplement for farm animals and a raw ingredient in pet food. The use of fertilizer was minimal owing to the better lucrativity of MBM being a protein feed. This condition altered abruptly in 1994, when the EU outlawed the usage of MBM for ruminant feed and, for that matter food for all animals in 2001 (Ylivaino et al., 2008). The epidemic of bovine spongiform encephalopathy (BSE), also known as "mad cow disease," was the reason behind this. In 2002, EC Regulation No. 1774/2002 was passed by the European Parliament and the Council, which further limited the adoption, as a fertilizer, of MBM. In the cement industry, Meat Bone Meal was then utilized as a burnt, landfill, or as an optional energy. However, prohibition on MBM as a soil conditioner was abolished within EU zones in the spring of 2006 (Ylivaino et al., 2008).

In European Union seventeen (17) products of animal meals and processed animal protein (PAP) remained distributed as follows by 2005: 52 percent were cremated, 23 percent meant as food for pet, and 20 percent were utilized as fertilizers (Coelenbier, 2006). By 2008, according Nielsen 2009, the allocation had shifted slightly: energy production (incineration) provided just 39 percent of the total, having lost ground to tamed animal feed (33 percent), and then fertilisers (24 percent). These disparities might stand attributable partly to the evaluation being done in 2008 inside E U on 20 products rather than 17 products.

There is some variety across distinctive set ups with regards to current meat and bone meal production procedures, however Nielsen (2003), suggested the following primary procedures: 1) Slaughterhouse by-products (bones, skulls, skins, intestines, etc.) are brought in closed containers to the factories, 2) the items are milled, 3) at a heating temperature of (80-90°C) the milled meat is coagulated, 4) by pressing, the solid material is separated from the liquid, 5a) at 110°C, the solid component is dried, 5b) the fat is separated from the wet portion by heating it at 105° C. 6a) remaining dry-product is assessed, sterilized at 133°

C, crammed, then kept for supply; 6b) the fat remains sterilised at 125° C before being packed and kept for distributed. The waste of water produced through the procedure is either totally treated and discharged, or it is partially preserved and routed to municipal wastewater treatment plants for additional treatment. Biofilters treat the air in the ventilation system (Nielsen 2003). MBM is then used as a nitrogeneous fertilizer.

As reported by Jeng et al, (2004), regardless the fact that MBM is made up of 8% nitrogen compounds and only a small percentage of total nitrogen is mineral N, the low C/N ratio (about 4) of MBM offers a lot of opportunity for N mining. In an incubation experiment by Mondini et al, (2008) revealed that the high rise in accessible nitrogen plus the augmentation of the biomas coupled with the activities of the microorganisms within the soil indicated MBM's potential as an effective organic fertilizer. Soil treatment with MBM resulted in a significant elevation in extractable NH_4 and NO_3 (approximately half of the additional nitrogen), as well as increased microbial content and activity. Furthermore, as demonstrated by respiration dynamics, the growth of microbial biomass stayed relative to the rate of application of MBM, and the additional freely accessible carbon produced a restriction in other key nutritive elements (Mondini et al., 2008). Salomonsson et al.(1994, 1995) studied the effects of MBM as a nitrogen fertilizer and reported that seed yields of spring wheat between MBM and urea were not significantly different, but both performed much better than slurry manure. When the nitrogen application was split, MBM produced an increased protein content and yield relative to urea or manure.

As a result, it was suggested that the MBM treatment be divided and, in supplement to half of the fertilizers administered at sowing, and additional rate be provided during the Growth Stage (GS) to boost protein content of the grain. To achieve the similar concentration of protein and the yield, it was suggested that, the amount of N in MBM could be lesser than the slurry manure. Salomonsson et al. (1995) reported that protein content in grain fertilized with MBM recorded the same yield as that of grain fertilized with urea. Furthermore, various field trials with cereals have been done in Finland to compare the ammendment impact of MBM-N versus artificial fertilizers. MBM produced similar grain yields to chemical fertilizer (20N-3P-9K Kemira's Y3) in barley and oats (Chen L., 2008). Furthermore, in Finland, Kivelä (2007) conducted a three-year field experiment, with MBM fertilized oats at a rate of 96 percent of Kemira's Y3® chemical fertilizer. When compared to mineral Y3 fertilizer, MBM had a 24 percent stronger residual effect (Kivelä, 2007). Though synthetic N fertilizer produced elevated seed yield of barley relative to MBM in a pot trial, according to Jeng et al. (2004) , increasing the rate of application of MBM had a significant increase in yields. Because of the comparatively high carbon-to-nitrogen ratio of the growth medium (sand/peat combination), this could have been largely attributable to N immobilization.

This logic is supported by the fact that there was no period of N immobilization in the subsquent field experiment with spring wheat. The soil C:N ratio (9) and better nitrogen impact was realised even for less quantities of MBM (N 50 kgha^{-1}). With increased Nitrogen levels (N 100 kgha^{-1}), M.BM and synthetic N fertilizer had similar yileds during a field trial. Jeng et al.(2004) stated that, applying BM (Bone Meal) to cereal crops during spring, a relatively higher efficiency of N at least 80% or greater is realised compared to chemical fertilizers. Further more, Jeng et al. (2006), claimed MBM has greatest impact when soils have low levels of SOM (organic matter) and a restricted provision of nitrogen released from the organic matter.

Jeng et al, (2004), discovered that MBM has the same or slightly lower NUE (25-42 percent in the field) relative to artificial N fertilizer (43 percent). In a study involving MBM and urea on wheat, the two did not differe significantly in nitrogen uptake efficiency but both performed much better than slurry manure in the majority of situations (Salomonsson et al., 1994, 1995). Increased rates of N application, raised protein content of flour and the time of dough development while softening dough decreased by Fredriksson et al. (1997, 1998). Furthermore, Salomonsson et al, (1995) opined that the quality of the seed yield had no complications of mould, fungus, or any contaminations when MBM fertilization was used, and peromed significantly similar to urea, and manure slurry. Pb and Cd levels in grains were also minor compared to the standards set by the Swedish National Food Administration and industry guidelines (Salomonsson et al, 1995).

The environmental impact of MBM is a critical consideration. In a laboratory experiment to determine the effect of MBM on nitrogen and phosphorus leaching, Jeng and Vagstadt (2009) reported that leached nutrients from MBM-treated columns decreased in a three fold lower relative to chemical N fertilizer-treated columns, giving about 13-17 percent NO_3-N leaching losses relative to 31 percent for synthetic fertilizer. Losses in nutrient are likely to be substantially reduced when there is vegetation. In any case, because losses due to leaching rose with higher rate of MBM application and because N-mineralization occurs very quickly, it was suggested that application during late autumn and early spring must not be done (Jeng and Vagstadt 2009). They further stated that MBM's increased P level prohibits it from meeting all of a plant's N requirements.

MBM as a Phosphorus Fertilizer

Giving the scarcity of mineral P fertilizers (mostly phosphate rock), it is critical to boost the rate of restoration of substantial P reserves by including by-products of animal products to give crops nutrients (Smil, 2000; Werner, 2003; Kivelä, 2007). The level of phosphorus in MBM ranges between 5.0 and 9.0 percent, depending on the meat component of the raw material. The majority of MBM-P is found in the bone fraction as phosphate of calcium ($Ca_5(PO_4)_3OH$) and in organic state in the meat portion. However, the phosphorus in MBM is characterized to be be barely dissolvable due to its chemical composition (freely plant accessible (P-AL) concentration 19 - 40 percent) (Ylivainio and Turtola, 2009; Ylivainio et al, 2008; Jeng et al, 2004). Jeng et al, (2006) stat ed that , the amount of residual phosphorus in soils usually determines the efficacy of added P. As a phosphorus fertilizer, MBM considerably raises the accessible labile P pool resulting in the soils' ability to adsorb more phosphorus (Jeng et al, 2006). Kahiluoto and Vestberg (1998) found that bone meal absorbed substantially more P than Kola apatite in leek seedlings infected with arbuscular mycorrhiza. Bone meal gretaly raised the the acetate-extractable P content of soil but the acetate-extractable P content of soil was not affected Kola apatite. Only on traditionally managed cereal monocropped land did arbuscular mycorrhiza inoculated seedling improved phosphorus uptake; but on organically farmed soil, the effect was even negative.

As a result, it can be concluded that the existence of arbuscular mycorrhiza in soil can considerably enhance MBM-P uptake under specific conditions (Kahiluoto and Vestberg, 1998). In a greenhouse experiment by Jeng et al, (2006) to investigated the ammendment impacts of MBM and synthetic NPK fertilizer on barley and ryegrass, they found that when N supply was equal, NPK and MBM treatments do not have any positive effect on yields of barley and ryegrass. MBM-P has a relative effectiveness of P of around 50% when compared with phosphate-P and can hence be called good phosphatic fertiliser.

Furthermore, it was discovered in field studies that the P in MBM had a lasting impact a year after application. There was no need for additional P on any plots that was treated with at least 500 kg MBM ha^{-1}. In any case, it should be remembered that MBM's N/P ratio is substantially lower than cereals' typical ratio of nutrient uptake, culminating in phosphorus buildup in the soils at environmentally dangerous amounts if MBM is applied annually. As a result, utilizing MBM to provide crops' nitrogen fertiliser requirements, there is no need for P addition the next season (Jeng et al. 2006). In a three year pot trial with ryegrass by Yilvaino et al, (2008) to examine the availability of phosphrus from Meat Bone Meal, Superphosphate (SP) and cattle dung, it was observed that just 19 percent available phosphorus from Superphosphate and cattle dung was supplied, while P available from MBM grew to 63 percent. Another major element affecting supply of phosphorus from MBM is the pH of the soil. In acid soils, MBM might be an effective active phosphorus fertiliser than in neutral to alkaline pH soils. Ylivaino et al, (2008) recommend MBM as a longlasting P source for permanent crops in soils that are non-calcareous because it had the highest impact elevating acid soluble phosphorus levels in the trial soils.

The field trials that followed the greenhouse experiment backed the finding that MBM-P has a longer effect, especially on perennial plants. MBM's phosphorous availability was only 18 percent more than that of SP-P in the first year of application. However, MBM's P was equivalent to SP-P in subsequent seasons. In three to four years of testing, MBM-P was shown to be 32 percent as available as SP-P. Furthermore, in grassland, 3-4 years after treatment had the greatest MBM-P availability (about 100 percent of SP-P) (Ylivainio and Turtola, 2009). Leaching of P is minimal regarding MBM-environmental phosphorus consequences of soils (Jeng and Vagstadt, 2009). For all treatments, annual orthophosphate (PO_4-P) losses were low, seldom exceeding 0.3 kg ha^{-1} or 0.5 percent of total P applied. When MBM is used as a nitrogen fertilizer, the losses are likely to increase significantly. In comparison to the other treatments, the maximum rate of application of Meat Bone Meal (2280 $kgha^{-1}$ or 180 $kgha^{-1}$ N) resulted in considerably larger losses of PO_4-P (Jeng and Vagstadt, 2009). There are several case studies on crop production with various fertilizer kinds, application rates, and nitrogen levels:

Recycled Abattoir Fertilizers

The past years has recorded the use of abattoir waste termed meat and bone meal as a main nutrients source and therefore recycled into fertilizers and incorporated into Agronomic lands either as feed for animals or organic nitrogen and phosphorous fertilizers. Presently, due to the BSE crisis in 1999 it is only used as fertilizer. Based on this concept, novel recycled abattoir waste fertilizer (Thallo) has also emerged and been found to be very promising for future farm management practice (Darch et al, 2019).

Impact of Recycled Abattoir Fertilizer on Soil Quality, Crop Quality and Crop Yield Improvement

Constant applications of abattoir waste fertilizer have been found to increase soil organic matter (Sayara et al, 2020; Darch et al, 2019). This subsequently lead to soil pH improvement. The acidification of soil as a result of acidity generated during the process of nitrification resulting from repeated applications of N fertilizer could be remedied through to the addition of abattoir waste fertilizer as manure which can serve in buffering the soil against a decrease in pH (Brady and Weil, 2016). According to Campbell et al, (1986), soils that received regular addition of recycled abattoir fertilizers improve its physical properties. According to Assefa and Tadesse (2019), improvements in physical soil quality characteristics are generally indicated by increases in aggregate size and stability, macro porosity, water infiltration, and soil OM. To mention a few, researchers have shown that recycled abattoir fertilizers help to improve soil structure (Darch et al., 2019), increase porosity (Bhunia et al., 2021), water holding capacity (Arumugam et al., 2012), decrease evaporation rates (Sayara et al., 2020) and increase water infiltration into the soil (Matheyarasu et al., 2015).

The production of stable aggregates is critical for maintaining crop yield by enhancing the structure of the soil, which serves as conduits for water, elements, and gases transport while also providing an ideal environment for microbial activity. Aggelides et al. (2000) point out that stability of aggregates primarily depends on dynamics and content of SOM. Few research have found that chemical fertilizer application improves cohesion of aggregate (Edwardset al, 2011; Savage & Johns, 2015), but Bandyopadhyay et al, (2010), Xin et al, (2016), and Zhou et al, (2017) found no differences or even decrease in comparison to unfertilizedplots. Organic modifications, on the other hand, increased the amount of SOM that linked soil particles together into aggregates. Zhang et al. (2012; 2014) discovered that aggregation stability and associated binding agents had a favorable association. According to other studies, organic treatment reduced the fraction of micro-aggregates and increased SOM accumulation in macro-aggregates (Lin et al., 2019; Darch et al., 2019).

Fertilizer Type Effect

Crops cultivated with natural ammendments produce yields widely acknowledged to be much lower than that of agricultural products grown with mineral fertilizers. In an eight-year study in Norway, Eltun et al. (2002) found that mean yields of grassland from orthodox farming prcatices ranged from 7 to 22 percent lesser compared to conventional farming practices. Organic farms in Sweden and Norway have reduced yields of grassland (5 to 21 percent) than conventional farms, according to Offermann and Nieberg (2000). They further opined that the main cause for this disparity could be due to the fact that organic fertilizer mineralization rates are often slower in the northern latitudes, where shorter growth period exists. Tammeorg (2014), on the other hand, discovered no statistical difference within the fertilizers in his research.

On the highest nitrogen level, the only exception was NK, which yielded significantly less than MBM P and K. Because there were no statistically significant differences in cumulative yield impacts between MBM and mineral Y4PK fertilizer at any nitrogen level, these findings are consistent with prior MBM research on ryegrass and cereals in Scandinavian nations (Chen, 2008; Salomonsson et al, 1994, 1995). Furthermore, MBM treatment impact was significantly and persistently longer than chemical fertilizers in Tammeorg's (2014) study on two higher treatment levels (Y4PK and NK). However, studies from Jeng et al, (2004) and Kivelä (2007) show that MBM has a lesser fertilization performance than mineral fertilizers, ranging from 81 percent to 96 percent in the case of spring wheat and oats.

Despite this, all of the studies suggest portray MBM as a hugely effective natural soil ammendment, with a fertilization efficacy of 80% compared to synthetic nitrogenous fertilizers. When compared to organic fertilizers, Kivelä (2007) attributed such a large effect to the increased concentration of plant-accessible nutrients (27 to 29 percent of dry matter) whereas Mondini et al, (2008) linked it to the comparatively quick mineralization of organic nitrogen forms. The reduced C:N ratio (about 4) of MBM has a role in the comparatively quick transformation of nitrogen organic forms (Brady and Weil 2002; Jeng et al, 2004). Mondini et al. (2008) found that MBM treatment resulted in a significant rise in retrievable ammonium and nitrate (approximately 50 percent of added nitrogen), as well as improved microbial content and activity in soil. The reduced C/N ratio of natural fertilizer generates strong micro-organism function, quick breakdown of additional organic compounds, and enhanced concentrations of crop-accessible nitrogen, (Brady and Weil 2002). Furthermore, Rajala (2004) claims that a fertilizer's decreased C/N ratio supports the improvement of nutrient mobilization from soil organic matter. According Jeng et al, (2004, 2006), MBM has a reasonably high phosphorus concentration (between 5 - 9 percent), but the easily crop accessible portion adds between 19 and 40 percent.

Nitrogen Level Effect

The most efficient fertilizer application rate, according to Antikainen et al. (2005), is determined by the soil type, plant type, weather conditions and fertilizer type. In contrast to Tammeorg's work, the increased yields of ryegrass dry matter is in tandem with the level of nitrogen utilized, with the best yields occurring at a nitrogen content of 240 kg N per hectare). This finding is consistent with Kivelä's (2007) findings from a field experiment. According to Kivelä (2007), oat yields from MBM and chemical fertilizer addition vary significantly among 60, 90, and 120 kg ha^{-1} rates of N. Jeng et al, (2004), on the other hand, recorded no statistical changes in yields of wheat when MBM at a rate of 100 and 200 kg N ha^{-1} were used. The scientists also discovered that barley yields did not differ significantly at levels of 117 kg ha^{-1} and 234 kg ha^{-1} MBM-N. According to Tammeorg (2014), the comparative treatment effect between MBM and Y4PK on three rates of N was greatest on the moderate rate of N (160 kgha^{-1}), obtaining 111.7 % in the current research. So far, rationalizations demonstrate that the response of yield to nitrogen application primarily depends on the soil's plant-accessible nitrogen concentration. MBM has the greatest impact on soils that have a low level of SOM in addition to a reduced amount of nitrogen released from SOM (Tammeorg, 2014). Plants, on the contrary, may not use all of the nitrogen available to them. According to Tammeorg (2014), because of the low organic matter content of the soil, the moderate rate of N (160 kgha^{-1} N) may be the best MBM-N rate of application

MBM and Potassium Content of Fertilizer

Despite being a geatly active natural replacement for synthetic nitrogen and phosphorus fertilizers, MBM has a low potassium concentration (0.5

percent). MBM's limitation, according to Tammeorg (2014), is due to the considerable need for extra potassium fertilizer in several farm soils. The availability of research on the influence of Meat Bone and Meal based fertilisers combined with extreme potasium containing fertilisers on yield is limited. Furthermore, current study shows that both of these combinations (MBM P and K and MBM L) produced greatest yields of dry matter despite the statistical insignificant differences (Tammeorg, 2014). Consequently, despite the great fertilizing capacity of a blend of potassium fertilizers and beef bone meal, there is a dearth of potassium sources that may be useful in organic farming. In addition to the potasium liquid extract used in Tammeorg's experiment, other researchers as Rajala (2004), Stamford et al. (2006), and Elosato (2009) reported an alternative in potassium sulphate and biotite. More studies need to be done to solicit avenues to improve MBM's performance as an NPK fertilizer, and viable mineral PK fertilizer substitutes should be considered.

Soil Fertility and Nutrient Uptake Efficiencies in Recycled Abattoir Waste Fertilizer Amended Soils

Jones (1998), reported that phosphorus deficiency might cause the roots to produce more organic acids, which increases the rhizosphere microorganisms activity and proliferation. Toal et al, (2000) observed that when the activities of the micro-organisms in the rhizosphere increase, the release of organic phosphorus is higher. Salomonsson et al. (1995) working on winter wheat, found that the MBM-N had a nutrient use efficiency (NUE) ranging from 13 to 22 percent, while the mineral counterpart yielded 17 and 24 percent, respectively. Work on barely was further revealed that the MBM-N yielded a

NUE ranging from 11 to 18 percent, while the chemical counterpart gave 29 to 38 percent (Jeng et al., 2004).

These findings support that of Tammeorg (2014), who showed that nitrogen input effectiveness was 11-19 percent for MBM and 15-17 percent for Y4PK. MBM-N, on the other hand, has been shown to have significantly greater uptake and efficiencies of nitrogen. According to Salomonsson et al, (1994) and Jeng et al, (2004), the NUE from meat bone meal on spring wheat is found to be between 25 to 42 percent, whilst chemical counterpart are a bit better varrying from 32 and 43 percent. Jeng et al, (2004) related this dissimilarity in part to variances in carbon:nitrogen ratio in the growing media, since a higher carbon:nitrogen ratio leads to increased nitrogen restriction. Tammeorg (2010) also pointed out that this discrepancy is due in part to the assumption of constant plants and soils N rates when estimating the NUE of N input.

Effecting content evaluation of N, as suggested by the rationalizations, would benefit in making the outcome extra acceptable and hence extra comparable. In terms of uptake efficiency of phosphorus, MBM-P is typically thought to be less efficient than mineral fertilizers (Tammeorg 2010). Tammeorg confirmed this, stating that Phosphorus Upatke Efficiency (PUE) varied from 9 to-11 percent for MBM to 18 to 21 percent for Y4PK. The results are comparable to the work done by Ylivainio and Turtola (2009). MBM had 13 percent PUE in the first year of their trial, whereas mineral superphosphate had a PUE of 23 percent. In the pot reaserch of ryegrass by Ylivaino and Turtola, the rate of P application was same to the decreased rate of treatment of 60 kg ha^{-1} P, in the present investigation.

This variation is due to MBM's reduced easily available phosphorus content compared to mineral phosphate fertilizers. However, Ylivaino and Turtola (2009) and Ylivaino et al, (2008) demonstarted that a considerable levels of MBM-P remains accessible to subsequent season, since the yields variation in the pot trial involving ryegrass became level in third experimental year, with efficiency of superphosphate at 63 percent. Ylivaino and Turtola (2009) in their study discovered that, after three to four years the comparative efficiency of phosphorus of MBM was 100 percent compared to the efficiency of the superphosphate. In field trials with spring wheat, Jeng et al. (2006) discovered that the phosphorus in Meat and Bone Meal exerted a lasting impact after a year of treatment, with no extra demand for P at a minimum application of 500 kg MBM ha^{-1}. The most balanced nutrient condition in soil is related with the maximum nutrient utilization efficiency of Meat and Beal Meal nitrogen and phosphorus on the moderate treatment rate (160 kg ha^{-1} N). On this tratment rate, it appears to be the minimum surplus nitrogen and phosphate, and a potassium shortfall is not currently inhibiting ryegrass development (Ylivaino and Turtola 2009). The law of minimums states that the accessibility of the greatest ample nutrient in the soil determines the accessibility of the smallest ample nutrient found in the soil.

The value of knowledge about nutrient uptake efficiency has been highlighted in previous rationalizations. These are of the utmost agronomic importance for improving the crop management design systems that increase nutrient efficiency while reducing fertilizer use.

Changes in Soil Quality

Post-planting soil analyses are beneficial for differentiating between differences in fertility of soil and demonstrating the limitations of fertilizer application. For example, Tammeorg (2010) found that MBM-P has a strong residual effect since the P concentration in postharvest soils is outstanding at all application levels. Additionally, the process of P stocks mobilization from soil through enhanced actions of micro-organisms in the rhizosphere, which was attributed to a degree in the case of low P treatments, has been observed to increase soil P level for all treatments (Tammeorg, 2010).

Nonetheless, high P application levels were observed to have a possible effect on the majority of the microbes. The Tammeorg, 2010 also discovered that the post-harvest soil potassium concentration for all ammendments was insignificant except two increased levels of PK control, indicating that ryegrass has a relatively high K requirement and, as a result, requires more potassium fertilization. Furthermore, the similar outcome was observed in the case of magnesium, with all treatments lowering the original Mg level in the soil below the acceptable limit. Tammeorg (2010) found that, in addition to having a superior lasting impact, MBM-P leads to a greater Ca concentration and a elevated pH in the soil compared to Y4PK chemical fertilizer. As a result, the comparatively elevated Ca concentration of MBM (11 to 15 percent) has been found to be advantageous in reducing the additional expenses that would be needed to lime the soil if chemical fertilizers were applied.

MBM use as Organic Source of Nutrients

Due to the slight nitrogen-to-phosphorus ratio and reduced potasium level of MBM, Tammeorg (2010) found that its nutrient content (8-6-1) does not correlate to plant nutrient demands. MBM's N:P ratio is substantially lower than cereals' usual ratio of nutrient uptake, leading to P addition in soils at rates that are environmentally hazardous if MBM is applied annually (Jeng et al, 2006).

According to the study by Kivelä et al, (2005) and Jeng et al, (2006), if MBM is applied to augment the crops n itrogen requirement, no phosphorus addition should be made the next year (or even throughout the entire rotation of the crop). Aside from MBM's low potassium content (0.5 percent), most arable soils have a necessity for extra potassium fertilizer (Tammeorg, 2010). However, Rajala (2004) revealed that biotite and potassium sulphate are two of the best possible solutions for extra K in organic natural farming. Because MBM nutrients must be mineralized from their organic state, the growing conditions exert a considerable impact on the fertilizer impact of MBM. The growing medium, along with water availability, is determined to have the greatest impact on MBM nutrient mineralization. Meanwhile, Kivelä (2007), and Jeng et al. (2004) found dry clay and peat soils to be unfavorable. As a result, Gruvaeus (2002) and Kivelä (2007) found that the MBM nutrients accessibility is considerably lower on clayey soils (the impact was emphasized further in the dry season).

The texture of beef bone meal determines how it is applied to fields; granulated forms may be added by drilling or broadcast with chemical broadcasters (Tammeorg, 2010). Kivelä et al, (2005) opined that wet liming equipment, on the other hand, is the most efficient way to apply meal type fertilizer. They reported that the most significant practical issue faced by organic cultivators in Finland taking part in MBM fertilization farm experiment in 2003 and 2004 was the employment of mainly moist and dry liming machines for MBM meal type. Kivelä et al, (2005) opined that the caking of the fertilizer was discovered to be the problem, and the alternatives explored (chemical or manure broadcaster) were practically not feasible. According to Elosato (2009), the MBM-based granular fertilizers should be applied to either cultivated field directly prior to sowing using a mineral spreader. An alternative to rapid seeding would be immediate soil cultivation, which would cover the applied fertilizer using 5 to 10 cm of soil. As a result, the fertilizer covered by the soil will become damp, allowing for the gradual discharge of nutrients for microorganisms and plants. The benefit of this approach, according to Elosato (2009), is that it enables for the seeding to be postponed for some days, but the nutrients would still be available and ready for crops immediately once sowing is done. Several experts suggest that MBM addition should be split into two phases throughout a single growth period. MBM fertilization, for example, boosted the protein content of spring wheat yields partially prior to planting and partially at growth stages (Salomonsson et al., 1994). One downside of this strategy is the potential physical damage to crops caused by fertilizer broadcasting apparatus.

The concerns of dust and odor with MBM was highlighted in a report on section of farmers who participated in an experiment involving MBM fertilization in 2003 and 2004 in Finland (Kivelä et al, 2005). Though it isn't much of a challenge because human susceptibility to such issues varies greatly, there is less proof of sensitive reactions induced by MBM dust. Nonetheless, Diaz-Jara et al, (2001) documented an allergic reaction and occupational asthma in a young butcher as a result of inhaling the dust from cow bone. Huhtanen et al, (2007) reported an instance of industrial asthma in an employee opened to

MBM dust on a regular basis at an MBM manufacturing plant in Finland. Furthermore, Huhtanen et al, (2007) recommended using good respirators once exposed to meat bone meal dust and avoiding direct exposure to MBM if allergic reactions occur. Furthermore, MBM fertilizer granulation is projected to significantly alleviate dust-related issues. Finally, it is worth noting that academics such as Kivelä et al, (2005 and 2007) have discussed the economics of MBM fertilization. The greater harvest and protein concentration of the produce receiving the application of fairly inexpensive MBM are included in this discussion, making MBM fertilizer use economically possible, especially on organic farms. Tammeorg (2010) pointed out that rising prices of crude oil will likely enhance the cost of chemical fertilizers, which, in addition to steadily rising of organic foodstuff prices, shows a favourable future for MBM fertilizer use.

Potential of Thallo to Improve Yields and Nutritional Composition of Crop

Darch et al. (2019) found that the unique multi-element fertilizer Thallo® is capable of delivering yields of crop that can be compared to standard fertilizers derived from rock phosphate, with the added benefit of raising important mineral concentrations. In a pot study with wheat and grass, the authors compared Thallo, which is made from slaughterhouse and recycled industrial by-products, to standard mineral fertilizers. Yields were equivalent in soil amongst the fertilizer kinds, while Thallo exhibited a yield advantage in a low-nutrient substrate. Elemental concentrations in plant material often mirrored fertilizer concentrations, and Thallo fertilized plants had significantly higher levels of certain critical elements like selenium and zinc. Furthermore, Thallo treated crops had much reduced levels of the hazardous element cadmium. Manganese levels were highest in the Thallo fertilizer, but they were highest in the plants fertilized with synthetic fertilizer, demonstrating the difficulty of determining if crops will take up the nutrients.

Soil health and quality are enhanced with the application of Thallo. Its tight granular form limits its loss to the atmosphere. Thallo will aid in the better management of farmlands to increase biodiversity from soil microbes for the benefit of plants, insects, fish, birds, and mammals, including livestock, all of which contribute to the production of wholesome foods, healthy soils, clean water, and greenhouse gas sequestration. Furthermore, the associated bone and organic waste re-use sequesters carbon cost by returning it to soil via our organo-mineral fertiliser, where it, together with the associated minerals, is efficiently incorporated back into the nutrient cycle.

Potential Adoption Opportunities and Challenges of Thallo

Thallo works by not only supplying slowly released nutrients to the plants, but also feeding the soil. Implying that it serves well the needs of both soil and plant. Research on crop and soil nutrient dynamics on the same or different research sites would be less cumbersome using one source of efficient fertilizer such as Thallo. Typified of elemental’s patented process means that valuable organic matter can be extracted through improved decomposition (Darch et al, 2019). Therefore, future studies are stippled with the advantage of getting relatively short research timelines. In addition, through its function, Thallo establishes a uncontaminated, effective path to return biosecure concentrated organic matter to the soil. Therefore, risk associated with researches using Thallo as main study material is highly negligible.

However, a couple of challenges may persist in the pursuant of research in this regard. Because of the size of the livestock, there is a strong likelihood that predicting the amount of slaughterhouse waste based on assumptions from literature will result in either lower or greater abattoir waste estimation records in selected study regions when using Thallo for research. Moreover, there may be limited monitoring of types and number of livestock slaughtered in the selected abattoirs to be used for the study.

Fortunately, Darch et al, (2019) research has demonstrated the ability of livestock waste fertilizers to increase key element concentrations in wheat and grass while sustaining yields. Considering high rate consumption of cereals worldwide, extending the research scope to cover other cereals aside wheat could provide useful information to agronomists, farmers, chemist and all stake holders in the agriculture industry.

Research Gaps

Darsch et al, (2019) reported that there is a paucity of information about recycled abattoir waste fertilizers. Most of the studies done with abattoir waste fertilizers have been on MBM and to some extent blood meal. Most of these researches have been done outside sub-Saharan africa.

Darsch et al. (2019) found that mineral and micronutrient-enhanced recycled abatoir waste fertilizers (Thallo) on wheat uptake and yields in a controlled environment pot trial and found intriguing connections between fertilizer elemental makeup, elements themselves, and plant absorption in their research. Their research evaluated the performance of Thallo (a unique multi-element fertilizer made from slaughterhouse and recycled industrial by-products) in terms of crop yields to that of traditional rock phosphate fertilizers.

The researchers were also interested in seeing if the fertilizer had the added benefit of raising vital mineral concentrations. In a pot study with wheat and grass, the fertilizer was compared to traditional mineral fertilizers. They discovered that yields were equivalent amongst fertilizer kinds in soil, although Thallo had a yield advantage in a low-nutrient substrate. Elemental concentrations in plant material often mirrored fertilizer concentrations, and Thallo fertilized plants had significantly higher levels of certain critical elements like selenium and zinc. Furthermore, Thallo treated crops had much reduced levels of the hazardous element cadmium. Manganese concentrations were highest in the Thallo fertilizer, but they were highest in the plants fertilized with synthetic fertilizer, demonstrating the difficulty of whether the crops will take up the nutrients. In conclusion, fertilizers from livestock wastes are capable of increasing the key element levels in wheat and grass while sustaining yields. In this regard, longer-term on-farm experiments are needed to evaluate the effectiveness of the agronomic and biofortification potential of micronutrient-improved fertilizers made from recycled slaughterhouse and industry by-products, such as Thallo.

Furthermore, there appears a limited information about how organo-mineral fertilizer applications affect the contents of soil N, P and K and their uptakes by crops under field conditions. The recycled abbatoir waste fertilizer, Thallo has the capability to enhance the quality of soil and yields of crop, but no research has so far been done with Thallo on tropical soil.

CHAPTER THREE

RESEARCH METHODOLOGY

The study area, experimental design, and sample methodologies of this study are all described in this chapter. It also describes the many actions carried out during the experimental period, as well as the types of data obtained, as well as how and when the data were collected. It also includes a summary of the techniques utilized in the samples' laboratory analyses. Finally, the statistical tools, software, and packages used in the data processing and analysis are highlighted in this chapter.

Study Area

The experiments were undertaken at the School of Agriculture Teaching and Research Farm of the University of Cape Coast (UCC) and Jukwa.

School of Agriculture Teaching and Research Farm

Part of the research was also conducted at UCC School of agriculture Research and Teaching Farm which falls within Ghana's coastal savannah agro ecological zone with latitude: 5° 06' 19.26" N longitude: -1° 14' 47.76" W. Cape Coast has two rainy seasons: late March to early July and September to early November. The average annual rainfall is 1100 mm, with a maximum of 1400 mm and a minimum of 800 mm (GMS 2021). The average monthly temperature in the area is between 24 and 28 °C with March being the hottest month (maximum temperature of 31°C). Due to the sea breeze, the mean monthly relative humidity is often high, ranging between 85 and 99 % (FAO, 2005).

Jukwa

Jukwa lies between the longitudes of 1° 16' W and 1° 27' W, and the latitudes of 5° 20‘ N and 5° 30' N. It is located 18 kilometers north of Cape Coast in Ghana's Central Region. Jukwa receives two rainfall seasons in a year; a major rainfall season (March to July) and minor rainfall season (begining in September to the middle of November). It has a total annual rainfall of 1328 mm GMS, 2021). Acoording to Twumasi (2001), the area records mean monthly temperature ranging from 22°C to 27°C and around 90% relative humidity. Geological study by Paijmans and Jack (1960) indicates that Jukwa has the intrusive granite gneiss from the granite complex of Cape Coast. The soil in Jukwa is Gleyic Acrisols from the Kakum Series (Owusu-Bennoah et al, 2000).

Production of Recycled Abattoir Waste Fertilizer (Thallo)

Elemental Digest Systems Ltd produces Thallo, a recycled P fertilizer (EDS). It's made up of a blend of post-meat bone mineral and other slaughterhouse organic wastes including lairage, first stomach content, blood, hoof, and horn, then ground into a smooth slurry. The slurry is then mixed with concentrated sulfuric acid and oxidizing chemicals, followed by the addition of a metal ion catalyst. It was then sterilized using a high-temperature, high-pressure procedure certified by the Department for Environment, Food, and Rural Affairs (Defra), as well as an EDS proprietary chemical process (International Patent Application Publication No. WO2014202986). Some chemical composition of Thallo is presented in table 1.

Table 1. Chemical Composition of Thallo

Component	Value
Electrical Cond.(mmhos/cm)	36.30
Nitrogen (g N kg^{-1})	1.80
Phosphorus (g P kg^{-1})	55
Potassium (g K kg^{-1})	13.42
Magnesium (g Mg kg^{-1})	5.36
Calcium (g Ca kg^{-1})	185.70
Sodium (g Na kg^{-1})	22.78
Sulphur (g S kg^{-1})	4.64
Dry Matter (%)	98.9
Molybdenum (mg/kg)	1.30
pH	12.4
Zinc (mg/kg)	138.15
Copper (mg/kg)	118.54

Table 2: Chemical Properties of the soils used before planting

	Location	
Parameter	UCC	Jukwa
pH	6.3	6.4
Total Nitrogen (%)	0.09	0.02
Organic carbon (%)	0.63	0.59
Available Phosphorus (ug g^{-1})	0.22	0.19
Exch. potassium(cmolc^{-1} kg)	0.7	0.53

Tests Crops Used and their Varieties.

In this study, four cropes were used. Maize and cabbage were used for the both agroecological zones. However, sweet potato and cowpea were used only in the coastal savanna.

Table 3: Test crops used and their varieties

Crop	Variety
Cabbage *(Brassica olaracea)*	Green Boy F1
Maize *(Zea Mays)*	Lake White
Sweet potato *(Ipomea batata)*	OFSP (apomuden)
Cowpea (*Vigna unguiculata*)	Black eyed pea

Experimental Design

The experimental design used was randomized complete block design (RCBD). The treatments were Recycled abattoir waste fertilizer (Thallo), conventional NPK and control and the respective application rates are shown in Table 3. Each treatment had four replications, giving a total sub plots of 12.

The study involved application of a recycled abattoir waste fertilizer, Thallo and inorganic NPK (15-15-15) fertilizer. The Thallo (1.845 tons ha^{-1}) and inorganic NPK fertilizer were both added to supply 100 N kg ha^{-1}, 265 P kg ha^{-1} and 198 K kg ha^{-1}.

Table 4: Soil Amendments used and their Rate of Application

Treatment	Application rate (kg ha^{-1})
Control	0
Thallo	1845
NPK (N, P_2O_5, K_2O)	100 : 265 : 198

The treatment also included a control (no inorganic fertilizer, no Thallo) plot. The inorganic NPK fertilizer was applied to match the amounts of N, P and K in the Thallo fertilizer. Therefore, the N in the inorganic NPK fertilizer was supplemented with urea, while the N and K in the Thallo fertilizer were supplemented with Urea and Muriate of potash.

Field Experiment

There were 3 treatments involving Thallo, conventional NPK fertilizer and control.

Four crops were used for the experiment namely cabbage (vegetable), maize (cereal), potato (tuber) and cowpea (legume). Cabbage and maize were planted in the Semi-Deciduous and Coatsal Savannah agro-zones but the potato and cowpea planted only at the Coastal savannah.

Soil Sampling for Pre Planting Analysis

A bulk sample of the top soil was collected by the systematic sampling method described by Pleysier (1990). At both sites, the field was divided into sub-plots measuring 3 m x 3 m with 2m between beds. At each site a starting point was selected at random and the remaining sampling points located at uniform intervals. The sampling was done to a depth of 20 cm to get a bulk sample. The bulk soil sample was thoroughly mixed, air-dried for seven days and pulverized. The dried soil sample was sieved through a 2 mm sieve and used for preliminary analyses

Land Preparation, Site Demarcation and Plotting

Sites were identified at both agro-ecological zones, the vegetation were cleared and the plants debris removed. Using a tape measure, garden lines and marking sticks or pegs, the sites were demarcated. At both farms and locations the site was divided into two independent blocks (20 m x 18 m) separated with a 5 m interval. One plot was for the cultivation of maize and the other for cabbage. There were twelve sub plots with dimensions 3 m by 3 m on each independent block. Sub-plots or beds were 2 m apart. Another plots with the same dimension was set up at UCC school farm for the cultivation of sweet potatoes and cowpea.

Seed Bed Preparation

At both sites raised seed beds were prepared with the dimension 3 m by 3 m and 2 m apart using mattock and spade. Ridges with the same dimension were also raised at UCC school farm for the potatoes. The bases and sides were firmed to prevent wash off or possible erosion. The surfaces were conditioned and made even by removing all debris, weeds, stones, and other foreign materials.

Nursing of Cabbage Seeds and Seedling Transplanting

A site was chosen at the UCC school farm for the nursing of the cabbage seeds. Two beds with size 1.5 m^2 with 1 m between them were prepared using spade. The seeds were sown by the drilling method ie a thin shallow trench was made by the index finger and the seeds dropped in and covered with soil. The sown seeds were covered with thin layer of soil and mulched. Beds were then watered regularly until germination occurred in three days. Soon after germination, the mulch was removed and light shade raised 30 cm above the seedbeds. The shade was to protect the delicate seedlings from the intense heat of sunlight and the impact of heavy raindrops.

Seven days after germinations, the seeds were pricked out onto two bigger beds and spaced out at the interval of about 4 cm apart to avoid overcrowding of seedlings. The pricked out seedlings were watered and shaded to enable them become established.

Thirty days after nursing (3rd October, 2020) the cabbage seedlings were transplanted onto both sites the same day. The seedlings were uprooted with a hand trowel and transferred onto the beds at the UCC school farm site. The spacing used was 0.6m x 0.6m. The seedlings meant for the Jukwa site were transported and planted same day after being uprooted with the same planting distance and population. Experimental fields were watered every 3 days to maintain water at field capacity. Differencnes in soil moisture content was determined and the difference indicated how much by mass must be added.

Maize Planting

On the 2nd October, 2020, the maize seeds were planted at stake on the same day at both sites. The planting distance was 75 cm x 40 cm. There were three seeds per hill and thinned out two weeks after germination to maintian one plants per stand. A total plant population of 30 was maintained per plot.

Planting Sweet Potatoes

On 2nd October, 2020 the sweet potatoes were planted. Ridges were created on each plot. Vines were cut into pieces of 20 cm with three leaves on them. The vines were carefully put into the soil and firmed and watered. The planting distance used was 60 cm x 60 cm and the plant population was 30 stands per plot

Planting of Cowpea

On the 2nd October, 2020, the cowpea seeds were planted at stake at UCC school farm. The seeds were sown at a distance of 60 cm x 60 cm. There were three seeds per hill and thinned out to one per stand two weeks after germination to maintain a total plant population of 30 cowpea stands per plot. A non-nitrogen fixing crop (maize) was grown on an adjacent plot under identical conditions as the legume to help estaimate N fixed by cowpea using the difference method (Azam and Farook, 2003).

Cultural and Maintenance Practices

Watering/Irrigation and Weeding

These were done as and when they became necessary. Manually, weeding was done using hoes and cutlasses. There was reliance on rains but when rains did not fall, handheld watering can and sprinklers were used to water the land and the crops.

Pest Control

In order to protect the plants especially from fall army worm, the plants were sprayed with contact insecticides (*pawa*) two weeks after planting. Four days later, a systematic insecticide (optima) was added. The application was done every three weeks until tasselling and bulbing. Intermittently an organic neem extract was used on the maize plant to give further protection against pests.

Fertilizer Application

The Thallo was applied seven days after germination in the case of maize and cowpea and ten days after transplanting the cabbage and two weeks after planting sweet potato at rate of 61.5 g per plant. Two weeks later Urea, Triple Superphosphate (TSP) and Muriate of Potash (MoP) were added to supply the supplementary Nitrogen (N), P_20_5 (P) and K_2O (K) at a rate of 3.8 g, 8.6 g and 1 g per plant respectively.

Basal inorganic NPK 15-15-15 fertilizer was applied seven days after germination in the case of maize and cowpea, ten days after transplanting in the case of cabbage and two weeks after planting in the case of sweet potato to supply N: P_2O_5: K_2O, respectively, at the rate of 12.0 g per plant. Two weeks after each NPK application, Urea, TSP and MoP were used to provide the supplementary Nitrogen (N), P_2O_5 (P) and K_2O (K) at a rate of 0.55 g, 2.83 g and 1.9 g per plant respectively. All the applications were done by the ring placement. A drilled ring, 4 cm away, 5 cm deep was made around the base of the plant and fertilizer placed in the drill and covered with soil.

Post-Harvest Soil Sampling

Soil samples were collected from the field at a depth of 0-20 cm from five different selected plants from each plot after harvesting to form a composite sample. The bulk soil sample was thoroughly mixed, air-dried for seven days and pulverized. The dried soil sample was sieved through a 2 mm sieve and stored for laboratory analyses for pH, organic carbon, nitrogen phosphorus and potassium on each plot.

Field Data Collection

Cabbage

At two weeks after transpanting, four stands from each sub plot was marked, observed and used for non-destructive agronomic data collection. Parameters measured included leaf area, plant height and chlorophyll content of the cabbage. Two weeks after transplanting, cabbage D-leaf was measured for length and width from the stalk by meter rule for four weeks. Leaf length L (cm) was measured from the lamina tip to the point of intersection of the lamina and the petiole, along the midrib of the lamina, while leaf width W (cm) was measured from end-to-end between the widest lobes of the lamina perpendicular to the lamina mid-rib.

Plant height was measured with a meter rule from the soil level to the apex of the plant. The chlorophyll content index of the plant was determined with the chlorophyll meter, CCM-200 plus (apogee instrument).

At maturity (3 months), however, all plants within the subplots excluding border plants were used for yield data measurements and laboratory analysis. The plants were harvested by cutting the head at the lowest point, leaving the loose outer leaves attached to the stalk.

Parameters measured included number of leaves, fresh leave weight, plant height, stalk girth, head circumference, fresh head weight and fresh root weight.

The number of leaves from the stock up before the heads was counted manually to obtain the number of leaves per plant or stand. The counted leaves were then weighed on a scale to get the fresh leaves weight.

Head circumference was measured using a piece of rope around the widest middle portion and found its equivalent on a meter rule. The heads were weighed using an electronic balance (FX-3000 IWP, SHS, inside suyer hybrid sensor by AND company limited)

After cutting the head, the roots were carefully removed by digging around the base of the plant to loosen the soil and gently taking the root out with soil around it. The uprooted roots were then placed in a bowl of water to soften the soil around the roots for easy wash. To remove any leftover soil particles, they were gently rinsed under running water. The washed roots were then weighed on an electronic balance as described above. The undesirable outer leaves on the head were removed and the heads washed under running tap and cut into slices and mixed together. A composite bulk sample of the head, roots and leaves were taken seperately in a brown envelope and kept in the oven at 60^0C for four days prior to laboratory analysis. This also reduced the bulk weight for easy storage. The oven dried samples were re-weighed, milled individually, placed into ziplock bags, labeled and kept in a cool dry place for laboratory analyses.

Maize

Four weeks after sowing, four stands from each sub plot were marked, observed and used for non-destructive agronomic data collection for five weeks. The leaf area, plant height, stem girth and chlorophyll index content were measured.

Plant height was measured with a meter rule from the top of the soil to the apex of the plant. Vernier caliper was used to measure the stem girth whilst the chlorophyll meter was used to measure the chlorophyll content of the leaves.

At maturity (100 days) all plants within the subplots excluding border plants were harvested for yield data measurements and laboratory analysis.

The dried ears were harvested by cutting from the base attached to the stem and the leaf. Parameters measured included ear fresh weight, circumference, length, composite shelled bulk weight and thousand seed weight. The ears were de-husked and weighed on a scale to obtain the fresh weight. Meter rule was used to measure the length of the ear from smaller end to the broader end of the ear. The ears were shelled, put together and weighed to obtain the composite bulk weight of the seeds. Thousand seed weight was done by manually counting thousand seeds from the composite bulk weight and weighed on a scale. Sample of the seeds were taken, dried and milled and stored in zip lock bag prior to laboratory nutrients analyses

Screening for Disease and Pest Attack in Maize

At four weeks after sowing the plants were screened for streak mosaic for 5 weeks. Visually, this was done by counting the amount of plants on each sub plot that had been attacked, as well as the severity of the attack. Pest attack was done at harvesting. This was done visually. Each plot's harvested ears were shelled and inspected for pest infestation on the cob..

Sweet Potato

At maturity (3.5 months) all plants within the subplots excluding border plants were harvested for yield and nutrient analyses. Parameters taken were number of tubers , tuber weight vine length, marketable tubers , vine diameter, number of leaves, circumference and length . Sweet potato number of leaves were manually counted and the tuber circumference were measured using a piece of rope around the widest middle portion and found its equivalent on a meter rule. The Meter rule was used to measure the length of the tuber from the smaller end to the broader end of the tuber. The marketable tubers were selected (considering the size, length, shape, physical state ie rotten, chewed by insects, holes etc) and counted and weighed. The above and below ground biomas were measured and sample taken for oven drying, reweighed and dry matter determined and milled for nutrient analyses.

Cowpea

At maturity (90 days) all plants within the beds or plots excluding border plants were harvested for yield and nutrient analyses. Parameters taken were number of leaves, the number of branches, plant height, number of pods per plant, pod weight, pod length, number of seeds per pod and 100 seed count and yield determined. The number of leaves, branches and pods per plant was manually counted. The meter rule was used to measure the length from one tip/end to the other tip of the pod. Each pod was weighed using a scale. The pod was split opened and the number of seeds counted. The seeds from each plot were thoroughly mixed and hundred seed weight measured using a scale. Samples were taken and used for laboratory analyses.

Determination of Leaf Area of Maize and Cabbage

A general equation has been reported by some researchers to calculate the leaf area of maize (*Zea mays* L.) (Dwyer and Stewart 1986, Mokhtarpour, 2010).

$$\mathrm{LA} = \mathrm{L}x\mathrm{W}x\mathrm{A} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. equation\ 1$$

where LA is leaf area (m^2)

L is length (m)

W is leaf width (m) and

A is constant (A = 0.75)

In the case of cabbage the equation predicted by the Olfati et al**,** (2010) can also be used to calculate the leaf area of cabbage

$$\mathrm{LA} = 5.5981 + 0.8961\, W \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.. \text{equation 2}$$

where LA is leaf area (m^2)

L is length (m)

W is leaf width (m) and

5.5981 and 0.8961 are the modelling constant obtained by Olfati et al**,** (2010)

Laboratory Analyses

Determination of Soil pH

Rowell (1994) method was used to determine soil pH in a 1:2.5 soil:water ratio. An electronic balance was used to weigh 10 g of soil sample and transferred into well-labeled plastic bottles . Exactly 25 mL of deionized water was added and shaken for 1hour on an electronic mechanical shaker. A pH meter was caliberated using buffers of 4 and 7 before the readings were taken. The electrode was inserted into the top of the soil water solution, the pH was read and the readings recorded. An average of four replications for each sample was calculated.

Total Nitrogen Determination

A modified version of Rowell's (1994) Micro-Kjeldahl method was used to determine total nitrogen in the soil samples. Much of the nitrogen in soil exists in the form of protein in which N is present primarily as the amino acid group ($-NH_2$) attached to carbon ($-C-NH_2$). In the Kjeldahl procedure, this form of N is oxidized to $(NH_4)_2SO_4$ by concentrated H_2SO_4. A 0.5 g soil was taken using an electronic balance into a digestion flask and 3 mL of digestion mixture added to the samples and digested for exactly two hours at 380 °C in a fume chamber. After the digestion, the samples were brought from the digestion block, allowed to cool down for 15 minutes and then diluted with 50 ml distilled water.

After everything was set up, for approximately 20 minutes, steam was circulated through the steam distillation equipment. Approximately 20 mL of the digested soil sample was taken using a pipette and then transferred into the reaction chamber for the distillation. The mixture was then topped with 10 mL of alkali (NaOH). The mixture was then distilled for about 10 minutes into 150 mL flat bottom flask that contained 5mL indicator of boric acid positioned beneath the condenser of the apparatus collecting 50mL of the distillate. Against M/140 HCl, the distillate was then titrated. The end point was reached when the colour changed fom green to wine red. Similar experiment was repeated using blank solution instead of soil solution

Calculation:

$$\% \text{ N } = \frac{(S-B)x \; solution \; volume \; x \; 100}{sample \; weight \; x \; aliqout \; volume} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad equation \; 3$$

Where S = Sample titre value

B= Blank titre value

Soil Available Phosphorus (P) Determination

Available phosphorus was analyzed using the Bray 1 method (Maghanga et al. 2015). 10mL Bray 1 extraction solution (15 mL, 1 M (NH_4F) + 25 mL 0.5 M HCl) was added to a 1 g sample of soil already measured into a 40 mL centrifuge tube. Approximately 2 mL aliquot of the filtrate was transferred using pipette to 25 mL conical flask. Exactly 4mL of the B reagent, a colour forming reagent was added and allowed to stand for 25 minutes for colour development.

The concentrations (absorbance) of the samples were taken using a spectrophotometer at a 882 nanometers wavelength. Standard solutions of different concentrations: 0, 0.2, 0.4, 0.6, 0.8, and 1.00 ug P mL^{-1} of P were prepared from 5 ug/ P mL standard P stock solution in a 25 mL volumetric flask. A graph of concentrations against the absorbance of the standard solutions were ploted using excel following the determination of the soil samples actual concentrations from the plotted graph.The final concentrations of the soil phosphorus in each sample were calculated using the formula below:

Calculation:

$$\text{µg P/g soil } = C \; x \; \text{DF} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation (4)}$$

Where

C is concentration obtained from the graph (mol/cm^{-3})

DF is dilution factor

Determination of Exchangeable Potassium

The Ammonium acetate extraction (Zhang et al., 2012) method was used. The flame photometer was used to read the concentrations of the various soil samples for potassium and sodium. A set of working standards 0.0, 2.0, 4.0, 6.0, 8.0, and 10 ug mL^{-1} were prepared and the reading were taken for both the standards and samples using the flame photometer. Excel sheet was used to plot a graph of concentration against absorbance and the final concentration was determined using the formular below ;

Calculations

$$\mu gK/g \quad = \frac{C \times V}{w} \text{ .... Equation (5)}$$

Where c is concentration (mol/cm^{-3})

V is solution volume (cm^{-3})

W is the sample weight (gsoil^{-1})

Plant Biomass Analyses

The prepared plant parts samples (edible parts- head, tuber and seed,) were taken through proximate and mineral analyses. Proximate analyses included moisture, ash, Oil/ Fat, protein, crude fibre and carbohydrate**.** Mineral elements determined include total nitrogen, exchangeable bases (potassium, sodium, calcium and magnesium) and phosphorus,

Determination of Mineral Elements Concentrations in the Edible Biomas

Preparing Sample Solutions for N, K, Na, Ca, Mg, and P Determination

Preparing solutions for samples for analysis of elements includes a prosess of oxidation. This process which is required for the removal of any organic matter prior to the performance of full elemental analyses.

Digestion of Sulphuric Acid-Hydrogen Peroxide

Stewarte et al (1974) method was used for the digestion process. Digestion mixture for the sample made up of : 350 ml H_2O_2 (Hydrogen Peroxide), 0.420 g powdered selenium, 14.0 gram Li_2SO_4 (Lithium Sulphate), and 420.0 ml H_2SO_4 (Sulphuric Acid). Exactly 1 g of dried milled sample was taken using an electronic mass balance and poured into a 100 mL Kjeldahl glass tubes. In a similar manner the blank digestions were done. When digestion was done a 100 mL volumetric flasks was used to collect the digests before making it up to volume.

Colorimetric Determination of P using the Ascorbic Acid Method

The procedure requires the preparation of colour forming reagent and P standard solutions (Rowell, 1994). The colour forming reagent is made up of reagents A and B. Reagent A is made up of 12 g ammonium molybdate in 20ml distilled water 0.2908g of potassium antimony tartarate in 100mL distilled water and 1L of 2.5M H_2SO_4. The three solutions were mixed together in a 2 L volumetric flask and made up to volume with distilled water.

Reagent B was prepared by dissolving 1.56g of ascorbic acid to every 200mL of reagent A. A stock solution of $100\mu gP/mL$ solution was prepared from which $5\mu gP/mL$ solution a set of working standards of P with concentrations 0, 0.1, 0.2, 0.4, 0.6, 0.8 and $1.0\mu gP/mL$ in 25mL volumetric flasks. 2mL aliquot of the digested samples were pipette into 25mL volumetric flasks. 2mL aliquot of the blank digest were pipette into each of the working standards to give the samples and the standards the same background solution.

Ten mililitre (10ml) of distilled water was added to the standards as well as the samples after which 4 mL of reagent B was added and their volumes made up to 25 mL with distilled water and mixed thoroughly. The flasks were allowed to stand for 15 minutes for colour development after which the absorbances of the standards and samples were determined using a spectrophotometer at a wavelength of 882.nm. A calibration curve was plotted using their concentrations and absorbances. The concentrations of the sample solutions were extrapolated from the standard curve.

Calculation

If C = μgP/mL obtained from the graph,

then μgP/g (sample) = $\frac{\text{C x Dilution Factor}}{\text{weight of sample}}$ .... Equation (6)

Determination of Potassium and Sodium

This followed the mixed acid digestion method by Stewarte et al. (1974).

Potassium and sodium in the digested samples were determined using a flame photometer. In the determination the following working standards of both K and Na were prepared: 0, 2,4,6,8 and 10 μg/mL. The working standards as well as the sample solutions were aspirated individually into the flame photometer and their emissions (readings) recorded. A calibration curve was plotted using the concentrations and emissions of the working standards. The concentrations of the sample solutions were extrapolated from the standard curve using their emissions.

Calculation

μgK/g $= \frac{\text{C x solution volume}}{\text{Sample weight}}$ ....Equation (7)

Where C is concentration (moldm^{-3})

Determining Calcium and Magnesium using EDTA Titration

This followed the Spectrophotometric method describe by Page et al, (1992). The cations are chelated with ethylene diaminetetra-acetic acid (EDTA) in this process. The process included determining calcium and magnesium together, as well as determining calcium alone and magnesium detrmined by difference

With de-ionised water a 10 mL aliquot of the sample solution was diluted to 150 mL in a 250 mL conical flask. Approximately 15 mL buffer solution, 1 mL of potassium cyanide, 1 mL hydroxylamine hydrochloride, 1 mL of potassium ferro-cyanide as well as 1 mL triethanolamine (TEA) were also added. Five drops of EBT were and titrated against 0.005 M EDTA (Ethylene Diaminetetra-Acetic Acid). Calcium was detremined in a similar manner but after five drops of calcon indicator were added instead of EBT.

Calculations

% Mg + Ca $= \frac{\text{M.EDTA x 24.31 x T}}{\text{w}}$ ....Equation (8)

% Ca $= \frac{\text{M.EDTA x 40.08 x T}}{\text{w}}$ ....Equation (9)

Where

M. EDTA= 0.005 M ethylene diaminetetra-acetic acid

T = titre value

W= sample weight (g)

Nutritional Analyses

Determining the Dry Matter

This followed the procedure described by AOAC (2008). After washing with de-ionised water, Porclain Crucibles were cleaned, oven-dried, and weighed. 10 g fresh samples were weighed into crucibles. To achieve uniform heat distribution, Crucibles with its content were scattered in the oven. For approximately 48 hours they were kept in the 105 °C thermostatically controlled oven. Using a desiccator, the samples were cooled and weighed after removing them from the oven 48 hours later. Each sample was repeated three times. The moisture content was then calculated as the percentage water loss by the sample.

Determination of Ash

After being gently heated in an oven at 105 °C for around 60 minutes, the dried samples were moved to a 550°C temperature furnace for 24 hours (overnight) (AOAC 2008). The samples were kept in this temperature till all the particle of carbon were burned out. The dish containing the ash was taken from the furnace, cooled by dessicator before weighing. The ash contents was therefore determined as being a percent of the original sample.

Oil/ Fat Determination

This followed the procedure described by AOAC (2008). A milled sample weighing about 10-12g was placed in 50 x 10mm Soxhlet extraction thimble before transferring it into a soxhlet extractor with a capacity of fifty millilitre. A clean, 250 mL dry conical flask was weighed on an electronic balance and a 150 mL petroleum spirit was transferred into the flask before connecting it to the soxhlet extractor for extraction. Using heating mantle as a source of heat the extraction was carried out in 6 hours. After the 6 hour extraction, the flask was disconnected and placed in a an oven for 2 hours at 60°C. After cooling in a desiccator, the conical flask was removed then weighed. Content of fat and oil were calculated as follows:

Calculation

Percent (%) Crude Fat/Oil = $\frac{w \times 100}{g}$ ....Equation (10)

Where w is weight of oil (g) and

g isweight of sample (g)

Protein Determination

This was done using the modified version of Rowell (1994) Micro-Kjeldahl method. The amount of protein in the plant sample was computed using the content of nitrogen in the food. Employing the kjeldahl method as described in page 70, the protein content was established. The protein dertmination is presented below :

%N = $\frac{\text{(Sample titre value – Blank titre value) X 0.1 x0.01401 x 100}}{sample\ weight\ X\ 10}$..................Equation (11)

% Protein = %N x 6.25

Crude Fibre Determination

Exactly 1 g sample was weighed into a boiling flask and 100 mL 1.250 percent solution of H_2SO_4 added before boiling for 35 minutes (AOAC, 2008). The boiled sample filtered in a numbered sintered glass crucible. The residue was placed back into the boiling flask with the addition of 100 mL of 1.2 percent NaOH solution before boiling for 30 mins. The boiled solution was again filtered before washing the residue using boiling water and methanol. After being oven dried overnight at 105°C, the crucible was weighed. For about 4 hours, the crucible was put in a 500 ^{o}C temperature furnace. It was slowly allowed to equilibrate with room temperature using a desiccator before being re-weighed.

Calculation

Percent (%) CF = $\frac{w}{s} \times 100$ ....Equation (12)

Where w is weight (g)

s is sample weight (g)

Carbohydrate Determination

The AOAC (2008) method was used in determining the carcohydrates. Approximately 50 mg grounded sample weighed into 50 mL round bottom flask in addition to 30 mL de-ionised water. To slowly simmer on a heated plate for two hours, a bubbled glass was inserted on the neckline. Periodically, the mixture was increased upto 30 ml and slightly left to cool. Right before the development of color the extract was prepared. A blank was made using the same procedure. In boiling tubes, 2 mL of each standard solution, as well as extract and water blank, were pipetted. The identical treatment was applied to both the standards and the samples.

The standards were used to make a calibration graph, which was then used to compute how much glucose did the sample aliquot contain. The measurement or determination for the blank was carried out in the similar manner, with the necessary subtraction.

Soluble carbohydrates (%) = $\frac{\mathrm{C} \times \mathrm{v}}{10 \times \mathrm{al} \times \mathrm{s}\ (\mathrm{g})}$ .... Equation (13)

Where C is concentration carbohydrate from the graph (mol/mL)

V is extract volume (mL)

Al is aliquot (mL)

S is sample weight (g)

Determination of Yield and some Agronomic Indices

Total Yield per Hectare

The total seed yield of maize and cowpea, head yield of cabbage and tuber yield of sweet potato was calculated as follows

$$Y/ha = \frac{Ws\ x\ pp\ x\ 10{,}000}{sps} \text{ ………………….. …………………..Equation (14)}$$

Where Ws is seed, head or tuber weight per stand/plant (kg)

Pp is planting pollution per sub plot

Sps is sub plot size (m^2)

Harvest index

The harvest index was determined by the procedure by Sharma and Smith (1987) using the formular below;

$$HI= \frac{grain\ yield}{above\ ground\ biomas} x\ 100 \text{ ....Equation (15)}$$

This can be interpreted as

$$HI= \frac{economic\ yield}{above\ ground\ biological\ yield}\ x\ 100 \text{ .... Equation (16)}$$

N_2 Fixation

The N_2 fixation was calculated using the N-difference approach. The total nitrogen content of cowpea and non-leguminous crop (maize) was measured using the micro Kjeldahl method. The N_2 fixed was calculated by the difference method (Azam and Farook 2003) as follows:

$$\text{N Fixed} = \text{total N (fixing crop)}$$
$$- \text{total N (non} - \text{fixing crop)}..Equation\ (17)$$

$$\text{N Fixed} = \text{total N (cowpea)} -$$
$$\text{total N (maize)} \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots \ldots . \ldots . Equation\ (18)$$

Nutrient Uptake

Nutrient uptake was calculated to evaluate the amount of nutrient (N, P and K) utilized by the plant in kilograms per hectare.

$$\text{Nutrient uptake} = \frac{\textit{dry weight of plant x nutrient absorbed by plant}}{100}\ \textit{equation}\ (19)$$

Nutrient use Efficiency

As proposed by Dobermann (2005), NUE is defined as

$$\text{NUE} = \frac{\text{crop yield F (kg/ha)}}{\text{amount of fertilizer applied (kg/ha)}}\ \text{............ ....Equation (20)}$$

Recovery Efficiency

As proposed by Dobermann 2005 (RE) is defined as

$$\text{RE} = \frac{\textit{nutrient uptake } (F)(kgha) - \textit{nutrient uptake } C\ (kgha)}{\textit{amount of fertilizer applied } (kgha)}\ \text{.......Equation (21)}$$

Where: F is plant receiving fertilizer *and*

C is plant without fertilizer

Physiological Efficiency

As proposed by Dobermann (2005) PE is defined as

$$\text{PE} = \frac{\textit{Yield } F(kg) - \textit{Yield } C\ (kg)}{\textit{Nutrient uptake } F(kg) - \textit{Nutrient uptake } C\ (kg)}\ \text{...................Equation (22)}$$

Agronomic Efficiency(AE)

AE was determined by using the formula proposed by Dobermann (2005) and is stated below as;

$$\text{AE} = \frac{\textit{Yield } F(kg) - \textit{Yield } C\ (kg)}{\textit{Quantity of nutrients applied } (kg)}\ \text{...................................... Equation (23)}$$

Analysis of Data

Using the Genstat statistical program (One-way ANOVA), the data was analyzed with the results expressed as mean and standard deviation. Fisher's unprotected LSD test was used to compare mean values of soil chemical characteristics, crop production, and nutritional composition of field trials, with

P-values less than 0.05 ($P < 0.05$) regarded statistically significant. The association between soil characteristics and crop yield was determined using Pearson correlation.

CHAPTER FOUR

RESULTS

Some Chemical Properties of the Soil and Thallo used

The pH of the soils at the study sites were slightly acidic. The total N concentration for UCC and Jukwa were 0.09% and 0.02% respectively. Total organic carbon was 0.63% for the UCC soil whilst Jukwa recorded 0.59%. The phosphorus concentrations were 0.22 ug g^{-1} for Jukwa and 0.19 ug g^{-1} for UCC. The UCC soil recorded potassium concentration (0.7 $cmolc^{-1}$ kg) higher than Jukwa soil (0.53 $cmolc^{-1}$ kg) (Table 2)

The thallo has high total N and P. It contains some levels of K, Ca and Mg. other elements such as Zn, Mo, S, and Cu are also available in it (Table 1).

Soil Chemical Properties, Growth and Yield Responses Following the Application of Recycled Abattoir Waste Thallo and Inorganic NPK Fertilizer on Maize

NPK and Recycled Thallo Fertilizer Effect on Soil Chemical Properties

Table 5 shows the chemical characteristics of the soil after Thallo and conventional NPK fertilizers were applied in two different agro zones. Soil pH significantly ($P<0.05$) increased in experimental plots amended with Thallo for both agro ecological zones. Application of the NPK fertilizer decreased soil pH though the difference was insignificant. More than the control treatment, the amended Thallo and NPK soils significantly increased percent N of soils in both zones. At UCC the percent increase was 102 and 175 for Thallo and NPK respectively whilst at Jukwa the increase was 113%, and 138% for Thallo and NPK respectively.

Similarly, the application of Thallo and NPK positvely increased SOC than the control treatment in Jukwa. At UCC, only Thallo amended plots recorded significant SOC increase relative to the control and NPK treated plots.

Table 5: Soil Chemical Properties After Maize Harvesting at Two Agro ecological Zones

Location	Treatment	pH	Total Nitrogen	Organic carbon	Available Phosphorus	Exchangeable potassium
Jukwa	Control	6.22a	0.069a	0.51a	0.12a	0.22a
	NPK	6.30a	0.14b	1.09b	132.90b	0.31b
	Thallo	6.52b	0.19c	1.94d	170.80c	0.48c
UCC	Control	6.30a	0.08a	0.58a	0.20a	0.25ab
	NPK	6.29a	0.17b	0.71a	125.20b	0.30b
	Thallo	6.53b	0.19c	1.54c	156.00c	0.45c
P-Value		<0.05	<0.05	<0.05	<0.05	<0.05
LSD		0.13	0.003	0.03	4.53	0.05

Means attached with the same alphabets are statistically similar according to Fisher's unprotected LSD test at $P \leq 0.0$ 5.

The P content in NPK and Thallo treated soils were all higher than the control soil in both agro zones in an increasing order: Control<NPK<Thallo. The level of exchangeable K reduced across the experimental site compared to the pre planting soil. However, Thallo treated soil recorded significantly higher exchangeable K values compared with the control and NPK plots in both ecological zones. The trend of increase followed control < NPK < Thallo in Jukwa and control = NPK < Thallo for UCC experimental soils.

In general, the order of increase for SOC, N, P and K followed control<NPK<Thallo for Jukwa whilst UCC showed a trend of increase for N and P in the order; Control<NPK<Thallo, and pH, SOC and K followed Control=NPK<Thallo.

Across the two agro zones, all the treatments were similar in pH, N, P and K. With respect to SOC, control and NPK in both sites was similar. However, NPK at Jukwa increased the SOC significantly than its counterpart at UCC. Thallo at Jukwa also recorded higher SOC value (1.942%) significantly different from its counterpart (1.54%) and NPK (0.71%) at UCC.

Effect of Thallo and NPK on the Agronomic Indices of Maize

The changes in height, chlorophyll content, leaf area, tasselling and fruiting of maize to the application of Thallo and inorganic NPK fertilizer are shown in Figures 1, 2, 3, 4 and 5 respectively.

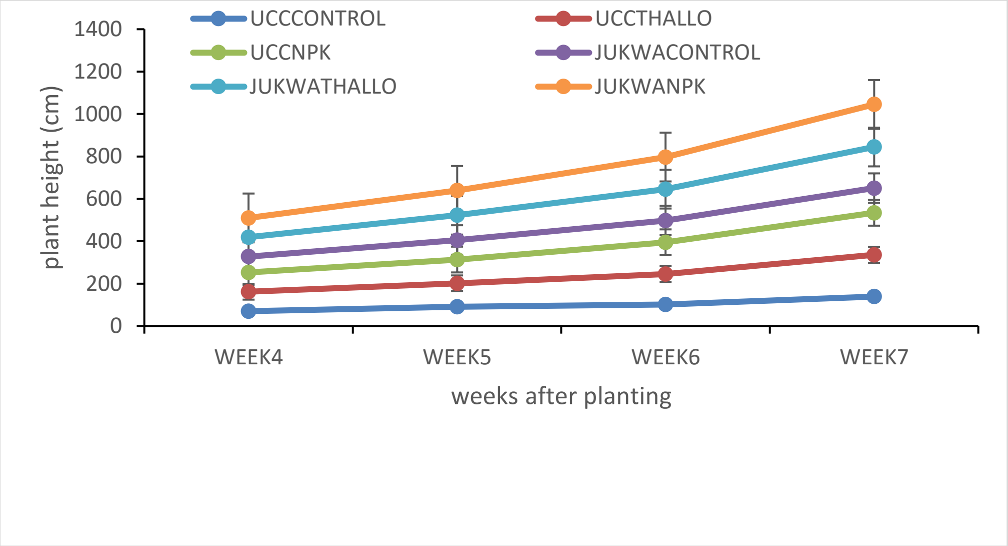

Figure 1: Effects of NPK and Thallo on maize plant height from 4th to 7th week

Figure 1 shows the height of maize plant from week 4 to week 7 after planting as influenced by NPK and Thallo. The application of Thallo at UCC recorded plant height similar to NPK at week 4. The two were significantly different from the control. Similar trend was recorded at Jukwa. Across the two agro zones, Thallo at UCC had the highest mean plant height. At week 5, Thallo and NPK application resulted in the significant increase of plant height over the control but the two were statistically similar for both ecological zones. NPK treated soil at UCC recorded the highest plant height during week 6 that was significantly different from both Thallo and control. The trend of increase followed control<Thallo<NPK. However at Jukwa, both NPK and Thallo recorded similar plant heights that were significantly higher than the control. Comparing the two experimental sites, NPK recorded similar plant height that was significantly higher than all the other treatments.

During week, NPK and Thallo addition to the experimental plots at UCC increased the plant height relative to the control. NPK however, recorded the highest plant height at UCC but it was similar to that of Thallo. Across both zones, NPK at Jukwa recorded the highest mean plant height.

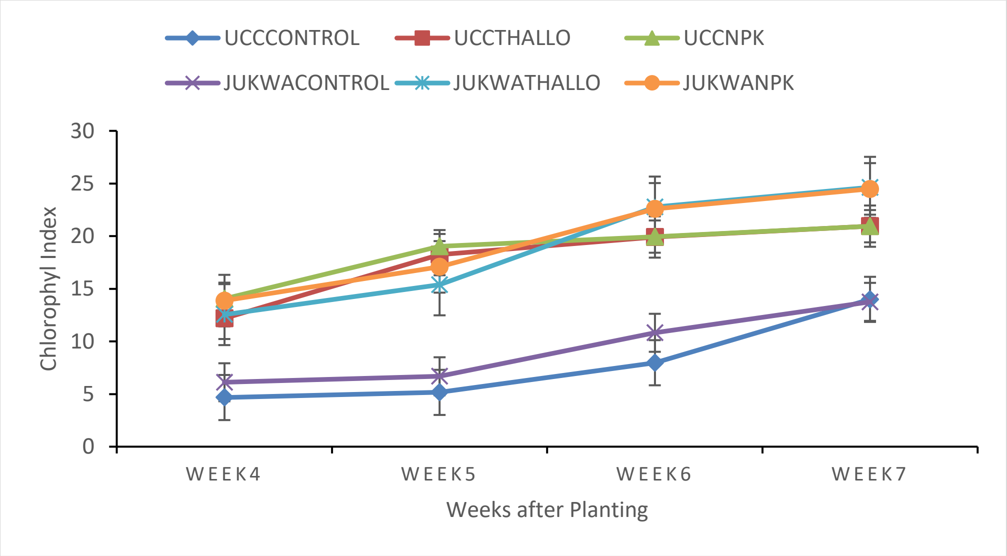

Figure 2: Effect of NPK and thallo on chlorophyll index from 4th week to 7th week after planting

The impact of NPK and Thallo on the chlorophyll index of maize from week to week 7 after sowing is displayed in Figure 2. NPK at UCC during week 4, 5 and week 6 recorded significantly higher chlorophyll content relative to control and Thallo. The trend of increase followed control<Thallo<NPK. Thallo

recorded significantly higher content than control. At week 7, NPK and Thallo did not show any significant difference between them but they were significantly different from control observed at Jukwa. Across the zones, NPK at UCC recorded the highest mean chlorophyll content. Also during week 6, all treatments at Jukwa recorded content level significantly higher than similar treatments at UCC.

During the 7th week, NPK and Thallo at UCC recorded significantly higher chlorophyll content compared to control but both were statistically the same. Similar trend was recorded at Jukwa. However, control, NPK and Thallo at Jukwa recorded higher chlorophyll content than similar treatments at UCC.

Figure 3 represents the effects of NPK and Thallo on maize leaf area from 4th week to 7th week after planting.

For both sites, and at week 4, the control recorded a significantly reduced leaf area relative to NPK and Thallo in a order of NPK=Thallo>control. When comparing the two agro zones, there was no significant difference between the respective treatments. However, the application of Thallo at both sites recorded highest mean leaf area.

At week 5, control was significantly lower relative to NPK and Thallo with a trend of control<NPK<Thallo at UCC.

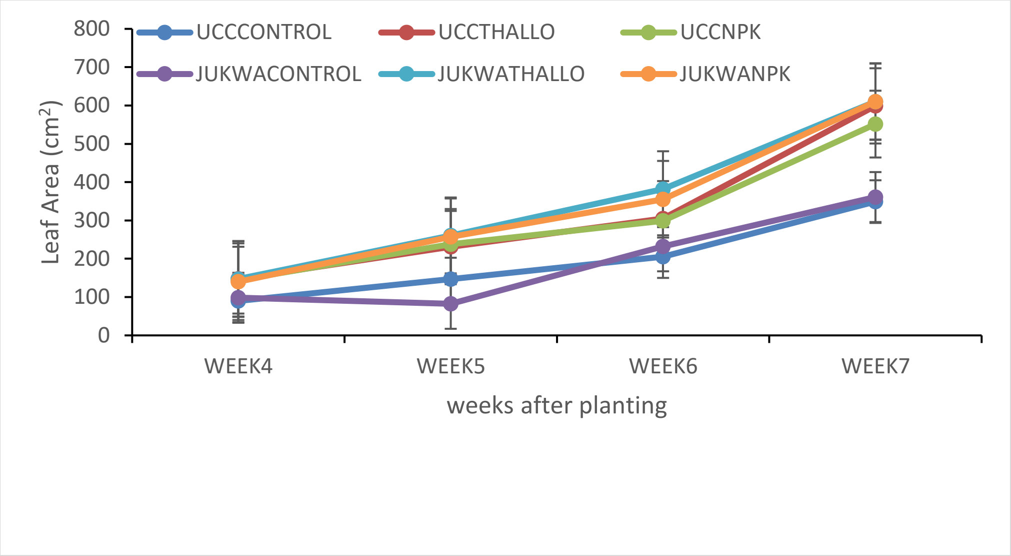

Figure 3: Effect of NPK and Thallo on leaf area of maize from week 4 to week 7.

The leaf area values measured at week 6 were not significantly different between NPK and Thallo at UCC. However, Thallo and NPK application caused a significant increase in leaf area compared with the control. At Jukwa, thallo increased the leaf area relative to the control and NPK. The trend of increase followed Control<NPK<Thallo. Contrasting the two experimental sites, all treatments at Jukwa recorded significant high leaf area than their counterparts at UCC with Thallo at Jukwa recording the highest significant value

At the 7th week, leaf area values showed significant differences among the treatments at UCC, in increasing order control of Control<NPK<Thallo. In the same week there was no any significant difference between NPK and Thallo at Jukwa. However, the two were significantly different from the control. Comparing the two sites, NPK and Thallo at Jukwa recorded the highest significant leaf area than their counterparts at UCC.

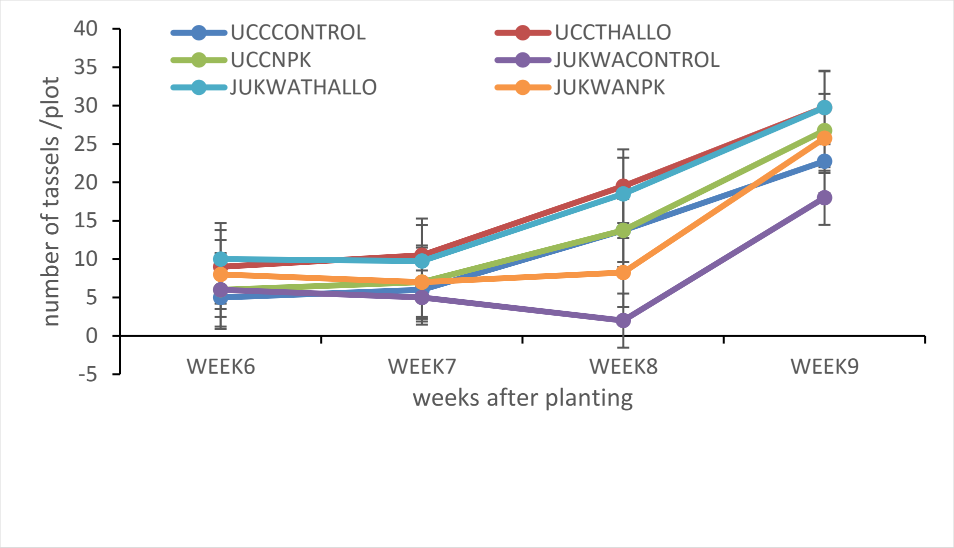

Figure 4: NPK and Thallo effect on the number of tassells of maize from 6th to 9th weeks after planting

The application of Thallo consistently (week 6, 7, 8 and 9) and significantly increased the avearge number of tassels relative to the control and the NPK for both zones (Figure 4). Also, the control had lower number of tasselling compared to the NPK. The trend of reduction followed Thallo>NPK>control. Across, the two agro zones, Thallo at Jukwa recorded the highest mean number of tasselling.

Similarly at weeks 6, 7, 8 and 9, the control treatment although recorded lower values of percent tassels greater than with those of inorganic NPK treatments, the difference was not statistically different at UCC. In Jukwa, the increase in tasselling followed the order control<NPK<Thallo for all sampling periods. Thus, the control plot recorded significantly lower value compared to NPK in week 6-9. Comparing the tasselling response across the two agro zones, thallo recorded the highest tasselling rate and values obtained for same were similar.

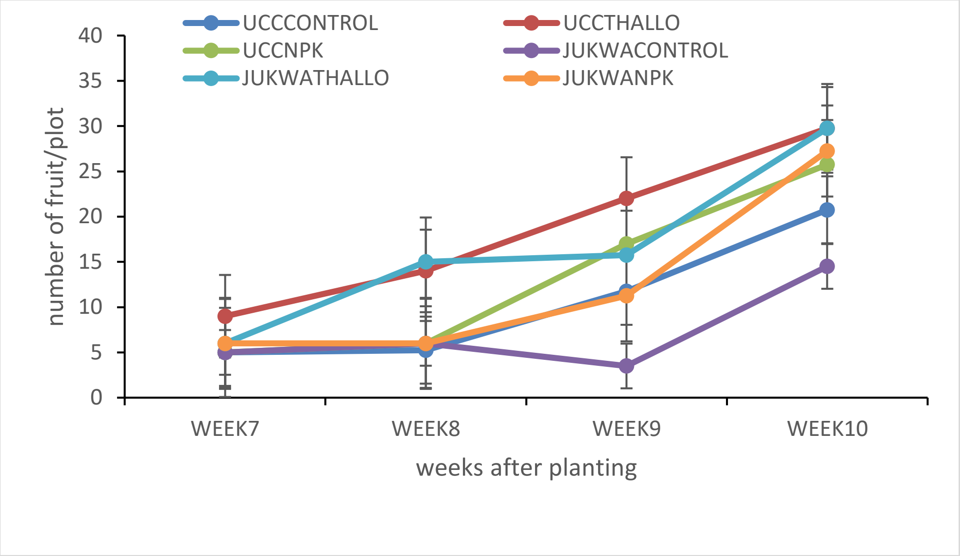

Figure 5: Effect of NPK and Thallo on the rate of fruiting 7th to 10th weeks after planting.

At week 7, 8, 9 and 10, Thallo increased fruiting significantly compared to the control and NPK at UCC. Additionally, values obtained for the control and NPK were similar. In contrast, during week 7, 8, 9 and 10 Thallo recorded the highest fruit count but statistically similar to NPK at Jukwa. Generally, the application of Thallo at UCC recorded the highest fruiting among the treatments. By the week 10, the addition of Thallo significantly increased the number of fruits relative to control and NPK. The trend of increase was in the order of control < NPK < Thallo at both agro zones.

Effect of Thallo and NPK on Maize Grain Yield Indices

The effects of Thallo and NPK on ear length (cm), ear circumference (cm), ear weight (g) of maize are displayed in Table 6. For both locations, Thallo showed highest value in terms of ear length. At Jukwa, there was significant increase by 29 % and 31 % upon crop exposure to NPK and Thallo amendments respectively relative to the control. However, Thallo and NPK were statistically the same. At UCC, the application of Thallo significantly increased ear length by 11 % and 13 % relative to the control and NPK respectively. There was no significant different between control and NPK. Across both experimental sites, NPK and Thallo at Jukwa were statistically similar to NPK and Thallo at UCC. However, thallo at UCC recorded the highest mean value for ear length (19.19cm).

Table 6: Effect of NPK and Recycled Thallo fertilizer on the mean ear length, ear weight and ear circumference of maize in two agro zones

Location	Treatment	Ear length (cm)	Ear circumference (cm)	Ear weight (g)
Jukwa	Control	13.45a	14.14a	106.0a
	NPK	17.39bc	16.84bc	209.1c
	Thallo	17.57bc	17.25c	214.2c
UCC	Control	17.28b	15.30ab	182.2b
	NPK	16.95b	15.88bc	192.1b
	Thallo	19.19c	16.61bc	223.5d
	p-value	<0.05	<0.05	<0.05
	LSD	1.203	1.05	29.08

Means attached with the same alphabets are statistically similar according to Fisher's unprotected LSD test at $P \leq 0.0 5$.

At Jukwa, NPK and Thallo increased significantly (p<0.05) the ear circumference of maize by 20% and 23% respectively elative to control. The increase ears for Thallo and NPK were not different statistically. At UCC, the ear circumference for control, NPK and Thallo were statistcally similar, though thallo recorded more than 9% and 5% increase in ear circumference than the control and the NPK. Across the two zones, the control, NPK and Thallo at

Jukwa were statistically similar to the control, NPK and Thallo at UCC respectively.

At Jukwa, the NPK and Thallo increased the ear weight significantly compared to the control with a percent increase of 97 and 102 respectively. However, thecear weight for the NPK and Thallo were statistically similar. At UCC, the Thallo increased the ear weight significantly (p<0.05) more than the control and NPK over 22% and 16% respectively. The control and NPK were statistically similar with values of 182.2 g and 192.1 g respectively. Comparing the two sites, Thallo treatment at UCC recorded higher mean ear weight value (223.5 g) than control and NPK treatments. The ear weight for the NPK and Thallo at Jukwa were statistically different from the weight for the NPK and Thallo at UCC respectively. However, control at UCC recorded significant higher value than its counterpart at Jukwa

Effect of Thallo and NPK on Grain Yield of Maize

The 1000 seed weight and grain yield of maize in response to NPK and Thallo are shown in Table 7. Comparing to NPK and Thallo, the control had lower grain yield at Jukwa. The lower yield was about 118% and 123% relative to Thallo and NPK respectively. The grain yield for Thallo and NPK were similar statistically. At UCC, the Thallo recorded higher grain yield than the control treatement and NPK by 129% and 18% respectively.

NPK significantly increased the grain yield by 93% over the control. Across the two zones NPK and Thallo at Jukwa recorded significantly higher yield than NPK treatment at UCC. However, thallo at UCC recorded the highest grain yield significantly different from all other treatment.

Relative to control and NPK, Thallo significantly ($p<0.05$) increased the 1000 seed weight of the maize at Jukwa. NPK also recorded higher 1000 seed weight significantly ($p<0.05$) over the control.

Table 7: Impact of NPK and Recycled Thallo fertilizer on 1000 seed weight and seed yield of maize in two agro zones

Location	Treatment	1000 Seed Weight (g)	Grain yield (t ha^{-1})
Jukwa	control	258.0a	2.07a
	NPK	286.5b	4.51c
	Thallo	324.0cd	4.62c
UCC	control	300.0c	2.13a
	NPK	301.5c	4.13b
	Thallo	343.5d	4.88d
	p-value	< 0.05	<0.05
	LSD	16.75	0.46

Means attached with the same alphabets are statistically similar according to Fisher’s unprotected LSD test at $P \leq 0.0\ 5$.

The Thallo increased the 1000 seed weight by 26% and 13% over control and NPK respectively. NPK recorded about 11% increase more than the control. At UCC, the Thallo treated soil significantly ($p<0.05$) increased the 1000 seed weight with a percent increase of 15 % and 14% over control and NPK. Statistically, control and NPK were similar. Across the agro zones, control at UCC was significantly ($p<0.05$) higher in 1000 seed weight (300.0 g) than same at Jukwa. All treatments at UCC recorded higher values than their counterparts at Jukwa with Thallo at UCC recording the highest 1000 seed weight (343.5 g)

The level of pest and disease attack on maize following the application of NPK and Thallo is shown in Table 8.

At Jukwa, control recorded the highest pest infestation, followed by NPK with Thallo recording the least attack. The difference between control and NPK was insignificant but the two were significally higher than the Thallo. NPK and Thallo treated soils recorded lower incidence of disease attack on the plant.

Between the two the attack was statistically similar but significantly ($p<0.05$) lower from the control. The trend of decrease in the incidence of pest and mossaic followed Thallo < NPK ≤ control and Thallo ≤ NPK < control respectively.

At UCC, Thallo recorded significantly ($p<0.05$), the least level of pest infestation followed by NPK with control obtaining the significantly highest level of pest attack.

Thallo amended soil observed the least incidence of disease infestation when compared with control and NPK. Across, the two experimental sites, all the treatments at UCC recorded higher number of disease and pest attack than their counterparts at Jukwa.

The results of plant height at harvesting, above ground dry biomass and harvest index are represented in Table 9.

At Jukwa, Thallo recorded significantly higher plant height at harvesting by 24.5 % and 6% over control and NPK respectively. Similar significant differences were observed in plant height at UCC and followed the order; Control<NPK<Thallo. Comparing the two agro sites, Control, NPK and Thallo were similar to their respective similar treatments in both sites.

Table 8: Susceptibility of maize to pest and maize streak mossaic attack following the application of NPK and recycled Thallo fertilizer in two agro zones

Location	Treatment	Pest infested ears	Diseases infected plants
Jukwa	Control	5.25b	5.00b
	NPK	3.25b	1.50a
	Thallo	0.00a	0.00a
UCC	Control	11.50c	22.00c
	NPK	6.75b	17.50c
	Thallo	0.75a	0.25a
	p-value	<0.05	<0.05
	LSD	4.429	3.336

Means attached with the same alphabets are statistically similar according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

At Jukwa, the above ground dry matter ranged from 6677 kg ha^{-1} to 10018 kg ha^{-1} with the control recording the least and Thallo, the highest. NPK recorded statistically similar value for above ground dry matter. NPK and Thallo treatments were higher than the control. At UCC, control recorded the least value for above ground dry matter compared to NPK and Thallo. The difference observed between control and NPK was statistically similar. Thallo on the other hand significantly ($p < 0.05$) increased the above ground dry matter content compared to control and NPK. Across the the two agrozones, control at Jukwa recorded the least value with Thallo at UCC recording highest ($p < 0.05$) harvest index.

Regarding the harvest index, control recorded the least harvest index of 31.52% followed by Thallo (46.2%) and then NPK (48.06%) at Jukwa. The value obtained for both NPK and Thallo was statistically similar but the two showed significant ($p < 0.05$) difference from the control.

Table 9: Mean plant height, above ground biomass and harvest index of maize at harvesting following the application of NPK and Thallo in two agro ecological zones

Location	Treatment	Plant height (cm)	Above ground drymatter (kg ha^{-1})	Harvest index (%)
Jukwa	Control	192.40a	6677a	31.52a
	NPK	223.40b	9395b	48.06b
	Thallo	237.60c	10018b	46.20b
UCC	Control	192.40a	9095b	35.71a
	NPK	225.60b	9015b	45.87b
	Thallo	236.20c	10374c	47.11b
	p-value	< 0.05	< 0. 05	< 0. 05
	LSD	4.05	1149.50	4.67

Means attached with the same alphabets are statistically similar according to Fisher’s unprotected LSD test at $P \leq 0.0\ 5$.

However, both control and Thallo had similar harvest index ($p > 0.05$). At UCC, Thallo recorded higher ($p < 0.05$) harvest index relative to NPK. Across the two sites, control and Thallo at Jukwa were statistically similar to their counterparts at UCC. However, NPK at Jukwa recorded the highest mean value (48.06 %) for harvest index.

Effect of Thallo and NPK on the Proximate Quality of Maize

The proximate component in the maize grain is presented in the Table 10 There was no significant difference recorded in the dry matter, moisture content and fiber content, ash content and protein contents among the treatments at both agro experimental sites. Comparing the two sites, control recorded the highest dry matter and lowest moisture content. Thallo at UCC recorded the highest fibre content with NPK at UCC recording the highest ash content. Regarding carbohydrate content of maize seed ($p > 0.05$), similar values were obtained for the three treatments at Jukwa. The NPK significantly ($p < 0.05$) increased the carbohydrates content at UCC and followed; NPK>Thallo >Control. Across the two zones, all the treatments at Jukwa recorded significant ($p < 0.05$) greater carbohydrates levels relative to similar treatments at UCC.

The protein content among the treatments at Jukwa was similar. At UCC, NPK recorded the highest protein content and followed the order; Control=Thallo<NPK. Comparing the different agro zones, all treatments at Jukwa were significantly lower in protein level relative to their respective similar treatments at UCC.

Effect of NPK and Thallo on The Mineral Concentrations in the Maize Grain

Table 11 shows the mineral concentration of the maize grain. Thallo recorded significantly lower concentration of phosphorus than the control and NPK at Jukwa with NPK recording significantly higher P value relative to the control. The trend of decrease followed NPK>control>Thallo. At UCC control treatment recorded phosphorus concentration wich was higher than NPK but statistically similar. The two were significantly higher than Thallo.

Table 10: Effect of NPK and Thallo on proximate parameters in maize

		Seed Dry Matter (%)	Moisture (%)	Fiber (%)	Ash (%)	Carbohydrate (%)	Protein (%)	Lipids (%)
Location	Treatment							
Jukwa	Control	90.80a	9.19a	2.62a	1.13a	83.12c	8.23a	3.61a
	NPK	90.51a	9.49a	2.69a	1.45ab	84.43c	8.87a	3.87ab
	Thallo	90.36a	9.64a	2.67a	1.11a	84.43c	8.18a	3.62a
UCC	Control	90.82a	9.18a	2.63a	1.38ab	81.63b	10.63b	3.73ab
	NPK	90.47a	9.53a	2.79a	1.54b	79.50a	12.43c	3.72ab
	Thallo	90.27a	9.73a	2.89a	1.24ab	81.04b	10.82b	4.01b
	p-value	<.05	<.05	<.05	<.05	<.05	<0.05	< 0.05
	LSD	0.71	0.71	0.37	0.28	1.37	1.01	0.23

Means attached with the same alphabets are statistically similar according to Fisher’s unprotected LSD test at $P \leq 0.05$.

Table 11: Effect of NPK and Thallo on concentrations of mineral elements in maize

		Nitrogen	Phosphorus	Potassium	Calcium	Magnesium	Sodium	Zinc	Iron
		(%)	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ug g^{-1})	(ugg^{-1})	(ug g^{1})	(ug g^{1})
Location	Treatment								
Jukwa	Control	1.316a	3845b	1973a	48.28a	910a	156.3a	124.9c	14.35a
	NPK	1.419a	4336c	1912a	48.73a	803a	157.3a	112.5c	15.41a
	Thallo	1.308a	3380a	1831a	44.27a	883a	157.7a	128.6d	19.69b
UCC	Control	1.701b	4923d	1849a	61.88bc	1175b	156.3a	86.1a	21.05b
	NPK	1.990c	4894d	1913a	70.96c	1166b	178.7a	87.4a	23.17c
	Thallo	1.731b	4355c	1871a	59.31b	1124b	156.0a	91.2b	40.07d
	Pvalue	<0.05	<0.05	Ns	<0.05	<0.05	Ns	<0.05	<0.05
	LSD	0.16	516.40	187.40	6.98	84.70	25.78	17.86	2.82

Means attached with the same alphabets are statistically similar according to Fisher's unprotected LSD test at $P \leq 0.05$.

Grain N concentration of maize showed no statistical difference among the treatments at Jukwa. However at UCC, NPK treated soil recorded N concentration of 1.990% in the grain which is significantly different from the control and Thallo. Meanwhile Control and Thallo were statistically similar. In contrast, all treatments at UCC recorded significantly higher N than the similar treatments at Jukwa. Potassium concentrations in both sites were not significantly different from each other. However, control at Jukwa recorded higher mean value of potassium than all the other treatments.

At Jukwa, control, NPK and Thallo recorded Ca levels that were statistically similar, though, control and NPK obtained higher mean value than the Thallo. At UCC, NPK increased the Ca concentration relative to control and Thallo with the trend Thallo<Control<NPK. In contrast, all the treatments at UCC recorded higher concentration of calcium than their respective similar treatments at Jukwa.

At Jukwa Thallo recorded about 10% increase in the magnesium concentration of maize grain over the NPK but was lower relative to the control. However at UCC, control and NPK increased the Mg concentration by 5% and 4% relative to Thallo. Contrasting the two agro zones, all the treatments at UCC significantly increased the Mg concentration relative to similar treatments at Jukwa, the highest concentration recorded by Control at UCC.

There was no significant difference among the treatments in both agro ecological zones with respect to the concentration of sodium in the grains. However, NPK recorded slight elevation in sodium concentration over all other treatments.

The concentration of zinc in the maize grain was higher at Jukwa. Thallo increased Zn concentration than the control and NPK treatments by 37% and 28% respectively. Thallo recorded higher concentration of Zn at UCC with percentage increase of more than 15% over the two treatments. Comparing the two sites, all treatments at Jukwa recorded significantly higher values than their counterparts at UCC with Thallo at Jukwa recording the highest Fe value than all the other treatments. At Jukwa experimental site Thallo treated soil significantly ($p<0.05$) increased the concentration of iron in the maize grain relative to the control. Thallo increased iron concentration by over 37% and 29% over control and NPK. Control and NPK were statistically similar. At UCC, there was significant ($p<0.05$) elevation in the iron concentration relative to the control and NPK with percent increase of 90 % and 73% over the control and NPK. The control recorded least iron concentration relative to NPK. The trend of increase followed Control<NPK<Thallo. Across the two agro zones, all treatments at UCC recorded Fe values greater similar treatments at Jukwa. However, Thallo at UCC recorded significant Fe concentration ($p<0.05$) greater than the remaining treatments

Effect of Thallo and NPK on the Nutrient uptake and Nutrient use Efficiency of Maize

The N, P and K uptake and use efficiencies by maize are displayed in Table 12.

The application of inorganic NPK and Thallo at Jukwa significantly ($p<0.05$) elevated N uptake by 240% and 234% respectively over the control. However, NPK and Thallo were statistically similar though NPK recorded higher N uptake. Similarly, at UCC, the N uptake in response to NPK and Thallo were significantly higher relative to control with percent increases of 20 and 31 respectively. However, Thallo increased the N uptake relative to NPK but the increase was insignificant. In both agro zones the N uptake followed an increasing trend of; control < NPK =Thallo.

Table 12 NPK and Thallo on nutrient uptake and use efficiencies

		Nutrient Uptake			Nutrient Use Efficiency		
Location	Treatment	N	P	K	N	P	K
Jukwa	Control	85.90a	14.14a	12.92a			
	NPK	292.30b	89.29bc	39.40bc	45.13b	17.03b	22.79b
	Thallo	287.20b	74.18b	40.30bc	46.22b	17.44b	23.34b
UCC	Control	303.70b	88.69bc	33.26b			
	NPK	363.60c	89.81bc	35.00bc	41.33a	15.60a	20.88a
	Thallo	396.90c	99.88 c	42.94c	48.80c	18.42c	24.65c
	P-value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	LSD	39.01	14.14	5.94	1.91	0.72	0.97

Means attached with the same alphabets are statistically similar according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

The P uptake at Jukwa ranges between 14.14 to 74.10 with control recording the least P uptake. The application of inorganic NPK recorded higher P uptake but similar to Thallo. The trend of decrease followed NPK=Thallo >control. At UCC, Thallo significantly increased the P uptake by over 13% and 11% relative to both control and NPK. Across the zones, Thallo at UCC recorded the highest mean value of P uptake.

Thallo and NPK significantly ($p<0.05$) increased the K uptake by 204% and 212% respectively over the control at Jukwa. At UCC, Thallo significantly increased the K uptake by 29 % and 23% respectively over the control and NPK. Control and NPK showed similar values in terms of K uptake. Across the two zones, Thallo recorded the highest K uptake (42.9)

Both NPK and Thallo at Jukwa did not show any significant difference in the N and P use efficiency by the maize at Jukwa. The K use efficiency among the treatments was similar at Jukwa but differed at UCC.

At UCC, Thallo obtained the N use efficiency significantly higher by about 18% over NPK, P use efficiency by 18% over NPK. Comparing both agro sites, NPK and Thallo at Jukwa recorded significantly (0.05) higher P uptake than NPK at UCC with Thallo at UCC recording significant ($p<0.05$) P use efficiency relative to all the other treatments.

Across the two experimental zones, NPK and Thallo at Jukwa significantly increased ($p<0.05$) the N use efficiency by 8 % and 10% respectively relative to NPK at UCC. However, Thallo at UCC recorded significantly the highest N use efficiency relative to all other treatments.

There was no significance difference between NPK and Thallo with respect to P use efficiency at Jukwa. However at UCC thallo significantly increased the P use efficiency by 19% relative to NPK. Across the two agro zones, Thallo at UCC recoreded P use efficiency significantly higher.

Thallo significantly increased the K use efficiency by 17% over NPK at UCC but showed no difference statistically at Jukwa. Across the two agro zones, NPK at Jukwa significantly increased the K use efficiency relative to its counterpart at UCC with Thallo at both sites recording statistically similar K use efficiency.

Effect of Recycled Abattoir Waste (Thallo) and Inorganic NPK Fertilizer on Soil Fertility, Cabbage Growth, Yield and Nutritional Quality

NPK and Thallo on Soil Chemical Properties after Cabbage Harvesting

The chemical composition of the soils before planting and the Thallo fertilization are shown in Tables 3 and 4 respectively in Chapter Four.

The effect of NPK and Thallo on some soil chemical properties after cabbage harvesting are shown in Table 15. At Jukwa, Thallo treated soil increased the pH more than the control and NPK treated soil. Again, the application of Thallo elevated the total N by 150% and 650% than NPK and control respectively. The NPK recorded higher value significantly ($p<0.05$) different from control. The increase in the total N was in the order of control < NPK<Thallo.

With respect to soil organic carbon, the application of Thallo significantly elevated the soil organic carbon (SOC) by 77% and 121% over the NPK and control respectively at Jukwa. At UCC, The SOC was also increased by 60% by NPK compared to the control.

Table 13: Correlation matrix between yield and yield indicators of maize and soil chemical properties after harvesting at jukwa site

PARAMETERS	GY	EC	EL	EW	TSW	ADM	PH	pH	OC	N	Av P
EC	.942**										
EL	.914**	.851**									
EW	.967**	.963**	.917**								
TSW	.810**	.815**	.704*	.809**							
ADM	.913**	.848**	.779**	.847**	.848**						
PH	.951**	.904**	.915**	.933**	.891**	.888**					
pH	.673*	.598*	.681*	.639*	.796**	.631*	.822**				
OC	.804**	.808**	.746**	.783**	.929**	.788**	.928**	.883**			
N	.908**	.813**	.863**	.890**	.911**	.863**	.958**	.811**	.917**		
Av P	.926**	.902**	.859**	.898**	.917**	.872**	.986**	.844**	.968**	.999**	
Exch K	.783**	.789**	.665*	.750**	.935**	.804**	.874**	.870**	.964**	.930**	.933**

**significant correlation at the 0.05 level (2-tailed).

* significant correlation at the 0.05 level (2-tailed).

GY: Seed yield, EC: Ear circumference, EL: Ear Length, TSW: 1000 seed weight, ADM: Above ground dry matter, EW: Ear weight, PH: Plant height, OC: Organic carbon, N: Nitrogen, Av P: Available Phosphorus, Exch K: Exchangeable Potasium.

Table 14: Correlation matrix between NPK Uptake and their Use parameters

Parameters	NU	PU	KU	NUE	PUE	KUE	NPE	PPE	KPE	NAE	PAE	KAE	NRE	PRE
PU	.921**													
KU	.846**	.896**												
NUE	.654**	.575**	.759**											
PUE	.654**	.575**	.759**	1.000**										
KUE	.654**	.575**	.759**	1.000**	1.000**									
NPE	0.168	0.221	.445*	.472*	.472*	.472*								
PPE	0.219	0.231	.420*	.444*	.444*	.444*	-0.004							
KPE	0.391	0.205	0.317	.608**	.608**	.608**	0.334	-0.152						
NAE	0.14	0.195	.511*	.626**	.626**	.626**	.463*	.647**	0.354					
PAE	0.14	0.195	.511*	.626**	.626**	.626**	.463*	.647**	0.354	1.000**				
KAE	0.14	0.195	.511*	.626**	.626**	.626**	.463*	.647**	0.354	1.000**	1.000**			
NRE	0.34	0.323	.576**	.758**	.758**	.758**	0.329	.707**	.432*	.938**	.938**	.938**		
PRE	0.117	0.216	.451*	.559**	.559**	.559**	0.311	.654**	0.238	.953**	.953**	.953**	.923**	
KRE	0.186	0.243	.564**	.658**	.658**	.658**	.446*	.674**	0.296	.984**	.984**	.984**	.936**	.956**

** significant correlation at the 0.01 level (2-tailed).

* significant correlation at the 0.05 level (2-tailed).

NU: nitrogen Uptake, PU: Phosphorus Uptake, KU: Potasium Uptake, NUE: Nitrogen Use Efficiency, PUE: Phosphorus Use Efficiency, KUE: Potasium Use Efficiency, NPE: Nitrogen Physiological Efficiency, PPE: Phosphorus Physiological Efficiency, KPE: Potasium Physiological Efficiency, NAE: Nitrogen Agronomic Efficiency, PAE: Phosphorus Agronomic Efficiency, KAE: Potasium Agronomic Efficiency, NRE: Nitrogen Recovery Efficiency, PRE: Phosphorus Recovery Efficiency, KRE: Potasium Recovery Efficiency

The phosphorus value was increased significantly by Thallo than control and NPK treatments in an increasing order of Control<NPK<Thallo. Thallo recorded significantly ($P<0.5$) exchangeable K values greater than the control and NPK but control was similar to NPK. The Thallo recorded K value of 150% and 61% more than the control and NPK respectively.

The NPK significantly increased the total N relative to the control with over 100%. Similarly, the Thallo significantly ($p<0.05$) increased the SOC by 140% and 50% over the control and NPK respectively.

NPK treated soil recorded higher SOC by 60% over the control. The available phosphorus was increased by both Thallo and NPK with respect to control. Thallo recorded increased P value significantly ($p<0.05$) higher compared to the control and NPK. The percent increase was 118% and 32% relative to control and NPK respectively. NPK increased the P by 65% relative to the control. There was a significant ($P<0.5$) difference in the exchangeable K value among the treatment. Thallo recorded the highest K value significantly ($p<0.05$) different from both control and NPK with a percent increase of 51% and 92% respectively over the two. However, the NPK obtained mean K value which statistically similar to the control.

Across the two agro ecological zones, the control, NPK and Thallo recorded statistically similar pH and available P values. With regards to N and SOC, all the treatments at UCC recorded significantly higher values than their counterparts at Jukwa. With respect to SOC, control and NPK in both sites were similar.

Table 1: Effect of NPK and Thallo on chemical properties after harvesting

Location	Treatment	pH	Total Nitrogen (%)	Organic Carbon (%)	Available Phosphorus ug g^{-1}	Exchangeable Potassium Cmolc kg^{-1}
Jukwa	Control	6.27a	0.02a	0.56a	0.13a	0.20a
	NPK	6.26a	0.06b	0.70b	1.110b	0.31b
	Thallo	6.71b	0.15d	1.24d	1.500c	0.50c
UCC	Control	6.25a	0.05b	0.68b	0.210a	0.29b
	NPK	6.26a	0.10c	1.09c	1.092b	0.23b
	Thallo	6.65b	0.17e	1.63e	1.442c	0.44c
	p-value	<0.05	<0.05	<0.05	<0.05	<0.05
	LSD	0.113	0.04	0.07	0.396	0.12

Means attached with the same alphabets are statistically similar according to Fisher’s unprotected LSD test at $P \leq 0.0\ 5$.

With K, control at UCC was significantly higher than its counterpart at Jukwa. Thallo and NPK at both sites were similar with their respective counterparts

Effect of NPK and Thallo on Agronomic Indices of Cabbage

Figure 6 shows the height of cabbage plant from week 4 to week 7 as influenced by NPK and Thallo.

At week 4 (SP 1), control at UCC recorded the lowest plant height relative to NPK and Thallo.. Thallo was significantly different from both control and NPK, with NPK significantly increasing the height relative to control. The trend of increase followed control<NPK<Thallo. Similar trend was recorded at Jukwa. Across the two agro zones, Thallo at UCC had the highest mean plant height significantly higher than all other treatment except Thallo at Jukwa.

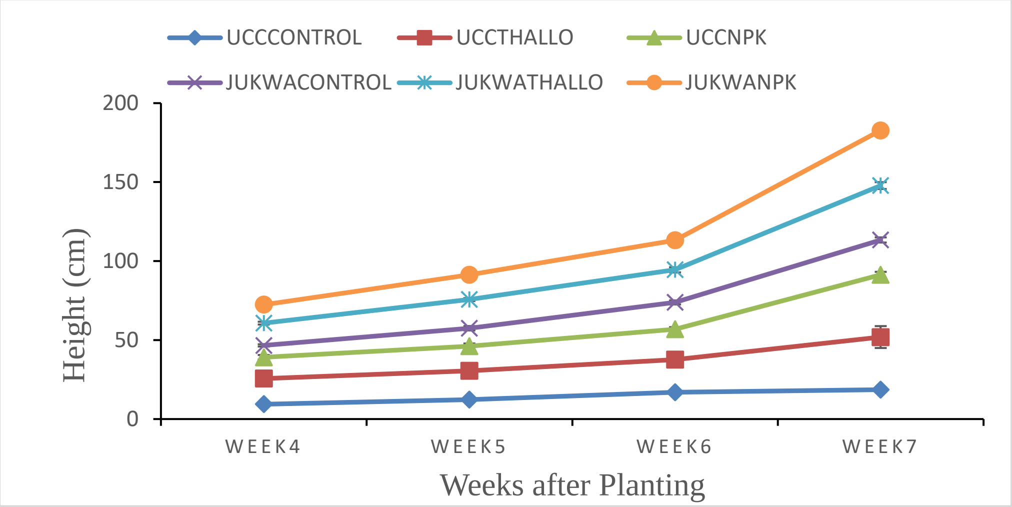

Figure 6: Effect of PK and Recycled Thallo fertilizer on cabbage height from 4th to 7th week after transplanting

At week 5, Thallo at UCC recorded the highest plant, followed by NPK and control. Thallo significantly increased the plant height relative to the control and NPK. NPK was significantly higher relative to control. Similar trend was followed at Jukwa. However across the different agro sites, all treatments at UCC were statistically similar to their respective treatments at Jukwa. However, Thallo at Jukwa and UCC recorded the highest mean plant height.

Control at UCC recorded the lowest plant height during the 6th week followed by NPK and the Thallo. NPK and Thallo were statistically similar but significantly different from control. The trend of increase followed control>Thallo>NPK. At Jukwa, Thallo recorded higher mean plant height followed by NPK and control. However, the increase was insignificant among the treatments. Comparing the two experimental sites, Thallo at both UCC and Jukwa recorded similar plant height higher than all other treatments.

During week 7 at UCC, NPK and Thallo amended soils recorded increased plant height than compared to control treatments . Though NPK increased the height relative to Thallo but the increase was insignificant. At Jukwa similar order was followed. Across both zones, NPK at UCC recorded the highest mean plan height significantly higher than all other treatments except thallo at UCC

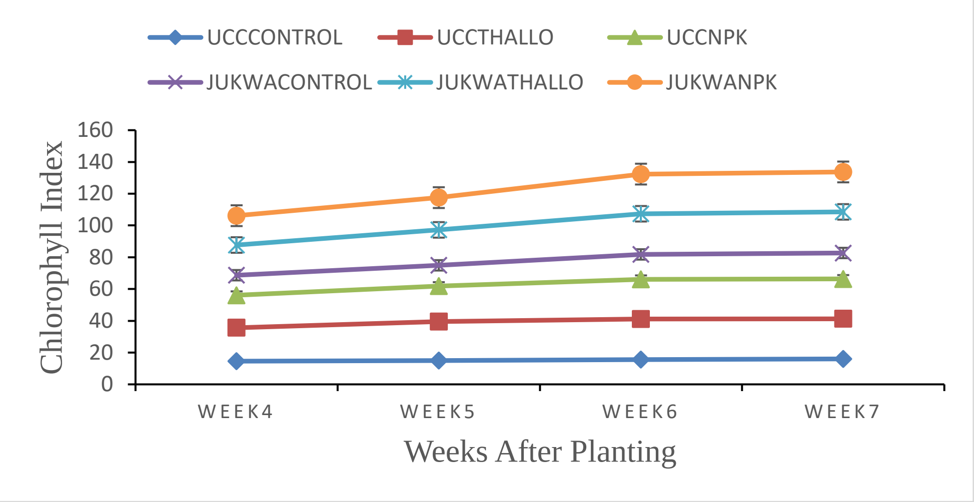

Figure 7: Effect of NPK and Recycled Thallo fertilizer on the chlorophyll content of cabbage from 4th week to 7th week after transplanting

The impact of NPK and Thallo on the chlorophyll index of maize from week to week 7 after sowing is displayed in Figure 7.

Thallo at UCC during week 4 recorded the highest chlorophyll content (21.025) followed by NPK with control recording the least content (14.58). Thallo and NPK significantly increased the chlorophyll index relative to the control. But NPK and Thallo did not show any significant difference. The same trend of increase was observed at Jukwa. Across the two zones, Thallo at UCC recorded the highest mean chlorophyll index.

At UCC during week 5, control obtained the least mean value for chlorophyll content at UCC with 15.644, followed by NPK with 22.444 and Thallo recording the highest value with 24.419. Thallo and NPK were statistically similar at significantly higher than control. Similar order was observed at Jukwa with Thallo and NPK significantly increasing the chlorophyll content relative to the control. Across both agro zones, all treatments at UCC recorded higher mean value than similar treatments at Jukwa. However, Thallo at UCC recorded the highest chlorophyll content

The trend during the 6th week was similar to that of week 5. However, control, NPK and Thallo at UCC recorded same chlorophyll content as those recorded at Jukwa.

During the 7th week at UCC, NPK and Thallo recorded same chlorophyll index (25) that was significantly higher than control. Similar trend was recorded at Jukwa with Thallo and NPK recording same chlorophyll content. Across, the two agro zones, all treatments at UCC recorded same value compared to similar treatments at Jukwa.

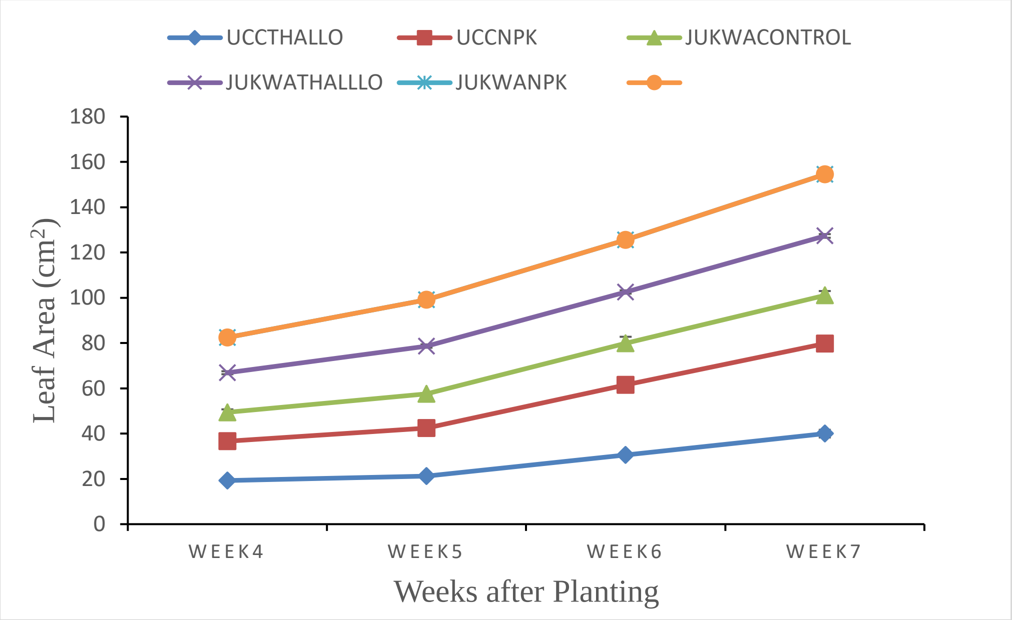

Figure 8: Impact of NPK and Thallo on the leaf area of cabbage from 4th week to 7th week after transplanting.

During the 4th week at UCC, control the lowest leaf area, followed by NPK with Thallo recording the highest. Thallo and NPK significantly increased the leaf area relative to the control but the two were statistically similar. The same trend was recorded at Jukwa. Comparing the two agro zones, Thallo at UCC recorded the highest leaf area compared to all other treatments.

At UCC during week 5, 6 and 7, both Thallo and NPK recorded same leaf area significantly higher than the control. At Jukwa thallo recorded the highest leaf area followed by NPK in week 5. Both were significantly different from the control but did not show any significant difference between them. At week 6 NPK and Thallo recorded same leaf area value of 22m^2 significantly higher than that of control (18.4m^2). At week 7, NPK recorded the highest mean leaf area followed by Thallo and control. NPK and Thallo were statistically similar but significantly different from the control. Comparing the two agro ecological zones, Thallo at UCC recorded the highest leaf area at week 5 compared to all other treatments. At week 6 and 7 NPK and Thallo recorded the highest leaf area relative to other treatments.

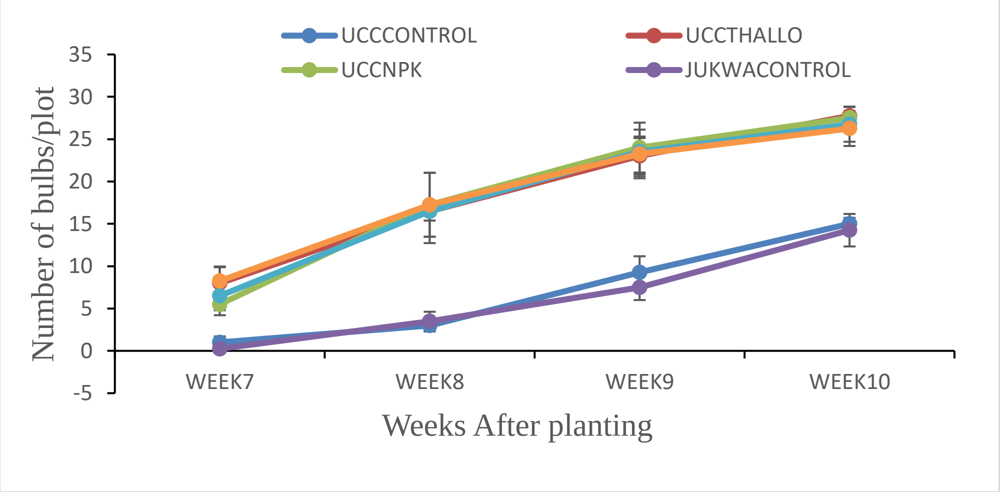

Figure 9: Impact of NPK and Thallo on the rate of bulbing of cabbage from 7th week to 10th week after transplanting.

During week 7, Thallo at UCC recorded the highest number of bulbs relative to control and NPK. NPK also increased the number of bulbs relative to control. Thallo and NPK significantly elevated the bulb formation relative to the control. However, Thallo was statistically similar to NPK. At Jukwa, NPK have more number of bulbs formated than Thallo and control treatments. Thallo and NPK were statistically similar but both significantly different from control. Across, the two agro sites, NPK at Jukwa had the highest number of bulbs formation.

During week 8 NPK at UCC recorded the highest bulb formation followed by Thallo and control. The rate of bulb formation was statistically similar between NPK and Thallo but both significantly increased the bulb formation over the control. Similar trend was observed at Jukwa with NPK and Thallo significantly increasing the bulb formation relative to control. Across the two sites, NPK at Jukwa and UCC recorded the highest mean bulb formation.

Week 9 NPK at UCC recorded higher mean bulb formation with control obtaining the lowest. NPK and Thallo were significantly higher than control but were statistically similar. Thallo and NPK at Jukwa recorded same number of bulb formation significantly higher the control. Across both agro zones, NPK at UCC recorded the highest mean number of bulb formation.

At week 10, Thallo and NPK at UCC obtained the same number of bulb formation (27) significantly higher than control. Similar trend was observed at Jukwa. Across the zones, Thallo and NPK at UCC recorded higher bulb formation.

Effect of NPK and Recycled Thallo Fertilizer on the Mean Head Circumference and Mean Head Fresh Weight of Cabbage in two agro zones

Table 16 shows the effects of NPK and Thallo on the head circumference and head yield of cabbage in different agro zones.

At Jukwa, NPK and Thallo recorded significant ($p<0.05$) head circumference value relative to the control. NPK and Thallo were statistically similar. Both NPK and Thallo recorded about 35% higher in head circumference than the control. At UCC, similar trend was observed. NPK and Thallo elevated the head circumference significantly by over 25% and 25% than the control. But no staistical difference was observed among NPK and Thallo.

Table 16: The impact of NPK and Recycled Thallo fertilizer on the mean head circumference and mean head fresh weight of cabbage in two agro ecological zones

Location	Treatment	Head circumference (cm)	Head fresh weight (g)
Jukwa	Control	25.80a	298.80a
	NPK	34.88b	530.80b
	Thallo	34.78b	600.40c
UCC	Control	33.69b	555.90b
	NPK	42.19c	950.10d
	Thallo	41.25c	1165.00d
	P-value	<0.05	<0.05
	LSD	4.66	271.03

Means attached with the same alphabets are statistically similar according to Fisher’s unprotected LSD test at $P \leq 0.0\,5$.

Across the two agro ecological zones, all the treatments at UCC recorded values significantly ($p<0.05$) greater than similar treatments at Jukwa. NPK and Thallo treated soil at UCC recorded significantly higher mean values of 42.19cm and 41.25cm respectively.

Thallo at Jukwa recorded the highest fresh head weight (600.4 g) than both NPK and the control. However, the control treatment recorded the lowest fresh head weight about 44% less than the NPK and over 50% less than the Thallo. The order of decrease followed the trend control<NPK<Thallo.

At UCC, Thallo significantly elevated the head weight relative to control with over 100% increment. Thallo recorded the highest mean head fresh weight of 1165.8g representing about 23% more than the NPK but the two were statistically the same.

Across the two sites, all treatments at UCC recorded mean values significantly higher than their respective counterparts at Jukwa. Thallo at UCC recorded the highest mean head fresh weight than NPK and control treatments.

Effect of NPK and Thallo fertilizer on the Mean Number of Leaves, Harvest Index and Root Shoot Ratio of Cabbage in two agro ecological zones

The mean number of leaves at harvesting, harvest index and shoot ratio of cabbage as influenced by the application of NPK and Thallo fertilizers are displayed at Table 17.

No significant difference was seen among the treatments with regarding the number of leaves at harvesting. Nonetheless, at Jukwa, Thallo recorded higher mean number (18.31) of leaves at harvesting than NPK and control.

At UCC, control had the lowest mean number of leaves (18.12) followed by NPK (19.25) with Thallo having the highest mean number (21.75). However, the mean leaf count recorded by Thallo at UCC was the highest among all the treatments in both sites. The result also showed significant ($p<0.05$) difference in root shoot ratio among the treatments at both sites and agro zones.

At Jukwa, Thallo recorded the highest mean root shoot ratio value (21.51) than both NPK and the Control. However, NPK elevated root shoot ratio higher than the control treatment. The trend of increase followed control<NPK<Thallo.

Table 17: NPK and Recycled Thallo fertilizer influence on the mean number of leaves, harvest index and Root Shoot ratio of cabbage in two agro zones

Location	Treatment	No. of leaves at maturity	Harvest index (%)	Root-Shoot Ratio
Jukwa	Control	15.94a	41.45ab	9.73a
	NPK	17.19a	41.59ab	15.18b
	Thallo	18.31a	47.37b	21.51c
UCC	Control	18.12a	37.81a	16.11b
	NPK	19.25a	50.78c	15.67ab
	Thallo	21.75a	49.43c	20.66c
	P-Value	Ns	<0.05	<0.05
	LSD	4.64	8.77	3.99

Means attached with the same alphabets are statistically similar according to Fisher’s unprotected LSD test at $P \leq 0.0\ 5$.

At UCC, Thallo again recorded increase in the shoot root ratio (20.66) significantly differentt ($p<0.05$) relative to control and NPK. This value shows 28% and 32% increment over the values recorded by control and NPK respectively. The control however, recorded slightly higher mean value than NPK but it was significantly similar to NPK. The increase followed the order control=NPK<Thallo.

Contrasting the two agro experimental sites control at Jukwa recorded significantly ($p<0.05$) lower shoot root ratio relative to its counterpart at UCC. NPK treated soils at both Jukwa and UCC recorded similar value statistically similar to the value recorded by control at UCC. Thallo at both sites recorded statistically similar values.

The impact of NPK and Thallo on percent harvest index of cabbage in the two different agro zones exhibited significant difference among the treatments. At Jukwa there was no significant difference in harvest Index among all the treatments. However, Thallo recorded the highest mean harvest index (47.37%) with the control and NPK recording almost the same values (41.45% and 41. 59% respectively). Thallo showed about 14% higher in the harvest index over the control and NPK.

Across the two sites, however, both NPK and Thallo at UCC performed significantly ($p<0.05$) better than similar treatments at Jukwa. On the hand, control at Jukwa recorded higher mean percent harvest index (41.45%) than its counterpart at UCC (37.81%)

Effect of NPK and Recycled Thallo Fertilizer on the Mean Head Yield of Cabbage in two agro ecological zones

The obtained head yield of cabbage after the application of NPK and Thallo are expressed in kg ha^{-1} and shown in Table 18

At Jukwa NPK and Thallo were significantly different from the control. NPK recorded about 77% higher head yield than the control with the Thallo recording over 100% more than the control. There was no statistical different between NPK and Thallo. However, Thallo recorded higher mean head yield than NPK in excess of about 13%.

At UCC Thallo recorded head yield significantly ($p<0.05$) higher than control and NPK. With this, Thallo recorded a percentage increase of 109% and 23% over the control and NPK respectively. NPK treated soil obtained higher head yield than the control treatment recording mean yield of 31671 kg/ha representing over 71% increase relative to control (18.53 t ha^{-1}). The trend of increase was in the order control<NPK<Thallo

Comparing both sites, all the treatments at UCC recorded significant ($p <0.05$) better mean head yield relative to similar treatments in Jukwa. Control at UCC was statistically similar to NPK and Thallo at Jukwa but significantly higher than control at Jukwa. Thallo treated soil at UCC recorded significantly higher head yield in all two sites.

Table 18: The Influence of NPK and Thallo fertilizer on the mean head yield of cabbage in two agro ecological zones

Location	Treatment	Head Yield t ha^{-1}
Jukwa	Control	9.96a
	NPK	17.69b
	Thallo	20.02b
UCC	Control	18.53b
	NPK	31.67c
	Thallo	38.86d
	P-Value	<0.05
	LSD	9043.5

Means attached with the same alphabets are statistically similar according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

Effect of Thallo and NPK on the Proximate Components of Cabbage

The proximate component in the cabbage as influenced by NPK and Thallo is presented in Table 19. At Jukwa, Thallo and control recorded the highest mean dry matter content (14.27%) relative to NPK (12.36%). However, the three were not statistically different. At UCC, Thallo increased the dry biomass by 48% more than the control. NPK and Thallo were statistically similar even though the former recorded a 22% decrease in dry matter compared to the latter. NPK and control were statistically similar. Across the different agro zones, Thallo treated soil at UCC recorded the highest significant ($p<0.05$) value in connection with percentage dry biomas content.

No statistical difference was observed in the moisture content among the treatments at Jukwa experimental site. At UCC, Thallo treated soil recorded value significantly lower than the control but statistically similar with the NPK. Comparing the two agro zones, Thallo treated plot at Jukwa recorded the significantly lower mean moisture content relative to all other treatments.

Regarding fiber content in the cabbage, no significant difference was observed at Jukwa even though Thallo recorded the highest mean value. At UCC, NPK treated plot significantly ($p<0.05$) increased the fiber content by 57% relative to the control. NPK and Thallo treated plots were similar statistically. Even though Thallo increased the fiber content by 128% relative to control, it was not significantly different. Across the two zones, NPK at UCC recorded the highest mean fiber content.

At Jukwa, Thallo elevated the ash content of the cabbage by 139% more than the unamended control plot. NPK also increased the ash content by 120% over the control but there was no significant different between the two. At UCC, Thallo once again recorded the highest ash content (6.455) significantly different from the control but statistically similar to NPK. Comparing the two agro zone, all the treatments were statistically the same.

There was significant difference observed among the treatments regarding the carbohydrates content of cabbage. At Jukwa, the control recorded carbohydrates higher than the NPK and Thallo. However, NPK and Thallo were statistically similar recording 72.27% and 70.78% respectively. Similar trend was observed at UCC, with control obtaining significantly higher value carbohydrates content relative to NPK and Thallo. Across the two experimental sites, control at UCC recorded the highest carbohydrates content (80.67%) There was no significant difference recorded in the protein and lipids components among the treatments at both agro experimental sites.

Effect of Thallo and NPK on the Mineral Compositions of Cabbage

The mineral concentration of cabbage as affected by application of Thallo and NPK is shown in Table 20. Nitrogen concentration of the cabbage showed significant difference among the treatments at Jukwa. Thallo treated soil recorded N concentration of 3.703% which is significantly ($p<0.05$) different from the NPK but statistically similar to the control. At UCC, Thallo recorded the highest N concentration (4.237%) but was statistically similar to both NPK and control. In contrast, all treatments at UCC recorded higher N concentration than the similar treatments at Jukwa but were not significantly different except the NPK that differed from similar treatment at Jukwa.

Table 19: Effect of NPK and Thallo on proximate parameters in cabbage head

Location	Treatment	Dry Matter (%)	Moisture (%)	Fiber (%)	Ash (%)	Carbohydrates (%)	Protein (%)	Lipids (%)
Jukwa	Control	14.27a	85.73b	3.21ab	2.80a	77.72b	10.03a	6.2a
	NPK	12.36a	87.64b	4.46ab	6.17ab	72.27a	13.45a	3.653a
	Thallo	14.27a	85.73b	5.10ab	6.68b b	70.78a	13.62a	3.83a
UCC	Control	14.26a	85.74b	2.46a	3.39a	80.67b	8.53a	4.96a
	NPK	16.51ab	83.49ab	5.63b	5.18ab	71.36a	12.82a	5.02a
	Thallo	21.14b	78.86a	4.94ab	6.46b	70.87a	13.52a	4.23a
	p-value	0.05	0.05	<0. 05	<0.05	<0.05	<0.05	<0.05
	LSD	4.26	4.26	2.02	2.32	3.99	3.50	2.49

Means attached with the same alphabets are statistically similar according to Fisher’s unprotected LSD test at $P \leq 0.05$.

With regards to phosphorus concentration, NPK recorded the highest mean value at Jukwa followed by Thallo and control. These concentrations were not significantly different from each other. Similar observation was made at UCC where NPK recorded higher P concentration (6159 ug g^{-1}). The order of increase followed NPK<Thallo<Control. No significant difference was observed among the treatments. Across the agro zones, all the treatments at Jukwa recorded P values significantly ($p<0.05$) lower than similar treatments at UCC.

Potassium concentrations exhibited significant differences within the treatments in both agro zones. At Jukwa, control recorded lower mean value of potassium compared to the other treatments. The trend of decrease followed Thallo>NPK>Control.

Control at UCC obtained the highest mean concentration of K with 49671ug/g that was not significantly different from NPK and Thallo. Comparing the two agro zones, control and NPK at UCC recorded significantly higher K concentrations than similar treatments at Jukwa. However, Thallo at UCC recorded higher mean K concentration than its counterpart at Jukwa but the two were statistically similar.

With regards to calcium concentration, Thallo recorded the highest calcium level at Jukwa, followed by NPK and control. Thallo significantly differed from both control and NPK but the two were not significantly different. At UCC, control recorded significantly ($p<0.05$) increased Ca concentration relative to Thallo but was similar to NPK. Both control and NKP increased Ca level by 23% and 21% respectively over Thallo. Across the two zones, all the treatments at UCC recorded significantly higher Ca level than similar treatments at Jukwa except Thallo that showed no statistical difference. Control at Jukwa recorded the highest mean Ca level compared all the treatments.

Thallo recorded 14% increase in the magnesium concentration over the control and NPK at Jukwa. However, Thallo recorded a decreased Mg concentration (2916 ug/g) relative to control (3118 ug/g) and NPK (2964 ug/g) at UCC. Contrasting the two agro zones, all the treatments at UCC obtained increased mean magnesium concentration relative to similar treatments at Jukwa, the highest concentration was recorded by Control at UCC. However, no significant difference existed among the ammendments within and across the agro ecological zones.

At Jukwa there was no significant difference among the treatments with respect to sodium. However, NPK treated soil recorded the highest mean Na concentration (963 ug g^{-1}) followed by Thallo (922 ug g^{-1}) and control (571 ug g^{-1}). At UCC, NPK recorded increased Na concentration compared to the other treatments. Control obtained higher Na level (2937 ug g^{-1}) than Thallo (2062 ug g^{-1}). Comparing the two agro sites control and NPK at UCC obtained significantly higher Na concentrations than all the treatments at Jukwa. NPK recorded the highest mean Na concentration.

With respect to Zinc concentration, no significant difference was shown among the ammendtments within and across both agro zone. However, at Jukwa, control and Thallo recorded higher Zn concentration of 35.10 ug g^{-1} and 35.03 ug g^{-1} respectively over NPK. The same values are the highest across the two zones.

Table 20:Influence of NPK and Thallo on concentrations of mineral composition in the cabbage head

Location	Treatment	Nitrogen (%)	Phosphorus ug g^{-1}	Potassium ug g^{-1}	Calcium ug g^{-1}	Magnesium ug g^{-1}	Sodium ug g^{-1}	Zinc ug g^{-1}	Iron ug g^{-1}
Jukwa	control	3.54ab	3172a	27888a	6570a	2544a	571a	35.10a	54.93a
	NPK	2.86a	3749a	30743ab	5743a	2561a	963a	29.51a	43.15a
	Thallo	3.70b	3648a	32825ab	7183b	2908a	922a	35.03a	64.60a
UCC	Control	3.48ab	5215c	49671c	10518c	3118a	2937b	26.92a	66.05a
	NPK	4.01b	6159c	48243c	10158c	2964a	3426b	26.70a	77.37a
	Thallo	4.24b	5378c	41753bc	8094b	2915a	2062ab	26.62a	78.08a
	p-value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	LSD	0.62	1404.00	8765.00	2157.60	725.70	1123.50	9.20	23.59

Means attached with the same alphabets are statistically similar according to Fisher's unprotected LSD test at $P \leq 0.05$.

At Jukwa experimental site Thallo treated soil increased the concentration of iron relative to the control and NPK. Control obtained higher mean Fe concentration (54.93 ug g^{-1}) than NPK (43.15 ug g^{-1}). At UCC, Thallo recorded the highest mean iron concentration (78.08ug/g) relative to the control and NPK. Relative to control NPK obtained higher mean Fe concentration (77.37 ug g^{-1}). The trend of increase followed Control<NPK<Thallo. Across the two agro ecological zones, all treatments at UCC recorded Fe values greater than similar treatments at Jukwa.

Effect on Thallo and NPK Nutrient Uptake and Nutrient use Efficiency of Cabbage

The response of maize grain to the effect of NPK and Thallo on NPK uptake and NPK use efficiencies is displayed in Table 21.

At Jukwa, Thallo recorded the highest N uptake (104 kg ha^{-1}) representing 106% and 68% more than the control and NPK respectively. NPK recorded higher N uptake (23%) more than the control. Thallo recorded the highest N uptake (342.8 kg ha^{-1}) at UCC, followed by NPK (214.6 kg ha^{-1}) and control (91.5 kg ha^{-1}). Thallo demonstrated significant ($p < 0.05$) difference from NPK and the control.

NPK also showed significant difference relative to control. The trend of increase followed control>NPK and Thallo. Across the two zones, all the treatments at UCC obtained values significantly higher than their similar treatments at Jukwa except control. Thallo at UCC recorded significantly higher value than all the treatments.

The P uptake at Jukwa ranged between 4.60.14 kg ha^{-1} to 10.22 kg ha^{-1} with control recording the least P uptake. Thallo recorded the highest P uptake relative to control and NPK.

Table 21: Impact on Thallo and NPK nutrient uptake and nutrient use efficiency of cabbage

		Nutrient uptake (kg ha^{-1})			Nutrient use efficiency (kg ha^{-1})		
Location	Treatment	N	P	K	N	P	K
Jukwa	Control	50.40a	4.60a	39.3a			
	NPK	61.80a	8.13a	66.9a	176.9a	66.76a	89.35a
	Thallo	104.00a	10.22a	92.6a	200.1a	75.53a	101.08a
UCC	Control	91.50a	15.38ab	139.0ab			
	NPK	214.60b	33.30bc	261.8bc	316.7b	119.51b	159.95b
	Thallo	342.80c	43.63c	340.6c	398.6c	146.64b	196.26b
	p-value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
	LSD	70.55	12.87	99.9	86.5	32.65	43.70

Means attached with the same alphabets are statistically similar according to Fisher’s unprotected LSD test at $P \leq 0.0\ 5$.

The trend of decrease followed Thallo >NPK>control. At UCC, Thallo increased the P uptake by over 183% and 31% relative to Control and NPK. NPK recorded higher P uptake than control. Thallo was significantly different from control but similar to NPK. Across the zones, all treatments at UCC obtained significantly ($p<0.05$) higher P uptake than similar treatments at Jukwa except control. Thallo at UCC recorded the highest mean value of P uptake.

With regards to potassium uptake, Thallo recorded the highest K uptake (340.6 kg ha^{-1}) at Jukwa followed by NPK (66.9 kg ha^{-1}) and control (39.3 kg ha^{-1}). At UCC, the K uptake ranged from 139 kg ha^{-1} to 340 kg ha^{-1}. Thallo recorded the highest mean K uptake with control recording the least uptake of

K. Thallo significantly ($p<0.05$) increased the K update by 145% over the control. However NPK and Thallo were statistically similar. Across the two zones, treatments at UCC significantly increased the K uptake relative to similar treatments at Jukwa except control. Thallo at UCC recorded the highest K uptake (340.6 kg ha^{-1}) significantly higher than all other treatments except NPK at UCC.

The nutrient use efficiency was measured to estimate the impacts of nutrient addition on the yield hence the control was omitted since no amendment was added.

Thallo treated soil at Jukwa recorded higher N use efficiency (200.1 kg ha^{-1}) compared to NPK (176.9 kg ha^{-1}) at Jukwa. However, the two did not show any significant difference in the N use efficiency by the plant. At UCC, Thallo elevated the N use efficiency significantly ($p<0.05$) by 25% over NPK. Across the two experimental zones, N use efficiency by NPK and Thallo at UCC increased significantly ($p<0.05$) compared to similar treatments at Jukwa. However, Thallo at UCC recorded significantly the highest N use efficiency relative to all other treatments.

At Jukwa, Thallo increased the P use efficiency (75.53 kg ha^{-1}) relative to NPK but did not show statistical difference. At UCC, Thallo elevated the P use efficiency by 23% over NPK. Comparing both agro sites, NPK and Thallo at UCC recorded higher P use efficiency than at Jukwa. Thallo at UCC recorded the highest P use efficiency (146.64 kg ha^{-1}) than all the other treatments.

At Jukwa, NPK recorded lower K use efficiency (89.35 kg ha^{-1}) that was not significantly different relative to Thallo (101.08 kg ha^{-1}). At UCC, thallo recorded a higher K use efficiency (196.26 kg ha^{-1}) than NPK representing 23 % increase relative to NPK. Across the two agro zones, all the treatments at UCC recorded significantly increased K use efficiency relative to their counterpart at Jukwa with Thallo at both UCC recording the highest K use efficiency.

Table 22 shows the correlation between the soil chemical properties and the yield parameters.

There was a positive correlation between the pH, SOC, N, P and K indicating that the increase in the nuyrients availability had a direct influence on the yield and other yield parameters. The head circumference was also affected positively the N and P, K and SOC except the pHand number of leaves

Effect Of NPK and Thallo on Nutrients Use Efficiency Indices in Cabbage

At Jukwa the agronomic efficiency of N. P and K showed no difference between the treatments. However, at UCC, Thallo recorded significantly ($P<0.5$) higher agronnomic N, P and K efficiencies relative to NPK treatments.

At Jukwa, Thallo N and K physiological efficiencies were significantly higher than that of NPK, but P efficiency for both treatments were similar. At UCC, Thallo recorded significantly higher N physiological effieciency relative to NPK. Both P and K physiological efficiencies were similar fir the two treatmensts.

Thallo recorded higher N recovery efficiencies at Jukwa relative to NPK but P and K recovery efficiencies showed no significance difference. At UCC. the N, P and K recovery efficiencies for Thallo treated soil were significantly (P<0.5) higher than the NPK treated soil.

Growth, Yield and Nutritional Quality of Sweet Potato in Thallo Amended Soil.

Pre-planting chemical properties of experimental soil and analytical properties of the Thallo used for the experiment are presented in tables 3 and 4 respectively in Chapter Three.

Effect of Thallo and NPK on Some Soil Chemical Properties after planting Sweet Potato

Table 2: Some soil chemical properties after harvesting sweet potatoat UCC

Treatment	pH	Total nitrogen %	Organic carbon %	Available Phosphorus ug/g	Exchangeable potassium Cmolc^{-1}
Control	6.19a	0.05a	0.61a	0.17.50a	0.21a
NPK	6.24a	0.11b	1.09b	114.40b	0.25b
Thallo	6.53b	0.19c	1.83c	154.60c	0.29c
P-value	<0.05	<0.05	<0.05	<0.05	<0.05
LSD	0.17	0.01	0.05	8.76	0.03

Means attached with the alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0$ 5.

Table 22: Correlation matrix between yield and yield indicators of cabbage head and soil chemical properties after harvesting

Parameter	HY	HC	NL	SR	pH	OC	N	Av P	Ex. K	LFW	LDW	HFW	HDW
HC	.931**												
NL	0.563	0.487											
SR	.667*	.666*	0.285										
pH	.594*	0.396	0.431	.604*									
OC	.721**	.596*	.579*	.805**	.915**								
N	.780**	.676*	0.573	.860**	.857**	.978**							
Av P	.840**	.776**	0.557	.870**	.795**	.934**	.980**						
Exch K	.652*	.583*	.610*	.639*	.744**	.883**	.854**	.823**					
LFW	.897**	.926**	0.439	.741**	0.436	.646*	.752**	.853**	.609*				
LDW	.895**	.904**	0.467	.754**	0.485	.660*	.744**	.848**	.594*	.966**			
HFW	1.000**	.931**	0.563	.667*	.594*	.721**	.780**	.840**	.652*	.897**	.895**		
HDW	.926**	.843**	.635*	.775**	.728**	.857**	.916**	.939**	.719**	.856**	.835**	.926**	

**significant correlation at the 0.01 level (2-tailed).

* significant correlation at the 0.05 level (2-tailed).

Where HY: Head yield, HC:head circumference, NL: number of leaves. SR: Root shoot ratio, pH: soil pH, OC: Organic carbon, N: nitrogen, AvP: Available Phosphorus, Ex. K: Exchangeable Potassium, LFW: leaf fresh weight. LDW: leaf dry weight HFW:head fresh weigt HDW: head dry weight

Table 23: Effect of NPK and Thallo on Agronomic, Physiological and Recovery efficiencies of NPK in cabbage

		Agronomic Efficiency			Physiological Efficiency			Recovery Efficiency		
Location	Treatment	N	P	K	N	P	K	N	P	K
Jukwa	Control									
	NPK	77.33a	29.18a	39.06a	141.7a	7246a	285.1c	0.1142a	0.01332a	0.1391a
	Thallo	100.56a	37.95a	50.79a	202.4b	7225a	189.6b	0.5362b	0.02120a	0.2689a
UCC	Control									
	NPK	131.42b	49.59b	66.37b	101.3a	7087a	113.2a	1.2315c	0.06764c	0.6204b
	Thallo	203.31c	76.72c	102.68c	281.2b	7649a	113.1a	2.5129d	0.10662d	1.0180c
	p-value	<.001	<.001	<.001	ns	Ns	<.001	<.001	<.001	<.001
	LSD	71.51	26.98	36.11	100.7	6344.9	65.95	0.4733	0.03229	0.3457

Table 3: Correlation matrix between NPK Uptake and their Use parameters of cabbage

Parameter	NU	PU	KU	NUE	PUE	KUE	NPE	PPE	KPE	NAE	PAE	KAE	NRE	PRE
PU	.962**													
KU	.958**	.996**												
NUE	.849**	.806**	.794**											
PUE	.849**	.806**	.794**	1.000**										
KUE	.849**	.806**	.794**	1.000**	1.000**									
NPE	-0.105	-0.106	-0.109	0.252	0.252	0.252								
PPE	-0.142	-0.156	-0.171	0.043	0.043	0.043	-0.192							
KPE	0.025	-0.003	-0.031	.454*	.454*	.454*	.674**	.480*						
NAE	.834**	.799**	.782**	.956**	.956**	.956**	0.312	-0.074	.433*					
PAE	.834**	.799**	.782**	.956**	.956**	.956**	0.312	-0.074	.433*	1.000**				
KAE	.834**	.799**	.782**	.956**	.956**	.956**	0.312	-0.074	.433*	1.000**	1.000**			
NRE	.963**	.886**	.880**	.881**	.881**	.881**	-0.019	-0.173	0.076	.878**	.878**	.878**		
PRE	.877**	.853**	.845**	.863**	.863**	.863**	0.029	-0.16	0.073	.868**	.868**	.868**	.941**	
KRE	.865**	.827**	.831**	.863**	.863**	.863**	0.043	-0.132	0.073	.856**	.856**	.856**	.933**	.988**

**significant correlation at the 0.01 level (2-tailed).

* significant correlation at the 0.05 level (2-tailed). NU:nitrogen uptake, PU: phosphorus uptake, KU: potssium uptake NUE: nitrogen use efficiency, PUE: phosphorus use efficiency KUE: potassium use efficiency

Soil pH increased in experimental plots amended with Thallo. Application of the NPK fertilizer decrease the pH by 0.06 unit but was not insignificantly different from that of the control. Relative to the control and NPK the application of Thallo significantly ($p<0.05$) increased the percent N of the soil. The percent increase was 280 and 73 over control and NPK respectively. The Application of NPK also significantly increased percent N relative to the control with percentage increase of 120.

Similarly the application of Thallo significantly (0.05) elevated the soil organic carbon (SOC) in relation to the control and NPK. Thallo increased the percent SOC by 200 over the control and 68 over the NPK. The NPK amended plot recorded significant percent SOC increase relative to the control with a percent increase of 79. Both NPK and Thallo recorded values of available P higher than the control treatments in the order Control<NPK<Thallo. Thallo application elevated the available P content in the soil by 120% and 35% more as against the control and NPK respectively.

Addition of Thallo and NPK significantly increased exchangeable K content in the soil more than the control treatment . Thallo obtained a percent rise of 38% over the control whilst the NPK recorded 19% increase over the control.

NPK and Thallo on Agronomic Performance of Sweet Potato at Harvesting.

The response of vine length, vine girth and number of leaves of sweet potato to the application of Thallo and inorganic NPK fertilizer at harvesting are shown in Figures 10, 11and 12 respectively.

The vine length increased in the experimental plots amended with Thallo and NPK (Fig 10). Thallo and NPK increased the vine length by 51% and 41% over the control respectively. However, the application of the NPK fertilizer decreased vine length compared to the Thallo though the difference was insignificant.

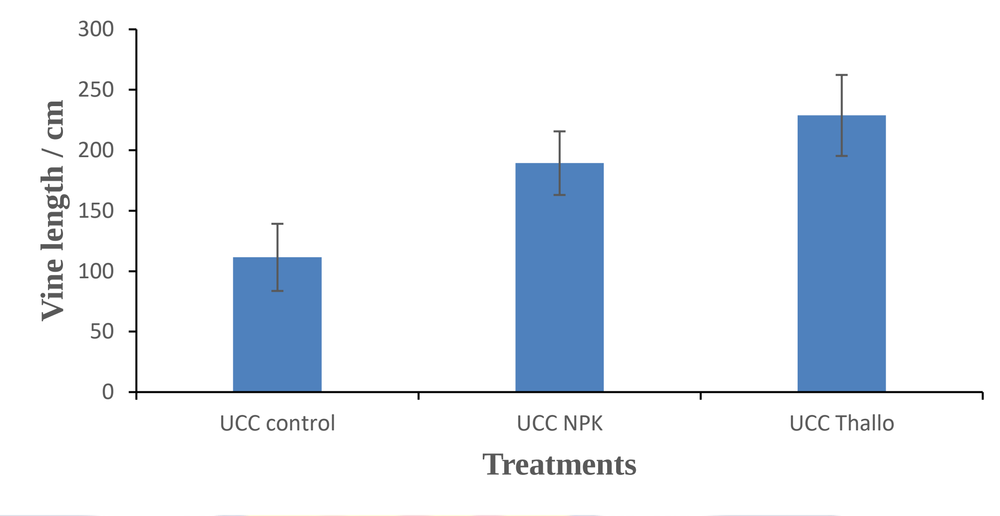

Figure 10: Effect of NPK and Thallo on sweet potato vine length at maturity

Thallo recorded the highest mean vine girth followed by NPK with control recording the least. However, the increase was insignificant (Fig 11).

Number of leaves increase in the Thallo amended experimental plots with a percent increase of 40.5 (Fig 12). NPK increased the number of leaves compared to control but there was no statistical difference. NPK fertilized plot decreased the number of leaves relative to Thallo but the difference was insignificant.

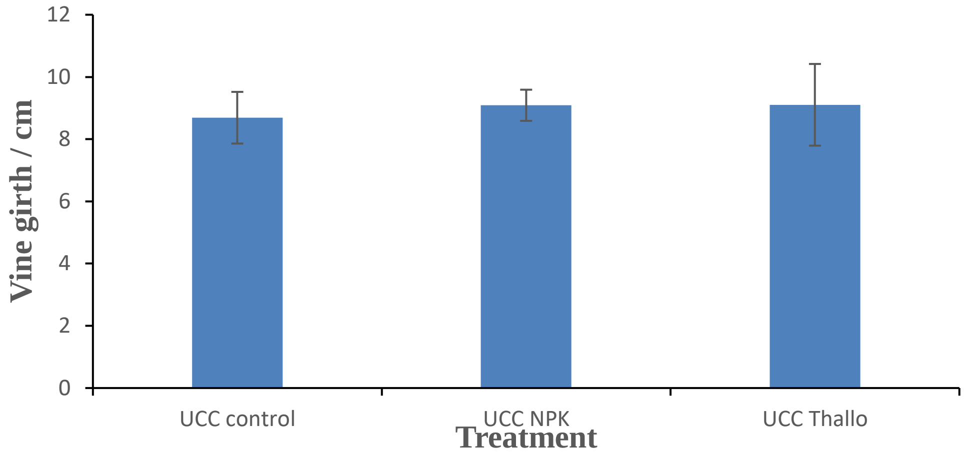

Figure 11: Effect of NPK and Thallo on sweet potato vine girth at harvesting

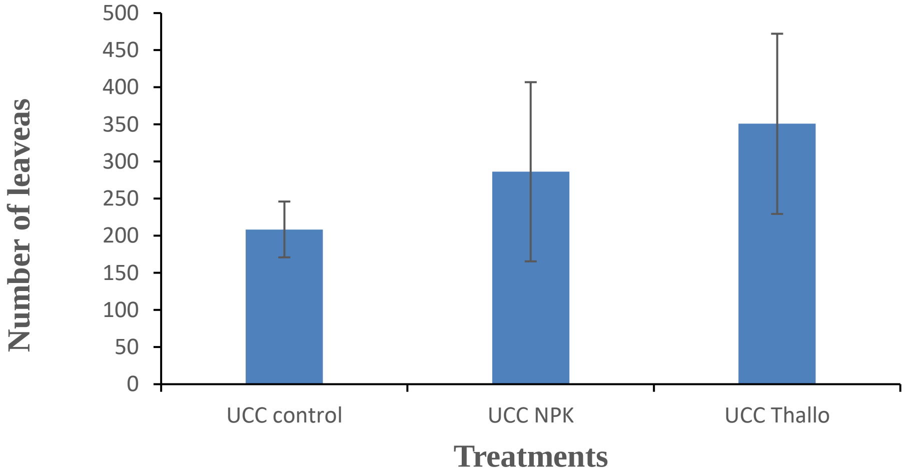

Figure 12: Effects of NPK and Thallo on the leaf number of sweet potato at harvesting

Tuber yield and Marketability of Sweet Potato Following the Application of NPK and Thallo

The effect of Thallo and NPK in the tuber legnth, tuber circumference has been displayed in Table 26. The application of Thallo and NPK fertilizers significantly ($p<0.05$) elevated the tuber length relative to the control with percent increase of 34 and 28 respectively for NPK and Thallo.

Table 26: Tuber Circumference and Length and Numbers of Leaves at Maturity as Influenced by the Application of NPK and Thallo

Treatment	Tuber Length (cm)	Tuber Circumference (cm)	No of leaves Plant^{-1}
Control	20.25a	16.50a	208.50a
NPK	25.95b	23.13b	286.20ab
Thallo	27.04b	23.86b	350.80b
P-value	<0.05	<0.05	<0.05
LSD	4.22	2.98	113.50

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0 5$.

However, NPK and Thallo recorded values that were statistically similar. Similar trend was observed for tuber circumference. Thallo amended soil significantly increased the tuber circumference by 45% over the control whereas NPK increased the circumference by 40% over the control. However, Thallo and NPK were statistically similar. The trend of increase of tuber length and circumference followed Control<NPK=Thallo.

Table 27: Effects of NPK and Thallo on number of tubers and marketable tubers of sweet potato

Treatment	Number of tubers/plot	Marketable tuber/plot	Tuber Weight/plant (g)	Marketable weight/plant (g)
Control	27.25a	16.00a	426.30a	244.0a
NPK	34.25b	24.25b	580.30a a	412.6b
Thallo	40.75c	36.25c	998.20b	885.5c
P-value	<0.05	<0.05	<0.05	<0.05
LSD	4.14	5.10	161.60	118.20

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0 5$.

Thallo amended plot obtained the highest mean tuber numbers per plant stand proceeded by NPK having the control recording the least. Thallo increased the number of tubers by 16% compared to NPK but it was not significant. Thallo and NPK increased the tuber number relative to control with a percent increase of 50 and 26 respectively.

Control recorded the lower number of marketable tubers than Thallo. NPK treated plot recorded higher number of marketable tubers relative to control. Relative to control both Thallo and NPK recorded high marketable tubers. Thallo amended plot significantly increased marketable tubers by 125% and 52% over control and NPK respectively. NPK treated plot significantly elevated the number of marketable tubers by 50% over control.

Thallo treated plot recorded the highest weight per plant relative to NPK and control. NPK increased the weight of plant by 36% relative to the control though the increase is insignificant. Thallo significantly elevated plant weight with a percent increase of 134 and 72 over control and NPK respectively. Control recorded the lowest marketable weight significantly ($p<0.05$) lower than NPK and Thallo. Thallo recorded marketable tuber weight significantly ($p<0.05$) different relative to NPK and Control.

Table 28 represents the influence of NPK and Thallo on tuber yield, marketable tuber yield and percent marketability of sweet potato.

Thallo amended plot recorded highest tuber yield followed by NPK with control recording the least tuber weight. NPK recorded tuber yield more than the control treatment. Thallo elevated the tuber yield by 134% and 72% than the control and NPK. The trend of increase was control=NPK<Thallo.

Control recorded the lowest marketable tuber yield with Thallo recording the highest marketable tuber yield. NPK treated plot recorded higher marketable tuber yield relative to control. Relative to control both Thallo and NPK recorded high marketable tuber yield. Thallo treated plot significantly ($p<0.05$) increased marketable tuber yield by 262 % and 114% over control and NPK respectively.

Table 28: Effects of NPK and Thallo on total tuber yield (t ha^{-1}), Marketable yield (t ha^{-1}) and percent marketability (%) of sweet potato

Treatment	Totaltuber yield (t ha^{-1})	Marketable yield (t ha^{-1})	% marketability
Control	14.210a	8.135a	59.36a
NPK	19.343a	13.752b	70.69a
Thallo	33.272b	29.518c	88.86b
P-value	<.001	<.001	0.003
LSD	5387.1	3938.7	13.55

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

NPK treated plot significantly elevated the marketable tuber yield by 69% over control. The trend of increase followed control<NPK<Thallo.

With regards to tuber marketability, the plot amended with Thallo recorded high percentage marketability significantly higher than control and NPK. NPK treated plot recorded higher percent marketability than the control. The increase in percent marketability followed control=NPK<Thallo.

Thallo and NPK on the above and ground biomass of sweet potato.

Effect on above ground and below ground dry biomass of sweet potato as influenced by the application of NPK and Thallo are shown in Table 29.

Thallo and NPK treated plots obtained increased above ground dry biomass relative to control. Both significantly increased the above ground biomass by 46 % and 40 % over control respectively. Thallo recorded higher above ground biomass compared to NPK but the difference was statistically similar.

Table 29: Effects of NPK and Thallo on above and below ground dry biomass of sweet potato

Treatment	Aboveground Biomass (kg ha^{-1})	Belowground Biomass (kg ha^{-1})
Control	1462a	2984a
NPK	2050b	3564a
Thallo	2140b	6353b
P-value	<.002	<.001
LSD	1336.1	874.1

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

Regarding below ground dry matter, NPK treated plot recorded 19.4 % increase over the control but the increase was insignificant. Thallo amended soil recorded below dry biomass by 113 % and 78 % than the control and NPK treatments. The trend of increase was control=NPK<Thallo.

Impact of NPK and Thallo Nutrients Uptake and Efficiency of Sweet Potato

Table 30 shows the impact of NPK and Thallo on the nutrient uptake and use efficiency.

NPK amendment recorded higher N uptake than the control treatment but the difference were insignificant. Control and NPK recorded significantly ($p<0.05$) lower N uptake relative to Thallo. Similar trend was observed for P. Thallo treated soil recorded increased K uptake which was significantly higher than both control and NPK. However, control recorded significantly lower K uptake compared to NPK. The trend of increase for N and P followed control=NPK<Thallo but K followed control<NPK<Thallo.

Thallo recorded increased N, P and K use efficiencies which is higher than the NPK treatment. The Thallo recorded significantly higher percent increase of N, P and K use efficiencies by Thallo was 52% respectively over the NPK treated plot.

Table 30: Soil nutrient uptake and nutrient use efficiency following the application of NPK and Thallo fertilizers.

	Nutrient Uptake ($kg\ ha^{-1}$)			Nutrient Use Efficiency ($kg\ ha^{-1}$)		
Treatmet	N	P	K	N	P	K
Control	210.00a	54.40a	97.30a	0.00a	0.00a	0.00a
NPK	290.70a	86.50a	160.30b	773.70b	292.0b	390.8b
Thallo	571.90b	172.00b	256.60c	1330.90c	502.2c	672.2c
P-value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
LSD	158.00	30.39	64.90	154.90	58.50	78.20

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

The influence of NPK and Thallo on nutrient use efficiency indices are shown in Table 31.

Plot amended with Thallo elevated the agronomic efficiencies of nitrogen, phosphorus and potasssium than NPK. The increase was significant ($p < 0.05$) relative to NPK giving a percent increase of 271 for all three nutrients respectively. Regarding physiological efficiency Thallo treated plot recorded high N, P and K compared to the NPK treated plot. However, the difference was statistically is insignificant. NPK amended plot recorded the least N, P and K recovery efficiencies relative to Thallo treated plot. Thallo significantly elevated the recovery efficiencies of N, P and K by 340, 266 and 167 respectively compared to NPK.

Effect of Thallo and NPK on the Nutritional Quality of Sweet Potato

The proximate component in the potato tuber is presented in the Table 32. There was no significant difference recorded in the dry matter, moisture content, ash and carbohydrates among the treatments.

Thallo and NPK amended soils recorded fibre content significantly higher than the value recorded by the control. NPK and Thallo recorded statically similar value but increase the fibre content 82% more than the control.

Soil treated with NPK recorded high protein content significantly higher compared to control and Thallo. Control obtained high protein level relative to Thallo treated soil though the difference was insignificant.

Table 31: Effect of NPK and Thallo on Agronomic, Physiological and Recovery efficiencies of NPK in sweet potato

	Agronomic efficiency			Physiological efficiency			Recovery efficiency		
Treatment	N	P	K	N	P	K	N	P	K
Control	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a	0.00a
NPK	205.3b	77.5b	103.7b a	233.1b	643.1b	478.9b	0.806b	0.121b	0.32b
Thallo	762.5c	287.7c	385.1c	263.9b	646.4b	545.7b	3.619c	0.443c	0.80c
P-value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
LSD	269.90	101.80	136.30	70.90	222.20	259.30	1.88	0.14	0.41

Means attached with the same alphabets are not statistically different according to Fisher’s unprotected LSD test at $P \leq 0.0\ 5$.

The mineral concentration of the sweet potato tuber is shown in Table 33. The tuber N concentration of sweet potato showed statistical difference among the treatments NPK treated soil recorded tuber N of 1.601 % which is significantly higher than both control and Thallo with a percent increase of 33 and 51 percent over control and Thallo.

NPK recorded the highest P level, followed by thallo with the control obtaining the lowest P level. However, the difference among the treatments were not significant. Similar trend was observed with Potasium except that control recorded lower K content than Thallo. Soil amended with Thallo recorded the highest level of calcium relative to control and NPK. Thallo increased significantly the calcium content by 82% and 51.7% relative to control and NPK respectively. However, NPK elevated the calcium content significantly by 30 relative to the control. The trend of increase followed Control<NPK< Thallo.

Thallo amended soil recorded magnesium concentration higher than NPK and the control. Thallo increased the magnesium content by 25 compared to NPK. However, this increase was insignificant. However, both and NPK and Thallo significantly increased the magnesium relative to control with a percent increase of 123 and 87.

However, Thallo recorded elevation in sodium concentration relative to control but the increase was insignificant. Control recorded significantly high sodium level compared to NPK and Thallo with per cent difference of 26 and 14 relative to NPK and Thallo respectively.

The soil amended with Thallo recorded the highest Zinc content (105 ug g^{-1}), followed by control (103 ug g^{-1}) with NPK obtaining the least Zn value (98 ug g^{-1}). However, the differences were statistically similar.

Regarding iron concentration, Thallo recorded higher Fe value relative to control and NPK. Soil treated with NPK also recorded higher Fe level compared to the control. NPK and Thallo significantly increased the Fe level by 111% and 87% over the control respectively.

N-Fixation, Nutritional Quality, Growth and Yield of Cowpea (Vigna Unguiculata L. Walp) in Thallo Amended Soils

The chemical properties of both the soil and Thallo are displayed in Table 2.

Effects of soil NPK and Thallo on selected soil chemical properties after harvesting of cowpea

Table 36: Effect of Thallo and NPK on soil properties after harvesting cowpea

Treatment	pH	Total nitrogen %	Organic carbon %	Available Phosphorus ug g^{-1}	Exchangeable potassium Cmolc kg^{-1}
Control	6.19a	0.06a	0.48a	0.150a	0.22a
NPK	6.32a	0.19b	0.69b	109.50b	0.28ab
Thallo	6.57b	0.20b	1.98c	150.10c	0.35b
P-value	<0.05	<0.05	<0.05	<0.05	<0.05
LSD	0.16	0.01	0.01	3.34	0.07

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0 5$.

Table 32: Effect of NPK and Thallo on proximate parameters in sweet potato

Treatment	Dry Matter (%)	Moisture (%)	Fiber (%)	Ash (%)	Carbohydrates (%)	Protein (%)	Lipids (%)
Control	88.13a	11.87a	3.006a	7.456a	80.37a	8.681a	0.4877a
NPK	87.52a	12.48a	3.400b	8.015a	78.12a	10.006b	0.4634a
Thallo	88.01a	11.99a	3.405b	7.567a	80.31a	7.940a	0.7823b
p-value	0.554	0.554	<0.05	0.796	0.069	<0.05	<0.05
LSD	1.290	1.290	0.2241	1.956	2.152	0.924	0.1544

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0$ 5.

Table 33: Effect of NPK and Thallo on mineral concentrations in sweet potato

Treatment	Nitrogen (%)	Phosphorus ug g^{-1}	Potassium ug g^{-1}	Calcium ug g^{-1}	Magnesium ug g^{-1}	Sodium ug g^{-1}	Zinc ug g^{-1}	Iron ug g^{-1}
Control	1.39a	3636a	6413a	230.30a	273.10a	915.00b	103.9a	30.15a
NPK	1.60b	4776a	7100a	329.10b	704.40b	674.70a	98.1a	56.42b
Thallo	1.27a	3945a	5876a	480.20c	829.00b	782.80a	105.4a	61.52b
p-value	<0.05	0.072	0.062	<0.05	<0.05	<0.05	0.788	<0.05
LSD	0.1478	998.2	999.3	122.7	253.5	159.1	25.70	5.92

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0$ 5.

Table 34: Correlation matrix between yield and yield indicators of sweet potato and soil chemical properties after harvesting

PARAMETERS	NT	MNT	TTY	MTY	PM	pH	OC	N	Av P	Exch K	VL	TC	TL	ADM
MNT	.926**													
TTY	.909**	.877**												
MTY	.900**	.951**	.970**											
PM	.744**	.938**	.724**	.864**										
pH	.718**	.723**	.824**	.814**	.603*									
OC	.912**	.941**	.936**	.962**	.848**	.830**								
N	.905**	.946**	.934**	.965**	.865**	.826**	.997**							
Av P	.886**	.908**	.896**	.920**	.828**	.796**	.984**	.984**						
Exch K	0.147	0.218	0.34	0.344	0.185	0.708**	0.785**	.854**	.718**					
VL	0.468	.653*	0.511	.635*	.697*	.625*	0.524	0.541	0.444	0.366				
TC	.738**	.671*	.702*	.678*	0.562	.6s54*	.771**	.784**	.843**	-0.132	0.27			
TL	0.565	0.52	.626*	.591*	0.449	0.535	.705*	.712**	.777**	-0.233	0.072	.802**		
ADM	0.051	0.048	0.135	0.124	0.074	0.237	0.288	0.272	0.388	-0.081	-0.12	0.548	.673*	
BDM	.858**	.823**	.944**	.913**	.666*	.871**	.932**	.915**	.887**	0.446	0.436	.651*	.625*	0.233

**** significant correlation is at the 0.01 level (2-tailed).**

*** significant correlation is at the 0.05 level (2-tailed).**

NT: number of tubers, MNT: marketable number of tubers, TTY: total tuber yield, MTY: marketable tuber yield, PM: percent marketability, pH: soil pH, N: soil nitrogen, Av P: available phosphorus, Exch K: exchangeable potassium. VL: vine length, TC: tuber circumference, TL: tuber length, ADM: above ground matter, BDM: below ground dry matter

Table 4: Correlation matrix between NPK Uptake and their Use parameters

Parameter	NU	PU	KU	NUE	PUE	KUE	NPE	PPE	KPE	NAE	PAE	KAE	NRE	PRE
PU	.957**													
KU	.892**	.888**												
NUE	.844**	.920**	.848**											
PUE	.844**	.920**	.848**	1.000**										
KUE	.844**	.920**	.848**	1.000**	1.000**									
NPE	0.389	0.523	0.511	.799**	.799**	.799**								
PPE	0.572	.624*	.709**	.823**	.823**	.823**	.831**							
KPE	0.442	0.547	0.383	.777**	.777**	.777**	.905**	.687*						
NAE	.971**	.979**	.902**	.883**	.883**	.883**	0.465	.645*	0.474					
PAE	.971**	.979**	.902**	.883**	.883**	.883**	0.465	.645*	0.474	1.000**				
KAE	.971**	.979**	.902**	.883**	.883**	.883**	0.465	.645*	0.474	1.000**	1.000**			
NRE	.984**	.932**	.879**	.807**	.807**	.807**	0.341	.581*	0.386	.975**	.975**	.975**		
PRE	.956**	.992**	.888**	.902**	.902**	.902**	0.502	.618*	0.522	.991**	.991**	.991**	.948**	
KRE	.874**	.857**	.975**	.800**	.800**	.800**	0.442	.713**	0.314	.908**	.908**	.908**	.902**	.878**

** significant correlation at the 0.01 level (2-tailed).

* significant correlation at the 0.05 level (2-tailed).

NU: nitrogen Uptake, PU: Phosphorus Uptake, KU: Potasium Uptake, NUE: Nitrogen Use Efficiency, PUE: Phosphorus Use Efficiency, KUE: Potasium Use Efficiency, NPE: Nitrogen Physiological Efficiency, PPE: Phosphorus Physiological Efficiency, KPE: Potasium Physiological Efficiency, NAE: Nitrogen Agronomic Efficiency, PAE: Phosphorus Agronomic Efficiency, KAE: Potasium Agronomic Efficiency, NRE: Nitrogen Recovery Efficiency, PRE: Phosphorus Recovery Efficiency, KRE: Potasium Recovery Efficiency

Table 36 displays the effect of Thallo and NPK on soil properties after harvesting cowpea.

Soil pH ranged from 6.1 to 6.6. The soil with no treatment recorded the least pH value followed by NPK with Thallo recording the highest value. The soil pH significantly ($p<0.05$) increased in the experimental plot amended with Thallo. Relative to control, application of the NPK fertilizer decreased soil pH though the difference wa s insignificant. The treatments significantly impacted the percent soil nitrogen giving a range of 0.06% and 0.2%. Thallo recorded the highest percent N with the control recording the least. Relative to the control, the application of Thallo and NPK significantly ($p< 0.05$) elevated thes percent N within the soil with an increase of 233% and 216% respectively. The addition of Thallo significantly increased the soil organic carbon (SOC) more than the control and NPK treatments. NPK treated plot recorded SOC value higher than that of the control. The order of increase followed control<NPK<Thallo.

Similar trend was observed for available P. Thallo amended soil significantly ($p<0.05$) elevated available P by 278% and 216% relative control and NPK respectively. NPK treated soil also significantly ($p<0.05$) increased the soil available P by 37% compared to the control.

Exchangeable potassium value ranged between 0.2 to 0.35. NPK treated soil increased the K value relative to the control but the difference was insignificant. The Thallo significantly increased the K level by 59% and 25% over the control and NPK.

Agronomic Performance of Cowpea at Harvesting Following the Application Of NPK and Thallo Fertilizers.

Plant height, pod length and number of pods influenced by the application of Thallo and inorganic NPK fertilizer are shown in Figures 13, 14 and 15 respectively.

Cowpea height at harvesting as influenced by NPK and Thallo ranged from 40 cm to 52 cm (Fig 13). Control recorded the lowest plant height with Thallo recording the highest. Relative to control, plant height increased significantly ($p<0.05$) in the experimental plots amended with Thallo and NPK However, the application of the NPK fertilizer decreased the plant height compared to the Thallo though the difference was insignificant.

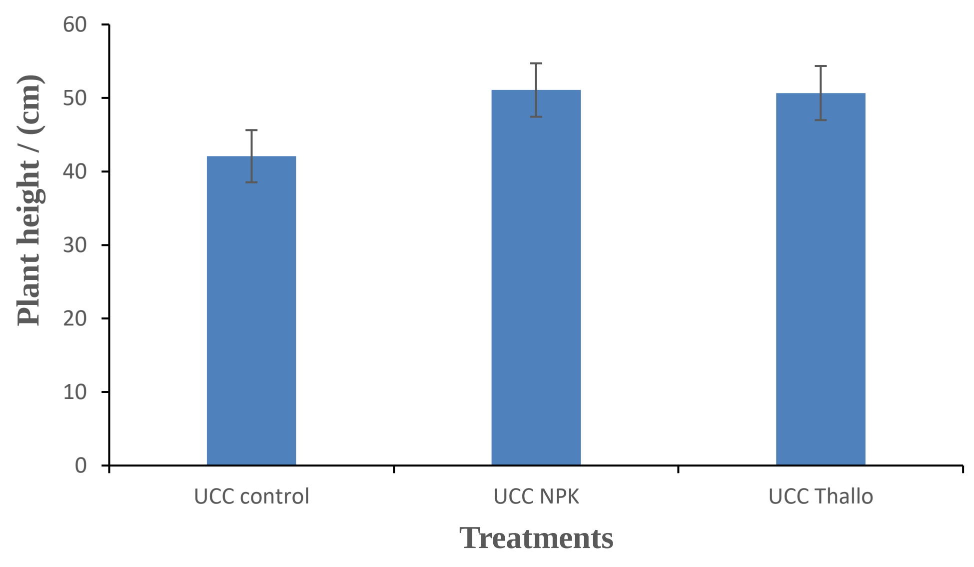

Figure 13: Plant height influenced by NPK and Thallo on cowpea at harvesting

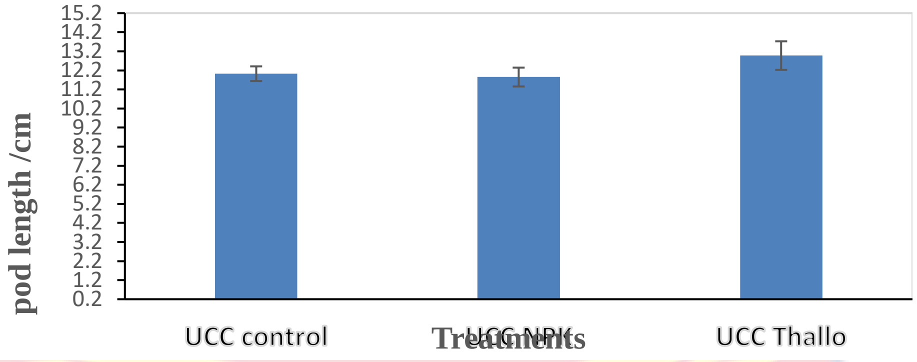

Figure 14: Effect of NPK and Thallo on pod length of cowpea at harvesting

Pod length as affected by the application of Thallo and NPK was within the range of 11cm to 13 cm (Fig 14). Thallo recorded the lengthy pod with the control obtaining the shortest. Relative to control, pod length increased significantly ($p<0.05$) in the experimental plots amended with Thallo. Thallo elevated the pod length relative to NPK but the difference was insignificant.

Thallo amended plant had the highest average pods number with the control recording the least. Thallo significantly produced higher number of pod than NPK and the control treatments. NPK and control plots were insignificant (Fig 15).

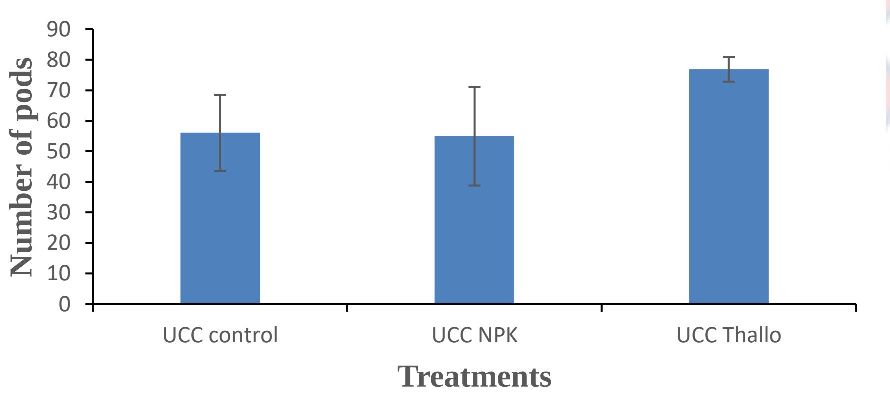

Figure 15: Effects of Thallo and NPK on the number of pods of cowpea at harvesting

Effect of NPK and Thallo on the Number of Branches, Leaves Number, Shoot Root Ratio and Harvest Index at Harvesting of Cowpea

Number of branches, number of leaves, shoot root ratio and harvest index at harvesting following NPK and Thallo addition have been displayed in Table 37.

The lowest number of branches was recorded by control, followed by NPK with Thallo recording the highest number. Thallo and NPK significantly ($p<0.05$) increased the number of branches relative to control with a percent increase of 75 and 56.7 respectively. However, the difference between Thallo and NPK was insignificant.

Control recorded the lowest number with Thallo recording the highest number of leaves. NPK significantly ($p<0.05$) elevated the number of leaves compared to control but decreased the number relative to the Thallo. Thallo significantly ($p<0.05$) elevated the number of leaves compared to both control and NPK. The trend of increase followed; control<NPK<Thallo.

The shoot root ratio as influenced by the treatments was within the range 5.33 to 8.95. Thallo obtained the highest shoot root ratio followed by NPK whilst control recorded the least ratio.

Table 37: Effect of NPK and Thallo on Number of Branches, Number of Leaves, Shoot Root Ratio and Harvest Index of Cowpea at Harvesting

Treatment	Numberof branches Plant^{-1}	Numberof leaves Plant^{-1}	Shoot:Root Ratio Plant^{-1}	Harvest Index (%)
Control	6.40a	35.22a	5.33a	22.74a
NPK	10.03b	63.95b	6.56a	23.17a
Thallo	11.20b	70.90c	8.95a	35.96b
p-value	<0.05	<0.05	0.403	<0.05
LSD	0.571	2.999	5.87	10.18

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

Thallo treated plants recorded high percent harvest index relative to control and NPK. The results recorded by control was lower than the NPK. Thallo increased the percent harvest index by 58 and 53 more than the control and NPK treatments. The difference between control and NPK was statistically similar.

Impact of NPK and Thallo on Nodule Formation and N-fixation

Table 38 represents the effect of NPK and Thallo on number of nodules, active nodules, percent activity and N-fixation of cowpea.

The plot with no amendment recorded the least number of nodules (18.77) with thallo recording the highest number of nodules (47.17). Thallo increased the nodules number more than the control and NPK by 151% and 137%. NPK and control recorded nodules numbers that were statistically the same.

Table 38 NPK and Thallo application on number of nodules, active nodules, percent activity and N-Fixation

Treatment	Number of nodules/plant	Active Nodules/plant	Active nodules (%)	N-Fixation (%)
Control	18.77a	9.95a	46.88a	62.50a
NPK	19.88a	10.62a	466.14a	67.86b
Thallo	47.17b	31.32b	66.49b	72.94c
P-value	<0.05	<0.05	<0.05	<0.05
LSD	2.02	3.59	10.00	0.37

Means attached with the same alphabets are not statistically different according to Fisher’s unprotected LSD test at $P \leq 0.0\ 5$.

The number of active nodules was lower on the control amended plot. Thallo significantly increased the active nodules with a percent increase of 214 and 194 more than the control and NPK .

Percentage of active nodules was significantly affected by the treatment. Control obtained the least percentage followed by NPK and then the Thallo. Thallo significantly increased the activity percentage relative to control and NPK. NPK increased the percentage activity compared to control but the difference was insignificant.

With regard to N-fixation, Thallo amended plot recorded the highest fixation with control obtaining the least. Thallo significantly ($p<0.05$) increased the N-fixation in relation to control and NPK. Control recorded percentage N-fixation significantly lower than the plot treated with NPK fertilizer. The trend of decrease followed Thallo>NPK>control.

Yield and Yield Indices of Cowpea Following the Application of NPK and Thallo Fertilizers

Number of seed per pod and pod weight as influenced by the application of NPK and Thallo fertilizers are shown in Table 39.

The number of seed in a pod varied between 7.57 and 15.85. Thallo amended plot recorded the highest number of seed in a pod whereas control recorded the least number. Thallo significantly increased the number of seed compared to control and NPK. NPK amended plot significantly increased the seed number per pod relative to control. The increase followed the trend; control<NPK<Thallo. Weight per pod ranged from 1.475 to 2.375. Control recorded lightest weight of the bean pod with Thallo obtaining the heaviest pod. The pod weight recorded by NPK treated plant increased by 5.4% relative to the control even though the increase was insignificant. Thallo however, significantly ($p<0.05$) elevated the pod weight by 60.8% and 52.5% over control and NPK respectively.

Table 39: Effect of NPK and Thallo on number of seed per pod and pod weight

Treatment	No. seed /pod	Pod weight (g)
Control	7.57a	1.48a
NPK	11.75b	1.56a
Thallo	15.85c	2.38b
p-value	<0.05	<0.05
LSD	1.57	0.32

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

The influence of NPK and Thallo fertilizers on 100 seed weight and seed yield are shown in Table 40.

Thallo treated plant recorded the highest 100 seed weight followed by NPK treated plant with no treatment plant obtaining the least seed weight per plant. Thallo significantly (p<0.05) increased the 100 seed weight relative to control and NPK by 33.3% and 29% respectively. NPK insignificantly increased the 100 seed weight relative to control.

Table 40: Effect of NPK and Thallo on 100 seed weight and seed yield

Treatment	100 seed weight (g)	Seed Yield (t ha^{-1})
Control	15.00a	2.75a
NPK	15.50a	2.92a
Thallo	20.00b	6.09b
P-value	< 0.05	< 0.05
LSD	3.063	1137

Means attached with the same alphabets are the same according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

The ammendemnts significantly influenced the seed yield. Thallo amended plot recorded the highest seed yield with control recording the least yield per hectare. Thallo significantly increased the seed yield relative to control and NPK by 121% and 109% respectively. No treatment plot decreased the yield relative to the NPK treated plot but the increase was insignificant.

Effects of Thallo and NPK on nutritional quality of Cowpea

Proximate components as influenced by the application of NPK and Thallo are displayed in Table 41. NPK amended plot recorded highest dry matter content followed by control with Thallo recording the lowest dry matter content. Thallo recorded dry matter content significantly lower relative to control and NPK. However, NPK insignificantly ($p<0.05$) increased the dry matter content compared to the control. The moisture content followed a reverse trend of the dry matter with Thallo recording significantly the highest moisture content than the control and NPK. Control recorded moisture content similar to the NPK .

The highest fiber and protein contents were recorded by Thallo followed by NPK and then control. The increase was not significant.

There was no significant difference among the treatments with respect to carbohydrates and lipids contents. However, NPK treated plant recorded the highest carbohydrates contents with Thallo obtaining the lowest level of carbohydrates. Control recorded the highest lipids content relative to Thallo and NPK with NPK recording the least.

The ash content as affected by the treatments ranged from 4.08 to 3.55 %. No amended plant recorded the highest ash content with Thallo recording the least ash content. Control and NPK significantly increased the ash content relative to Thallo. Control and NPK recorded statistically similar percentage of ash content.

The mineral content of cowpea seed as influenced by the addition of NPK and Thallo are shown in Table 42. There was no significant difference observed in the concentration of nitrogen, phosphorus and potassium in the cowpea seed among the treatments. However, Thallo recorded the highest N concentration followed by NPK and then control.

Control recorded the highest concentration of P and K with Thallo recording the least P and K. Concentration of calcium ranged between 500 ug $g^{-1}$to 861 ug g^{-1}. Thallo recorded the highest Ca concentration (860.9 ug g^{-1}) followed by NPK (858 ug g^{-1}) with control recording the least (511.3 ug g^{-1}). Thallo and NPK significantly increased the Ca concentration by 68.4 % and 67.8% respectively relative to control. No significant difference was observed between the Ca concentrations in the seed for the NPK and Thallo treatments.

Control recorded the lowest magnesium concentration followed by NPK with Thallo recording the highest level. Thallo increased the concentration of Mg relative to NPK but the difference was insignificant. Control significantly recorded the lowest Mg concentration by 15% and 11% relative to Thallo and NPK treatments respectively.

The concentration of sodium ranged between 297 ug g^{-1} to 233 ug g^{-1}. Control recorded the highest concentration with NPK obtaining the lowest concentration of Na. Control recorded significantly higher Na concentration than Thallo and NPK. Thallo significantly increased the Na level compared to NPK. The trend of increase followed NPK<Thallo<Control.

The zinc concentration in the seed as influenced by the treatments varied between 65.5 ug g^{-1} and 181 ug g^{-1}. NPK treated plant recorded the lowest Zn content (65.5 ug g^{-1}) with Thallo obtaining the highest Zn concentration (180.1 ug g^{-1}). Thallo significantly increased the Zn concentration relative to control and NPK. NPK treated plant significantly reduced the Zn concentration compared to the control. The order of Zn concentration increase followed; NPK<control<Thallo.

Significant difference was observed with regards to iron concentration in the cowpea seed as influenced by the treatments. NPK and Thallo significantly increased the Fe concentration by 103% and 69% respectively compared to Control. NPK significantly reduced the Fe concentration by 20.5% relative to Thallo. The increase followed the trend; control<NPK<Thallo.

Effect of NPK and Thallo on N, P, and K uptake and use efficiency of cowpea

The influence of NPK and Thallo on the N, P, and K uptakes and use efficiencies are shown in Table 43.

Effect of NPK and Thallo on N, P, and K uptake and use efficiency of cowpea

The influence of NPK and Thallo on the N, P, and K uptakes and use efficiencies are shown in Table 43.

Table 41: Effect of NPK and Thallo on proximate components of cowpea

Treatment	Dry Matter	Moisture (%)	Fiber (%)	Ash (%)	Carbohydrate (%)	Protein (%)	Lipids (%)
Control	90.70b	9.30a	4.40a	4.08b	67.65a	22.41a	1.46a
NPK	91.20b	8.80a	4.54a	3.86b	67.83a	22.47a	1.30a
Thallo	90.05a	9.95b	4.63a	3.55a	67.41a	23.02a	1.40a
p-value	<0.05	<0.05	0.88	<0.05	0.83	0.61	0.36
LSD	0.63	0.63	1.01	0.33	1.58	1.48	0.24

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0 5$.

Table 42: Effect of NPK and Thallo on mineral concentrations of cowpea

Treatment	Nitrogen (%)	Phosphorus (ug g^{-1})	Potassium (ug g^{-1})	Calcium (ug g^{-1})	Magnesium (ug g^{-1})	Sodium (ug g^{-1})	Zinc (ug g^{-1})	Iron (ug g^{-1})
Control	3.59a	6015a	4804a	511.30a	1743a	297.40c	93.00b	34.60a
NPK	3.59a	6008a	4763a	858.00b	1950b	150.60a	65.50a	58.42b
Thallo	3.68a	5816a	4520a	860.90b	2049b	233.00b	180.10c	70.38c
p-value	0.61	0.82	0.27	<0.05	<0.05	<0.05	<0.05	<0.05
LSD	0.24	809.00	396.60	124.90	141.20	7.22	13.25	3.11

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0$ 5.

Table 43: NPK and Thallo effect on nutrient uptake and nutrient use efficiency of cowpea

	Nutrient Uptake (kg ha^{-1})			Nutrient Use Efficiency (kg ha^{-1})		
Treatment	**N**	**P**	**K**	**N**	**P**	**K**
Control	24.46a	4.07a	3.28a			
NPK	25.94a	4.35a	3.44a	29.16a	11.01a	14.73a
Thallo	56.22b	8.84b	6.89b	60.94b	23.00b	30.78b
P-value	<0.05	<0.05	<0.05	<0.05	<0.05	<0.05
LSD	11.50	1.69	1.42	9.35	3.53	4.72

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.0\ 5$.

The uptakes of nitrogen, phosphorus and potasium varied from 24.46 kg ha^{-1} to 56.22 kg ha^{-1} for N, 4.066 kg ha^{-1} a to 8.842 kg ha^{-1} for P and 3.275 kg ha^{-1} to 6.885 kg ha^{-1} a for K.

Thallo recorded the highest nitrogen, phosphorus and postassium uptakes followed by NPK with the lowerest reported for the control treatments. Thallo significantly increased the N, P and K uptakes relative to control and NPK.

With regards to nutrient use efficiency, Thallo significantly increased the N, P and K use efficiencies by 109% relative to NPK

Table 44: NPK and Thallo application on nutrient use efficiency indices

Treatmet	Agronomic efficiency			Physiological efficiency			Recovery efficiency		
	N	P	K	N	P	K	N	P	K
Control									
NPK	1.7a a	0.64a	0.86a	105.5a	717.8a	845.1a	0.014a	0.0010a	0.00085a
Thallo	33.4b	12.63b	16.91b	146.8a	699.8a	932.7a	0.317b	0.0180b	0.01823b
P-value	<.001	<.001	<.001	0.116	0.013	0.015	<.001	<.001	<.001
LSD	11.51	10.11	5.81	145.7	482.2	628.6	0.1043	0.00543	0.00672

Means attached with the same alphabets are not statistically different according to Fisher's unprotected LSD test at $P \leq 0.05$.

Table 44 shows the influence of NPK and Thallo on agronomic, physiological and recovery efficiencies of cowpea.

Thallo treated plant recorded the highest agronomic efficiencies with NPK recording the lowest. Thallo significantly increased the N, P and K agronomic efficiencies by 186.4, 187 and 187 % respectively compared to NPK treated plant.

There was no significant difference observed among the treatments regarding N, P and K physiological efficiencies. However, Thallo recorded higher N and K whereas NPK recorded higher P physiological efficiencies.Thallo significantly increased the N, P and K recovery efficiencies by 216%, 170% and 204% respectively compared to NPK.

Properties after Harvesting

SY: Seed yield, NSP: Number of seed per pod, HSW: Hundred seed weight, HI: harvest index, N-fix: Nitrogen fixation, pH: soil pH, OC: soil organic matter, N: soil nitrogen, Av.P: available phosphorus, Exch.K: Exchangeable potassium, NPP: Number of Pods per Plant, PH: Plant Hieght, NN: Number of Nodules, AN: Active Nodules.

Table 45: Correlation Matrix Between Yield and Yield Indicators of Cowpea and Soil Chemical

PARAMETER	SY	NSP	HSW	HI	N-fix	pH	OC	N	Av.P	Exch.K	NPP	PH	NN
NSP	.810**												
HSW	.762**	.713**											
HI	.834**	.582*	.786**										
N-fix	.735**	.843**	.682*	.628*									
Ph	.768**	.802**	.673*	.617*	.858**								
OC	.923**	.891**	.803**	.731**	.829**	.851**							
N	.745**	.868**	.707**	0.407	.817**	.692*	.644*						
Av.P	.816**	.962**	.734**	.628*	.903**	.857**	.923**	.882**					
Exch.K	.728**	.805**	0.574	0.421	.591*	.624*	.753**	.705*	.800**				
NPP	.851**	.606*	0.406	.612*	0.502	0.477	.685*	0.341	.580*	0.535			
PH	0.303	0.561	0.21	0.137	0.511	0.489	0.463	.765**	.689*	.650*	0.169		
NN	.902**	.817**	.805**	.718**	.769**	.807**	.984**	0.81**	.847**	.687*	.660*	0.34	
AN	.902**	.820**	.833**	.730**	.761**	.788**	.977**	0.554	.865**	.727**	.633*	0.413	.982**

**significant correlation at the 0.01 level (2tailed).

* significant correlation at the 0.05 level (2-tailed).

Table 46: Correlation matrix between NPK Uptake and their Use parameters

Parameters	NU	PU	KU	NUE	PUE	KUE	NPE	PPE	KPE	NAE	PAE	KAE	NRE	PRE
PU	.921**													
KU	.846**	.896**												
NUE	.654**	.575**	.759**											
PUE	.654**	.575**	.759**	1.000**										
KUE	.654**	.575**	.759**	1.000**	1.000**									
NPE	0.168	0.221	.445*	.472*	.472*	.472*								
PPE	0.219	0.231	.420*	.444*	.444*	.444*	-0.004							
KPE	0.391	0.205	0.317	.608**	.608**	.608**	0.334	-0.152						
NAE	0.14	0.195	.511*	.626**	.626**	.626**	.463*	.647**	0.354					
PAE	0.14	0.195	.511*	.626**	.626**	.626**	.463*	.647**	0.354	1.000**				
KAE	0.14	0.195	.511*	.626**	.626**	.626**	.463*	.647**	0.354	1.000**	1.000**			
NRE	0.34	0.323	.576**	.758**	.758**	.758**	0.329	.707**	.432*	.938**	.938**	.938**		
PRE	0.117	0.216	.451*	.559**	.559**	.559**	0.311	.654**	0.238	.953**	.953**	.953**	.923**	
KRE	0.186	0.243	.564**	.658**	.658**	.658**	.446*	.674**	0.296	.984**	.984**	.984**	.936**	.956**

** Correlation is significant at the 0.01 level (2-tailed).

*Correlation is significant at the 0.05 level (2-tailed

NU: nitrogen Uptake, PU: Phosphorus Uptake, KU: Potasium Uptake, NUE: Nitrogen Use Efficiency, PUE: Phosphorus Use Efficiency, KUE: Potasium Use Efficiency, NPE: Nitrogen Physiological Efficiency, PPE: Phosphorus Physiological Efficiency, KPE: Potasium Physiological Efficiency, NAE: Nitrogen Agronomic Efficiency, PAE: Phosphorus Agronomic Efficiency, KAE: Potasium Agronomic Efficiency, NRE: Nitrogen Recovery Efficiency, PRE: Phosphorus Recovery Efficiency, KRE: Potasium Recovery Efficiency

CHAPTER FIVE

DISCUSSION

Response of Soil Chemical Properties, Maize Growth, Yield, Nutritional Quality and Nutrient Use Efficiency following the Application of Thallo and NPK

Response of Some Soil Chemical Properties to NPK and Thallo Application

At the end of the experiment, Thallo improved the soil chemical properties. This is attributable to the conducive soil atmosphere created by the Thallo that resulted in mineral N, organic carbon, available phosphorus and exchangeable potassium.

NPK treated soil reduced the pH of the experimental soil at UCC and Jukwa respectively compared to initial pH of the soils. This decrease in soil pH by the NPK treatment could be as a result of low basic cation content in NPK and N transformational process associated with the application of N fertilizers. This confirms the findings of Palmer et al., (2011) who opined that inorganic fertilizer such as NPK accelerated soil acidification. Also, soil pH decreased due to the liberation of H^+ during urea hydrolysis and NPK fertilizer transformation in soil (Palmer et al., 2011). On the other hand, Thallo exerted a liming effect on both soils by increasing significantly the pH by 0.12 units and 0.23 units at Jukwa and UCC respectively compared to initial soil pH. This is consistent with the ash content and high pH of the Thallo used for the experiment (Table 4). The decomposition of the Thallo may have released high contents of basic cations (Ca, Mg, K and Na) which increased the pH of the experimental soil. Brady & Weil (2016) explained that the presence of basic cations (e.g exchangeable K) displace acidic cations (Al^{3+}), causing the pH to be elevated. The increase in pH in Thallo amended soils provides an advantage for nutrient availability, enhanced macro fauna and microbial activity and reduce aluminum toxicity to plants roots. Brady and Weil., (2016) explained that P precipitation, aluminum toxicity, and reduce N mineralisation, earthworm turnover, occur at low pH.

Although mineral N content increased in amended soils, Thallo recorded significant value relative to the control and the NPK in all experimental soils. This might be due to high total and available N reserves of same. Thallo fertilizer might undergo slow decomposition resulting in the steady release of plant N into the soil. Also, due to the high N reserves, utilized available N is restored continuously in soil. In contrast, the NPK had readily soluble nitrogen and are either taken up by plant, volatilized and or leached causing its rapid depletion in soil.

Thallo increased the organic carbon content by 280% and 77 % over control and NPK respectively at Jukwa and by 166% and 117% over control and NPK respectively at UCC. Higher OC could be due to mineralization of Thallo to released labile carbon. Organic C is a major source of energy to soil microbes, helps to bind soil aggregates to form a good soil structure and overall driver of soil productivity (Palmer et al., 2011). The application of Thallo as organic source could therefore be a prudent approach in enhancing the organic C content of soils in these agro zones in the humid tropics.

In terms of available P, Thallo increased the soil P content in all the experimental soils. The high amount of available P in the Thallo, together with related factors like increase in pH and mineralization of organic P from the

Thallo may be responsible for the enhanced elevation of Available P in the soils compared with the NPK.

The significant K fertilization effect across the experimental zones is consistent with the properties and the effects of the Thallo. The Thallo applied contained high amounts of basic cations and may have the retention and exchange of K.

Effect on Agronomic Performance of Maize

Consistently, all the mean plant height for all treatments increased in all the two agro zones. At weeks 4 and 5 at both sites, NPK and Thallo treated soils recorded similar plant height but significantly different from the control. During the 6th and 7th weeks NPK at both sites out grew Thallo treated soil recording higher plant height significantly different from both Thallo and control. Although Thallo was increasing weekly it was at a decreasing rate but NPK increased at an increasing rate from week 6 after planting to week 7. This increase in maize plant height by the inorganic fertilizer could be as a result s to readily available N of inorganic fertilizers. It therefore suggests that N in Thallo was gradually released. This results confirms the opinion of Chen (2008), who opined that increase in plant height by NPK amended soil could be attributed to the availability of nutrients as inorganic NPK fertilizer is readily soluble, thereby releasing nutrients easily following their addition to the soil (Chen, 2008).

At 7th week Thallo increased the leaf area relative to control and NPK. This is attributable to increased release of nutrients at this point by the Thallo as inorganic NPK releases nutrients readily upon application. This is because higher level of nitrogen was released that enhanced the vegetative growth which ultimately increased leaf area helping to maintain functional leaf area during the growth period.

Chlorophyll index (Fig 2) was similar for NPK and Thallo at both sites from week 4 and 5. NPK increased the chlorophyll index in the 6th week relative to the thallo treatment. This is due to quick release of N by inorganic fertilizers since the two amendments were applied same day. At week 7, NPK and Thallo treated soils at both sites were similar. This may be as a result of release of N at this point by Thallo well enough after going through decomposition to cause elevation of chlorophyll index similar to that of NPK.

The results of this work indicated a significant difference between NPK and Thallo with regard to tasselling and fruiting of maize. Thallo significantly increased the rate of tasselling and fruiting across all the two experimental zones. This increased rate of tasseling and fruiting may be associated with the release of nutrients by Thallo to speed up such physiological processes.

Effects of NPK and Thallo on the Mean Yield and Yield Attributes of Maize

From Table 6, significant difference existed among the treatments with regard to ear length, ear diameter and ear weight as shown. Maize plots amended with Thallo had superior mean of the three attributes across the two experimental zones. Thallo treated plots had higher yields maybe due to increased nutrient availability. Also, higher nutritient availability during the reproductive stage might have also boosted grain filling, resulting in increased cob weight. The ear weight, ear length and ear diameter all showed positive correlation (Table 13) with N, P K and OC of the soil. At both zones Thallo reported enhanced 1000 seed weight over inorganic NPK. The increase in 1000-

grain weight above control and NPK was mostly due to a more balanced supply and availability of nutrients during the reproductive phase, which enhanced the filling of the grains and consequently grain weight. Grain yield was also significantly affected in both experimental sites by the treatments. Thallo amended soils recorded the highest mean grain yield compared to control and NPK in all the two agro zones. The observed yield increase according to Udom & Bello (2009) is due to availability of plant nutrients. A threefold increase of maize yield of abattoir waste was observed by Ragályi & kádár (2012).

This result agrees with the work of Darch et al., (2019) who recorded a substantial elevation in yield of sand-grown grass with Thallo compared with mineral fertilizers. This is confirmed with positive correlation between yield and the 1000 seed weight (r =0.962), ear circumference (r =0.785), ear length (r = 0.779) and ear weight (r = 0.829) (Table 13). The yield also showed positive correlation with all the nutrients in the soil (Table 13).

Impact of NPK and Thallo on Maize Response to Pest and Disease Attack

Significance difference existed among the treatments effects on the crop’s response to pest and disease attacks (Table 8). The result showed that maize grown on Thallo treated plots recorded lower incidence of pest attack and mosaic streak attack.

The presence of some micro elements in the Thallo may aid to increase the crop's resilience to disease and pest attacks, resulting in a low incidence of pest and disease attack. This confirm the work of Nunes *et al*, (2014) who reported that presence of micro nutrients in plants improves the crops‘ resistance to pest and disease attacks.

Effect on Height At Maturity, Above Ground Dry Matter and Harvest Index of Maize

In all agrozones, this work clearly reveals that Thallo treatment impacted significantly on the plant height of maize at maturity relative to other amendments. Ability of Thallo to supply plant nutrients on a continual basis may be associated to its strong effect on maize height (Chen 2008; Gauri et al., 2006).

NPK and Thallo significantly increased the above ground dry matter relative to control at Jukwa. However, at UCC, Thallo significantly increased the above ground dry matter relative to control and NPK. This may be linked to the supply of plant nutrients especially N by both amendments. Dry matter production is believed to determine the photosynthetic assimilation or production with availability of N which will ultimately increases vegetative production (Sasson, 2017). Based on this Thallo improved the fertility of the amended soils through addition of essential nutrients and soil organic matter, which in turn improved the soil moisture and nutrient retention capacity (Karmal, 2009).

Across the two agro ecological zones, NPK and Thallo significantly increased the harvest index of maize more than the control (unamended), which can be explained by increased nutrients availability by Thallo and NPK (Mafi et al., 2013). The higher harvest index relative to the control means there is utilization of dry matter to grain yield in the maize produced from the amended plots.

Effects of NPK and Thallo on Proximate Components of Maize

This study showed no significant difference among the treatments on the dry matter, moisture and fibre contents of maize. This explains that both NPK and Thallo did not have any effect on the mentioned nutritional contents of the maize grain. However, the treatments exhibited significant difference among themselves with regards to ash, carbohydrates, protein and lipids contents of the grain. NPK treated soil recorded the highest ash content relative to control and Thallo amended soils across all the soil zones in this work. NPK treated soil yielded ash content similar to ones reported earlier by Matt et al., (2011) who recorded maize ash levels varying between 1.4% –3.3%. However, percentage range of ash by Thallo amended soils observed in this work was lower (1.1% – 1.2%) than the range reported. This is consistent with the findings of Ogunyemi et al. (2018), who found that maize grown using NPK fertilizer had the highest ash concentration compared with other amendments.

Maize lipid contents in this study varied between 3.6% and 4.0% with Thallo amended soil at UCC recording the significantly the highest fat content relative to control and NPK. This study also revealed that the use of NPK fertilizer produced higher lipids content than the control. This agrees with other researchers (Ndukwe et al., 2005). The carbohydrate levels of the maize varied significantly ($p < 0.05$) between the treatments. There was variation in carbohydrate content at both sites but at UCC Thallo recorded the highest carbohydrates content compared to NPK.

The range of percentage carbohydrate content recorded in this work is higher than the range recorded by Wilson et al., (1999) who obtained a marginally increased level of carbohydrate of about 72 percent to 73 percent, whereas Mlay et al, (2005) recorded 73.3 percent. The average levels of crude protein ranged from 8.1 percent to 12.4 percent. At UCC significant differences were observed among the treatments but no differences were shown at Jukwa. In all two sites, NPK recorded the highest protein content relative to Thallo and control. At UCC, the protein content of maize grown using NPK fertilizer was significantly higher. This confirms Matt et al., (2011), who found that higher nitrogen fertilization resulted in higher protein content in fertilized maize. This report echoed Worthington's (2001) findings that nitrogen from all types of fertilizers had an impact on the volume and quality of protein produced by plant.

The tropical soils are characterized by low pH, making them acidic. Most soils in the tropics are also deficient in plant nutrients especially nitrogen and phosphorus which affect crop growth and development. This study clearly revealed that Thallo significantly improved the soil fertility in different agro zones of Ghana. Soil chemical properties were increased by Thallo application in this work than NPK and control treatments. Thallo once again improved maize growth and yield significantly relative to NPK in all the experimental sites. The effect of Thallo on proximate components such as Dry matter, moisture, fibre, lipids and ash of the grains were similar to that of NPK. However, NPK had more effect on protein content than Thallo but less impact on carbohydrates.

What is more, Thallo had less influence on nitrogen, phosphorus, and magnesium concentrations in the grains compared to NPK. However, micro nutrients such as zinc and iron were significantly increased by Thallo in the maize grain. Both treatments had similar impact on the nutrients uptake by the plant but Thallo had elevated nutrient use efficiency across the experimental sites. Conclusively, this work revealed that Thallo had greater effects or impact on the soil fertility, growth, yield and nutritional quality of maize regardless of the agro zone

Effect of Thallo and NPK on Soil Chemical Properties, Cabbage Growth, Yield, Nutritional Quality and Nutrient Use Efficiency

Effect of NPK and Thallo on Soil Nutrient Status after Harvesting

The Thallo improved greatly the soil chemical properties in both agro zones. The Thallo treated soil had higher pH, total N, organic carbon, available phosphorus and exchangeable potassium.

Thallo exerted a liming effect on both soils by elevating the pH by 0.31 units and 0.35 units at Jukwa and UCC respectively which is significantly higher than NPK and control (Table 15). This increase in soil pH may be as a result of the ash content and high pH of the Thallo. NPK treated soil lowered the pH of the experimental soil by 0.14 units at Jukwa compared to initial pH of the soils. The decrease in soil pH by the NPK ammendment even though not significant may be linked to N transformational process associated with application of N fertilizers. This confirms the findings of Palmer et al., (2011) who reported that mineral fertilizers such as NPK elevated soil acidification.

Both NPK and Thallo significantly increased the total nitrogen of the soil relative to the control. However, Thallo recorded increased total nitrogen significantly higher relative to the control and the NPK in all experimental soils. This might be due to high N content of the Thallo which mineralized resulting in the release of N from the Thallo. Again the increased pH in the soil treated with Thallo helped in the release of N and other accessible nutrients within the soil.

Thallo elevated the soil organic carbon content by 55 and 43 % over control and NPK respectively at Jukwa and 59 and 33% over control and NPK respectively at UCC. The result indicated that Thallo amendment significantly enhanced SOC. Thallo might have also induced accelerated mineralization of the native soil organic carbon resulting in elevation of the total carbon in the Thallo amended soils.

In terms of available P, Thallo increased significantly the available P content of soil relative to control and NPK in all the two experimental soils. The elevated available P observed in this work upon Thallo application may be attributed to the high content of P in the Thallo coupled with factors such as increase in pH and mineralization of organic P from the soil. A positive significant correlation (Table 22) was found between pH and Available Phosphorus ($r = 0.80$; $p < 0.05$), indication that increase in pH enhanced the availability of phosphorus in amended soils (weil, 20016).

Relative to control and NPK, the application of Thallo significantly affected exchangeable K in the Thallo amended soils across the experimental zones. This may as a result of an increased and improved soil CEC. This revealed that the soil retained some of non-acidic cations or inorganic nutrients including potassium and other nutrients. In addition, the K elevation might also be associated with the increase in pH which affects positively the levels of basic cations such as Ca^{2+}, Mg^{2+} and K^{+} in amended soils. This is shown by the positive correlation (Table 22) between pH and exchangeable K ($r=0.74$, $p<0.05$).

Result of this work indicated that soil pH, total nitrogen, total organic carbon, available phosphorus, total exchangeable potassium showed positive correlation and significantly improved in the Thallo amended soils relative to control and NPK. This clearly shows that Thallo conferred excess nutrients in the treated plots and were not exhaustive hence their contributing to crop yield.

This confirms what Nunes et al., (2014) did. They reported improvements of soil Ca, Mg,N, K and available P as well as maize and soybean yields due to the application of abattoir waste composts.

Effect on Agronomic Performance of Cabbage

The increase in plant height by Thallo was at a decreasing rate whilst that of NPK was at an increasing rate. This suggests that Thallo slowly released its nutrient but NPK readily released its nutrients. The effect of NPK on the increasing rate of plant height has been reported by Chen (2008) who reported that increase in plant height by NPK amended soil could be attributed to the availability of nutrients as inorganic NPK fertilizer is a readily soluble, thereby releasing nutrient easily following their addition to the soil.

There was no significant difference between the NPK and Thallo treated soils with regard to leaf area. This suggests that both NPK and Thallo have no influence leaf number of the leaf are of the cabbage plant (Fig 7)

Chlorophyll index (Fig 8) also did not show any significant difference between NPK and Thallo at both sites. However, from week 4 to 6, Thallo recorded higher mean chlorophyll index than both control and NPK.

The results of this work also indicated that no significant difference was observed between NPK and Thallo with regard to bulb formation (Fig 9) of the cabbage plant. This suggests that NPK and Thallo have no effect on the bulb formation of cabbage.

Effect of NPK and Thallo on head Circumference (cm) and head weight (g) of Cabbage

The effect of Thallo and inorganic fertilizer on cabbage diameter was significantly different from the control in both sites (Table 16) There was statistically significant effect observed between Thallo and the control. This compares with the result obtained by Olaniyi et al., (2009) where cultivation of cucumber under the impact of organo mineral fertilizer resulted in increased mean value when compared with the control. Also the presence of nitrogen ensured vigorous plant growth and subsequently resulted in the highest diameter and thickness of heads. This was in conformity with the findings of Pramanik (2007) who reported similar result and opined that the diameter and thickness of head increased with the increasing level of nitrogen that favored the growth of plants. However, there was not significant difference between the two amendments in both zones as far as cabbage head circumference is concerned.

The impact of Thallo on cabbage head weight was significantly different from the control and inorganic fertilizer in both sites (Table 16). The result showed significant difference between the different treatments and the control on the weight of cabbage head in both sites. At both sites the lowest mean value was recorded by control (298.8 g and 555.9 g) followed by NPK (530.8 and 950.1 g) with Thallo recording the highest mean value (600.4 and 1165.8) for Jukwa and UCC respectively. Control and NPK at Jukwa were not significantly different from each other. However, at UCC, NPK and control were significantly differently from each other. Thallo at both sites was significantly from both control and NPK.

The higher head fresh weight could be attributed to the higher soil nutrients released from the Thallo which could be correlated to the increase in head fresh weight of cabbage. The significant difference observed agrees with the findings of Olaniyi et al., (2009) which reported higher mean value in fruit weight of cucumber under the application of organo mineral fertilizer.

Effect of NPK and Thallo on Harvest index (%), Shoot Root Ratio and number of leaves at maturity

There was significant difference in the harvest index among the treatments across both sites (Table 17). Thallo significantly increased the harvest index over the control in the two agro zones. However, Thallo recorded higher mean value of harvest index relative to NPK in the two agro sites. The increase in the harvest index may be attributed to the higher P and Zn levels in the Thallo fertilizer. Mafi et al,, (2013) reported that high P and Zn levels increase yield and HI. This was also confirmed by Fageria et al., (2011) who opined that there is positive relationship between harvest index and P and Zn fertilization.

However, no significant difference was observed on the number of leaves by the treatments but Thallo obtained the highest mean leaves number across the two locations compared to control and this could be as a result of nutrient differences.

It was observed in both Jukwa and UCC that the effect of the application of Thallo fertilizer on shoot root ratio was highly significant compared to both control and NPK. Thallo significantly showed higher mean shoot root ratio with about 120% and 42% at Jukwa 28% and 32% at UCC over the control and NPK respectively.

Cabbage Head Yield (t ha^{-1})

The gross yields of cabbage exhibited statistically significant differences due to the application of the amendments in both sites (Table 18). At Jukwa the maximum gross yield (20.02 kg ha^{-1}) was recorded by Thallo and it was statistically similar (17.69 t ha^{-1}) to the NPK but statistically different from the control (9.96 t ha^{-1}) which recorded the lowest. At UCC, Thallo amendment recorded significantly the highest head yield (38.86 t ha^{-1}) representing about 110% and 23 % over the control and NPK respectively. This observed yield increase could be as a result of adequate supply of soil nutrients by Thallo needed for growth and development of the plant, which led to the production of higher assimilate, that was judiciously partitioned into the economic parts of the plant. This corroborates the work by some researchers (Ylivainio et al., 2008, Nogalska, 2016) who reported on the beneficial impact of MBM on crop yields. Several studies conducted by Agegnehu (2017); Mekuria et al., (2014); and Major et al., (2010) showed that increase in yield can be attributed to the availability of soil nutrients by fertilizers. Parmar et al., (1999) reported that the higher yields in cabbage were associated with the increased rates of higher nitrogen supply. The results also confirms that of Udom & Bello (2009).

Effects of NPK and Thallo on Proximate Components of Cabbage Head

This study showed no significant difference among the treatments on protein and lipids contents of the cabbage head (Table 19). This implies that both NPK and Thallo did not have any effect on the named nutritional contents of the cabbage head. However, significant difference existed among the treatments with regards to dry matter, moisture content, ash, carbohydrates and fibre contents of the cabbage head. This is supported by Matt et al., (2011) who recorded a higher ash, carbohydreates and fibre contents in maize grown on NPK compared to control.

The result revealed high dry content recorded by Thallo though was not significantly different from control and NPK at there was significance difference at UCC. This resulted in lower moisture content not significant at

Jukwa but significant at UCC. This high moisture content recorded by Thallo treated soils with its corresponding low moisture content of the cabbage head is a suggestion that Thallo will increase storability and this will reduce the microbial infection and putrefaction of the cabbage head (Mlay et al., 2005). Regarding ash content, Thallo recorded higher level relative to control and NPK across the two zones. This increase was significant compared to control but similar compared to NPK this is in agreement with Matt et al., (2011). The increased ash content recorded may coming from high ash contet determined in the Thallo fertilizer. For carbohydrates content, both Thallo and NPK across the two agro zones recorded significantly similar lower level compared to the control. This suggest that both and NPK had no or little effect on the carbohydrates contents of the cabbage head.

Effects of NPK and Thallo on the Mineral Concentrations in Cabbage Head

An increase of N content was observed at Jukwa and UCC by the Thallo amended soils relative to the control and NPK (Table 20). At Jukwa the increase was significant but not significant at UCC. With regards to phosphorus, NPK recorded the highest mean P concentration in all the two zones relative to control and Thallo but the increase was not significant. The potassium concentration in the cabbage head was higher at Jukwa but lower at UCC. Similar trend was observed for calcium and magnesium. With regard to sodium NPK at both sites recorded higher mean concentration that control and NPK. The high levels of the basic cations (K, Mg and Ca) and P in the NPK treated soil would be attributed to the rapid breakdown of the NPK fertilizer. That notwithstanding, Thallo by these results has revealed it would have greater residual effect as it had higher N, P and K in the soil for subsequent crops to use.

Thallo in this work recorded higher mean levels with regards to zinc and iron concentrations across the two zones.

This result is in conformity with Darch et al., (2019) who reported an increased levels of Zinc concentration under the influence of Thallo on grass and wheat. Also Joy et al, (2015) reported that Zn-enriched fertilizers recorded elevations in Zn concentration in maize, rice and wheat grains. This is as a result of the zinc and iron contents observed in Thallo that might increase the Zinc and iron concentrations in the cabbage head from the Thallo amended soils.

Effects of NPK and Thallo on The Nutrient Uptake and use Efficiency by Cabbage

At Jukwa, Thallo recorded higher mean values for N, P and K uptakes. This increase was statistically similar to the control and the NPK (Table 21). Similar at UCC, Thallo recorded elevated levels of N, P, and K that was significantly different from control and NPK.

The increased nutrient uptake for Nitrogen, Phosphorus and Potasium in the Thallo treated plant could be due to the nutrients released by Thallo fertiliser making it accessible for use. The increase in the uptake of nutrients by cabbage head with application of Thallo is an indication that Thallo served as a storehouse of plant nutrients, which provide optimum nutrients for crop.

In addition, the results suggested that Thallo reduced the sorption and leaching of nutrients making available for plant uptake. The significantly ($P < 0.05$) high head yield (Table 18) and nutrients uptake (Table 21) by Thallo indicates that addition of nutrients improves nutrient uptake resulting in higher yield (Mekuria et al., 2014)

Regarding nutrient use efficiency, Thallo recorded higher mean values for N, P and K compared to NPK at Jukwa but the increase was not significant from NPK. At UCC, similar trend was observed except that Thallo recorded significantly higher N use relative to NPK.

The significant increased nutrient use efficiency in Thallo can be attributed to the readily available nutrient supplied by the Thallo. It is also observed from this work that nutrient use efficiency is directly dependent on the nutrient uptake by the plant. This is shown in the correlation matrix (Table 23). This further revealed that application Thallo can efficiently transform the applied nitrogen to economic yield.

Effects of NPK and Thallo on the Nutrient use Efficiency Indices of Cabbage

Thallo recorded increased mean agronomic efficiency of N, P and K across the two experimental sites (Table 23). However the increase was not significant at Jukwa but significant at UCC. This elevated agronomic efficiency by Thallo indicated high response of applied plant nutrient towards economic yield of cabbage head. This could be as result of optimum availability of plant nutrients as needed by crop and minimum nutrients losses resulting into efficient uptake and utilization of applied nutrients Sigh et al., (2008).

Regarding Physiological efficiency Thallo obtained higher N values that were significantly different compared to NPK in the two agrozones. This superior N value of physiological efficiency under Thallo treatment could be attributed to higher yield recorded under Thallo treatments, which indicated efficient conversion of source to sink by Thallo. This is supported bt Darch et al., (2019) who recorded high yield in a sand grown grass under Thallo treatment.

However, Thallo and NPK had no significant effect on P physiological efficiency across the two zones. K physiological efficiency as influenced by NPK was significantly higher at Jukwa but similar at UCC. This indicated that addition of NPK released enough K contributing to yield output of the cabbage head.

The result showed that under Thallo treatment nutrient recovery efficiency was higher in all the agro zones compared to NPK. With N recovery, the increase was significantly different in the two zones. With P and K, recovery efficiency was statically similar at Jukwa but significantly different at UCC. The elevated nutrient recovery in presence of Thallo may be attributable availability of nutrients supply to the root zone of the plants that might have improved the availability of nutrients to the plant (Udoma & Bello 2009). This finally might result in conversion of the applied nutrients to economic yield more efficiently and effectively. This further indicated the Thallo addition did not only act as a source of nutrients but also influenced their availability and uptake. From the correlation matrix table (Table 23), nutrient use efficiency, agronomic efficiency and recovery efficiency were correlated positively with total nutrients uptake.

This research clearly showed that Thallo improved the soil chemical properties resulting in fertility improvement in two agro ecological zones of Ghana. Cabbage growth and yield significantly improved relative to NPK in all the experimental sites. The effect of Thallo on proximate components such as protein and lipids was statistically similar to that of NPK. However, NPK had more effect on moisture and carbohydrate content than Thallo.

Furthermore, Thallo had influence on phosphorus, and sodium concentrations in the cabbage head compared to NPK. More so, micro nutrients such as zinc and iron were insignificantly increased by Thallo in the cabbage head. Under Thallo amendment, N, P and K uptake was elevated relative to NPK and control across the agro zones. Thallo treatments had greater impact on the nutrients use efficiency compared to NPK in all the zones.

Across the two zones, improvement by Thallo on cabbage growth and yield, soil fertility, proximate contents, mineral contents and nutrient uptake was significantly higher at UCC demonstrating that biophysical factors such as farm location and the initial soil fertility in the field greatly influenced the crop yield as UCC had better initial soil chemical properties. Conclusively, this work revealed that Thallo had greater effects or impact on the soil fertility, growth, yield and nutritional quality of cabbage.

The Impact of Recycled Abattoir Waste Thallo Fertilizer on the growth, yield, nutritional Quality and Nutrient Use Efficiency on Sweet Potato.

Effect of Thallo and NPK Addition on Soil Chemical Properties after Harvesting of Sweet Potato

Addition of Thallo significantly increased the pH up to 6.53 from the initial soil pH of 6.3. This may be as a result of ash content and high pH of the Thallo. Thallo have high liming effect resulting in increased soil pH (Brady & Weil, 2016).

Thallo significantly increased the organic carbon of the soil over control and NPK. This increase in organic carbon may be because Thallo could contain labile carbon that could elevate organic carbon of the Thallo amended soil.

Regarding available P content, Thallo treated soil increased the soil P content significantly. Related factors like increase in pH and mineralization of organic P from the Thallo may also contribute to the elevation of Available P in the soils. This is confirmed with significant positive correlation (Table 34) existed between pH and available phosphorus. This is an indication that increase in pH enhanced the availability of phosphorus in amended soils.

The application of Thallo also increased K levels in the soils across the experimental zones. The K elevation could be associated with the increased pH which affects positively the levels of basic cations such as $Ca^{2+,}$ Mg^{2+} and K^{+} in amended soils (Nunes et al., 2014). This is shown by the positive correlation (table 33) between pH and exchangeable K ($r=0.708$, $p<0.05$)

Addition Thallo improved the soil chemical properties. This improvements of soil chemical properties was reported by Nunes et al., (2014) who recorded high Ca, Mg,N, K and available P as well as maize and soybean yields due to the application of abattoir waste composts. This clearly shows that Thallo conferred excess nutrients in the treated plots and were not exhaustive hence their contributing to crop yield.

Effect of Thallo and NPK Fertilizers Application on Growth Parameters of Sweet Potato

Although the treatments had no significant effect on the vine length and vine girth (Fig 10 and 11), the plot ammended with Thallo obatined the highest values for these parameters. This could be due to the increase in the absorption of available nutrients by the plants. Thallo might also have had high stimulating effect of on various physiological phases in cell division and cell elongation due to its nitrogen content.

Similarly, the response of the plant to Thallo and NPK application exhibited no significant impact regarding the number of leaf (Fig 12) but Thallo recorded high mean number of leaves. This increased leaves number observed might be as a result of the favorable influence of Thallo in activating photosynthetic and metabolic processes in plants which increase plants growth. This also revealed that Thallo might have supplied nutrients to the soil in the form of organic matter which would mineralize to supply the nutrients needed by the plants that support plant growth and the formation of leaves.

Effects of NPK and Thallo on Yield Components of Sweet Potato

Tuber Length and Circumference

The impact of Thallo and synthetic fertilizer on length and diameter of sweet potato tuber was significantly different from the control (Table 26). Thallo fertilized crops had an average tuber circumference and length of 23.9 cm and 27.0 cm respectively, NPK fertilized crops had an average tuber circumference and length of 23.1 cm and 25.9 cm respectively and the control had an average tuber circumference and length of 16.5 cm and 20.2 cm respectively. This indicates that the Thallo fertilized crops produced the biggest tubers among all the treatment. The significant increase in size (length and diameter) of Thallo fertilized crops shows that the presence of other essential and micronutrient in the Thallo fertilizer may be responsible for the tuber's increased size since the amount of N, P and K in both the NPK mineral fertilizer and the Thallo fertilizer were the same. The supply of these various major nutrients including nitrogen and minor nutrients are needed by plant in the enlargement of its size, and hence increase in the length and circumference as revealed in this work (Olaniyi et al., 2009). Therefore, increased crop size is not only dependent on N, P and K but also due to micronutrient additions (Darch et al., 2019). The size of the tuber (length and diameter) positively correlated with soil OC ($r = .771$ $p < 0.05$ and $r = .705$ $p < 0.05$), N ($r = .784$ $p < 0.05$ and $r = .712$ $p < 0.05$) and P($r = .843$ $p < 0.05$ and $r = .777$ $p < 0.05$) respectively.

Number of Tubers Per Plant and Marketable Number of Tubers Per Plant

In relation to the number of tubers produced by the treatments, significant differences existed among the treatments (Table 27). Thallo fertilized soil recorded the highest number of tubers. This might be due to the high level of nutrients contained in this amendment and its ability to increase availability of native soil nutrient through higher biological activity. The increase in total number of tubers produced by NPK and Thallo is in agreement with a research conducted by Jalloh et al., (2016). In their work they assessed the growth and yield of sweet potato in response to different tillage methods and phosphorus fertilizer application rates in Ghana. Their findings showed that the number of tubers increased with increasing rate of phosphorus fertilizer to a certain point and the increase was significantly higher than the control which had no phosphorus input. Since both treatments added phosphorus to the soil, it can account for the increase in number of tubers produced. This shows that the application of NPK fertilizer can significantly increase the number of tubers produced by the crop but the addition of Thallo fertilizer to the soil will increase the number of tubers produced by the crop better than that of NPK because the number of tubers produced by Thallo fertilized crops was significantly higher than that of NPK fertilized crops. This is an indication that the Thallo fertilizer is a better alternative for increasing the number of tubers produced per given area of land than NPK fertilizers in terms of sweet potato production.

It was observed that the Thallo fertilized crops had the highest number of marketable tubers, statistically higher than the other ammendments whilst the control had the least number of marketable tubers significantly lower than the NPK fertilized crops. The significantly higher number of marketable tubers produced by Thallo fertilized crops is an indication that most of its tubers satisfied the criteria for selection for the market. Some of these criteria include the size, length, shape, physical state ie rotten, portions chewed by insects, holes etc. This result supports the work of Jalloh et al., (2016) who found out that the number of marketable tubers produced by sweet potato responded positively with the application of phosphorus fertilizer. Even though NPK mineral fertilizers can help increase the number of marketable tubers produced from sweet potato, Thallo fertilizer is a better alternative for this purpose as it gave a higher number of marketable tubers than the NPK mineral fertilizer. In addition the presence of micro nutrients in the Thallo might help to boost the resistant level of the crop against disease and pest attacks and other deformities.

Tuber Weight Per Plant and Marketable Weight Per Plant

Thallo treated plot produced significantly higher tuber weight per plant relative to control and NPK (Table 27). The higher tuber weight produced by Thallo could be attributed to the soil nutrients released from the Thallo which are absorbed by the plant. These absorbed nutrients, in addition to sunlight and water are used by plants for more photosynthetic activities resulting in the promotion of growth and yield which could translate into the increase in tuber weight of the sweet potato. The results recorded in this study are in line with Olaniyi et al., 2009. In their work, they reported increase in fruit weight of cucumber in organo mineral fertilizer amended soils.

The marketable weight of tubers per plant was significantly influenced by the treatments. Thallo treated plot yielded significantly, the heaviest marketable tubers per plant relative to both control and NPK. This is attributable to the increased number of marketable tubers produced by Thallo. In addition, the heavy tuber weight produced by the Thallo amended plots can also result in the high marketable weight of tubers produced by the Thallo fertilizer.

Total Yield Per Hectare, Marketable Yield Per Hactare and Percent Marketability

Taking the yield per hectare for the treatment the thallo was significantly higher than both the NPK and control (Table 28). Even though the NPK yield was higher than the control, they were not significantly different from each other. The increase in yield of the treatments over the control is in line with (Jalloh et al, 2016) who reported an increase in yield of sweet potato in response to the application of phosphorus fertilizer. The increase in yield in both the NPK and Thallo fertilizer treatment can be attributed to the presence of P in both fertilizers. Phosphorus fertilizer has a significant effect on sweet potato root yield, indicating that phosphorus is a key nutrient for sweet potato production (Jalloh et al., 2016). The findings are consistent with those of Issaka et al., (2014). This indicates why the control had lower yield than both the NPK and Thallo. Since there was no fertilization in the control, there was no input of P into the soil. This is in contrast to reports by FAO (2005), which indicated that while P is generally included in fertilizer mixtures, it does not appear to be vital for sweet potato yields, and that if it is removed, yields will not be affected. The low amount of native phosphorus in the experimental site might have contributed to the considerable response of sweet potato to fertilizers containing P in the study, highlighting the need for phosphorus application (Jalloh et al., 2016). The results indicates that there was postive correlation between the yield and the soil chemical proper ties (OC, N and P) (r = .936 p r = .934 r = .896)

The significant increase in yield of the thallo fertilized crops shows that even though yield depends on the amount of N, P and K present especially the amount of P available for plant use present in the soil; yield is not entirely dependent on only these nutrients. The difference between the number of tubers produced by NPK and Thallo is as a result of the additional nutrient available in the Thallo fertilizer which was not present in the NPK fertilizer. Yields of crop can be improved not by using NPK fertilizers alone, but also by adding micronutrients. (Darch et al., 2019). Hence Thallo is a better alternative for increasing yield of sweet potato.

The significant increase in the marketable tuber yield produced by the Thallo treated plot is due to the greater number of tubers produced and high marketable tuber weight recorded by the Thallo fertilizer relative to the other amendments.

Comparing Thallo treated crop with other treatments, the results did not only differ significantly among all the treatment in terms of total yield, there was also a difference among the treatment in terms of percentage marketability of the tubers produced by the treatments. The Thallo fertilized crops had 89%, NPK fertilized crops had 71% and control had 59% of their total tubers produced as being marketable. Thallo fertilized crops had the highest percentage indicating that most of its tubers satisfied the selection criteria for market, produced heavier tuber weight and marketable tuber weight per plant. This is confirmed with a positive correlation between the percentage marketability and the marketable number of tubers, total tuber yield, and marketable tuber yield ($r= .744$ $p<0.05$, $r=.938$ $p<0.05$, $r =.724$$p<0.05$,).

Effect NPK and Thallo on Proximate Components of Sweet Potato

Thallo treated plant and the control recorded higher dry matter contents relative to NPK. These values resulted in lower moisture content for Thallo amended plant and the control (Table 32). This suggests that the dry matter content of sweet potato can be decreased resulting in the increased of moisture by the application of NPK fertilizer. This would make the tuber more susceptible to disease attack and reduce the shelf lives because of high level of juice. Both NPK and Thallo amended plots produced tubers with significantly high fibre contents relative to the control. This implies that root tubers produced by inorganic NPK and Thallo fertilizers would have high digestibility.The highest carbohydrates content in sweet potato tubers was recorded by Thallo fertilizer even though it did not significantly differ from the control and the NPK. This implies that Thallo fertilizer would produce more energy in sweet potato derived from its carbohydrates.

Inorganic NPK fertilized tubers yielded high protein content significantly different from the control and Thallo treated plans. The higher level of crude protein found in tubers of plants treated with inorganic fertilizer might be as a result of better nitrogen supply to the tubers. The inorganic NPK fertilizer might have enhanced synthesis of protein and prevented build-up of amino acids. This study corroborates with the findings of Worthington (2001) who suggetsed that N in any type of fertiliser has influence on the quantity and value of protein produced by plants receiving such fertilizers.

Thallo fertilized plants produced tubers that contained high content of lipids significantly higher than the control and the NPK. This indicates that Thallo would support energy production by the plants as lipid is an indicator of energy production (twice that of carbohydrate).

Effects of NPK and Thallo on the Mineral Concentrations of Sweet Potato Tuber

The statistical analysis of data showed that NPK treated plants had significantly higher N concentration in the sweet potato tuber relative to the control and Thallo treated plants. There was no significant difference observed among the treatments with regards to potassium and phosphorus concentrations though NPK recorded the highest concentrations of these nutrients. This confirms that research done by Villordon & Clark (2014) and Duan et al., (2018). They were with the opinion that N plays a crucial function in the accumulation of dry matter and P and K uptakes as well as in the formation and enlargement of the sweet potato storage roots. The low tuber concentrations of nitrogen, phosphorus and potasium, following the addition of Thallo as observed in this study further revealed that Thallo would have greater residual effect as it had higher N, P and K in the soil for subsequent crop use.

Thallo treated plants recorded significantly high calcium and magnesium concentrations relative to control and NPK. Again, Thallo amended plots produced tubers that had sodium concentration lower than the control but higher than NPK even though they were statistically similar.

The increase in these mineral concentrations in the potato tuber as influenced by the application of Thallo might be attributable to concentrations of some exchangeable cations (C^{2+}, Mg^{2+}, and Na^{+}) in the treated soil, that affected the final mineral levels of potato tuber. These results could be explained by positive impact of Thallo on improving soil nutritional status.

No significant difference was observed among the treatments with regards to Zinc and iron. However, Thallo treated plants recorded increased iron and zinc concentrations in the potato tuber as compared to control and NPK. This may be attributed to the zinc and iron contents in the Thallo fertilizer that might have increased the Zinc and iron concentrations in the tuber produced by the Thallo amended soils. This finding is in agreement with the results of Darch et al, (2019). They revealed increased Zinc concentration following the application of Thallo to grass and wheat. Furthermore, Joy et al., (2015) reported that Zn-enriched fertilizers showed an increase in Zn concentration in maize, rice and wheat grains by 23%, 7% and 19% respectively

NPK and Thallo Fertilizers Effect on Nutrient Uptake and Nutrient use Efficiency

This work has shown that the treatments significantly influenced the nutrient uptake by the plant (Table 30). Thallo recorded increased N, P and K uptake values significantly higher compared to the control and NPK. The high nutrient uptake of N, P and K by the plant in the Thallo treated plant is attributable to the release of nutrients by Thallo fertilizer making it available for plant use. The increase in the uptake of nutrients by sweet potato tubers following the application of Thallo is an indication that Thallo served as a potential source of readily available nutrients and growth enhancing substance which provide optimum nutrients for crop. Furthermore, Thallo might have minimized the sorption and leaching of nutrients making them available for plant uptake. This is confirmed with the high tuber yield (Table 30) recorded by Thallo treated plant indicating that addition of nutrients enhances nutrient uptake resulting in higher yield. This confirms the opinion of Ojetayo (2011) who opined that when nutrients are made sufficiently available in soil for some time they are used effectively by plants. From this research it could also be observed that nutrient use efficiency directly depend on the nutrient uptake by the plant. This is evident in the correlation matrix (Table 35).

Effects of NPK And Thallo on the Nutrient use Efficiency Indices

The influence of the treatments on the N, P and K agronomic efficiencies was significant. Plots treated with Thallo recorded higher agronomic efficiencies for N, P and K relative to the NPK fertilized plot (Table 31). This increase in agronomic efficiencies influenced by Thallo application suggested that the plant nutrients applied optimally responded to the economic yield of sweet potato tubers.

With respect to Physiological efficiency Thallo obtained higher N, P and K values relative to NPK fertilizer but were not significantly different. This shows that the plants used each unit of nutrients acquired from applied Thallo fertilizer which resulted in greater responses to growth and yield. This elevated N, P and K value of physiological efficiency influenced by Thallo treatment could be as a result of increased above and below ground biomass yield recorded by Thallo, which indicated efficient conversion of source to sink by Thallo.

Regarding nutrient recovery efficiency the amendments had a significant impact on the crop. The plot treated with Thallo recorded high values for N, P and K recovery efficiencies significantly different from the NPK treatment. The significantly elevated N, P and K nutrient recovery efficiencies observed with the addition of Thallo may coming from increased nutrients supply to root zone of the plants that which resulted in the availability of nutrients to the plant. This research has further revealed that the application of Thallo also influenced nutrients availability and uptake in addition to acting as a source of nutrients.

From this work, it was evident that Thallo application significantly elevated the chemical properties of the amended soil. Sweet potato growth, tuber yield and marketability were increased following the application of Thallo fertilizer. The Thallo treated plots had high proximate components such as dry matter, fibre, carbohydrates and lipids compare to NPK. However, NPK had more impact on the moisture, ash and protein contents in the tuber than Thallo. Further, Thallo had less impact on nitrogen, phosphorus and potassium concentrations but greater impact on magnesium, calcium and sodium concentrations in the tube relative to NPK fertilized plot. Thallo increased the micro nutrients concentrations (zinc and iron) relative to control and NPK. Plot amended with Thallo fertilizer had significant higher impact on nutrients uptakes by the plants and significantly elevated nutrient use efficiency compared to control and NPK.

Conclusively, this work revealed that Thallo is a better alternative in improving soil fertility, growth, yield and marketability of sweet potato tubers. It would be a better option in the biofortification of sweet potato and residual reservation of soil nutrients for future plant use.

Response of growth, yield, N-Fixation and Nutrient Use Efficiency of Cowpea Following the Application of Thallo and Conventional NPK

Effect Of NPK and Thallo on Some Selected Soil Chemical Properties After Harvesting Cowpea

From this study, application of Thallo increased soil pH, total nitrogen, soil organic carbon, available phosphorus, and exchangeable potasium.

The rise in pH following the application of Thallo might be due to the liming effect exerted by Thallo resulting in the significant elevation of the soil pH. The presence of ash and high pH in the Thallo may be the cause of this increased pH. This suggests that Thallo mighty contain some basic cations that that have liming ability (Brady & Weil, 2016).

pH (6.55) recorded in the Thallo amended soil is within the optimum according to McCauley et al., (2009) and Neina (2019) that support soil microbial activity and availability of nutrient required for crop production.

Thallo increased N content than the control and NPK. In addition, the symbiotic nitrogen fixation caused as result of increase in active nodule numbers might also contribute to the elevation of total N observed in this work. This is shown with a positive correlation between the N fixation and active nodules in table 44 ($r=0.76$ $p < 0.001$) this supports the opinion of Ouma et al., (2016), who opined that cowpea nodules directly get involved in symbiotic nitrogen fixation.

The increase in soil organic carbon following the addition of Thallo could be attributed to the labile carbon released during the decomposition of the Thallo.

Thallo addition resulted in the increase available phosphorus content in the soil. Thallo contained high amount of P. this amount, together with factors like increase in pH and mineralization of organic P from the Thallo may be the cause of the enhanced elevation of available P in the soils compared with the NPK. A positive significant correlation (Table 45) occured between pH and Available Phosphorus ($r = 0.84$; $P < 0.05$) suggesting that increase in pH would enhance the availability of phosphorus in the Thallo amended soil

The significant increase in exchangeable K observed in this work may be due to the fresh of addition K from the applied Thallo fertilizer. The Thallo applied contained high amounts of basic cations and may have improved CEC particularly, the retention and exchange of K. These finding are similar as stated by Nunes et al., (2014).

Agronomic Performance of Cowpea at Harvesting Following the Application of NPK and Thallo Fertilizers.

The result of this work revealed that addition of Thallo elevated the height of the plant, pod length and number of pod per plant at harvesting.

Thallo amended plant recorded increased plant height relative to no amended and NPK amended crops. The observed increase may be attributed to the release of plant nutrient by Thallo.

Regarding pod length, addition of Thallo resulted in the production of lengthy pods relative to NPK and control. This elevation of pod length could be as a result of supply of adequate plant nutrients such as nitrogen which may lead to more vegetative growth thus promoting pod length. The findings are similar to those reported by Negi et al., (2004).

The increase in number of pod by Thallo addition may be as a result of ample provision of plant nutrients that would increase vegetative growth and more dry matter accumulation which may induce greater number of pods. Addition of Thallo significantly elevated the number of branches and leaves at harvesting compared to the other amendments (Table 37). This revealed that Thallo could have supplied nutrients to the soil in which would mineralize to supply the nutrients needed by the plant that could support plant growth and the formation branches and leaves.

Also, the shoot root ratio was increased by the addition of Thallo (Table 37). Thallo significantly increased the harvest index over the control and NPK (Table 37). This increase in the harvest index may be attributed to the higher P and Zn levels in the Thallo fertilizer. Mafi et al., (2013) reported that high P and Zn levels increase yield and HI. This was also confirmed by Fageria et al, (2011) who opined that there is positive relationship between harvest index and P and Zn fertilization.

Effect of NPK and Thallo on Cowpea Nodulation

The results of this work have shown that Thallo impacted significantly on the nodulation and N-fixation of cowpea (Table 38). Thallo amended plot recorded significantly increased number of nodules relative to control and NPK. Out of number of nodules recorded by the treatments, Thallo obtained the highest active nodules given a percent nodule activity of 66.49. The enhanced nodulation from the application of Thallo could be due to the addition of phosphorus from the amendment since Thallo contains high level of phosphorus. Thallo contains some micro nutrients that might be required by the rhizobia in nodule formation.

N-fixation was significantly increased by the Thallo treated soil relative control and NPK. In this work, number of nodules positively correlated with active nodules ($r = 0.98$, $p < 0.05$), pH ($r = 0.81$, $p < 0.05$), total nitrogen ($r = 0.81$, $p < 0.05$), available phosphorus ($r = 0.8$, $p < 0.05$), exchangeable potassium ($r = 0.69$, $p < 0.05$), and soil organic carbon ($r = 98$, $p < 0.05$). Nodules play vital role in the fixation of nitrogen into the soil by a process called symbiotic nitrogen fixation (SNF) and this process requires enhanced by soil conditions needed by the rhizobia to survive, increase root infection and carry out their activities. This is supported by Mor_on et al., (2005) who reported that increase in pH resulted in increased nodule number and consequently increased N-fixation. The increase in pH will also suppress the presence of some toxic metal ions (Al^{3+}, Cu^{2+} and Mn^{2+}) but favour non-acid tolerant rhizobia resulting in increased root infection and nodulation (Phares et al., 2020, Mendoza--Soto et al., 2015).

The increased N-fixation could also be attributable to the elevated concentration of available phosphorus in the soil which correlated positively with the number of nodules. This implies that the initiation and development of nodules were largely influenced by the availability of phosphorus in this study. This finding confirms previous reports that phosphorus play an important in nodulation through crop growth stimulation, initiation of nodule formation as well as enhancement of rhizobium-legume interaction (Karikari et al., 2015; Kyei-Boahen et al., 2017; Nkaa et al., 2014).

The increased concentrations of other soil nutrients such as soil organic carbon, total nitrogen and exchange potassium is an indication of an enhanced soil fertility which might have improved nodule formation Mor_on (et al., 2005) and for that matter enhanced N-fixation.

Cowpea Yield and Yield Indices as Influenced by Application of Thallo and NPK

Thallo amended plant recorded increased number of seeds per pod significantly higher than the no treatment plant (control) and NPK treated plant (Table 39). The number of seed per pot had a positive correlation with nitrogen, phosphorus and potassium (Table 45) and confirms the role of these nutrients in increasing seed per pod. Nitrogen speeds up the development of growth and whilst accelerating reproductive phases and protein synthesis, thus promoting increased number of seeds in the pod. This is in agreement with the findings of Negi et al., (2004).

Regarding the weight of each pod, Thallo significantly produced the heaviest pods elevating the weight per pod with a percent increase of 61% and 53% relative to control and NPK respectively (Table 39). The possible reason for this enhanced pod weight may be due to cumulative effects of nutrient (macro and micro), supplied by Thallo, on vegetative growth which ultimately resulted in to more photosynthetic activities leading to high production of biomass.

Yield

Results of this study showed that Thallo obtained the highest 100-seed weight (20g). This weight was significantly higher than those of control and NPK. This may be due to bigger seed size produced by Thallo fertilized plot.

Again this increase in the 100-seed weight by Thallo over that of control and NPK was also due to balanced supply and availability of nutrients throughout the reproductive stage that resulted in improved seed filling and resulting bigger seed weight. This is confirmed by the positive correlation between the 100-seed weight and soil nutrients (N, P, and K) as well as nodulation (number of nodules and active nodules).

Seed yield was increased due to application of soil amendments. Thallo amended soil significantly increased the seed yield relative to the control and NPK by 121% and 109% respectively.

This increased effect of Thallo on yield of seed might be attributable to the superior yield parameters including number of seed, hundred seed weight and harvest index as well as number of nodules and active nodules (Table 45). The observed yield increase in seed yields could be as a result of the adequate supply of both major and minor nutrients contained in the Thallo according to Udom & Bello (2009). This is supported by the positive correlation between the seed yield and pH ($r = .77$ $p < 0.05$), SOC ($r = .92$ $p < 0.05$), N ($r = .75$, $p < 0.05$), P ($r = .82$ $p < 0.05$) and K ($r = .73$, $p < 0.05$)

This finding is supported by Nogalska & Załuszniewsk (2020) who opined that MBM used instead of mineral fertilizers resulted in both economic and environmental benefits. Other works done using MBM compost and recycled slaughter house wastes have proved positive (Ragályi & kádár, 2012; Chen et al., 2011, Konopka et al., 2012 and Stępień & Wojtkowiak, 2013). A significant elevation of yield in sand-grown grass with Thallo compared with mineral fertilizers was observed by Darch et al., (2019).

Effects of NPK and Thallo on Nutritional Quality of Cowpea Seed

This study showed no significant difference among the treatments on fibre, carbohydrates, protein and lipids contents of the cowpea seed (table 41). This showed that the treatments, both NPK and Thallo, did not exert any significant influence on the named nutritional contents of the cowpea seed. However, significant differences existed among the treatments with regards to dry matter, moisture content and ash contents of the cowpea seed.

This study showed significant differences among the treatments regarding the dry matter and moisture contents of the cowpea seed. The result revealed high dry matter contents recorded by NPK and control which were significantly different from Thallo. This resulted in higher moisture content recorded by Thallo significantly lower relative to NPK and control. This low dry matter content recorded by Thallo treated soils with its corresponding higher moisture content of the cowpea seed is an indication that the seed will have lower storability and this will increase the microbial infection and spoilage of the cowpea seed resulting in reduced shelf life Ogunyemi et al., (2018). Regarding ash content, Thallo recorded reduced level relative to control and NPK. This agrees with Ogunyemi et al., (2018) who revealed that NPK fertilizer applied to maize plant yielded the highest ash content compared with other amendments.

The result showed no significant difference among the treatments with respect to N, P and K concentrations in the cowpea seed (Table 42). This suggests that none of the treatments exerted any impact on the mentioned nutrients content of the seed. However, Thallo treated plant recorded higher concentration of Ca and Mg. This increase may be attributed to the higher level of Ca and Mg in the Thallo fertilizer.

In addition Thallo significantly elevated the Fe and Zn concentrations of the cowpea seed relative to control and NPK. Darch et al., (2019), reported increased levels of Zinc concentration following the application of Thallo on grass and wheat. Also Joy et al., 2015 reported that Zn-enriched fertilizers recorded elevations in Zn concentration in maize, rice and wheat grains. The zinc and iron contents observed in Thallo might have increased the Zinc and iron concentrations in the cowpea seed from the Thallo amended soils.

NPK and Thallo Fertilizers Effect on Nutrient Uptake and Nutrient use Efficiency

The result of this work has shown that there was significant influence by the treatments on the nutrient uptake by the plant (Table 43). Thallo treated plant recorded increased N, P and K uptakes values significantly higher relative to the control and NPK. The elevated uptake of N, P and K by the Thallo treated plant may be as a result of the release and availability of nutrients by Thallo fertilizer making it accessible for plant use. Thallo might have also served as a potential source of readily available nutrients and growth enhancing substance which provided optimum plant nutrients for crop uptake. In addition, Thallo might have lowered nutrients sorption and leaching making the nutrients available for plant uptake. This is evident in the higher seed yield (Table 40) recorded by Thallo treated plant. This indicates that addition of nutrients enhances nutrient uptake resulting in higher yield.

The ammenments demonstrated significant variations with respect to nutrient use efficiency. The Thallo amended plots increased the nutrient use values of N, P and K than the control and NPK treatments. This is confirmed by Adesemoye et al., (2009) who same authors reported that mineral fertilizers often show low use efficiency, implying that just a part of the nutrients applied are taken up by plants. The significantly increased nutrient use efficiencies upon addition of Thallo might be due to adequate nutrients supplied by the Thallo fertilizer which increased the total performance of the plants by supplying economically optimum nourishment to the crop and at the same time reducing nutrient losses from the field. This supports the result of Ojetayo (2011) who opined that when nutrients are sufficiently supplied and made available in the soil for some time, they are effectively utilized by the plants. The results of this research have demonstrated that nutrients use efficiency is directly dependent on the nutrient uptake by the plant. This is evident in the correlation matrix (Table 45).

Effects of NPK and Thallo on the Nutrient use Efficiency Indices

The application of Thallo and NPK treatments exerted significant influence on the N, P and K agronomic efficiencies. Thallo treated plots recorded increased agronomic efficiencies for N, P and K relative to the NPK fertilized plot (Table 44). This elevation in agronomic efficiencies of N, P and K following Thallo application suggested that the applied plant nutrients might have sufficiently responded to the economic yield of the cowpea seed. Such results may mean that there is some amount of nutrients released and made available for plant uptake and use (Singh et al., 2008).

Regarding physiological efficiency the treatment had no significant effect on the plants. However, Thallo treated plants recorded increased N, P and K values relative to NPK fertilized plants. This revealed that the plants grown on Thallo amended plot used each unit of nutrients obtained from the applied Thallo fertilizer resulting in better plant growth and yield. The higher N, P and K physiological efficiencies obtained as influenced by Thallo treatment could be as a result of increased above ground yield (growth and yield parameters) recorded by Thallo indicating effective conversion of source to sink by Thallo.

Regarding nutrient recovery efficiency the amendments had a significant impact on the crop. The plot treated with Thallo recorded high values for N, P and K recovery efficiencies significantly different from the NPK treatment. The significantly elevated N, P and K nutrient recovery efficiencies observed following the application of Thallo may be as a result of conducive nutritional environment created in the root zone of the plants that which resulted in the availability of nutrients to the plant leading to the conversion of the nutrients applied to economic yield more efficiently and effectively. This research has further revealed that the application of Thallo also influenced nutrients availability and uptake in addition to acting as a source of nutrients. The nutrient use efficiency, agronomic efficiency and recovery efficiency as shown in the correlation matrix table (Table 46) indicates a positive correlation with total nutrients uptake .

This research clearly showed that Thallo exerted elevated improvement on the soil chemical properties resulting in fertility improvement. Cowpea yield significantly improved by Thallo fertilizer relative to NPK and control. The effect of Thallo on proximate components such fibre, carbohydrates, protein and lipids contents were statistically similar to that of NPK.

Furthermore, Thallo had similar influence on nitrogen, phosphorus and potassium concentrations in the cowpea seed, but lower sodium concentrations compared to NPK. However, micro nutrients such as zinc and iron in addition to calcium and magnesium were insignificantly elevated by Thallo in the cowpea seed. Nitrogen phosphorus and potassium uptakes and use efficiencies were significantly elevated by Thallo relative to NPK. Conclusively, this work revealed that Thallo had greater effects or impact on the soil fertility, growth, yield nutrient uptake and use as well nutrient contents of the cowpea seed.

CHAPTER SIX

GENERAL SUMMARY, CONCLUSION AND RECOMMENDATION

Summary

Towards solving the problem of soil fertility, crop yield and nutritional quality of crops as well as achieving long term maintenance of soil fertility, utilization of abattoir wastes amendments have been suggested (Nunes et al., 2014; Chen et al., 2011). positive effects of abattoir wastes amendments on the properties soil, yield and nutritional quality of crop have been reported in previous works. Abattoir wastes amendments such as Meat and Bone Meal (MBM), Bone Meal and blood meal meal have been widely used and proven to be effective. However a novel recycled fertilizer from abattoir waste (Thallo) produced by Elemental Digest (UK) was yet to be extensively investigated to test its efficacy for crop growth, yield, nutritional quality and soil nutrient improvement. This study was therefore, conducted with the following objectives:

1. Assess the effect of application of recycled abattoir waste fertilizer (Thallo) and Inorganic NPK fertilizer on selected soil chemical properties (N, P, K, OC and pH) in two agro ecological zones in Ghana
2. Investigate the impact of recycled abattoir waste fertilizer (Thallo) and Inorganic NPK fertilizer application on the growth and yield of maize, cabbage, sweet potato and cowpea in two agroecological zones in Ghana.
3. Examine the the influence of the application of Recycled abattoir waste fertilizer (Thallo) and Inorganic NPK fertilizer N-fixation and nutrient use efficiency in two agro ecological zones in Ghana

Soil chemical properties components determined included pH, SOC, N, P and K. Three treatments namely Recycled abattoir waste fertilizer (Thallo), conventional NPK and control were used. Each treatment had four replications, giving total sub plots of 12. Soils were amended with Thallo at a rate of 1845 kgha^{-1} and NPK at 100: 265: 198 kgha^{-1} and the experiment was set up using RCBD. Agronomic parameters were measured, yields were estimated and nutrients concentrations in the edible portions were also analyzed. Nutrients uptake and use efficiency were determined. Same chemical properties were determined as it was done in pre planting soil. All data were analyzed employing the Genstat statistical tool. By least significant difference (LSD), the treatment means were separated. The effects of the treatments confirmed significant at 5 % level of probability. Where correlation became necessary, the Pearson correlation test was undertaken to ascertain correlation link.

General Conclusions

Based on the outcomes of this work, the under listed findings and or conclusions were recognized;

1. Recycled abattoir waste fertilizer (Thallo) increased soil chemical properties (N, P, K, OC and pH) in Semi Deciduous Forest and Coastal Savannah ecological zones of Ghana
2. Thallo significantly increased the growth and yield of maize, cabbage, sweet potato and cowpea in the two agroecological zones in Ghana
3. Thallo significantly increased the N-fixation (only done in coastal savannah), nutrient uptake and nutrient use efficiency in two agro ecological zones in Ghana

4. Coastal savannah significamtly recoeded the highest chemical properties, yields and nutrient uptake.

Recommendations

The following recommendation are for future research.

1. Application of recycled abattoir watse Thallo fertilzer is recommended for semi deciduos and coastal savannah zones due to its ability to improve the soil ecosystem, increase the soils‘ fertility and improve growth and yield and Nitrogen, Phosphorus and Potasium uptakes and use efficiencies of maize, cabbage, sweet potatoe and cowpea.
2. The addition of the recycled abattoir Thallo fetilizer positively affected the concentration of nutrients in maize, cabbage, sweet potato and cowpea. Therefore, the use of Thallo is reccommended to be a better option in fortifying crops with these nutrients to curb hidden hunger.
3. Further studies should be carried out on test crops and other crops in different agro ecological zones with application of Thallo to ascertian its efficacy and improvement on crops in other agro zones.
4. Further research into the economic implication and cost-benefit evaluation of Thallo use in Ghana‘s farming systems should be done.
5. Research should be conducted to establish optimal concentrations of micronutrients in crops from Thallo amended soils.
6. Further work to ascertain the interaction of Thallo and seasonal variation on element concentrations in plants, nutritional composition, N, P and K uptakes and crop growth andf yields of particularly, in sub Saharan Africa.

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APPENDICES

Appendix A: pictorial display of abattoir waste Thallo fertilizer

A sample of Thallo fertilizer

Appendix B: pictorial dispaly of maize ears as affected by the ammendments

Ear from control, NPK and Thallo

Ear from control, NPK and Thallo

Ear from control, NPK and Thallo

Appendix C: Pictorial display of sweet potato tubers as affected by the ammendments

Sweet potato tuber from Thallo fertilized plot

Sweet potato tuber from NPK amended plot

Sweet potato tuber from no amended plot

Appendix D: cowpea grains as influenced by the ammendments

Cowpea grains from no treatment plot

Cowpea grain from NPK treated plot

Cowpea grain from Thallo treated plot