EFFECT OF INTEGRATING CHICKEN MANURE AND NITROGEN FERTILIZER ON NUTRIENT UPTAKE, GROWTH AND YIELD OF HYBRID MAIZE (*Zea mays* L.) IN MALAWI

Lusayo Aliko Mlotha

A Thesis Submitted to the Graduate School in Partial Fulfillment for the Requirements of the Award of Master of Science Degree in Agronomy (Crop production)

EGERTON UNIVERSITY

December, 2017

DECLARATION & RECOMMENDATION

Declaration

I declare that this research thesis is my original work and has not been submitted wholly or in part for any award in any Institution.

Lusayo Aliko Mlotha

(KM12/14297/15)

Signature...Date..

Recommendation

We confirm that this research thesis was prepared under our supervision and has our approval to be presented for examination as per the Egerton University regulations.

Prof. Josephine P. Ouma

Department of Crops, Horticulture and Soils

Egerton University.

Signature...Date..

Dr. Joyce J. Ndemo

Department of Crops, Horticulture and Soils

Egerton University.

Signature...Date..

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DEDICATION

I hereby dedicate this work to the Almighty God for the study opportunity and His grace throughout the studies; and to my parents, Mr. & Mrs. ML Mlotha for the support and guidance rendered throughout my life.

ACKNOWLEDGEMENT

In all, I thank God for His grace and provision of good health and courage that has led me through to successful of the studies.

I am also deeply grateful to Egerton University (Njoro main campus) for the admission into the institution to study. I sincerely thank also all the lecturers who taught me.

I salute my supervisors: Prof. Josephine P. Ouma and Dr. Joyce J. Ndemo of Crops, Horticulture and Soil Sciences Department, for their tireless efforts in providing guidance, editorial support and mentorship throughout the study period. It was a pleasure and an honour to learn from you.

This material is based upon work supported by the united States Agency for International Development as part of the Feed the Future initiative, under the CGIAR fund, award number BFS-G-11-00002, and the predecessor fund the Food Security and Crisis Mitigation II grant, award number EEM-G-00-04-00013.

I extend my thanks to the Officers in-charge of Makoka and Chitedze Research stations for allowing me to conduct the field research work in their stations. I also acknowledge the able supervision and guidance of Mr. Patterson Kandoje, Mr Osmund Chapotoka, and Mrs. Alice Mbayani and the Late Mr. Sunderson Suga from Zomba District Agriculture Office in Malawi, for allowing me to pursue my studies.

Finally, many thanks to my soulmate Alinafe Mwenebanda (Zaithwa) Mlotha for supporting me and course mates; Jared Ochieng`, Mercy Odemba and Anncetta Gakki at Egerton University for their support throughout my study period. God bless you always.

ABSTRACT

The use of mineral and organic fertilizer to produce maize in Malawi is essential to ensure high yields, due to a decline in soil fertility. Smallholder farmers however, apply sub-optimal amounts of inorganic fertilizers to produce maize due to high prices. The objective of the study was to evaluate effect of integrating chicken manure and mineral fertilizer on nitrogen uptake, growth and yield of hybrid maize in Malawi as a low cost measure. Field experiments were done in Lilongwe and Zomba districts, in the 2016/17 growing season. The treatments were arranged as a split plot in a randomized complete block design. The main plots were the hybrid maize, SC403 and SC627. The sub plots consisted of six fertilizer treatments: chicken manure (CM); CM and 22.5 kg N; CM and 45 kg N; CM and 67.5 kg N; CM and 90 kg N and a no input control. Chicken manure was applied at a constant rate of 4 t ha^{-1} and Urea was used as mineral N. Parameters measured included: maize growth parameters; N-uptake; grain yield with its attributes. Gross margin analysis of fertilizer treatments used. Data collected was subjected to analysis of variance using SAS programme and treatments mean were separated using Fishers least significant difference, at 5% probability level. The study indicated that CM and mineral fertilizer integration significantly influenced maize yield and growth parameters. Use of 67.5kg ha^{-1} N gave the best N-uptake with a mean value of 71.4 mg N plant^{-1}. Maximum girth and height mean values were attained with use of 22.5 kg ha^{-1} N. Use of 90 kg ha^{-1} N gave the highest grain yield of 6.3 t ha^{-1} and Chicken manure (4 t ha^{-1}) + 45kg mineral N had a mean yield of 4.6 t ha^{-1} which is higher than the average yield of 2.5-3.0 t ha^{-1}. Thus, the use of chicken manure and 45kg ha^{-1} N and SC627 variety ensures a 50% reduction in the cost of acquiring inorganic fertilizer besides boosting maize production for food security in Malawi.

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LIST OF ABBREVIATIONS AND ACRONYMS

ANOVA	Analysis of Variance
CEC	Cation Exchange Capacity
FAO	Food Agricultural Organization
FISP	Farm Input Subsidy Programme
GAP	Guide to Agriculture Production
IF	Integrated Fertilizer
LAI	Leaf Area Index
Mt	Metric tonnes
NUE	Nutrient Use Efficiency
SSA	Sub Sahara Africa
WB	World Bank

CHAPTER ONE

INTRODUCTION

1.1 Background information

The earth`s soil is being depleted of nutrients at a rate of 13 % more than the rate it is being replaced. The presence of natural elements like nitrogen (N), phosphorus (P) and potassium (K) is also on the decrease (Luhanga, 2012). Soil fertility decline is increasingly being viewed as a critical problem affecting agricultural productivity in sub-Saharan Africa (SSA) (Bationo *et al.*, 2004). The decline in soil fertility is as a result of a combination of high rates of erosion, leaching, removal of crop residues and continuous cultivation of the land without adequate fertilization or fallowing (Sanchez, and Jama, 2002). A fertile soil contains all the major basic nutrients for basic plant nutrition such as nitrogen, phosphorus and potassium as well as other micro nutrients and organic matter that improves soil structure and profile as well as water retention (SSSA, 2016).

In Malawi, the rate of soil nutrient depletion is at an average of 100 kg NPK/ha/year and yet the inorganic fertilizer rate use is very low (Henao and Baanante, 1999). This has resulted into low maize yields, the main staple for the Malawi`s population. Maize is mainly produced by smallholder farmers who own an average 0.23 ha of arable land. The major challenge for farmers most of whom are poor to sustainably produce maize is lack access to farm inputs such as fertilizer. Fertilizer application for maize production is important in order to achieve maximum yields. It enables the soil to supply nutrients to the plant for optimal growth and yields.

In 1993-94 production increased by 425% from 200 Mt to 1050 Mt, as there was a transition from one party to multi-party system of government and farmers were provided with farm inputs. In 1998, production increased by 44.9 % due to introduction of starter pack by government. In 2005-06, the Farm Input Subsidy Programme (FISP) was introduced and amassed a 113.1 % (2611 Mt from 1225 Mt) increase in maize production. Malawi has, however, been able to attain 6% agricultural growth target despite the Government spending a lot on farm input Subsidy programme (FISP) it introduced in 2005 (Matchaya *et al.*, 2014). The highest yield was recorded in 2014 where 3929 Mt maize was produced (Mundi index, 2016). In 2015, the yield went down by 27% (FAO, 2016).

Integrated nutrient approach is a systematic nutrient elements application method to plants involving the use of both organic and inorganic sources to meet the plant`s nutrient requirements. It involves determining the nutrient levels in particular manure that is used in crop production. Nutrient element supplementation of the organic source to meet the crop nutrient requirement is done by addition of mineral fertilizer. This is done to ensure maximum crop yield at a relatively lower cost as compared to use of inorganic fertilizer only. It is expected that the integration may reduce the cost of acquiring mineral fertilizer while maintaining maize yield.

1.2 Statement of the Problem

Hybrid maize requires high external inputs, mainly fertilizer for maximum grain yield production and is greatly affected by unevenly distributed and erratic rains arising from climate change. Soil infertility is the major challenge in maize production in Malawi. Most smallholder farmers in Malawi are poor and cannot afford to apply required quantities of inorganic fertilizer for maize production, due to high costs. The government of Malawi in 2005 introduced the farm input subsidy programme (FISP) aimed at improving maize crop production and targeted 1.6 million farmers of the current 11 million farmers. The beneficiaries of FISP ensured food security at household level but only afew farmers benefited from the program due to the high costs of running the programme. The Government has been reducing the number of beneficiaries as an exit strategy. Smallholder farmers therefore need other low cost sources of fertilizer. Currently, independent studies on the efficacy of chicken manure and inorganic fertilizers on maize production have been documented. However, there is a knowledge gap on testing of different rates of integrated chicken manure and different rates of inorganic fertilizer for improved growth and yield of hybrid maize in Malawi.

1.3 Objectives

1.3.1 General objective

The general objective of the study was to contribute towards food security by using integrated chicken manure and mineral fertilizer for improved hybrid maize (*Zea mays* L.) production in Malawi.

1.3.2 Specific Objectives

The specific objectives were to determine the:

1. Effect of integrated chicken manure and mineral fertilizer rates on nitrogen uptake by hybrid maize.
2. Effect of integrated chicken manure and inorganic fertilizer rates on growth and yield of hybrid maize.
3. Cost/benefit of hybrid maize production using integrated chicken manure and inorganic fertilizer.

1.3.3 Hypotheses

The following hypotheses are postulated:

1. Integrating chicken manure and mineral fertilizers application have no effect on nutrient uptake by the maize plants.
2. Integrating chicken manure and mineral fertilizers application have no effect on growth and yield of hybrid maize.
3. There are no differences in cost/benefits of maize production with application of integrated chicken manure and mineral fertilizer.

1.4 Justification of the study

Plants require essential nutrients for proper growth and high yields. A fertile soil should have good structure and the right quantity of nutrients available to the plant for growth and yield. With the arable land being used repeatedly due to land limitation, soils need to be replenished with nutrients to ensure maximum production. Use of sole organic manure leads to reduced crop yield, as they have less nutrients as per plant requirement even though it improves the soil structure (Palm, 2005). The use of inorganic fertilizer ensures steady crop production as the nutrients are available for plant growth directly after application (Savoy, 1999). Low use efficiencies of inorganic fertilizers coupled with their rising costs has challenged farmers towards its use (Aziz *et al.*, 2010). Most Malawian smallholder farmers are poor such that they cannot access inorganic fertilizer, in addition to the prolonged use detrimental effects to the environment such as soil acidity intensification and water pollution through nitrogen addition (Suge, 2011). Considering all these factors, there is a need for research on fertilizer sources which are affordable to smallholder farmers, and also that integrates the qualities of organic fertilizer and inorganic fertilizer to ensure sustainable crop production for food security (Suge, 2011).

CHAPTER TWO

LITERATURE REVIEW

2.0 Soil of Malawi and their fertility potentials

There is pressure on the arable land in Malawi to produce more food that can meet the population demand due to the steady population increase at 2.8% per year (Matchaya *et al.*, 2014). Most soils are nutrient deficient of the required micro and macro nutrients. The location of Malawi shows that it has tropical and subtropical environments, which are aggressive in soil formation (highly weathered).

Consequently, the soils that are formed have low inherent fertility because of their clay contents which are predominantly 1:1 kaolinite as opposed to 2:1 (iron oxides) which are all both inactive materials such that they have low content of rock minerals which can release nutrients when they break down. The most prevalent soils in the country are the red soils which include; Ferrisols, Ferruginous and Ferralitic soils which occur in the highlands and medium plateau physiographic units which have low inherent fertility attributes due to aggressive weathering (Havlin *et al.*, 2013). Hydromorphic soils (Gleysols) are also present in all parts of the country, characterized by high fertility but the soils have poor site drainage which hinders maize crop growth and development (Havlin *et al*., 2013).

A fertile soil contains all the major basic nutrients for basic plant nutrition, such as nitrogen, phosphorus and potassium as well as other micro nutrients, and organic matter that improves soil structure and water retention (Soil Science Society of America, 2016).

2.1 Maize production in Malawi

Maize is the main staple food for the Malawi`s population. It is mainly produced by smallholder farmers who own an average 0.23ha of arable land. The total arable land is 40.3% of the total land, and farmers are able to produce an average of 2100kg/ha^{-1} of maize (World Bank, 2016). Malawi has been able to attain the 6% agricultural growth target despite spending a lot on farm input Subsidy programme (FISP) that government introduced in 2005 (Matchaya *et al.*, 2014).

Politics is one of the major drivers of maize production in Malawi. In 1993-94 production increased by 425% from 200Mt to 1050Mt as the there was a transition from one-party to multi-party system of government where farmers were promised to be given farm inputs. In

1998, production increased by 44.9% due to introduction of starter fertilizer packages by government. In 2005-06, Farm Input Subsidy Programme was introduced and amassed a 113.14% (2611 t from 1225Mt) maize yield increase. The highest yield was recorded in 2014 where 3929 Mt maize produced (Mundi index, 2016). In 2015, the yield went down by 27% and in 2016, the yields were expected to go down further due to lack of access to inputs and erratic rains that were associated with the prevailing and weak El Niño episode (FAO, 2016).

The major challenge for smallholder farmers to sustainably produce maize is the access to farm inputs (Fertilizer) since application of manure only doesn't improve yield to the required level(Farhad *et al*,2009). Therefore, there is need to research on low cost technologies of improving soil fertility for the smallholder farmers to sustain maize production hence ensuring food security in Malawi.

2.2 Types of fertilizer used for maize production

Fertilizer is a natural or synthetic, chemical-based substance that is used to enhance plant growth and soil fertility through provision of macronutrients (Nitrogen, Phosphorus and Potassium) and micronutrient such as sulfur, magnesium, zinc and calcium(Affeidt and Allen, 2017). Fertilizer is classified generally as either Organic fertilizers (Sourced from plants and animals) and inorganic/chemical (Artificially synthesized) based on their nutritive characteristics.

2.2.1 Inorganic fertilizer

These are chemical fertilizers that are produced industrially which enables them to be nutritionally balanced by mixing both macronutrients and micronutrients in proportions as required by the plants. They are classified as nitrogen rich, phosphorus rich and potassium rich fertilizers. Depending on the number of elements present, they may be classified as simple or complex.

Worldwide, the use of inorganic fertilizer has increased from 120 Kg/ha to 140Kg/ha. Intensive utilization on chemical fertilizer has great impacts on the environment, as it aggravates soil degradation(Ayoola and Makinde, 2007), water pollution due to wash away by running water which results in water eutrophication, soil acidity which make other elements unavailable for absorption and inhibit root growth (Savoy, 1999), besides effects on humans and animals upon eating fertilized pants such as kidney, liver and Lung malfunctioning(Townsend *et al*, 2003).

2.2.2 Organic Fertilizers

Organic fertilizers are carbon-based compounds added to the soil to improve soil fertility which is derived from animal matter, human excreta or plant based materials. Its application needs to be maintained for sustainable agriculture(Efthimiadou *et al.*, 2010). The most commonly required plant nutrients are nitrogen, phosphorus and potassium. Nitrogen is required for the growth of vegetative parts, while the plants will have healthy roots if they get a sufficient amount of phosphorus. Phosphorus is also important for good flowers and fruits. Potassium makes the plant healthy by facilitating the circulation of nutrients within the plant (Organic Information Services Pvt Ltd, 2015). The use of organic fertilizers in crop production as a nutrient source is being advocated as a possible alternative way to expensive fertilizers in Africa (Reijntjes *et al.*, 1992). The use of organic fertilizer is promoted because of the following reasons: Firstly, replacement of scarce or non-existence of capital resources with labor resource and secondly, most green manures and ruminant animals like cattle have all essential nutrients including carbon, the energy source for soil microbes that regulates nutrient cycling (Sanchez, 1995).

The challenges faced with utilization of organic matter are: the low nutrient concentration in comparison with the inorganic fertilizer and the variability in their nutrient contents (Palm, 1995). Animal and plant manure materials contain and average 1-4% Nitrogen on a dry weight as opposed to inorganic fertilizer which contain 20-46% Nitrogen and are already dry. This influences the crop yield levels in fields treated with organic fertilizer to be lower than in those fields treated with chemical fertilizer (Blatt, 1991), hence most farmers preference in using chemical fertilizers. In Malawi, farmers are advised to apply organic manure at a rate of 4 t ha^{-1} (Luhanga, 2012). Retention of crop residues on land has potential to improve soil fertility. However, crop residues are usually burned rather than ploughed-in because they interfere with land preparation. But still, the ash being alkaline, has a neutralizing effect on the soil (Stroomgard, 1991).

2.2.3 Importance of organic fertilizers

Use of organic fertilizers avoids or reduces the deleterious effects attributed to the use of chemical fertilizer. The applying chemical fertilizer leads to the deterioration of soil characteristics and fertility, and as well it leads to a reduction in fruit nutrition values and edible qualities (Shimbo *et al.*, 2001). The use of organic fertilizer has many benefits including but not limited to: reduction of the dependence on artificial chemical products for different crop production; secondly, it improves the soil`s physical structure in soft and loose soils. Chemically, it increases nutrient availability to the plant and reduce nutrient leaching, and biologically, there is also high population of beneficial microorganisms produced in the soil. But most of it all, application of organic fertilizers improves quality of produce.

Soil productivity is the capacity of soil, in its normal environment, to support plant growth over a period of time. It is reflected on the volume of organic matter produced on a site (Poyry, 1992). Soil productivity is influenced by factors such as: Physical, Chemical and Biological. The interaction of these factors determines the amount of nutrients available to the plant for its growth.

Chicken manure availability for agricultural use in maize production is sustainable in Malawi. Poultry production is practiced by most smallholder farmers as it is regarded easier to manage as compared to other livestock. Presence of many poultry farms also ensures sustainable supply of chicken droppings as they are disposed off from the farms to ensure hygiene on daily basis.

2.2.3.1 Physical factors influenced by organic matter.

Soil aggregation, is the process of clustering soil particles into a single mass, such as a clod, block or prism (Brady and Weil, 2008). When the soil particles are too course i.e. sandy soils, the capacity to retain the nutrients is low because of deep water percolation and leaching as opposed to fine textured soils e.g. clay soils which have high inherent nutrient properties and reduced water percolation. Addition of organic matter to moderately weathered (2:1 Clay soils) soil ensures binding of micro aggregates together into macro aggregates, thus the organic matter stabilizes aggregates and aggregates stabilize organic matter (Six *et al.*, 2000).
Soil water availability, soil water is the water that is held within soil pores and is dependent on the amount of water present and the size of the pore spaces. Soil water interacts with soil particles making them to shrink or swell and also the soil water affects the acidity of the soil. Addition of organic matter to the soil increases the ability of the soil to water infiltration and hold water for plant absorption (Plant available water). However, addition of soil organic matter under severe dry and hot conditions may reduce water infiltration due to volatilization of organic matter portions which coat the soil particles causing hydrophobic condition (Doerr *et al.*, 2000).

Soil temperature, this is an important characteristic as it has an influence on plant and microorganism growth. Addition of organic matter which is usually dark in colour (in humus form) leads to soil temperature regulation, by controlling the thermal conductivity and heat capacity of soil. On the other hand, increased water content due to SOM-enhanced water holding capacity and soil aggregation results in increased soil temperature (Magdoff and Weil, 2002)

2.2.3.2 Chemical factors affecting soil productivity influenced by organic matter

The chemical properties of soil include nutrient status (inputs and outputs) and pH. The term pH describes the power of hydrogen and is defined as a measure of acidity and alkalinity of a solution. On the scale, 7 represents neutrality and lower numbers up to zero indicate increasing acidity and higher numbers up to 14, indicates increasing alkalinity. Most macronutrients such as Nitrogen, Phosphorus and Potassium are available for field crop use in the soil within the pH range of 5.5-7.5 (Mosaic, 2013). When the soil is more acidic or more alkaline, the nutrients are not accessible by the plants as the soil solution is highly concentrated with hydrogen ions which are cation acids hence reducing the base saturation of the soil.

Nutrient storage and release, the soil organic matter has large proportions of phosphorus and sulphur found in the soil as its constituents. The soil organic matter serves as a storage medium of nutrients and a short term supplier of these nutrients. Most of the nitrogen taken up by the plant comes from the organic pools that cycle through the microbial biomass. A study on corn showed that when 168kgN/ha was applied as inorganic fertilizer unlabeled N from mainly organic pools accounted for 70% of the Nitrogen taken up by the continuously growing corn (Omay *et al.*, 1998).

Cation Exchange Capacity, cation exchange capacity (CEC) is the total capacity of a soil to hold exchangeable cations. CEC is an inherent soil characteristic and it influences the soil's ability to hold onto essential nutrients and provides a buffer against soil acidification (GRDC, 2016). The CEC is an important chemical property that is used to classify soils. The colloidal fraction which consist of clay and humic organic matter is the center of chemical activity in the soil, including the capacity of ion exchange (Brady and Weil, 2008). For soils low in clay, soil organic matter is responsible for all the soil`s CEC. The CEC of humus per unit mass is higher and increases with rising pH than that of clay minerals. Base saturation is the percentage of the soil exchange sites (CEC) occupied by basic cations, such as potassium (K), magnesium (Mg), calcium (Ca), and sodium (Na) in the soil (Lincoln, 2001), and also affected by the acidity of the soil as they both adsorb to the soil CEC. Organic matter provides more capacity and ability to have more bases adsorbed to the humus.

Soil pH buffering, addition of soil organic matter improves the soil`s pH buffering capacity of the surface soils. The buffer capacity is attained as the organic matter contributes much to the soil`s CEC and also due to dissociation of weak functional group of the soil organic matter molecules (Magdoff and Barlet, 1985). This pH buffering characteristic is the main reason why agricultural management practices which add soil organic matter are favoured (Magdoff and Barlet, 1985)

Metal mobility, soil organic matter has the ability to affect the mobility of heavy metals that may or not serve as plant nutrients e.g. Zn and Cd. Addition of organic matter can either increase or decrease metal availability. Organometal complexes are formed when insoluble organic matter is added to the soil making the metals not available for plant uptake or leaching (Sauve *et al.*, 1998). However, When soluble organic components e.g. Carbon react, they increase metal availability by forming soluble Organometal complexes (Alvarez *et al.,* 1999), which results in reduced availability of Manganese and iron.

2.2.3.3 Biological factors affecting soil productivity influenced by organic matter.

The biological properties of soil include the multitude of organisms that thrive in soil, such as mycorrhizae, other fungi, bacteria and worms. The reduced population of microbes in the soil affects the nutrient availability of the soil. These microbes help in the mineralization of nutrients into usable form by the plants, e.g. in the conversion of ammonia to Nitrate in the soil. Other bacteria create a symbiotic relationship with legumes (Nodulation) and help in nutrient fixation in the soil. Organic matter decomposition also heavily depend on availability of the microbes hence the biological property of the soil being an important factor of the soil productivity.

2.3 Plant Nutrient uptake

Plants need essential nutrients for normal cell functioning, which results in growth and development of an organism. There are 15 essential elements that the plant needs in order to have a normal growth. These nutrient elements are either sourced from the atmosphere e.g. Hydrogen; Carbon and Oxygen, or from the soil e.g. Nitrogen, Potassium, Phosphorus, sulphur, Magnesium, calcium, iron, among others(CTAHR, 2007). Nutrient uptake from the soil requires soil moisture for the soil plant atmosphere continuum process. The most limiting nutrient in most soils for crop production is nitrogen. This element is required in formation of nucleic acids of DNA and also chlorophyll formation. Plants absorb nitrogen in form of

Nitrate (NO_3^-) and Ammonium ($NH4^+$) for use, mainly from the soil solution. If the plants don't access it in time, it can be lost through denitrification, volatilization, and run-off or leaching. For organic nitrogen to be utilized by the plant, it needs to be mineralized to ammonium and nitrate. In plant tissue, the nitrogen content ranges from 1 and 6%, upon analysis (CTAHR, 2007).

Phosphorus is a most limiting nutrient in the tropics mainly due to management challenges. In comparison to other macronutrients, the phosphorus concentration in the soil solution is much lower and ranges from 0.001 mg/L to 1 mg/L (Brady and Weil, 2002). It is available for plant absorption in orthophosphate form (H_2PO4) and moves into the plant root through diffusion. P is involved in plant processes such as energy transfer, protein synthesis and crop maturity (CTAHR, 2007) The solubility of phosphate minerals is very dependent upon soil pH. The soil pH for optimum phosphorus availability is 6.5.

Potassium (K) is a base cation beside calcium and magnesium which exist only in their cationic form (K^+, Ca^{2+}, Mg^{2+}) and not organic form. Most K exists in mineral form which is not available to plants. The exchangeable K (retained in CEC of soil) and the solution K are available for plant`s nutrition. Upon adsorption, K is involved in many enzymatic reactions, the synthesis of the energy compounds, translocation of carbohydrates within the plant and regulating gas exchange and water relations during transpiration (CTAHR, 2007). Generally, pH of the soil is the most determining factor of the availability of nutrients in the soil solution for plant absorption. Most macronutrients are available for plant utilization within the pH range of 5-7.5. Other factors that affect nutrient element uptake are; Soil moisture, temperature, Aeration, type of clay materials among others.

Nutrient elements contained in organic sources are released more slowly into the soil for absorption by the plants and are stored for a longer period of time hence ensuring a long residual effect(Ayoola and Makinde, 2007). Nutrients from organic sources are mineralized in the soil so that they are available for plant absorption. Nutrients are absorbed into the plants thorough the osmotic potential differences present with the soil plant and atmosphere continuum(GRDC, 2016).

2.4 Integrated organic fertilizer characteristics

Organic fertilizer does not meet the nutritional needs of crops because they contain a comparatively less quantity of nutrients compared to inorganic fertilizers to sustain maize growth and development (Suge *et al.*, 2011). Fertilizer integration involves using the organic manure and supplementing the nutrient deficit using inorganic fertilizer for crop production. Poultry manure is preferred because of its higher mineralization factor of0.45 which is higher than other manure types which have a mineralization factor of less than 0.25 and NH4+N, N, P205, K20 levels (44%, 68%, 64%, 45% respectively). Inorganic fertilizer component is added to the manure before decomposition, the mixture is placed in an air tight plastic bag for 21 days to facilitate decomposing resulting in the degradation of the different ingredients of the mixture into humus material. These attributes makes it affordable to most smallholder farmers to use as compared to the chemical fertilizer which is expensive.

CHAPTER THREE

MATERIALS AND METHODS

3.1 Study Site

The research study was conducted in two sites in Malawi (Fig. 1). The first was Chitedze Research Station. It is located in Lilongwe, the capital city at latitude 33° 38 ′ E, longitude 13°85′ S, and an altitude of 1146 m a.s.l. It is characterized by a warm weather with a mean diurnal temperature of 20.3°C temperature and an average unimodal rainfall of 860 mm. The rains fall between the months of December and April every year. The soil is sandy clay loam to sandy loam. The pH ranges from 5.9-6.2. Generally, the soil has low fertility.

The second site was Makoka Research Station. It is situated in Zomba which is 15°32′ South and 35° 11 ′ East at an altitude of 1029 m a.s.l, in south-eastern part of Malawi. The area has an average temperature of 21.1°C and an average annual rainfall of 1282 mm which fall between the months of November and March each year. The soils are mainly sandy loam to loam with a pH range of 4.5-7.0. Generally it has low fertility (Luhanga, 2012).

3.2 Experimental Treatments and Design

The experiment was in a split plot design (Figure 2). The main plot factor was hybrid maize (SC403 and SC627) and the sub plots consisted of six fertilizer treatments: chicken manure applied at 4 T ha^{-1}; chicken manure applied at 4 T ha^{-1} + 25% mineral N (22.5 kg N); chicken manure applied at 4 T ha^{-1} + 50% mineral N (45 kg N); chicken manure applied at 4 T ha^{-1}+75% mineral N (67.5 kg N); chicken manure applied at 4 T ha^{-1}+100% mineral N (90 kg N) and no fertilizer input, as a control (Table 1). The source of N was Urea (46%N) inorganic fertilizer.

The treatments (Table 1) were randomized and replicated three times in each site. The sub plot size was 6 rows each measuring 5 meters long, spaced at 75 cm. Each row had 20 plants and 120 maize plants per sub plot.

A buffer distance of 1m was set between main plots in a replicate and the replicates were spaced 1 m apart. The total experimental site area of one location was 1122m^2 (66 m ×17 m) (Figure 2).

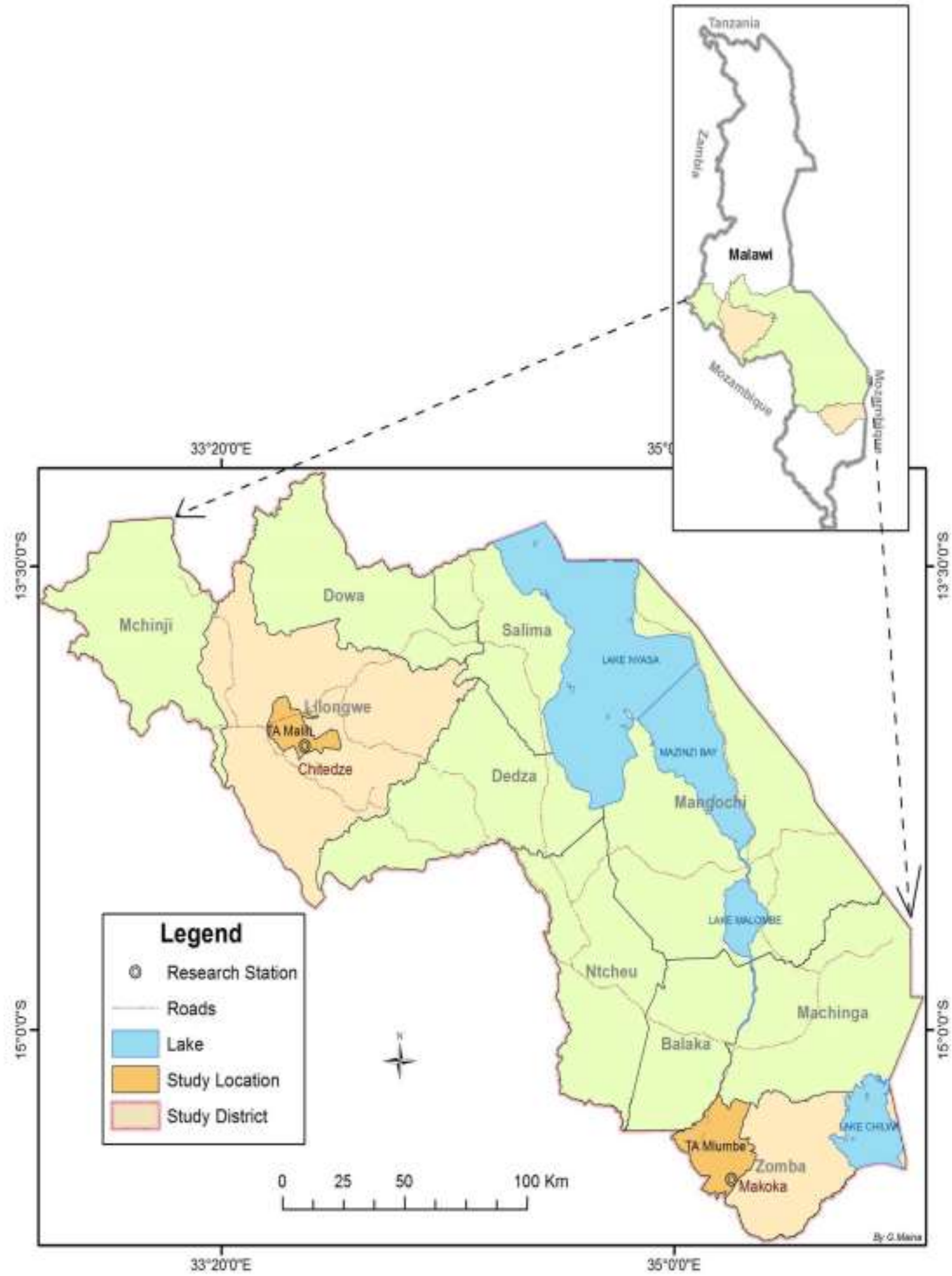

Figure 1: Malawi map showing the sites for the research areas in Lilongwe and Zomba.

Source: Ethiopian mapping Agency, prepared by G Maina (2017), Geography Dept. Egerton University.

Table 1: List of treatments Combinations

Treatment Name	Description
T1	4 T ha^{-1}CM + H1-SC 403
	4 T ha^{-1}CM + H2-SC 627
T2	4 T ha^{-1}CM + 22.5kg N ha^{-1} + SC 403
	4 T ha^{-1}CM + 22.5kg N ha^{-1} + SC 627
T3	4 T ha^{-1}CM + 45kg N ha^{-1} + SC 403
	4 T ha^{-1}CM + 45kg N ha^{-1} + SC 627
T4	4 T ha^{-1}CM + 67.5kg N ha^{-1} + SC 403
	4 T ha^{-1}CM + 67.5kg N ha^{-1} + SC 627
T5	4 T ha^{-1}CM + 90 kg N ha^{-1} + SC 403
	4 T ha^{-1}CM + 90 kg N ha^{-1} + SC 627
T6	No Input & SC 403
	No Input & SC 627

KEY: T= Fertilizer treatment; CM= Chicken manure.

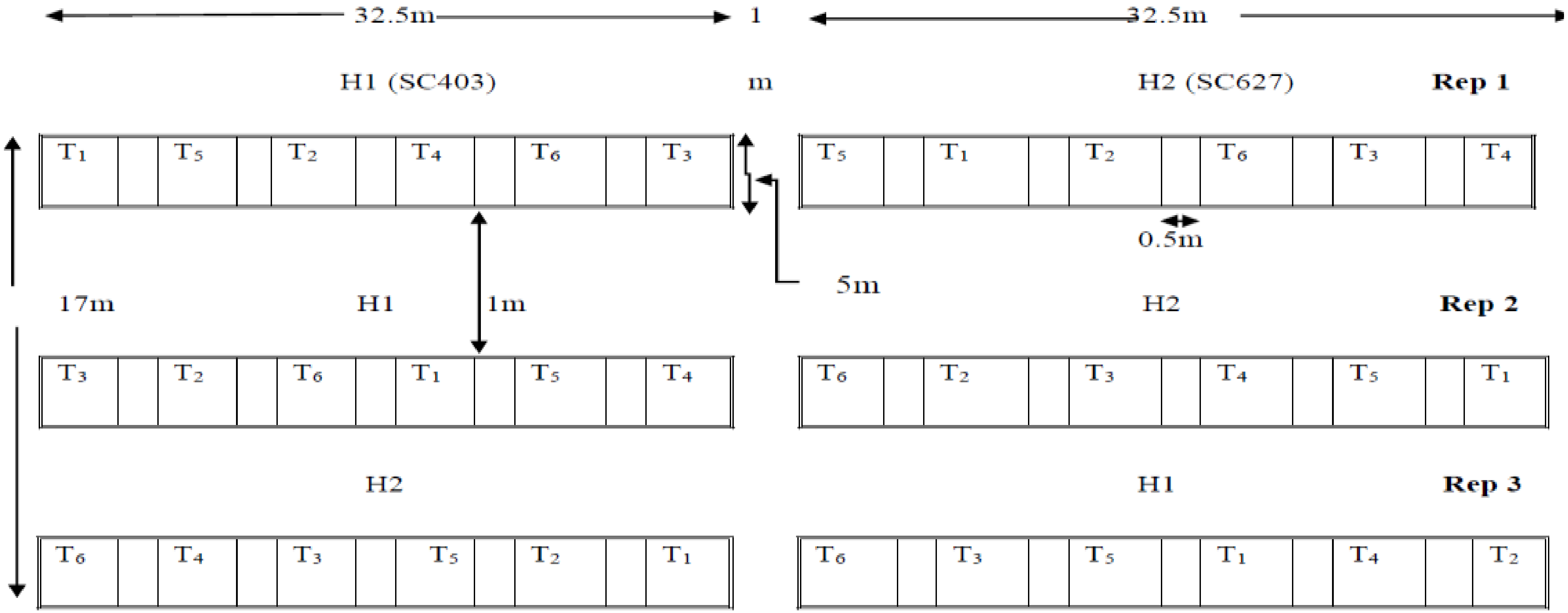

Figure 2: Experimental Layout; Split-Plot Design.

3.2.1 Inorganic and Organic fertilizer preparation

Closed chicken (*Gallus gallus domesticus*) manure (4.48% N) was used as an organic fertilizer source because it has a higher amount of nitrogen, phosphorus, and potassium as compared to other animal manure (Appendix 7). The manure was cured before use for nutrients mineralization and to prevent scorching of germinating plants by stabilizing it (Table 2). The curing was done by adding water and wood ash then covered it with maize stalks for 21 days. This is important because significant amount of nitrogen exists in the urine and may be lost through volatilization and denitrification (Raston, 2015).

Table 2: Ingredients for manure curing

Item	Quantity
Fresh Chicken manure	20 kg
Composted manure	10 kg
Ash	5 kg
Water	3 litres

The mixture of these ingredients was put in a pit under a shade for composting (Curing) for 21 days (Luhanga., 2012).

Inorganic fertilizer [Urea (46%N) and triple Supper phosphate (21%P_2O_5)] was bought from Malawi Agriculture Trading Company (ATC), an accredited inorganic fertilizer, seeds and chemicals distributor in Malawi.

3.3 Laboratory analysis of Soil and Chicken Manure

The research study involved two phases: (i) organic fertilizer and soil analysis, and (ii) plant nutrient uptake determination and plant growth/ yield production analysis (field experiment).

3.3.1 Soil and Manure sampling

Soil samples were collected in both sites using a transverse sampling method. An Edelman soil auger was used to collect 12 soil samples of top and sub soil in a single location at a depth of 15 and 45 cm respectively. The 12 samples were used to formulate composite samples of top and sub soils for laboratory analysis of physical and chemical properties.

Chicken manure characterization for nutrient content, a sample of cured chicken manure weighing 500g was randomly collected from the bulk of the cured manure.

Soil and manure samples that were collected were first registered, labelled then numbered for easy identification. The samples were then air dried in trays then ground using a motor and a pestle before being sieved through a 2 mm sieve (8 mesh). The sieved soil was then well mixed and filled in glass bottles with a representative sub-sample, with each bottle labelled on the inside as well as outside. Standard laboratory procedures were followed in analyzing the varying nutrient elements of the soil samples and the chicken manure.

3.3.2 Analysis of Nutrients

Soil organic Carbon was analyzed using Calorimetric method as according to Okalebo *et al.*, (2002). Determination of the amount of C from a standard curve was done according to the following equation:

$$\%OC = \frac{C(Mg)}{Sample(Mg)}(100)$$ ………………………………. Equation 1 (Chilimba, 2007)

Where: OC = Organic carbon.

Organic matter content was estimated by multiplying organic C by a factor of 1.724.

Exchangeable bases (P, Ca, Mg, K and Zn) were determined using The Mehlich 3 method as stipulated by Ziadin and Sen, (2008). Total Nitrogen was determined by Kjedahl method (Okalebo *et al.*, 2002). The calculation for nitrogen was done using the following formula:

$$\%N = \frac{Vt * 0.2Mg}{0.2g}(100)$$ …………………….. Equation 2.(Chilimba, 2007)

Then, $\%N = \frac{Vt}{10}$

Where: %N = Percent Nitrogen

Vt = Volume of titre

Soil PH of the samples obtained was determined using the glass electrode pH meter as according to the method of Okalebo *et al,* (2002).

Chicken manure characterization for total nitrogen determination was done using the Mehlich 3 method (Ziadin and Sen, 2008). The %N in the organic matter was derived using the following calculation:

$$\%N = \frac{(T - B) * N * 1.401}{0.20g}$$ ……………………………Equation 3 (Chilimba, 2007)

Where: T = ml of sample titrated
B = ml of blank titrated
N = Acid normality

3.4 Agronomic practices

The land was cleared and tilled to a depth of 45cm, giving a moderately fine tilth. Complete ridges were aligned at a spacing of 75cm apart and a height of 30cm before planting. Planting was done during the rainy season of 2016/17 in December. The chicken manure was applied 21 days before planting. Each sub plot (5 x 4.5m) had 120 maize plants planted at a regular interval of 25cm x75cm per plant. The fertilizer treatments were applied twice during the maize growing period, as basal and top dressing fertilizer. The basal fertilizer (Urea, 46% N) and phosphate fertilizer (21%P_2O_5) was used to supplement the cured chicken manure 7 days after planting. Top dressing fertilizer supplement to the chicken manure was applied 28 days after planting according to treatment. The most prevalent weeds were the annual weeds of grass family. Manual weeding using a hand hoes was used to control these weeds in the plots. Both primary (before basal fertilizer application) and secondary (before top dressing) weeding were done in both sites. After top dressing fertilizer application, ridge banking was done to ensure that the plants were properly supported by the soil to avoid excessive plant lodging. Finally, harvesting was done on a net plot which comprised of four 3 - meters long middle ridges, leaving 1 m guard row at each end of the ridge. Harvesting involved the removal of all above ground biomass for weighing. The tagged maize plants were harvested separately in each net plot.

3.5 Data collected

3.5.1 Seedling emergence and plant stand count

The total number of emerged shoots were counted manually 7 days after sowing per treatment plot and the data was recorded for comparison with plant stand at tasseling stage.

3.5.2 Leaf Area Index

Leaf Area was deduced by measuring the longest length and width leaf opposite to the cob for three sampled plants per sub plot. The Leaf area index was calculated using the following formula:

$LAI = k(L * W)$ ………………………….…………………… (Aikins & Afuakwa, 2012).

Where: L= Leaf Length (cm)
W= Leaf width (cm)
K= 0.75: Which is a constant for maize
LAI= Leaf Area Index

3.5.3 Stem girth

The stem girth data was collected on fortnightly basis, starting at 4 weeks after planting. The data was collected by measuring the stem thickness at the base of the maize stalk stem using a measuring tape. Three plant sampled plants in each sub-plot to obtain the average stem girth per sub-plot. (Enujeke, 2013)

3.5.4 Plant height

Maize height was determined using a measuring ruler. Three tagged maize plants were used per sub-plot. The plant height was considered from the node above ground to the end of the last node in meters, every fortnight from 4 weeks after planting.

3.5.5 Hundred - seed weight

The weight of the seeds was determined by using electronic scale, where 100 maize seeds were randomly sampled and weighed in grams from each sub plot after threshing and cleaning.

3.5.6 Biomass and grain yield

The weight of maize stalks was collected at physiological maturity state when the plants had dried. Three sampled maize stocks from each harvestable plot (4 middle plot rows) were cut just at the ground level. The aboveground biomass excluding the cobs was weighed and its weight recorded.

The maize gain was air dried and a moisture content meter was used to measure the moisture content level. Grain yield and cob weight from each net plot were measured at standard average moisture content of 13-14%. The grain yield was determined by multiplying average plant yield with the total number of plants per hectare (53,333 plants).

3.5.7 Plant tissue analysis

The samples for maize tissue analysis were collected at 50% tasseling stage to determine percentage of nitrogen in the leaves. A single leaf opposite and below the ear from the tagged plants at tasselling stage from five tagged plants(Kaiser *et al*, 2013). The total nitrogen percentage was calculated using the following equation:

$$\%N = \frac{(T-B)*N*1.401}{0.20g(Sample)}$$ ……………………………Equation 4 (Chilimba, 2007)

Where: T = ml of sample titrated
B = ml of blank titrated
N = Acid normality

The N-uptake amount was calculated using the following equation:

$$N-uptake=\langle\frac{ldw\times\%N}{100}\rangle*1000$$

Where: N-uptake = Nitrogen uptake
LDW = Leaf dry weight (g)
%N = percent of nitrogen in the leaf

3.5.8 The Cost/Benefit analysis (CBA)

The cost benefit was analyzed according to the formula of Michell *et al*., 1991.

$$GM=(TR-TVC)/Ha$$ …………………………..……..Equation 5 (Michell *et al*., 1991)

Where: GM = Gross margin;
TR = Total revenue
TVC = Total variable cost
Ha = Hectare

3.6 Data analysis

The data collected was subjected to Analysis of Variance (ANOVA) using SAS, version 8.2 (TS2M0) (Farhad *et al*., 2009). The treatments which were found to be significant were separated using the Fisher`s protected least significance difference (LSD) at 5% level of significance level.

The linear model that was fitted for the field experiment and used in data analysis was:

$$\mathbf{Y_{ijk}} = \mu + R_i + V_J + RV_{\langle IJ \rangle} + N_k + RN_{\langle ik \rangle} + VN_{\langle jk \rangle} + E_{ijkl}$$

Where:

μ = Overall mean, R_i = Effect of i^{th} Replicate, V_j = Effect of j^{th} variety, $RV_{(IJ)}$= Interaction effect of i^{th} replicate and j^{th} variety (Random error term), N_k = Effect of k^{th} treatment. $VN_{(jk)}$ = Interaction effect of j^{th} variety and k^{th} treatment, $E_{ij\kappa\iota}$ = Random Error Term and Y_{ijkl} = Yield.

CHAPTER FOUR

RESULTS

4.1 Effects of nitrogen level, maize variety and location on N-uptake, leaf area index and leaf dry weight

4.1.1 Main effects

N-uptake

The effect of fertilizer treatment, maize variety and location on nitrogen uptake by maize were significant ($p \leq 0.05$). Fertilizer treatment T5 (Chicken manure + 90kg mineral N) and T4 (Chicken manure + 67.5 Kg mineral N) fertilizer treatments had significantly ($p \leq 0.05$) higher values of 75.1 and 71.4 mg N plant^{-1}, respectively (Figure 3). Fertilizer treatment T_6 the lowest mean effect on nitrogen uptake (23.48 mg N plant^{-1}) (Table 3) but was not statistically different from T_1 (Chicken Manure 4t ha^{-1}) which had a nitrogen uptake of 27.22 mg N plant^{-1} (Figure 3). Maize variety SC627 had the highest mean N concentration (51.86 mg plant^{-1} compared to SC403 which had which had the least mean value of 44.39 mg N plant^{-1} (Table 3). Maize planted at Makoka had a significantly higher N concentration (52.71 mg N plant^{-1}) as compared to Chitedze which had a value of 43.55 mg N plant^{-1} (Table 3).

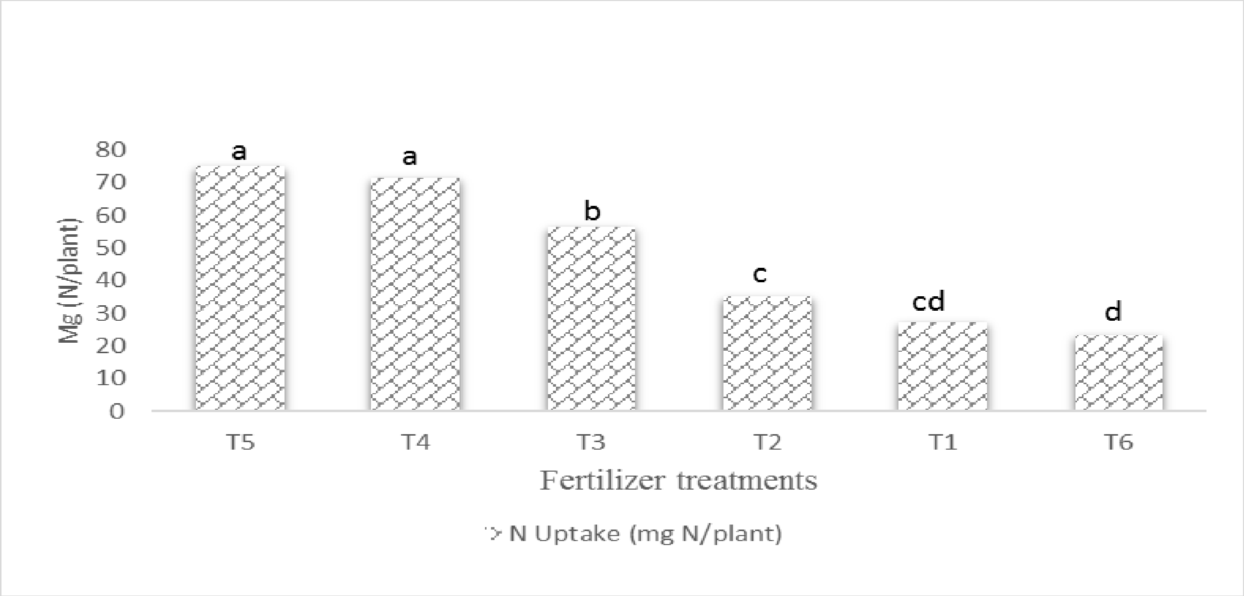

Figure 3: Effect of Nitrogen level on nitrogen Uptake (N-Uptake) of Maize in Malawi (2016/17 growing season)

Means with the same letters are not significantly different at P ≤ 0.05, T1= 4 T ha^{-1} chicken manure (CM), T2= CM + 22.5 kg mineral N + 21% P, T3= CM + 45 kg mineral N + 21%P, T4= CM + 67.5kg mineral N + 21%P, T5= CM + 90 kg mineral N + 21% P, T6= No fertilizer input.

Leaf area index

The effect of fertilizer treatment, maize variety on leaf area index (LAI) were significantly different (p ≤ 0.05) (Table 3). The T5 (chicken manure + 90kg mineral N) had a significantly higher mean LAI effect of 3.75 than other fertilizer treatments. T6 (No fertilizer input) had the least mean LAI effect of 1.22. Maize variety SC627 had a significantly (p ≤ 0.05) higher mean LAI value of 2.55 than SC403 maize variety which had LAI value of 2.41(Table 3). There was no significant difference (p ≤ 0.05) in terms of location effect in LAI between Makoka and Chitedze site.

Leaf dry weight

Maize variety SC627 had a significantly (p ≤ 0.05) higher mean Leaf dry weight (LDW) effect of 47.54g compared to SC403 maize variety which had a LDW of 47.12g (Table3). The effect LDW was no statistically significant (p ≤ 0.05) (Table 3). The effect of location on LDW was also not statistically different (p ≤ 0.05) as Makoka and Chitedze sites had a mean value of 48 g and 46.65 g respectively (Table 3).

Table 3: Effect of nitrogen level, maize variety and location on Leaf area index (LAI), leaf dry weight (LDW) and nitrogen uptake (N-Uptake) of maize in Malawi, 2016/17 season

Treatment	N-Uptake (mg N plant^{-1})	LAI	LDW (g)
Variety			
SC627	51.87a	2.55a	47.54a
SC403	44.39b	2.41b	47.12a
CV	23.18	11.55	8.88
LSD ($p \leq 0.05$)	5.34	0.66	2.13ns
Location			
Makoka	52.71a	2.48a	48.00a
Chitedze	43.55b	2.47a	46.65a
CV	23.17	11.55	8.88
LSD ($p \leq 0.05$)	5.34	0.66ns	2.14ns

Means with the same letters in the same column under a particular factor are not significantly different at $P \leq 0.05$.

4.1.2 Interaction effects of fertilizer rates, maize variety and location

N-uptake

The effect of location was highly significant ($p \leq 0.05$), where Makoka site had a significantly higher mean value (58.93 mg N plant^{-1}) than Chitedze site (42.3 Mg N plant^{-1}) (Figure 4). Treatment T5 (Chicken manure + 90kg mineral N) and T4 (Chicken manure + 67.5 Kg mineral N) fertilizer treatments had significantly ($p \leq 0.05$) higher values of 75.1 and 71.4 mg N plant^{-1} (Figure 4), respectively. Treatment T6 (No fertilizer input) had the least mean effect on N-uptake (23.48 mg N plant^{-1}) but was not statistically different from T1 (Chicken Manure 4t ha^{-1}) which had an N-uptake of 27.22 mg N plant^{-1} (Figure 4). Maize variety SC627 had the highest mean N concentration (51.86 mg plant^{-1} compared to SC403 which had which had the least mean value of 44.39 mg N plant^{-1} (Figure 4). Maize planted at Makoka had a significantly higher N concentration as compared to Chitedze.

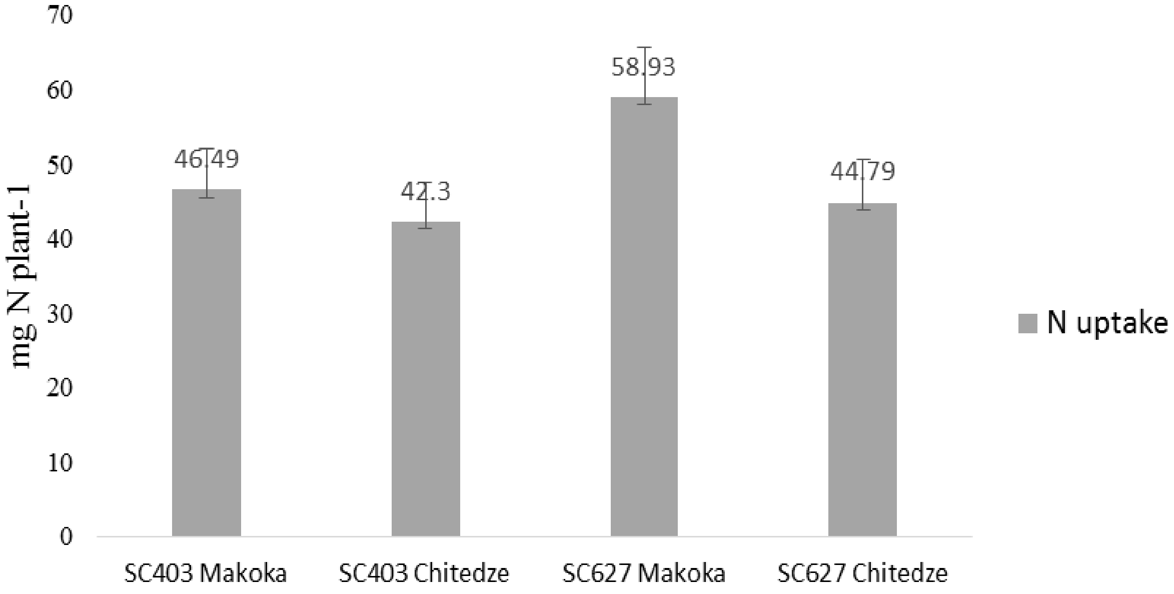

Figure 4: Interaction effect of Maize variety and location on nutrient uptake of hybrid maize in Malawi (2016/17 growing season)

Leaf area index

The effect of nitrogen level and maize variety interaction on leaf area index (LAI) was highly significant ($p \leq 0.05$) (Table 3). Treatment T5 (chicken manure + 90kg mineral N) and SC627 maize variety had a significantly higher mean LAI effect of 4.01 than other fertilizer treatments combinations. Fertilizer treatment T6 (No fertilizer input) and SC403 combination had the least mean LAI effect of 1.20. Maize variety SC627 attained higher LAI values than SC403 (Table 3). The effect of variety*location, nitrogen level*location and nitrogen level*variety *location were not significant at $p \leq 0.05$ (Appendix 1).

Table 4: Interaction of nitrogen level and variety on LAI (Mean ± SE) of hybrid maize in Malawi (2016/17 growing season)

	Maize varieties	
N treatment	**SC403**	**SC627**
T1 [4 T ha^{-1} chicken manure (CM)]	1.79 ± 0.02	1.81 ± 0.05
T2 (CM + 22.5kg mineral N)	2.16 ± 0.02	2.26 ± 0.01
T3 (CM + 45 kg mineral N)	2.67 ± 0.04	2.69 ± 0.04
T4 (CM + 67.5 kg mineral N)	3.13 ± 0.01	3.23 ± 0.03
T5 (CM + 90 kg mineral N)	3.48 ± 0.09	4.01 ± 0.11
T6 (No fertilizer input)	1.20 ± 0.02	1.24 ± 0.04
CV	11.55	11.55
R^2	0.89	0.89
LSD ($p \leq 0.05$)	1.11	1.11

± = Standard error term

Leaf dry weight

Nitrogen level*location interaction had a significant effect on leaf dry weight of the maize varieties (Table 4). Nitrogen level treatment T5 had a significantly ($P \leq 0.05$) higher effect on leaf dry weight (60.16g) at Makoka site as compared to the other fertilizer treatment interactions. Treatment T6 in which no fertilizer was used, had the lowest mean LDW value of 41g at Chitedze (Table 4). Makoka site had higher mean values of leaf dry weight as compared to Chitedze site (Table 4).

Table 5: Interaction of nitrogen level and location on leaf dry weight (g) (Mean ± SE) uptake of hybrid maize in Malawi (2016/17 growing season)

	Location	
Treatment	Makoka	Chitedze
T_1 [4 T ha^{-1} chicken manure (CM)]	42.16 ± 1.11	41.00 ± 1.03
T_2 (CM + 22.5kg mineral N)	43.50 ± 0.43	43.92 ± 1.23
T_3 (CM + 45 kg mineral N)	48.51 ± 1.09	48.16 ± 1.19
T_4 (CM + 67.5 kg mineral N)	54.84 ± 1.27	53.33 ± 1.20
T_5 (CM + 90 kg mineral N)	60.16 ± 2.55	57.00 ± 0.86
T_6 (No fertilizer input)	38.83 ± 0.95	36.50 ± 2.64
CV	7.90	7.90
R^2	0.89	0.89
LSd ($p \leq 0.05$)	3.10	3.10

± = Standard error term.

4.2 Effects of N-level, maize variety, location and sampling time on growth parameters

4.2.1 Main effects

Height

The effect of fertilizer treatments was significant at ($p \leq 0.05$) on maize height. Fertilizer treatment T_5 had a significantly higher ($p \leq 0.05$) mean maize height (188.34 cm) compared to other treatments (Table 6). Fertilizer treatment T_6 had the least mean height (37.57 cm) (Table 6). Maize variety SC627 was taller with a mean height of 114.22 cm (Table 6) as compared to SC403 maize variety which had a mean height of 112.61 cm (Table 6). The maize planted at Makoka were taller as compared to Chitedze site with a mean height of 118.19 cm and 111.63 cm recorded respectively (Table 6). Makoka site had taller maize plants (118.19 cm) which wa significantly different ($p \leq 0.05$) to maize planted at Chitedze which had a mean height of 111.64 cm (Table 6).

Girth

The effects of fertilizer treatment, maize variety and location on maize girth were significant ($p \leq 0.05$). Fertilizer treatments T_2, T_3 (Chicken Manure + (45 kg N mineral), T_4 and T_5 had girth means (cm) of 7.30, 7.4, 7.4 and 7.40 respectively which were not significantly different ($p \leq 0.05$) but higher than T_1 and T_6 mean values (Table 6). Fertilizer treatment T_6 had the least mean girth (6.02 cm) (Table 6). SC627 maize variety had a significantly higher ($P<0.05$) mean girth value (7.26 cm) as compared to SC403 maize variety (6.88 cm) (Table 6). The maize planted at makoka had a significantly higher ($p \leq 0.05$) mean girth (7.30 cm) as compared to those planted at Chitedze (6.84 cm) (Table 6).

Table 6: Effects of Nitrogen level; Maize variety and Location on Hybrid Maize (*Zea mays* L.) Plant girth and height in Malawi, 2016/17 growing season

Treatment	Height(cm)	Girth (cm)
Nitrogen level		
T_5 (CM + 90 kg mineral N)	188.34a	7.40a
T_4 (CM + 67.5 kg mineral N)	172.67b	7.49a
T_3 (CM + 45 kg mineral N)	149.42c	7.41a
T_2 (CM + 22.5 kg mineral N)	75.92d	7.31a
T_1 [4 T ha^{-1} chicken manure (CM)]	65.58e	6.41b
T_6 (No fertilizer input)	37.57f	6.02c
CV	6.79	10.98
LSD (P<0.05)	6.48	0.28
Variety		
SC627	114.22a	7.26a
SC403	112.61b	6.89b
CV	6.79	10.98
LSD (P<0.05)	3.74	0.16
Location		
Makoka	118.19a	7.30a
Chitedze	111.64b	6.84b
CV	6.79	10.995
LSD (P<0.05)	3.74	0.16

Means with the same letters in the same column under a particular factor are not significantly different at $P \leq 0.05$.

4.2.2 Interaction effect

Height

Maize plant height was significantly ($p \leq 0.05$) influenced highly by nitrogen level*variety and location effects. Similarly, nitrogen level*time, location*weeks and nitrogen level*maize variety interactions were all highly significant ($p \leq 0.05$) (Figure 7).

The nitrogen level*maize variety*location interaction effect on height of hybrid maize grown at Makoka was significantly ($p \leq 0.05$) higher than the maize grown at Chitedze (Table 7). Maize variety SC627 that was subjected to fertilizer treatment T_2 at Makoka had significantly ($p \leq 0.05$) higher mean height of 177.27 cm (Table 7). The highest height mean value at Chitedze was 173.97 cm that was subjected to nitrogen level T_4 (Table 7). Maize variety SC403 that was subjected to nitrogen level T_6 at Makoka site had the least mean height (109.90 cm) as compared to the other interactions in both sites (Table 7). Maize variety SC627 planted at Chitedze and supplied with T_5 fertilizer treatment had a lower mean height of 155.52 cm (Table 7). Generally, treatments at Makoka performed better than Chitedze interactions as per effect on maize height (Table 7).

Nitrogen level and time interaction effect on maize height was significant in all the sites (Figure 5). The interaction had the following equations derived: $Y_{T1}= 41.47x + 19.84$ with an R^2 of 0.87; $Y_{T2}= 46.01x\ 29.31$ with an R^2 of 0.85; $Y_{T3}= 45.02x + 33.25$ with an R^2 of 0.85; $Y_{T4}= 45.69x +34.83$ with an R^2 of 0.84; $Y_{T5}= 47.15x +28.77$ with an R^2 of 0.86; and $Y_{T6}= 16.46x +30.70$ with an R^2 of 0.88 (Figure 5).

In the 12th week (Final week of data collection), the mean heights for fertilizer treatments T_2, T_3, T_4 and T_5 were not significantly different at $p \leq 0.05$ but T_5 treatment had the highest mean height (Figure 5). Fertilizer treatment T_6 had the least mean heights that were significantly different ($p \leq 0.05$) at all the stages of growth as compared to the other fertilizer treatments (Figure 5). In week four after sowing, the maize had the lowest mean heights in both fertilizer treatments. Fertilizer treatments T_1 and T_6 had the least mean heights that were not significantly different ($P \leq 0.05$) with T_6 having the least value. The maize height for fertilizer treatments T_2, T_3, T_4 and T_5 were also not significantly different ($p \leq 0.05$) with T_3 having a higher mean value. The mean height of maize growth increased each time interval data was collected from fourth to twelfth week (Figure 5).

Table 7: Effect of nitrogen level, location and maize variety on maize height (cm) (Mean ± SE) in Malawi, 2016/17 growing season

	Makoka Site		**Chitedze site**	
	Variety		**Variety**	
Treatment	**SC403**	**SC627**	**SC403**	**SC627**
T1	121.29 ± 16.73	175.79 ± 21.29	149.68 ± 15.97	140.29 ± 17.44
T2	164.37 ± 19.75	179.87 ± 22.09	144.54 ± 16.38	170.68 ± 18.77
T3	167.73 ± 20.85	156.99 ± 20.87	170.31 ± 16.62	158.21 ± 19.51
T4	174.08 ± 20.36	177.27 ± 22.17	173.97 ± 16.62	152.35 ± 18.98
T5	175.68 ± 20.66	176.10 ± 21.42	173.52 ± 16.84	145.52 ± 20.54
T6	109.90 ± 17.32	126.28 ± 19.84	123.25 ± 15.87	130.93 ± 19.34
CV	12.44	12.44	12.44	12.44
R^2	0.95	0.95	0.95	0.95

T_1= 4 T ha^{-1} chicken manure (CM), T_2= CM + 22.5kg mineral N + 21% P, T_3= CM + 45 kg mineral N + 21% P, T_4= CM + 67.5 kg mineral N + 21% P, T_5= CM + 90 kg mineral N + 21% P, T_6= No fertilizer input.

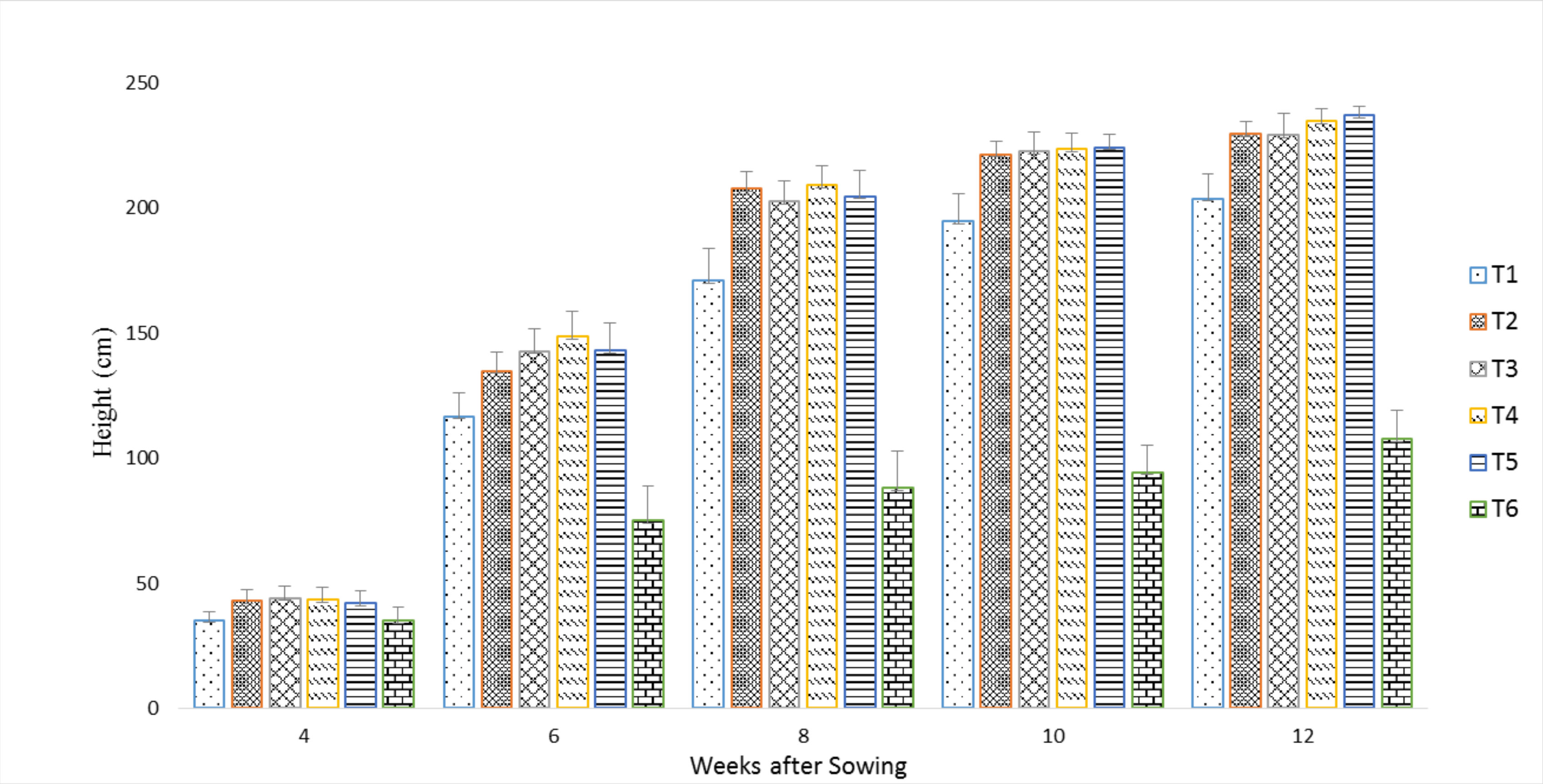

Figure 5: The progression of maize height after sowing at different growth periods in Malawi during 2016/17 growing season

T_1= 4 T ha^{-1} chicken manure (CM), T_2= CM 4 T ha^{-1} + 22.5 kg mineral N + 21% P, T_3= CM4t ha^{-1} + 45 kg mineral N + 21% P, T_4= CM 4 t ha^{-1} + 67.5 kg mineral N + 21% P, T_5= CM 4t ha^{-1} + 90 kg mineral N + 21% P, T_6 = No fertilizer input.

Girth

The girth of the hybrid maize was significantly ($p \leq 0.05$) influenced by the combined effects of nitrogen level*location*variety, nitrogen level*location and nitrogen level*variety (Appendix 1). Time interactions across the season did not statistically influence significantly (($p \leq 0.05$) the mean girth of the hybrid maize.

In the three way interaction effect (nitrogen level*variety*location interaction) on girth of SC403 hybrid maize variety grown at Makoka site and subjected to T_3 nitrogen level had the highest mean value 8.22 cm (Table 6). Maize variety SC403 subjected to nitrogen level T_6 had the least girth with a mean value of 5.44 cm (Table 6). Makoka site generally had a higher mean girth as compared to maize planted at Chitedze site. Maize variety SC627 generally had thicker maize stalks as compared to SC403 maize variety in all the sites.

Table 8: Effect of nitrogen level, location and maize variety on maize girth (cm) (Mean ± SE) in Malawi, 2016/17 growing season

	Makoka Site		**Chitedze site**	
	Variety		**Variety**	
Treatment	**SC403**	**SC627**	**SC403**	**SC627**
T1	5.75 ± 0.28	7.82 ± 0.21	5.77 ± 0.30	6.29 ± 0.36
T2	7.38 ± 0.25	7.72 ± 0.32	7.15 ± 0.19	6.97 ± 0.29
T3	8.22 ± 0.33	7.67 ± 0.16	6.78 ± 0.24	6.97 ± 0.39
T4	7.96 ± 0.27	7.74 ± 0.32	6.71 ± 0.24	7.55 ± 0.40
T5	7.86 ± 0.27	7.78 ± 0.33	6.94 ± 0.23	7.03 ± 0.38
T6	5.44 ± 0.44	6.31 ± 0.50	6.68 ± 0.32	7.23 ± 0.42
CV		10.98		10.98
R^2		0.81		0.81

T_1= 4 T ha^{-1} chicken manure (CM), T_2= CM + 22.5kg mineral N + 21% P, T_3= CM + 45 kg mineral N + 21% P, T_4= CM + 67.5 kg mineral N + 21% P, T_5= CM + 90 kg mineral N + 21% P, T_6= No fertilizer input.

4.3 Effects of nitrogen level, maize variety and location on maize yield attributes

4.3.1 Main effects

Maize grain yield

There were no significant ($p \leq 0.05$) interactions between nitrogen level*variety*location, nitrogen level*variety, nitrogen level*location nor variety*location interactions on maize grain yield. The effect of maize variety was significant at $p \leq 0.01$ level of probability on maize grain yield (Appendix 1) which was below the threshold set for this analysis. All the effects of nitrogen level treatments were significantly different. Nitrogen level treatment T_5 a significantly higher mean maize grain yield value of 6306 Kg ha^{-1} with treatment T_6 having the least mean effect on maize grain yield (1122 Kg ha^{-1}). Makoka site had a significantly ($p \leq 0.05$) higher mean effect on maize grain yield of 4330 Kg ha^{-1} as compared to Chitedze site at 3716.3 Kg ha^{-1} (Table 7).

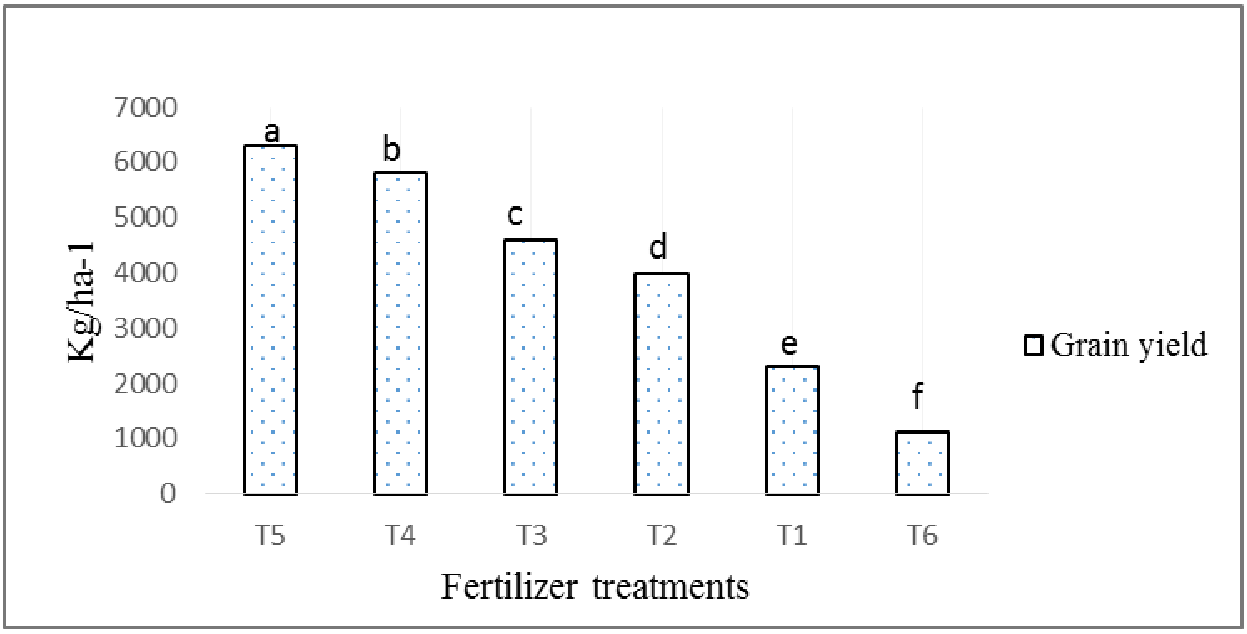

Figure 6: Effect of nitrogen level on hybrid Maize grain yield in Malawi (2016/17 growing season)

T_1= 4 T ha^{-1} chicken manure (CM), T_2= CM + 22.5 Kg mineral N + 21% P, T_3= CM + 45 Kg mineral N + 21% P, T_4= CM + 67.5 Kg mineral N + 21%P, T5= CM + 90 Kg mineral N + 21%P, T6= No input

100-seed weight

For 100-seed mass, SC627 maize variety had a significantly ($p \leq 0.05$) higher 100-seed weight mean of 42.09 g compared to SC403 variety which had a mean of 39.79g. Chitedze had a significantly higher ($p \leq 0.05$) mean value (43.90 g) as compared to Makoka (37.99 g).

Biomass

The effect of fertilizer treatment and location on maize dry matter yield were significant ($p \leq 0.05$). The highest mean biomass weight recorded was in T5 treatment (9703.1kg ha^{-1}) by fertilizer treatment T5 than other fertilizer treatments. The least mean biomass being effected by T6 (2003.7 kg ha^{-1}) (Table 7). The mean biomass between the 2 varieties was not significantly different ($p \leq 0.05$) with SC627 having a mean of 6097.37 kg ha^{-1} and SC403 6004.64 kg ha^{-1}. Makoka site had a higher mean biomass weight of 6278.52 kg ha^{-1} as compared to Chitedze site which had a mean biomass weight of 5823.48kg ha^{-1} (Table 7). The mean biomass between the varieties was not significantly different ($p \leq 0.05$).

Table 9: Inferential statistics on the effect of nitrogen level; maize variety and Location on Maize (*Zea mays* L.) Yield attributes of Hybrid Maize in Malawi, 2016/17 growing season

Treatment	**Yield (kg ha^{-1})**	**100-seed weight (g)**	**Biomass (kg ha^{-1})**
Variety			
SC627	4145.0a	42.09a	6097.37a
SC403	3901.4a	39.79b	6004.64a
CV	14.19	8.87	6.34
LSd (P<0.05)	2.74ns	1.74	183.78ns
Location			
Makoka	4330.0a	37.99b	6278.52a
Chitedze	3716.3b	43.90a	5823.48b
CV	14.18	8.87	6.34
LSd (P<0.05)	2.73	1.7396	183.78

Means with the same letters in the same column under a particular factor are not significantly different at $P \leq 0.05$.

4.3.2 Interaction effect

100-seed weight

The interactions of nitrogen level*variety*location and variety*location had no significant effect on 100-seed weight of maize. However, nitrogen level*location and nitrogen level*variety interactions were highly significant (Appendix 1). The nitrogen level* maize variety interaction had a significantly ($p \le 0.05$) higher mean effect on 100- seed weight of 45.65 g from treatment T_5 and SC627 treatment combination (Table 10). The least effect (31.53 g) was recorded from a T_6 and SC403 maize variety treatment combination (Table 8). Maize variety SC627 had higher mean effect values than SC403 maize variety (Table 10). The interaction effect of nitrogen level and location gave a higher 100-seed weight value (45.17 g) from the split plots subjected to nitrogen level treatment T_4 at Chitedze site (Table 11). The least mean effect (33.73 g) was recorded in treatment T_1 and Makoka site interaction (Table 11).

Table 10: Effect of nitrogen level rates and maize variety interaction on 100-seed weight (cm) (mean ± SE) of hybrid maize in Malawi, 2016/17 growing season

	Maize variety	
Treatment	**SC403 (g)**	**SC627 (g)**
T_1 [4 T ha^{-1} chicken manure (CM)]	38.42 ± 3.19	36.67 ± 0.94
T_2 (CM + 22.5 Kg mineral N)	37.21 ± 2.26	42.17 ± 2.19
T_3 (CM + 45 Kg mineral N)	42.25 ± 1.99	43.10 ± 1.32
T_4 (CM + 67.5 Kg mineral N)	40.67 ± 2.10	44.84 ± 1.71
T_5 (CM + 90 Kg mineral N)	43.67 ± 2.50	45.65 ± 1.78
T_6 (No fertilizer input)	31.53 ± 2.38	33.18 ± 2.78
CV	8.80	8.86
R^2	0.87	0.81
LSD (P<0.05)	1.73	3.01

CV= Coefficient of variation, LSD (P<0.05) = Least significant different, ± = Standard error.

Table 11: Nitrogen level*location interaction effect (Mean ± SE) on maize 100 seed weight (cm) in Malawi (2016/17 growing season)

Treatment	Location	
	Makoka (g)	**Chitedze (g)**
T_1 [4 T ha^{-1} chicken manure (CM)]	33.73 ± 1.60	41.35 ± 1.73
T_2 (CM + 22.5 Kg mineral N)	36.79 ± 2.08	45.08 ± 2.05
T_3 (CM + 45 Kg mineral N)	41.42 ± 1.44	43.91 ± 1.76
T_4 (CM + 67.5 Kg mineral N)	41.33 ± 1.17	45.17 ± 2.68
T_5 (CM + 90 Kg mineral N)	40.61 ± 1.11	42.69 ± 3.06
T_6 (No fertilizer input)	34.02 ± 1.84	34.68 ± 2.13
CV	8.87	8.87
R^2	0.82	0.82
LSD	1.73	1.73

CV= Coefficient of variation, LSD ($P<0.05$) = Least significant different, ± = Standard error.

Biomass

There was a significant effect ($p \leq 0.05$) of nitrogen level*location interaction on biomass (Appendix 1). The effect of variety on biomass accumulated was not significant ($p \leq 0.05$) nor the other interactions. The effect of fertilizer treatment and location interaction on maize dry matter yield was significant at $p \leq 0.05$ probability level threshold for the analysis (Appendix 1). Maize varieties that were subjected to nitrogen level T5 treatment at Chitedze site accumulated a higher biomass content of 9708.82 Kg ha $^{-1}$. The least biomass accumulated was recorded at Chitedze site under nitrogen level treatment T6 (Table 12).

Table 12: Nitrogen level*location interaction effect (Mean ± SE) on maize shoot biomass (Kg ha^{-1}) in Malawi (2016/17 growing season)

	Location	
Treatment	**Makoka (Kg ha^{-1})**	**Chitedze (Kg ha^{-1})**
T_1 [4 T ha^{-1} chicken manure (CM)]	3524.42 ± 119.07	3471.08 ± 103.07
T_2 (CM + 22.5 Kg mineral N)	4497.74 ± 51.37	3633.31 ± 63.83
T_3 (CM + 45 Kg mineral N)	8184.39 ± 233.70	7786.61 ± 218.60
T_4 (CM + 67.5 Kg mineral N)	9573.27 ± 200.38	8527.72 ± 220.91
T_5 (CM + 90 Kg mineral N)	9697.31 ± 141.48	9708.82 ± 136.34
T_6 (No fertilizer input)	2193.98 ± 161.58	1813.32 ± 184.75
CV	6.34	6.34
R^2	0.99	0.99
LSD ($p \leq 0.05$)	1.83	1.83

CV= Coefficient of variation, ± = Standard error.

4.4 Correlation coefficients for agronomic traits of maize variety production

All the variables were positively correlated to each other but at different levels and significance. Biomass, nitrogen uptake and leaf area index were all strongly correlated and significant at $p \leq 0.01$ while 100 seed weight was moderately correlated to yield at a significance level of ($p \leq 0.05$). The 100-seed weight was moderately correlated to all other variables at $p \leq 0.05$ significance level (Table 13). Nutrient uptake and LAI were strongly correlated to biomass at $P<0.05$ but weakly correlated to of biomass (Table 13). LAI had a strong positive correlation to Nitrogen uptake and significance at $p \leq 0.01$ (Table 13).

Table 13: Correlation coefficients of agronomic traits of hybrid maize in Malawi during 2016/2017 growing season

	Yield	100Sdwt	Biomass	N uptake	LAI
Yield	1.00				
100Sdwt	0.63**	1.00			
Biomass	0.91***	0.36**	1.00		
N uptake	0.75***	0.33**	0.79***	1.00	
LAI	0.91***	0.43**	0.94***	0.77***	1.00

LAI= Leaf area Index; 100Sdwt = 100 seed weight; N uptake = Nitrogen uptake; Yield = Maize grain yield per ha^{-1}.

4.5 Gross margin analysis of fertilizer level and Variety treatments on Maize production

All the treatment combinations ensured net profit margins except for the T_6 combinations which had net losses (Table 14). Treatment T_5 and SC627 maize variety treatment combination ensured the highest profit margin while T6*SC403 maize variety and T_6*SC627 interactions had the least margins which were net losses. Treatment T_4 and SC627 maize variety treatment combination had a higher profit margin as compared to T_5 and SC403 maize variety combination. Treatment T_1 interaction with both SC403 and SC627 maize varieties ensured a net gross margin of above break-even point of the analysis (Table 14).

Table 14: Gross margin analysis of fertilizer level and variety treatments for maize production in Malawi during 2016/2017 growing season

Fertilizer treatment	Maize Variety	Production Cost $	Yield (kg ha^{-1})	Unit price $	Revenue $	Net income $
T1	SC403	418.403	2358.49	0.21	491.35	72.95
T1	SC627	418.403	2245.15	0.21	467.74	49.34
T2	SC403	452.257	3791.08	0.21	789.81	337.55
T2	SC627	452.257	4178.47	0.21	870.51	418.26
T3	SC403	486.111	4509.59	0.21	939.50	453.39
T3	SC627	486.111	4683.29	0.21	975.69	489.57
T4	SC403	519.965	5424.78	0.21	1,130.16	610.20
T4	SC627	519.965	6228.15	0.21	1,297.53	777.57
T5	SC403	553.819	6204.41	0.21	1,292.59	738.77
T5	SC627	553.819	6408.84	0.21	1,335.18	781.36
T6	SC403	390.625	1119.97	0.21	233.33	-157.30
T6	SC627	390.625	1125.89	0.21	234.56	-156.06

Exchange rate: $1=MK720, T_1= 4 T ha^{-1} chicken manure (CM), T_2= CM + 22.5 Kg mineral N + 21% P, T_3= CM + 45 Kg mineral N + 21% P, T_4= CM + 67.5 Kg mineral N + 21% P, T_5= CM + 90 Kg mineral N + 21% P, T_6 = No fertilizer input.

CHAPTER FIVE

DISCUSSION

5.1 Integrated chicken manure and inorganic fertilizer rates on N-uptake by hybrid maize.

The applied fertilizer treatments resulted in varied maize growth response. Treatment combination T5 which was composed of chicken manure and 90 kg mineral N subjected to SC627 maize variety resulted in the highest LAI of 3.75 as compared to T6 (No fertilizer input) which had a LAI of 1.23. Increase in nitrogen level improved the maize plant`s growth and development efficiency. Leaf area index (LAI), Leaf dry weight (LDW) and Nitrogen uptake (N-Uptake) are important parameters to be analyzed as they are an integral part of plant growth and development. Leaf area is important in photosynthetic process as it affects the amount of sunlight radiation captured (Aikins and Afuakwa, 2012).Amin, (2010) also indicated that nitrogen is an important element in plant cell growth and elongation as it is a component of cell wall hence the increased effect on Leaf Area Index. Maize variety SC627 had a higher mean LAI of 2.54 as compared to the SC403 maize variety which had 2.41. This is attributed to the long pre-anthesis period of SC627 which allows for proper vegetative growth.

The primary function of leaves is to capture solar radiation and convert it to assimilates and dry matter accumulation through photosynthesis(Ghosh *et al*., 2004). The interaction of fertilizer treatment T5 and maize variety SC627 produced the highest LDW of 59 g per plant in both locations. Treatment T6 fertilizer level had the lowest mean leaf dry weight, which implies that the plants were not able to produce enough metabolites for dry matter accumulation. Leaf dry weight (LDW) indicates how efficient the plant was in utilizing the nutrients provided during photosynthate production and utilization (Aluko *et al*., 2014).

Fertilizer treatment T4 comprised of Chicken manure and 67.5kg mineral N had a higher Nitrogen uptake level of 83.88 mg N plant^{-1} but this was not significantly different ($p \leq 0.05$) from fertilizer treatment T5 which had a mean of 76.54 Mg N plant^{-1}. This implies that use of chicken manure and 67.5 kg mineral N (T4) ensured an optimal environment for nutrients absorption by the maize as opposed to T5 fertilizer treatment which might have made the soil more acidic rendering some elements unavailable for uptake. Nitrogen uptake analysis is important in evaluating how efficient are the plants are in absorbing nutrients from the soil for metabolic reactions in the plant. Excessive nitrogen supply is hazardous to maize plants as it dampens antioxidant capacity and grain filling in plants (Lingan *et al*.,2017).

5.2 Effect of integrated chicken manure and inorganic fertilizer rates on growth and yield of hybrid maize.

There were no significant differences ($p \leq 0.05$) in mean girth of maize plants subjected to fertilizer treatments level: T2; T3; T4 and T5, except fertilizer treatment T6 which had the least mean effect of 6 cm girth. The optimum girth was obtained at low nitrogen levels, and it implies that less nitrogen is required to have maize plants with a normal girth of 7.0-7.5cm. This can be attributed to the developmental stages of the plant, mostly stem development happens before reproduction stage peaks up hence more nutrients are not stored in grains but rather used for the plant statue development.

The highest mean girth of 7.26 cm was obtained in variety SC627, which implies that it capable of storing a lot of photosynthates for use during senescence as opposed to variety SC403 which had a lower mean girth hence having a lower sink for photosynthates storage. Makoka site had the highest mean girth as compared to Chitedze site and this is attributed to the optimal environmental factors such as rainfall and temperature in Makoka site as compared to Chitedze (Appendix 8).

On maize height, fertilizer treatment T5 had the highest mean effect of 188.34cm on the maize and was significantly different ($p \leq 0.05$) from all other fertilizer treatments with T6 treatment having the lowest mean height of 37.57cm. For maximum growth in height T5 fertilizer is the best, though it’s not the best attribute of maize survival as the maize is prone to lodging due to the effect of wind (Spitzer *et al*, 2015). Maize variety SC627 had a higher mean height of 114.22cm due to its genetic characteristics of longer pre-anthesis period and significantly different ($p \leq 0.05$) as compared to SC403 which had 112.61cm due to its shorter pre-anthesis period.

On time interval of plant growth, the plant`s height increased with time from the date of planting to the 12 week of growth which was the final week of data collection on growth traits. Between planting date and the fourth week plants experienced a steady increase in height as compared to the other intervals (Figure 5). Fertilizer treatment T6 which had no form of fertilizer applied to the maize varieties had the least growth rate during the 12 weeks when data was collected. This is attributed to the lack of supplementary nitrogen fertilizer application, therefore the plants probably relied only on the nitrogen present in the soil(Gungula *et al.*, 2005).

The growth in height for fertilizer treatment T2, T3, T4 with time in was not statistically different ($p \leq 0.05$) at all stages of development. This implies that for optimum height, fertilizer treatment T2 is the best economically as it produced the same results as fertilizer treatment T5. The extra N supplied by fertilizer treatments T3 to T5 was probably used for grain filling which ensured maize grain yield as illustrated in figure 6. During vegetative growth, most nutrients are used for cell growth as compared to other plant functions such as reproduction phase which includes grain filling. Besides this, in later stages of plant development photosynthesis rate declines due to decline in chlorophyll activity which signals the plant to utilize most of its energy in grain development for generation continuation and survival(Gungula *et al*., 2005).

The maize varieties at Makoka had the higher mean height of 44.2 cm and 43.60 cm for maize varieties SC627 and SC403 respectively in the fourth week after planting as compared to maize varieties at Chitedze site which had a mean height 39.99 cm and 35.98 cm for maize variety SC627 and SC403 respectively. This was due to the favorable conditions for nutrients uptake and maize growth. The even distribution of rainfall at Makoka site reduced the denitrification rate in the soil due to the cooling effect on the soil hence much nitrogen that was applied being taken up by the maize (Myrold and Tiedje, 2002). At Chitedze site, the reduced height and girth is attributed to the less water supply for regular soil nutrient absorption and uptake, hence imparting on cell division and elongation of the maize plants (Myrold and Tiedje, 2002).

Maize plants subjected to fertilizer treatment T6 (No fertilizer input) had a stunted growth in height due to lack of nutrients such as nitrogen which is essential for growth as it is a component of cell nucleus and production of hormones such as Auxins and Gibberellins which are essential for cell growth and elongation (Davies, 2004). Application of chicken manure (T_1) ensured a mean height that was statistically different ($p \leq 0.05$) from the no fertilizer treatment (T6). Fertilizer treatment T_2 (CM + 22.5kg mineral N + 21%P) ensured mean heights at all stages of maize development that were not significantly different to the other treatments where nitrogen supply was high.

5.3 Effect of integrated chicken manure and inorganic fertilizer rates on yield attributes by hybrid maize.

The yield of maize grain is a product of photosynthetic processes which happens in the maize leaves. The photosynthetic rate depends on the availability of resources such as plant nutrients, moisture, heat and the plant itself. The lower the resources the lesser capacity the plant has to produce its optimal grain yield. Biomass included all the above ground mass (stem, leaves and the tassels). Maize plant growth is determined by both genetic and environmental factors (Jurekova and Drazic, 2011).

Fertilizer treatment T5 (Chicken Manure + 90kg mineral N + 21%P) has the highest yield mean of 6.3 t ha^{-1} which is far beyond what smallholder farmers in Malawi get per hectare. Smallholder farmers yield an average of 2.2 t ha^{-1} (Denning *et al.*, 2009) which correlates to fertilizer treatments T2 (Chicken Manure + 22.5kg mineral N + 21%P) which had mean yield of 4.1 t ha^{-1}. This development is attributed to the good crop husbandly practices and the chicken manure having 4.48% Nitrogen, that was applied together with the inorganic fertilizer for plant`s use. Fertilizer treatment T_3 ensured judicious use of inorganic fertilizer in attaining an optimal farmers yield which is in line with what Ayoola and Makinde (2007) found that use of poultry manure reduces the amount of inorganic fertilizer used. The use of chicken manure at 4 tonnes ha^{-1} only resulted in a grain yield of 2 t ha^{-1} which is close to what average smallholder farmers in Malawi get, that is approximately 2.5 t ha^{-1} (Denning *et al.*, 2009) and was significantly different ($p \leq 0.05$) from T_1 treatment where manure was not applied. This result is supported by Ghosh (2004) who noted that applied manure is a source of soil organic matter which releases nutrients for plants absorption after decomposition and therefore accounts for the manured treatment compared to the non - manured treatments.

Fertilizer treatment T5 also produced significantly higher ($p \leq 0.05$) biomass the other fertilizer treatments. Maize variety SC627 had a higher mean yield of 4.1 t ha^{-1} and significantly different ($p \leq 0.05$) to maize variety SC403 which yielded 3.9 t ha^{-1}. The difference is attributed to the genetic make-up of the 2 varieties, as SC627 is a medium maturing variety having a potential yield of 9000 t ha^{-1} and SC403 maize variety being a medium maturing variety having a potential yield of 7000 t ha^{-1} (Luhanga, 2012).

The maize varieties that were grown at Makoka site gave a significantly higher ($p \leq 0.05$) mean biomass yield of 4.5 t ha^{-1} than Chitedze site which had a mean biomass yield of 3.6 t ha^{-1}. This difference may be attributed to the relatively even distribution of rainfall at Makoka as opposed to Chitedze which received uneven rains and some sporadic prolonged dry spell which affected plant growth and development.

Maize variety SC627 grown at Makoka produced the highest grain yield, 100-seed weight and biomass as compared to maize variety SC403 grown at Chitedze which produced the lowest mean values on both grain and biomass yield except on 100-seed weight where it had the second highest mean value. This result could be attributed to adequate fertilizer and evenly distributed moisture supply which were up taken by the plants for metabolic functions as opposed to Chitedze site which had erratic and unevenly distributed rains. This finding is supported by other studies which showed that availability of moisture and nutrients is translated in higher grain, biomass yield and heavier seeds (Moser *et al.,* 2005) (Efeoglu *et al.,* 2009).

Pearson correlation coefficient determination is important in data analysis as it quantifies the relationship between two variables in unit-free form whether there is positive, negative or no relationship (Rumsey, 2016). In this study, all the variables were positively correlated with different relationship levels to yield. Biomass, Nitrogen uptake and leaf area showed a strong positively correlated relationship of greater than 75% to the yield. This is attributed to the increased surface area for photosynthesis which ensured steady maize growth and development. Nitrogen acts through expansion of the leaf area as well as increasing leaf area duration which prolongs the active period for photosynthesis is other factors are adequately supplied, resulting in increased biomass and longer grain filling period hence better maize grain yield and larger seeds. The weak correlation between the cob weight to biomass and Nitrogen uptake could be attributed to genetic make-up of the maize varieties used as they were not late maturing varieties which focus much on grain filling and not increased cob mass due to short post-anthesis period.

5.4 Economics of integrated chicken manure and inorganic fertilizer hybrid maize production.

Gross margin analysis is important in evaluating treatment performance as it indicates and compares the return on investment of the different treatments (Ebben, 2004). Fertilizer treatment T_5 and SC627 maize variety interaction had the highest profit margin, this is attributed to the high yield levels attained. The use of manure only (T_1) ensured also a net profit from the investment and this can be attributed to high nitrogen levels recorded from the manure analysis (4.48% N) which is higher than the chicken manure from free range systems which has 1.1-2% N (Harison, 2014). The treatment where no fertilizer was applied to the maize (T_6) resulted in a negative gross margins as the yields were low and the current maize price set by the government couldn't reach the breakeven point to recover the costs of production.

CHAPTER SIX

CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

The research study was directed at determining an integrated chicken manure and inorganic fertilizer formulation that ensures optimal maize grain yield at a reduced cost of production. The conclusions from the study are:

I. Fertilizer treatment T_4 (Chicken Manure + 67.5kg mineral N + 21P) and maize variety SC 627 were efficient in nitrogen uptake by maize plants from the soil.

II. Fertilizer treatment T_5 (Chicken Manure + 90 kg mineral N + 21P) and maize variety SC627 produced the highest maize grain yield of 6.3 t ha^{-1}.

III. Chicken Manure + 90 kg mineral N and maize variety SC627 combination gave a highest profit margin of $ 781 from the mean grain yield of 6.4 t ha^{-1} at Makoka and Chitedze sites.

6.2 RECOMMENDATIONS

From the research study that was conducted and based on the conclusion, the following recommendations can be made:

I. Smallholder farmers in medium altitude areas of Malawi who do not have enough resources should use a combination of Chicken manure at 4 t ha^{-1} and 45 kg mineral N: Urea 46%N and SC627 maize variety for better maize yield to ensure food security at household and National level.

II. Those farmers who would want to grow maize for consumption and a surplus for sale should use fertilizer treatment T_5 [Chicken manure (4 t ha^{-1}) + 90 kg mineral N: UREA 46%N] and SC627 maize variety.

III. Further studies to determine the effectiveness of integrating varying Chicken manure and Inorganic fertilizers in different agricultural ecological zones should be carried out.

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APPENDICES

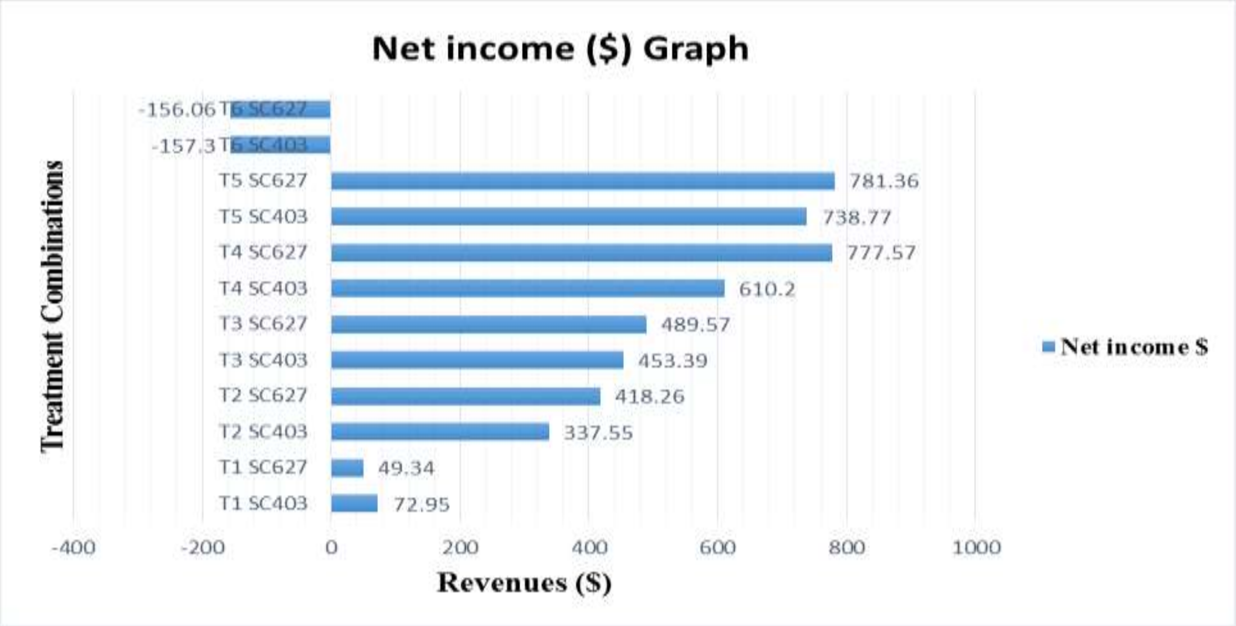
Appendix 1: Integrated Analysis of variance table illustrating the significance of different treatments and their interaction effects for the field experiment conducted in Malawi (2016/17 growing season)

				MEAN SQUARES					
Source of Variation	**Yield**	**100-seed weight**	**Cob weight**	**Biomass**	**Girth**	**Height**	**N-Uptake**	**LAI**	**LDW**
Rep	322364.0ns	6.470ns	26917.63ns	11921.0ns	5.846*	3011.8*	668.6*	0.01ns	13.53ns
Var	1067903.5*	96.038*	16105764.11***	154792.6ns	12.499***	2895.1***	1004.6**	0.32***	3.31ns
Rep*Var	18982.1ns	115.261***	94428.45ns	184053.1ns	6.650***	3565.3**	71.6ns	0.04ns	2.96ns
Nitro	48409182.6***	55.114**	995217.63**	127005787.3***	15.924***	12153.8***	6129.1***	10.23***	750.8***
Nitro*Var	314574.3ns	82.249***	203016.39ns	265096.1ns	4.434***	3588.5***	233.2ns	0.11***	10.21ns
Locn	6779606.2 ***	629.503***	2050661.88**	3727139.6***	19.302***	200.256ns	1512.1***	0.00ns	8.41ns
Var*Locn	409674.6ns	52.403ns	124628.35ns	96193.5ns	0.108ns	26655.9***	445.6*	0.00ns	32.83ns
Nitro*Locn	318268.0ns	38.654**	236750.73ns	542495.0**	9.166***	6826.9***	178.6ns	0.01ns	42.19*
Nitro*Var*Locn	257951.2ns	19.239ns	187368.63ns	299598.1ns	3.333***	2204.3***	152.9ns	0.00ns	5.08ns
Wks	-	-	-	-	71.330***	409172.1***	-	-	-
Vaar*Wks	-	-	-	-	1.124ns	3732.219***	-	-	-
Nitro*Wks	-	-	-	-	0.213ns	581.682*	-	-	-
Locn*Wks	-	-	-	-	0.175ns	2952.2***	-	-	-
Locn*Var*Wks	-	-	-	-	1.275ns	927.952ns	-	-	-
Nitro*Var*Locn *Wks	-	-	-	-	0.148ns	250.628ns	-	-	-
CV	**14.1896**	**8.86993**	**18.31558**	**6.340626**	**10.98475**	**12.44424**	**23.17491**	**11.55286**	**7.900031**
R^2	**0.95910**	**0.81978**	**0.806434**	**0.992313**	**0.808585**	**0.954924**	**0.905011**	**0.88784**	**0.895651**

Var = Variety, Rep = Replication, Locn = Location, Wks = Weeks after Planting, CV = Coefficient of variation

*, **, *** = Significance at 0.1, 0.05 and 0.001 respectively

Appendix 2: A graph of Net Income ($) for different fertilizer and Maize treatment combinations maize production in Malawi (2016/17 growing season)



Appendix 3: NPK Values of Different Animal Manure

	Nitrogen %	Phosphorus %	Potassium (Potash) %
Cow Manure	0.6	0.4	0.5
Horse Manure	0.7	0.3	0.6
Pig Manure	0.8	0.7	0.5
Chicken Manure	1.1	0.8	0.5
Sheep Manure	0.7	0.3	0.9
Rabbit Manure	2.4	1.4	0.6

Source: (Harison, 2014)

Appendix 4: The soil Characteristics of different parts of Malawi

Soil group	Occurancy	pH	CEC me%	Clay Content	Fertility status
Ferruginous (Acrisols &Ferrisols)	Mulanje & Thyolo (Southern region)	4.0-5.5 acid Strongly to Acid	2-6	1:1 Kaolinites 2:1 Illites Fe & Al oxides	Low fertility
Calcimorphic Alluvials (Fluvisols)	Nzimba, Kasungu & Nchinji plains (Central region)	4.5- 5.7 Strongly to moderate Acid	3-8	1:1 Kaolinite & halloysite Fe & Al oxides	Low fertility
Hydromorphic (Gleysols)	In wetlands throughout the country. (Nationwide)	6.7 – 7.5 Mod. Acidic to Slightly Alkaline	13-20	2:1 Illites & micas	High fertility
Lithosols (Leptosols)	In High altitude Chkhwawa and North Mzimba (Highlands)	4.0-5.5 Strongly acid to acid	4-10	1:1 Kaolinites & halloysite. 2:1 Illites & Fe & Al.	Low fertility, Shallow &Stoney

Source: Guide to Agriculture Production, 2008.

Appendix 5: Soil sampling sites indicating percentage deficient level of nutrients

ADD	DADO	Zn	Cu	Ca	Mg	K	P
MZADD	Mzimba	65	4	42	59	20	50
	Nkhatabay	54	8	42	51	43	64
SVADD	Nsanje	31	0	23	0	8	23
	Chikhwawa	58	0	0	0	4	33
MADD	Mangochi	40	16	26	3	3	18
	Zomba	63	14	45	10	16	47
	Machinga	27	5	0	0	5	55
	Balaka	30	5	0	5	5	45
	Namwera	59	0	37	9	11	20
KADD	kasungu	46	4	6	12	18	58
KRADD	Karonga	45	4	14	11	19	54
	Chitipa	49	7	7	9	16	54
BLADD	Mulanje	20	0	0	0	10	40
	BT/ Shire	58	28	25	3	2	36
	Phalombe	3	6	0	0	0	80
SLADD	Salima	41	0	11	6	0	28
National Mean		49	6	24	14	13	44

Source: (Luhanga, 2012).

Appendix 6: Pre and post chemical analysis of soil samples from sites used in the study

Site	pH	%OC	%N	P (ug/g)	K Cmol/kg	Ca	Tex. Class
Pre-analysis							
Makoka	4.8	0.2	0.01	78.8	0.09	0.33	SCL-LS
Chitedze	5.5	1.6	0.1	18	0.09	0.03	SL-SCL
Post- Analysis							
Makoka	6.4	0.5	0.1	14.5	0.1	1.9	SCL-LS
Chitedze	6.5	1.9	0.2	13.3	0.16	4.07	SL-SCL
Chicken manure			4.48				

SCL= Sandy clay loam, LS= Loamy soil, SL= Sandy loam

Appendix 7: Forms of Essential Elements Taken up by Plants

Element	Abbreviation	Form absorbed
Nitrogen	N	NH_4^+ (ammonium) and NO_3^- (nitrate)
Phosphorus	P	$H_2PO_4^-$ and HPO_4^{-2} (orthophosphate)
Potassium	K	K^+
Sulfur	S	SO_4^{-2}(sulfate)
Calcium	Ca	Ca^{+2}
Magnesium	Mg	Mg^{+2}
Iron	Fe	Fe^{+2} (ferrous) and Fe^{+3} (ferric)
Zinc	Zn	Zn^{+2}
Manganese	Mn	Mn^{+2}
Molybdenum	Mo	MoO_4^{-2} (molybdate)
Copper	Cu	Cu^{+2}
Boron	B	H_3BO_3 (boric acid) and $H_2BO_3^-$ (borate)

Source: (CTAHR, 2007)

Appendix 8: Mean data of weather parameters for Makoka and Chitedze sites for 2016/17 growing season

		2016			2017						
Site	**Parameter**	**Oct**	**Nov**	**Dec**	**Jan**	**Feb**	**Mar**	**April**	**May**	**June**	**July**
Makoka	Rain fall(mm)	0.7	112.60	176.60	308.9	152.7	200.9	9.8	1.4	7.9	0
	Max temp(˚C)	31.60	31.20	28.76	27.41	28.19	26.21	25.68	25.41	23.74	19.34
	Min temp(˚C˚)	17.90	19.43	19.62	19.19	18.88	17.30	16.13	14.34	12.31	8.78
Chitedze	Rain fall(mm)	13.5	3.3	81.6	246.1	489.1	138	70.9	0	0	0
	Max temp(˚C)	31.34	29.80	28.90	26.92	27.48	26.96				
	Min temp(˚C)	16.66	17.30	19.30	19.05	18.12	17.34				

Appendix 9: Research study pictures

Fertiliser top dressing and routine field hygiene management

Maize stand at six weeks after sowing.