# EFFECT OF FARMYARD MANURE AND MINERAL FERTILIZERS ON MAIZE YIELD AND SOIL PROPERTIES IN HUYE AND BUGESERA DISTRICTS OF RWANDA

**INNOCENT MUNYABARENZI**

**A148EA/22328/2011**

**A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF MASTER OF SCIENCE IN INTEGRATED SOIL FERTILITY MANAGEMENT AT KENYATTA UNIVERSITY**

**SEPTEMBER, 2014**

# DECLARATION

I hereby declare that this thesis is an original work and has not been submitted for a degree in any other university.

Signature………………………………… Date …………………………………..

**Innocent Munyabarenzi**

Department of Agricultural Resource Management
Kenyatta University, Kenya

This thesis has been submitted for examination with our approval as university supervisors.

Signature………………………………… Date …………………………………...

**Prof. Benson Mochoge**

Department of Agricultural Resource Management
Kenyatta University, Kenya

Signature………………………………… Date …………………………………..

**Dr. Nabahungu N. Léon**

Senior Principal Research Fellow
Rwanda Agriculture Board (RAB), Rwanda

# DEDICATION

To God almighty and Jesus Christ his only begotten son, for nothing is impossible with God and to my dearest wife Claudine and our wonderful children Pacifique, Grace, Fabrice and Serge. You are just cool.

# ACKNOWLEDGEMENT

I am especially grateful to Prof. Benson Mochoge of the Department of Agricultural Resource Management, my supervisor, who patiently and diligently offered advice and suggestions on the work. You were always there for me. May God through His son Jesus Christ give you His grace and peace!

I am particularly indebted to Dr. Léon Nabahungu of Rwanda Agriculture Board (RAB), my external supervisor for his input and most importantly his willingness to assist me each time I went to him. God bless you.

My appreciation goes to Rwanda Agricultural Board (RAB) for the input and most importantly willingness to assist me.

I acknowledge with special thanks the assistance in technical support and advice received from all laboratory staff of Rwanda Agricultural Board (RAB) especially Mr. Eustache Nkikabahizi, and all Microbiology laboratory staff of Kenyatta University especially Mr. Ng'ang'a.

Last but not the least my appreciation goes to AGRA Project and The Department of Agriculture Resource Management of Kenyatta University for their financial support without which it would have been impossible for me to undertake this project. You have put a smile on my face.

And to those I have not mentioned, God will surely reward you.

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# ABREVIATIONS AND ACRONYMS

**BNF** **:** Biological Nitrogen Fixation

**Cfu** **:** Colony forming units

**CIP** **:** Crop Intensification Program

**ECEC** **:** Effective Cation Exchange Capacity

**FAO** **:** Food and Agriculture Organization of the United Nations

**FYM** **:** Farmyard manure

**GDP** : Gross Domestic Product

**IFDC** : International Fertilizer Development Center

**IFIA** : International Fertilizer Industry Association

**ISAR** **:** Rwanda Agriculture Research Institute

**ISFM** **:** Integrated Soil Fertility management

**Kg/ha** **:** Kilograms per hectare

**Km**$^2$ **:** Square kilometer

**LSD** **:** Least Significant Difference

**MINAGRI** **:** Ministry of Agriculture and Animal Resources

**MINALOC** **:** Ministry of Local Government

**MINECOFIN :** Ministry of Finance and Economic Planning

**MSV** : Maize Streak Viruses

**NISR** **:** National Institute of Statistics of Rwanda

**NRM** **:** Natural Resource Management

| | |
|---|---|
| **RAB** | **:** Rwanda Agriculture Board |
| **SAS** | **:** Statistical Analysis System |
| **SSA** | **:** Sub-Sahara Africa |
| **TLB** | **:** Turcicum Leaf Blight |
| **TSP** | **:** Triple Super Phosphate |
| **WFP** | **:** World Food Programme |

# ABSTRACT

Agriculture in Rwanda is today characterized by low agricultural productivity due to soil fertility decline. This is mainly attributed to the mining of nutrients due to continuous cropping without adequate external addition of inputs. The adoption of Integrated Soil Fertility Management (ISFM) technologies such as the combination of organic manure and mineral fertilizers is being taken as one of solutions to this situation. A study was therefore, conducted to investigate the effects of farmyard manure and mineral fertilizers on maize yield response, crop nutrient uptake, nutrient use efficiency and to evaluate changes of bio-chemical soil properties brought about by the treatments applied. The study was conducted at the Research Stations of Rwanda Agriculture Board (RAB), namely, at Rubona in Huye and at Karama in Bugesera Districts in Southern and Eastern provinces of Rwanda,respectively. The experiment was arranged in a randomized complete block design (RCBD) with three factors : nitrogen, phosphorus fertilizers and farmyard manure. Nitrogen and phosphorus fertilizers were applied at three levels, 0, 50 and 100 Kg/ha for nitrogen and 0, 25 and 50 kg/ha for phosphorus while Manure levels were two (0 and 10 tons/ha). Maize was the test crop and was planted in plots measuring 4.5 x 4.5 m with a spacing of 75 x 30 cm. The experiments were replicated three times. Soils samples were analyzed for soil pH, soil organic Carbon, total N, available phosphorus,Potassium, CEC, ECEC, Exchangeable acidity and microbial status of the soil. Maize grains were dried after harvest and weighed at 12.5% moisture content. The data was analyzed by ANOVA using general linear model of SAS software. Regression and correlation were used to establish relationships between measured parameters. The results showed that maize grain yield,1000 grain weight and stover biomass were influenced significantly ($P<0.05$) by the application of farmyard manure and inorganic fertilizers. The combined applications produced yields which were significantly higher than organic or inorganic alone and the control. The highest grain yields of 8.92 tons ha$^{-1}$ and 7.11 tons ha$^{-1}$ were obtained in the combined treatments of farmyard manure with mineral fertilizer at a rate of 100 kg ha$^{-1}$ N, 50kg ha$^{-1}$ P mineral fertilizer and 10 tons ha$^{-1}$ manure at both sites (Rubona and Karama), while the controls recorded the lowest grain yields of 4.61 tons ha$^{-1}$ and 3.23 tons ha$^{-1}$ for Rubona and Karama sites,respectively. The combined treatments generally showed significantly higher nutrient uptake and nutrient use efficiency than the sole organic and inorganic fertilizers. In the evaluation of soil properties, total nitrogen, K and pH significantly decreased in plots treated with organic and inorganic fertilizers while soil organic C, available P, Ca, Mg and CEC increased generally in treatments under inorganic plus organic fertilizers. In the case of microbial biomass, there were slight increase for both bacteria and fungi after NP fertilizers and manure combined treatments. In both sites, maize yields responded more to nitrogen fertilizer than P fertilizer, an indication of low nitrogen content in the soils of Rubona and Karama.

# CHAPTER ONE

## 1.0 INTRODUCTION

### 1.1 Background

Rwanda is a landlocked country with a total area of 26,333km$^2$. According to the estimates of 2002 Census, Rwanda's population is 10 million and is projected to increase to 15 million by the year 2020. With 310 inhabitants per km$^2$, Rwanda is among the countries of Africa with the highest population density and the majority live in rural areas. The Rwanda's climate is conditioned by landscape in such a way that the further to the west, the lower the altitude, the warmer the temperature and the lesser the precipitation with annual rainfall ranging between 900 and 1,600 mm (MINAGRI, 2004).

Agriculture represents one-third of Rwanda's gross domestic product and employs 80 percent of its workforce (MINECOFIN,2002). Rwandan agriculture is today characterized by low agricultural productivity due to progressive soil fertility decline over the years. Increased use of both organic and inorganic fertilizer and other agro–inputs is necessary to help boost food security in Rwanda. However, the use of fertilizers to increase crop yields is at an early stage of development. Although the current use of fertilizers in the country (12 kg/ha/year) (MINAGRI 2009), is slightly above the average for the Sub-Saharan African (9kg/ha/year), it is far below the target of the Abuja Fertilizer Declaration of 50 kg/ha/year by 2015 (Sanginga and Woomer, 2009).

Maize (Zea mays L.) crop is the most important cereal and a widely distributed in Rwanda. As regards to cultivated area, it is produced on approximately 130.000 ha and ranks third (14%) in Rwanda production following bean (21.2%) and banana (19.6%)

MINAGRI (2009). Almost all agro-climatic zones of the country have great suitability in the production of maize (NISR, 2012).

Grown by 62% of farm households for various purposes (direct human consumption, for sale on the local market, or dried and stored for a stock of food security), maize plays an important role in the socio-economic life of rural households (Terpend *et al*., 2007).

According to FAO (2010), maize presents the highest average grain yield (around 4.5 t/ha) as compared with major cereals grown in Rwanda such as wheat (2.1 t/ha) and rice (3t/ha). However, the constraints to the development of this crop are many, which include soil fertility decline, lack of agricultural credit, access to good quality seeds, late onset of rains for planting and water control for producers (Terpend et al., 2007 and MINAGRI, 2011).

Nevertheless, the Government of Rwanda and partners in development are putting more efforts towards the development of the maize program. In that context, maize is among the selected crops in Crop Intensification Program (CIP), which is more profitable in terms of inputs access and value addition by smallholder farmers. The aim of the present study was to determine the effects of farmyard manure and mineral fertilizers application on maize yield as well as on some selected soil properties.

## 1.2 Statement of the Problem

Declining land productivity in Rwanda as a result of soil fertility reduction is a major problem facing smallholder farmers today. This decline primarily results from a continuous cultivation without adequate addition of external nutrient inputs (MINAGRI, 2004). Improved fertility management through combining organic and mineral fertilizers inputs can enable efficient use of the inputs applied and increase overall system productivity.

The prevailing fertilizers recommendations are blanket application which did not consider the Integrated Soil Fertility Management ( ISFM) practices such as inclusion of organic sources for example farmyard manure, cereal – legume rotation , intercropping, use of improved seeds, timely planting and weeding (IFDC, 2009).

Maize production offers many advantages. It is a product that contributes to food security (eaten fresh and dry) and it can be cultivated for income generation. However, at farm level yields are often very low because of poor nutrient use efficiency as a result of poor management of soil resources (organic and inorganic fertilizer inputs) (MINAGRI, 2004). Hence the need for the current study which incorporates some ISFM practices.

## 1.3 Objectives

### 1.3.1 Overall Objective:

The overall objective of this study was to increase food security through maize production and to improve soil productivity through use of organic and inorganic fertilizers.

### 1.3.2 Specific Objectives:

The specific objectives of the study were:

1. To determine the maize yield response to mineral and organic fertilizers application.
2. To determine the effect of organic and inorganic fertilizers on nutrient uptake and nutrient use efficiency by maize.
3. To evaluate changes due to treatments on some bio-chemical soil properties.

## 1.4 Research Hypotheses

The research hypotheses of the study postulated that:

1. There is positive response of maize grain yield to mineral and organic fertilizers application.
2. Application of mineral and organic fertilizers increase maize nutrient uptake and nutrient use efficiency.
3. Use of mineral and organic fertilizers affects soil bio-chemical properties.

## 1.5 Significance of the study

Nutrient deficiencies, mainly nitrogen (N) and phosphorous (P) are the most limiting soil fertility constraints to maize yields in Rwanda. By complementing cattle manure and mineral fertilizers (ISFM practice), soil productivity and smallholder farmers' livelihoods could be improved and result to increased incomes from higher maize yields production. Cattle manure is best provided by zero grazing approach which is currently being promoted in the whole country (MINAGRI, 2011).

The vision of Rwanda is to increase production of various food crops where maize crop has been identified as one of the crops that could contribute on this vision. In that context, maize is being among selected crops in Crop Intensification Program (CIP), which is more profitable in terms of accessing inputs and value addition to small land holdings (MINAGRI 2011).

Another aspect of this study is that comprehensive maize research regarding fertilizers has not been done in Rwanda because maize was never considered as a staple food in Rwanda.

### 1.6 Conceptual Framework

Low fertility of soils under study is manifested in chemical and biological properties, which in turn result in low yields. By adding cattle manure combined with inorganic fertilizer (N, P) and proper timing of planting, it is expected that soil physical, chemical and biological properties will be improved and consequently increase maize grain yields. Figure 1 shows the steps to be taken to improve soil productivity and the outcomes expected.

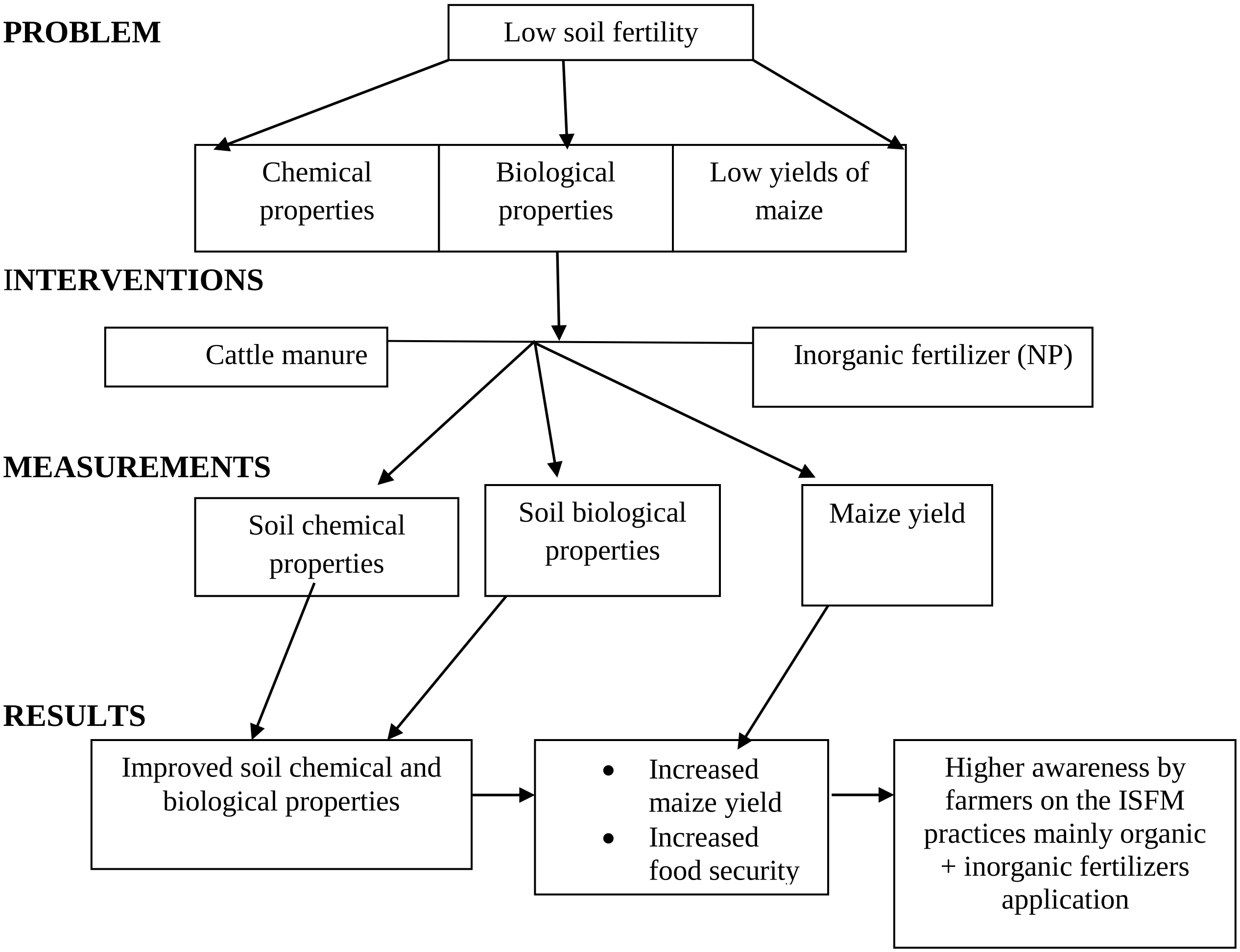

**Figure 1: Conceptual framework**

# CHAPTER TWO

## 2.0 LITERATURE REVIEW

### 2.1 Introduction

Everywhere in the world people settle first in areas with high potential fertile soils, adequate rainfall and mild temperatures. As populations grow, soil nutrient capital is gradually depleted when farmers are unable to sufficiently compensate losses by returning nutrients to the soil via crop residues, manures and mineral fertilizers. Increasing pressures on agriculture, result in much higher nutrient outflows and the subsequent breakdown of many traditional soil fertility maintenance strategies. These traditional fertility maintenance strategies such as fallowing, intercropping cereals with legume crops, manure production in mixed crop-livestock farming and opening new lands have not been replaced by an effective fertilizer supply (Sanders *et al*., 1996).

The bulk of food in Africa is produced on smallholder farms (Cleaver and Schreiber, 1994; Gladwin *et al*., 1997), where rapid depletion of nutrients is highest and the major problem affecting food production in Africa (Badiane and Delgado, 1995). This is because the smallholder farmer is poorly resourced and unable to invest in soil fertility inputs, particularly mineral fertilizers. This is not surprising since about half of Africa's population is classified as “absolute poor” subsisting on per capita incomes of less than 1 US$ per day (Badiane and Delgado, 1995).

The situation is critical especially when the poor farmer has to bear the full cost of production owing to the removal of subsidies on mineral fertilizers. The major effect of soil fertility decline is the reduction of food production as observed in most African countries, including Rwanda.

In order to sustain soil and crop productivity, it is necessary to explore alternative soil fertility replenishment strategies, which are effective and affordable to farmers, especially the smallholder farmer.

## 2.2 Soil Nutrient Depletion

The magnitude of nutrient depletion in Africa's agricultural land is enormous. Stoorvogel and Smaling (1990), indicated that, an average of 660 kg N ha$^{-1}$, 75 kg P ha and 450 kg K ha$^{-1}$ have been lost during the last 30 years from about 200 million hectares of cultivated lands in 37 countries of Sub-Saharan Africa, excluding South Africa. This is equivalent to 1.4 t of urea ha$^{-1}$, 375 kg of triple superphosphate (TSP**)** ha$^{-1}$ or 0.9 t of phosphate rock (PR) ha$^{-1}$ and 896 kg of potassium chloride (KCl) ha$^{-1}$ during the said period. These figures represent the balance between nutrient inputs (in fertilizers, manure, atmospheric deposition, biological nitrogen fixation (BNF) and sedimentation) and nutrient outputs (in harvested products, crop residue removals, leaching, gaseous losses, surface runoff and erosion (Stoorvogel and Smaling, 1990).

Food production has therefore depended on nutrient mining approach since very small amounts of nutrients are returned through fertilizer application (Ofori and Fianu, 1996). The use of crop residues as sources of nutrients and soil organic matter amendment has long been a major component of many farming systems in Africa.

## 2.3 Soil Nutrient Replenishment

The major pathways of soil fertility decline on farmlands include the loss of nutrients through erosion, leaching, volatilization, crop uptake and harvest without the corresponding replenishment. Soil nutrients replenishment is therefore a prerequisite for halting soil fertility decline. This may be accomplished through the application of mineral and organic fertilizers.

Nitrogen inputs at the field scale mainly come from inorganic fertilizers, biological nitrogen fixation (BNF), biomass transfers, animal manures or composts produced outside the field and nitrate capture from subsoil depths beyond the reach of crop roots. The main issue in replenishment is not the size of the capital N stocks, but the cycling rate (Giller *et al*., 1997). Therefore, appropriate strategies are those that will provide sufficient levels of N inputs while at the same time slowly rebuilding stocks. Replenishing N stocks by these strategies would require very large inputs of organic N. For example, an increase in soil organic N concentration in the topsoil from 0.1 to 0.3 % is equivalent to an application of about 320 t $ha^{-1}$ of dry biomass. Such large applications are clearly impractical, so in the short to medium term, increased soil N supply will depend on regular inputs of organic N sources (Sanchez, 1997). Given the largely biological nature of N cycle, organic inputs (manure and plant biomass application) play a crucial role in N replenishment. Also, organic inputs have an important advantage over inorganic fertilizers with regard to fertility replenishment, in that they provide a source of carbon for microbial utilization. Soil microorganisms need a C substrate for growth and energy. They utilize the N from organic inputs, which results in the formation of soil organic N. Part of the N bound in the more recalcitrant forms in the organic inputs will also build up soil humic substance.

Phosphorus replenishment is usually accompanied by nitrogen replenishment because most P-deficient soils are also deficient in N (Sanchez, 1997). Large applications of phosphorus can build the fertility of the soil either immediately or within a few years, and that the residual effect of such replenishment lasts for at least 10 years (Lopez, 1996). Application of superphosphate in the order of 150 to 500 kg P ha$^{-1}$ is probably the most direct way to replenish P capital and the effect lasts for several years in high P-fixing soils (Goedert, 1987). The phosphorus content of plant residues and manures is normally insufficient to meet crop requirements. Plant materials applied as organic inputs (biomass transfer, manures and composts) contain 8 to 12 kg P ha$^{-1}$ when applied at the rate of 4 t dry matter ha$^{-1}$ (Palm, 1995). The decomposition of organic inputs produces organic acids that may dissolve (solubilize) phosphate rock. A combination of phosphate rock with compost has been shown to increase the availability of phosphorus (Negassa *et.al*, 2003). In intensive cropping, soil productivity can be sustained only through integrating mineral phosphorus application with organic inputs (manure, composts and plant residues) and this is the most effective means of replenishing soil phosphorus.

Potassium deficiencies do occur in specific circumstances, but is not to the same extent as N and P deficiencies. The level of K-mining is six times that of P-mining, but crop responses to K fertilization, however, are rare in Africa except in sandy savanna soils (Ssali *et al*., 1986). This is probably due to the high K capital in many parts of Africa, even though it is rapidly being depleted.

### 2.4 Use of Organic Manures

Animal manures are valuable sources of nutrients and the yield-increasing effect of manure is well established.

The organic manure improves soil fertility by influencing its physical, chemical and biological properties. It improves water circulation and soil aeration, and increases the soil moisture holding capacity (Soltner, 1985). According to Nyle and Brady (2003), the organic manure also improves the soil by the formation of clay humic complexes which increase the soil adsorbent capacity of basic nutrients (calcium, magnesium and potassium) and enhances the activity of microorganisms involved in the mineralization process.

Hoyt and Turner (1975) cited by Nabahungu, (2003), stated that the soil pH can also be significantly increased by adding organic residues into the soil. This is attributed to higher concentrations of basic nutrients in organic amendments and hydrous oxides reduction in soils (Hue, 1992). Plants can only use nutrients that are in an inorganic form. Manure N and P are present in organic and inorganic forms, and are, therefore totally unavailable to plants. The organic forms must be mineralized or converted into inorganic forms over time before they can be used by plants.

The availability of K in manure is considered similar to that in commercial fertilizer since the majority of K in manure is in the inorganic form (Motavalli *et al*., 1989). In general, 90 to 100 % of K in manure is available during the first year of application. Zhang *et al*. (1998) found that 2 kg manure-N were equivalent to 1 kg of urea-N in terms of plant uptake and yield response during the first year following cattle feedlot manure application. Manure increases also P in the soil (Sommerfeldt and Chang, 1985; Chang *et al*., 1990; CAST, 1996). The manure requirements for most of the crops are high, ranging from 5 to 20 tons of fresh manure per $ha^{-1}$. Manure, when applied, will be mineralized gradually and nutrients become available.

However, the nutrient content of manure varies, and the reason is that the fertilizer value of manure is greatly affected by diet, amount of bedding, storage and application method (Harris *et al*., 2001). Cross and Strauss (1985) reported the following nutrient contents for municipal wastes, 0.4 – 3.6 % N, 0.3– 3.5 % $P_2O_5$, and 0.5 – 1.8 % $K_2O$, while Leonard (1986) reported 1.1 % N, 1.1 % $P_2O_5$ and 0.5 % $K_2O$ for poultry manure at 70 % moisture content.

## 2.5 Use of Mineral Fertilizers on Crop Production

Mineral fertilizers are used to supplement the natural soil nutrient supply in order to satisfy the demand of crops with a high yield potential and produce economically viable yields; compensate for the nutrients lost by the removal of plant products or by leaching or gaseous loss (IFIA, 2000). In Rwanda, mineral fertilizers have contributed to increased yields of maize even though achieving potential yields is still a challenge due to other important factors involved in crop production (MINAGRI, 2011). In most recent projective studies of global agricultural production into the 21st century, suggest that a global food crisis is unlikely but that many countries and regions will continue to suffer from chronic malnutrition. From a resource perspective, growing world population and per capita incomes will likely require more intensive agricultural crop production. Higher yields will in turn increase the demand for agricultural inputs, especially mineral fertilizers (FAO, 2004).

Lack of credit, poor marketing capabilities, high transport costs, lack of availability of fertilizer, inadequate demand to stimulate investment in production and distribution, lack of crop markets, devaluation of domestic currencies and weak extension services constrain fertilizer use. The lack of credit has been identified as a major determinant of fertilizer use in many African countries including Rwanda especially for poor and middle households (IFDC, 2009). The assessment of agricultural inputs market in Rwanda reveals that agri-inputs use in Rwanda is among the lowest in Africa, only 15% of the farmers used mineral fertilizers in 2005 while 26% of the farmers in 2011 were reported having used mineral fertilizers alone or in mix with organic fertilizers (IFDC, 2009; MINAGRI, 2011). The reasons are mainly unavailability of right agri-inputs at the right time and of right amounts in rural areas. Equally important is the cost of agri-inputs, farmers' purchasing power, poor extension services and the weakness of the private sector. Fertilizer recommendations are outdated and so the advisory sector does not stand confident (IFDC, 2009). However, many reports in the literature have shown that continuous use of sole fertilizers may lead to shortage of nutrients not supplied by the chemical fertilizers and may also lead to chemical soil degradation (Mafongoya *et al.*, 2006).

## 2.6 Importance of Combined Organic and Mineral Fertilizers

Integrated nutrient management implies the maintenance or adjustment of soil fertility and of plant nutrient supply to an optimum level for sustaining the desired crop productivity on one hand and to minimize nutrient losses to the environment on the other hand. It is achieved through efficient management of all nutrient sources. Nutrient sources to a plant growing on a soil include soil minerals and decomposing soil organic matter, mineral and synthetic fertilizers, animal manures and composts, by-products and wastes, plant residue, and biological N-fixation (BNF) (Singh *et al.*, 2002).

For sustainable crop production, integrated use of chemical and organic fertilizer has proved to be highly beneficial. Several researchers have demonstrated the beneficial effect of combined use of chemical and organic fertilizers to mitigate the deficiency of many secondary and micronutrients in fields that continuously received only N, P and K fertilizers for a few years, without any micronutrient or organic fertilizer. Research has shown that that combinations of organic and mineral fertilizers result in greater crop yields compared with sole organic or sole mineral fertilizers (Chivenge *et al*., 2009). Vanlauwe et al. (2002b) reported that grain yield increases of up to 400% over the control in cases where the control yields are low. This increase in grain yield has been attributed to improved N synchrony with combined inputs through direct interactions of the organic and N fertilizers.

Based on the evaluation of soil quality indicators, Dutta *et al*. (2003) reported that the use of organic fertilizers together with chemical fertilizers, compared to the addition of organic fertilizers alone, had a higher positive effect on microbial biomass and hence soil health. Application of organic manure in combination with chemical fertilizer has been reported to increase absorption of N, P and K in sugarcane leaf tissue in the plant and ratoon crop, compared to chemical fertilizer alone (Bokhtiar and Sakurai,2005). Kaur *et al*. (2005) compared the change of chemical and biological properties in soils receiving FYM, poultry manure and sugarcane filter cake alone or in combination with chemical fertilizers for seven years under a cropping sequence of pearl millet and wheat. Results showed that all treatments except chemical fertilizer application improved the soil organic C, total N, P and K status. Sutanto *et al*. (1993) in their studies on acid soils for sustainable food crop production noted that farmyard manure and mineral fertilizer produced excellent responses. Boateng and Oppong (1995) studied the effect of farmyard manure and method of land clearing on soil properties on maize yield and reported that plots treated with poultry manure and NPK (20-20-0) gave the best yield results.

In Rwanda, farmers still need to pursue sustainable intensification to maintain food security, mitigate the effects of weather variability and climate change, protect land and increase incomes (IFDC, 2002). ISFM is a sustainable approach that acknowledges the need for both organic and mineral inputs to sustain soil health and crop production due to positive interactions and complementarities between them (ASHC, 2012).

## 2.7 Crop Nutrient Uptake and Nutrient use Efficiency

### 2.7.1 Crop Nutrient Uptake

The goal of balancing nutrient inputs with crop removals is twofold; it reduces the build-up of nutrients and addresses environmental concerns while keeping soil fertility management costs to a minimum. Actual uptake and removal of nutrients varies with crop yield, variety and soil fertility from year to year. Crop nutrient uptake is affected by soil and climatic conditions. Low soil moisture, poor aeration due to compaction or excessive moisture, low soil temperature and high lime in the root zone, nutrient imbalances and other factors may restrict uptake of plant nutrients (CFI, 1998).

Maximum nutrient uptake varies among crops and generally occurs prior to maximum growth rates but plants require a balanced supply of nutrients throughout their development (Jones *et al*., 2011). These authors also reported that low nutrient uptake early in the early stages of plants growth lowers nutrient quantity for the seed affecting both yield and quality. Crop nutrient uptake rates are different at each growth stage and crop growth rates vary with crop, variety and growing conditions. Sanchez and Doerge (1999) and Jones *et al*. (2011) also reported that timing the application of nutrients so that they are available before peak crop nutrient demand as critical. Adequate nutrients early in the growing season are necessary to maximize yield and ensure that especially N and P are available for good grain and seed fill.

Nutrient uptake is dependent on both the ability of the roots to absorb nutrients and the concentration at the surface of the roots. Roots spread out both laterally and vertically as the plant grows to take advantage of areas within the soil that have more water and nutrients. Nutrient uptake varies with stage of plant growth (Jones and Jacobsen, 2001). Plants have been reported to have difficulty in absorbing nutrients in dry soil because most nutrients are elemental and not in ionic forms. Therefore during the dry seasons, nutrient levels in plant tissues may be lower than normal (Sanchez and Doerge, 1999). Potassium and other nutrient deficiencies commonly occur in crops during dry years even though the soil test shows adequate amounts. Tillage practices are also reported to influence soil temperature, moisture and aeration which eventually affect nutrient uptake. Fertilizer placement may also influence nutrient availability and may depending upon conditions, either enhance or reduce nutrient uptake (Jones *et al*., 2011). Mahamoud *et al*. (2009), as quoted by Malathesh (2005) reported that P uptake increased at different growth stages of maize with increasing rates of nitrogen and phosphorus. Nitrogen content of maize grain ranged between 1.36 and 1.75 percent and P content between 0.15 and 0.22 percent, with nitrogen rates of 5 to 200kg/ha. Under irrigated conditions the relative N uptake was related to fertilizer application and soil nitrate contents. N content in maize stalk was increased by N fertilizer application up to 300kg/ha (Malathesh, 2005). Similarly, the N amount in the grains of maize generally increased with increasing nitrogen application. Sharma (1983) as quoted by Malathesh (2005) found out that addition of FYM at 12t/ha along with fertilizer levels of up to 60kg N, 30kg $P_2O_5$ and 30kg $K_2O$ per hectare significantly improved the nitrogen uptake by the maize crop.

Mahmoud *et al*. (2009) reported that the increase of N uptake appeared to be more obvious when compost was mixed with the mineral N fertilizer as compared to the 100% compost or 100% N mineral fertilizer alone on improving soil physical properties or to a higher mineralization of composts which is due to mineral N inputs. Crop response to P depends on the availability of P in the soil solution and the ability of the crop to take it up. The ability of a plant to take up P depends on its root distribution relative to P location in the soil. This is because P is highly immobile in soil and does not move far in the soil to get to the roots.

### 2.7.2 Nutrient Use Efficiency

Efficient use of nutrients in agriculture may be defined differently when viewed from agronomic, economic or environmental perspectives (Mikkelsen, 2005). Nutrient use efficiency can be expressed in several ways: by partial factor productivity (PFP, kg crop yield per kg nutrient applied); Agronomic Efficiency (AE, kg crop yield increase per kg nutrient applied); Apparent Recovery Efficiency (RE, kg nutrient taken up per kg nutrient applied) and Physiological Efficiency (PE, kg yield increase per kg nutrient taken up) (Roberts, 2008).

Estimates of fertilizer use efficiency usually differ depending upon the climate, crop and soil conditions and fertilizer parameters (fertilizer kind, rate, time and method of application) and management practices (Munir *et al*., 2006). Over or under application of fertilizer result in reduced nutrient use efficiency or losses in yield and crop quality. Soil testing is thus crucial for determining the nutrient supplying capacity of the soil and also for making appropriate fertilizer recommendations (Roberts, 2008). Roberts (2008) emphasized that great synchrony between crop demand and nutrient supply is necessary to improve nutrient use efficiency, especially for N.

Nitrogen Use Efficiency (NUE) is a term used to indicate the ratio between the amount of fertilizer N removed from the field by the crop and the amount of fertilizer N applied (Brentrup and Palliere, 2010). Crop removal efficiency, that is removal of nutrient in harvested crop as a percentage of nutrients applied, is commonly used to explain further the nutrient use efficiency (Roberts, 2008). Kayuki *et al*. (2012) reported that at very high N application rate the NUE declined despite the slight increase in grain yield and this had earlier been reported by Kogbe *et al*. (2003). Maranville *et al*. (2002) added that nitrogen use efficiency (grain weight per unit of N supplied from soil and/or fertilizer) is reduced due to poor crop cultural practices, sub-optimal yields and N losses or deficiency of other nutrients.

The efficiency of fertilizer P use by crops ranges from 10 to 30% in the year that is applied. The remaining 70 to 90% becomes part of the P pool which is released to the crop over the following months and years (Malhi *et al*., 2002 and Johnston and Syres, 2009). Phosphorus use efficiency is sometimes measured by expressing total P uptake as a percentage of the P applied (Syres et al., 2008). Kogbe and Adediran (2003) reported that PUE increased until 40kg/ha but declined with increase in P application in the soil.

Application of 40kg $P_2O_5$ /ha appeared to be the optimum since at higher rates, the yields were depressed.

## 2.8 Maize Response to N and P Fertilizers

The major objective of an efficient fertilization program is to be certain that adequate N and P are available during the growing season so that plant growth and yields are not limited by nutrient supplies (Alley *et. al*, 2009). The maize must have adequate quantity of nitrogen (N) and phosphorus (P) for profitable production. The maize plant requires N and P soon after germination to initiate the growth of stems, leaves and ear structures. Significant amounts of N are transferred from leaf tissue to grain during the grain-fill process. Phosphorus uptake is more constant throughout the season and generally parallels to dry weight increases.

Inadequate N availability during the first two to six weeks after planting can result in reduced yield potentials (Jones, 1985). However, the majority of N is needed during the period of maximum growth (month prior to tasseling and silking). Phosphorus availability is equally critical during the early stages of plant growth because the movement of P to plant roots is reduced with cold soil temperatures (Sharpley *et al.*, 1994). Thus, P deficiencies are most often observed during the early part of the growing season.

The beneficial and environmentally sensitive maize production requires that N and P be managed in an efficient manner. Economic returns from the use of these nutrients can be maximized, when the potential for surface and groundwater enrichment with N and P can be minimized with the use of appropriate technology (use of proper application rates, methods, and timing). Nitrogen and P uptake follows the same general trend as plant grows (Alley *et al.*, 2009). Zingore (2011) in his study concluded that the application of N and P alone led to a significant increase in maize grain yields on the high fertility fields, but on the depleted soils, baseline yields were very low, and were increased to less than 1 t/ha by applying N and to less than 2 t/ha by applying N and P. Mukuralinda *et al*. (2010) on their study on P uptake and maize response to organic and inorganic fertilizer inputs in Rubona, Southern Province of Rwanda showed that the combination of green manure with TSP at a rate of 50 kg ha$^{\mathbf{-1}}$ significantly increased maize yield from 24 to 508 % when compared to the control. Equally, the same study showed higher P uptake (15.6-18.6 kg ha$^{-1}$) than the control (5 kg P ha$^{-1}$).

## 2.9 Role of Soil Biota in Soil Fertility Improvement

In soil, microorganisms occur in great numbers and variety. They are essential for maintaining soil fertility and plant growth as they play an important role in nutrient cycling and availability (Fritze *et al*., 1994). Microorganisms being a part of all natural and man- made ecosystems, compose biocenoses, which are significant, and essential biochemical elements responsible for the entirety of biogenic element transformation in the soil environment which exert critical effects on biochemical activity and ecological stability, as well as biological productivity of many fields such as forest, agricultural and grassland ecosystems. Soil organisms mediate both the synthesis and decomposition of organic matter and therefore influence cation exchange capacity, the soil N, S, and P reserve, soil acidity and toxicity, and soil water holding capacity (Lavelle and Spain 2001).Soil microbes are involved in biochemical transformations of mineral fertilizers, particularly NPK fertilizers, and organic commercial fertilizers such as urea; synthesis of biologically active substances (amino acids, vitamins, antibiotics, toxins) and nitrogen fixation from the atmosphere (Kennedy and Gewin, 1997).

Increased soil microbial activity can improve carbon turnover, increase crop nutrient supply and produce a more stable soil structure. Soil microbes improve structure by stabilizing the aggregation of soil particles through the production of organic ‘glues’ and fungal hyphal networks (Martens, 2001). The disruptive effect of tillage in intensive stubble retention cropping systems could be reduced significantly by the associated increase in microbial activity (Martens, 2001). Soil microbes also reduce the loss of inorganic fertilizers through erosion and leaching by short-term immobilization of the nutrients from the inputs. Further, soil microbes play a key role in the stabilization of soil structure as well as reduced reliance on agrochemicals and persistence of pesticides in soil (Martens, 2001). The two main soil microbial groups, fungi and bacteria often play different roles in nutrient cycling and are affected differently by changes in soil pH, moisture, C:N ratio and substrate type (West, 1986).

## 2.10 Environmental Factors Affecting Maize Production

Maize is grown in tropical, sub-tropical and temperate climates (FAOAGL, 2002). The highest production, however, occurs between 21 and $27^0$C with annual precipitation of 500 to 2000 mm. Soil water availability is often the main factor limiting rain fed maize production. In these water-limited systems, efficient capture and retention of precipitation is essential to maximize crop growth. This is especially true for summer annual crops such as maize, which exhibit yield reductions in response to soil water deficits at any growth phase (Roygard *et al*., 2002). Moisture stress is thought to cause average annual yield losses in maize of about 17% per year in the tropics (Edmeades *et al*., 1992), but losses in individual seasons have approached 60% in regions such as southern Africa (Rosen and Scott, 1992).

The maize crop can tolerate a wide range of temperatures (from 5 to $45^0$C), but very low or very high temperatures can have a negative effect on yield. Nielsen (2007) found that maximum temperatures greater than $32^o$C around tasseling and pollination speeded up the differentiation process of their productive parts and resulted in higher rates of kernel abortion and yield reduction. Soil characteristics have an important bearing on the productivity of the maize crop. Olson and Sander (1988) described suitable soil environment for maize and observed that maize is grown across a wide range of soils from raw sands to clays, strongly acid to strongly alkaline soils, and shallow to deep soils, with large variations in crop productivity. Below pH 5, toxicity of Al, Mn and Fe may be encountered, though maize is relatively tolerant. At very low pH, soils are likely to be deficient in P due to tying up with the active Al component.

In addition, production of NO3- from NH4+ is greatly retarded due to inactivity of the nitrobacter organism. At high pH levels, nutritional problems are often encountered with the elements P, Zn and Fe. For example, in calcareous soils with pH 7.5 to 8.4, P is deficient because virtually all phosphate ions are converted to low solubility tricalcium phosphate, forming carbonated apatite (Olson and Sander, 1988). They further noted that Zinc and Fe might also have low solubilities at high pH and be deficient to the crop.

# CHAPTER THREE

## 3.0 MATERIALS AND METHODS

### 3.1.0 Description of the Study Areas

The study was conducted at two sites, Rubona and Karama which are sub-stations of the Soil Research Stations of Rwanda Agriculture Board (RAB) (Fig. 2).

### 3.1.1 Rubona Station

This sub-station is situated in Southern Province of Rwanda, Huye District. The area lies between latitudes S $02^0$28’875’’ and longitudes E $029^0$45’790’’ of the Greenwich meridian. The altitude of Rubona is estimated at 1650 m above sea level. The annual rainfall is estimated to be between 1160 and 1400 mm, while the average annual temperature is $18.9^0$C. The area experiences a long dry season of 2-3 months (Jun – August) each year. The soils in this area are Ultisols according to USDA classification (ISAR,1987) and are clay loam/sandy clay in textural class.

### 3.1.2 Karama Station

This Station is situated in Eastern Province of Rwanda, Bugesera District. The area lies between latitudes S $02^0$16’001’’and longitudes E $030^0$15’351’’ of Greenwich meridian. The altitude of Karama station is estimated at 1400 m above sea level. The annual rainfall of the area is around 855 mm with an annual average temperature of $20.8^0$C. The area is characterized by a long dry season of 3-4 months. The soils are classified under oxisols according to USDA classification and are clay and loam sandy in textural class (ISAR, 1987).

Figure 2 shows the location of Rubona and Karama in Huye and Bugesera Districts of Rwanda.

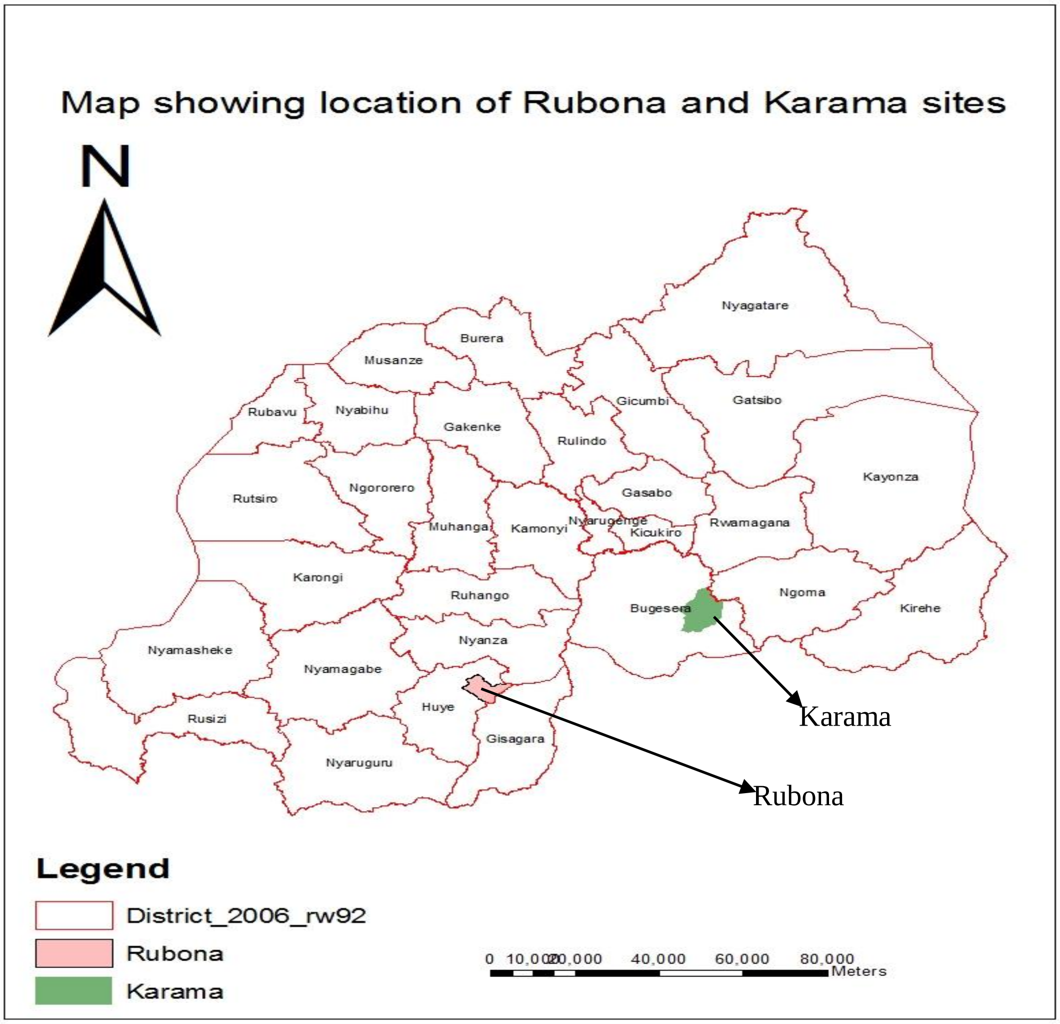

**Figure 2: Map of Rwanda. Source: ArcGIS, NRM Unit (RAB).**

### 3.2. Initial soil Fertility Status

In order to characterize the soil of the experimental fields, samples were taken across the fields from two depths, 0-20 and 20-40 cm and bulked for laboratory analysis. In the laboratory, part of the soil samples were air-dried, crushed using a wooden mortar and pestle and then sieved through a 2 mm mesh. The other part of soil samples was stored in fridge ($4^0$C) for mineral N and microbial analyses. The sieved samples were stored in polythene bags for laboratory chemical and physical analyses at the Soil Research

Laboratory of RAB at Rubona. The physical and bio-chemical properties of the soil before planting are shown on Table 1.

**Table 1: The initial physical and bio-chemical characteristics of the soil at Rubona and Karama sites**

| Properties | Rubona site | | Karama site | |
|---|---|---|---|---|
| | **0-20cm** | **20-40cm** | **0-20cm** | **20-40cm** |
| pH($H_2O$) | 5.7 | 5.7 | 5.8 | 6.09 |
| Total N(%) | 0.38 | 0.40 | 0.28 | 0.30 |
| Organic (%) | 3.08 | 3.04 | 1.71 | 1.57 |
| Available P(mg kg$^{-1}$) | 7.62 | 11.78 | 3.22 | 3.05 |
| NH4$^{+}$mg/kg$^{-1}$ | 25.93 | 25.17 | 24.00 | 21.83 |
| NO3$_{-}$mg/kg$^{-1}$ | 19.83 | 18.83 | 17.33 | 17.17 |
| Exchangeable K(cmolkg$^{-1}$) | 0.58 | 0.75 | 0.75 | 0.61 |
| Exchangeable Ca(cmolkg$^{-1}$) | 3.07 | 2.84 | 2.33 | 2.13 |
| Exchangeable Mg(cmolkg$^{-1}$) | 0.15 | 0.21 | 0.32 | 0.33 |
| Exchangeable Na(cmolkg$^{-1}$) | 0.04 | 0.03 | 0.02 | 0.03 |
| Acidity (H$^{+}$) (cmolkg$^{-1}$) | 0.47 | 0.47 | 0.37 | 0.35 |
| CEC (cmolkg$^{-1}$) | 17.06 | 16.37 | 10.82 | 10.90 |
| ECEC (cmolkg$^{-1}$) | 4.31 | 4.3 | 3.79 | 3.45 |
| Sand (%) | 28.6 | 29.7 | 26.0 | 28.2 |
| Silt (%) | 3.6 | 5.1 | 2.7 | 3.0 |
| Clay (%) | 67.8 | 65.2 | 71.2 | 68.9 |
| Soil textural class | Clay loam | Clay loam | Clay loam | Clay loam |
| Bulk density (gcm$^{-3}$) | 1.32 | 1.44 | 1.37 | 1.46 |
| Bacteria (cfu/g10$^{6}$) | 0.95 | 1.40 | 0.65 | 1.38 |
| Fungi (cfu/g10$^{3}$) | 5.13 | 4.73 | 6.57 | 5.5 |

The initial soil status analyzed before the commencement of the experiments showed that the soil was fairly fertile in terms of physical properties and some chemical properties.

The soil textural class was Clay loam at both Rubona and Karama sites. The soil pH before application of treatments ranged from 5.7 which is moderately acidic at Rubona site to 6.09 which is slightly acidic at Karama site (Table 1). The soil available P was low at Karama (3.22 mg kg$^{-1}$ at 0-20cm and 3.05 mg kg$^{-1}$at 20-40 cm) and high at Rubona site (7.62 and 11.78 mg kg$^{-1,}$ respectively, at 0-20 and 20-40 cm depths).The exchangeable cations (K, Na, Ca and Mg) were not also high at the two sites. The total N(0.38%) and organic carbon(3.08%) were moderate. The bulk density of the top soil (0-20 cm) was 1.32 $gcm^{-3}$ and 1.44 $gcm^{-3}$ at 20-40 cm depth at Rubona while in Karama site, the bulk density was 1.37 $gcm^{-3}$ and 1.46 $gcm^{-3}$ at 0-20 cm and 20-40 cm depths, respectively.

The analysis for microbial biomass at the initial stage showed 0.95 $cfu/gm10^6$ and 1.40 $cfu/gm10^6$ for bacteria, and 5.13 $cfu/gm10^3$ and 4.73 $cfu/gm10^3$ for fungi, at the depths 0-20 cm and 20-40 cm, respectively, at Rubona site. While at Karama site, the number of bacteria recorded was 0.65 cfu/gm $10^6$ and 1.38 $cfu/gm10^6$at 0-20 cm and 20-40 cm, respectively, while the number of fungi recorded was 6.57cfu $gm10^3$ and 5.5 $cfu/gm10^3$ with respect to the depths.

### 3.3. Characterization of Manure Used in the Experiments

The manure used in the experiment was analyzed for pH, total N, available P and exchangeable cations (Ca, Mg, K, $Al^{3+}$ and $H^{+)}$ following the procedures as outlined by Okalebo *et al*.,(2002). Table 2 shows the results of manure characterization.

**Table 2: Some chemical composition of the manure used in the experiments**

| pH($H_2O$) | N% | Av.P(ppm) | Ca(meq/100g) | Mg(meq/100g) | K(meq/100g) | $Al^{3+}$(meq/100g) | $H^+$(meq/100g) |
|---|---|---|---|---|---|---|---|
| 7.9 | 0.45 | 10.75 | 22.90 | 12.70 | 46.22 | Trace | 0.24 |

### 3.4. Rainfall pattern during season A 2013 at Rubona and Karama stations

Table 3 shows the amount and distribution of rainfall received during the growing season at both sites.

**Table 3: Rainfall pattern at Rubona and Karama during the growing season**

| | Rubona | | Karama | |
|---|---|---|---|---|
| **Month** | **Rainfall (mm)** | **No. of rainy days** | **Rainfall (mm)** | **No. of rainy days** |
| **September** | 31.4 | 8 | 71.4 | 6 |
| **October** | 128.2 | 14 | 68.6 | 12 |
| **November** | 143.9 | 21 | 166.3 | 10 |
| **December** | 181.0 | 22 | 57.0 | 7 |
| **January** | 102.5 | 16 | 23.0 | 5 |
| **February** | 34.0 | 3 | 64.9 | 4 |
| **March** | 233.4 | 21 | 67.8 | 10 |
| **Total** | **854.4** | **105** | **519** | **54** |

**Source: RAB, Meteo. Services.**

Rubona received higher rainfall (854 mm) than Karama (519 mm) during season A of 2013. In terms of rainfall pattern, rainfall at Rubona was well distributed throughout the season, recording a total of 105 rainy days as compared to 54 rainy days at Karama during the same period.

### 3.5. Experimental Design and Treatments Layout

The experimental sites were located at Rubona and Karama were conducted on the RAB experimental fields. The two trials sites,that is Rubona and Karama are located in Huye and Bugesera districts, respectively. The treatments were a factorial design arranged in a randomized complete block design (RCBD) with three factors ( nitrogen, phosphorus and manure) at three levels for nitrogen (0, 50 and 100 kg/ha), three levels for phosphorus ( 0, 25 and 50 kg/ha) and two levels for manure (0 and 10 tons/ha) resulting to 18 treatments. The experiment was replicated three times.

**Table 4: The experimental treatments and their design**

| Treatment No. | N in Kg /ha | P in Kg /ha | FYM in t/ha |
|---|---|---|---|
| **T1** | 0 | 0 | 0 |
| **T2** | 0 | 0 | 10 |
| **T3** | 0 | 25 | 0 |
| **T4** | 0 | 25 | 10 |
| **T5** | 0 | 50 | 0 |
| **T6** | 0 | 50 | 10 |
| **T7** | 50 | 0 | 0 |
| **T8** | 50 | 0 | 10 |
| **T9** | 50 | 25 | 0 |
| **T10** | 50 | 25 | 10 |
| **T11** | 50 | 50 | 0 |
| **T12** | 50 | 50 | 10 |
| **T13** | 100 | 0 | 0 |
| **T14** | 100 | 0 | 10 |
| **T15** | 100 | 25 | 0 |
| **T16** | 100 | 25 | 10 |
| **T17** | 100 | 50 | 0 |
| **T18** | 100 | 50 | 10 |

### 3.6. Planting and Fertilization

Maize variety, ZM 607 was used as the test crop. The planting dates were on 16th October 2012 at Karama and on 22th October 2012 at Rubona sites. Land preparation was done by hand using hoes, loosening a layer of up to 0-20cm depth. Planting holes were prepared where the soil and cattle manure were mixed. Plot size was 4.5 m x 4.5 m with a spacing of 75 cm between the rows and 30 cm within the rows. Two seeds were planted per hole and thinned to one 10 days after emergence. At planting, TSP was applied and incorporated in the planting holes while urea was topdressed in two splits; one at three weeks and another at six weeks after emergence. Fertilizers were pre-weighed for each plot before going to the field and applied using dollop cups to ensure uniform distribution to all plots. The trial was maintained weed free during the entire study period.

### 3.7. Yield Measurements

The grain and straw harvesting was done on 21th March 2013 at Karama and on 29th March 2013 at Rubona. The whole plants on the plots were harvested, except for the border rows, by cutting at the ground level and weighed as fresh weight. A sub-sample of 6 plants were randomly selected and weighed. The plants were then separated into ears (cob + grains) and stover (stem, leaves and husks). The plant parts namely ears and stover were weighed and their weights recorded as fresh weights. The ears were further separated into cobs and grains after shelled and weighed. The various plant parts were put in brown paper envelopes, oven dried at $60^0$C for 48 hours and then weighed as dry matter. The lengths of six husked maize ear per plot were measured with tape and the mean value calculated. All the weights were converted and calculated on a dry weight basis.

The ear girth was also taken from a sample of six ears per plot with the use of tailor’s tape and the values were recorded and averaged. One thousand numbers of grains were also counted from each plot and weighed.

### 3.8. Soil Sampling and Analysis

Soil sampling was done at the beginning of the experiment before planting for initial soil properties status and another at the end of the experiment for purposes to evaluate soil property changes due to treatments. The soil properties analyzed included soil pH, soil organic carbon, available N ($NH_4^+$ and $NO_3^-$), total nitrogen, calcium, magnesium, sodium, potassium, CEC and ECEC. Microbial population (bacteria and fungi biomass) was also determined at the beginning and at the end of the experiments. Bulk density and soil texture were determined at the beginning of the experiment.

### 3.8.1. Soil pH

Soil pH was measured in a 1:2 soil-water ratio using a glass electrode (H19017 Microprocessor) pH meter. Approximately 25 g of soil were weighed into a 100 ml polythene beaker and 50 ml of distilled water was added to the soil. The soil-water solution was stirred thoroughly and allowed to stand for 30 minutes. After calibrating the pH meter with buffers of pH 4.01 and 7.00, the pH was read by immersing the electrode into the upper part of the soil solution and the pH values recorded.

### 3.8.2. Total Nitrogen and Carbon in Soil

Both total N and C in the soil were determined using the flash combustion method using the CN Elemental Analyzer (Krotz *et al*., 2013). Fifteen grams of soil was weighed in a tin capsule. This was done twice: first after filling the tin capsule and second after folding the tin capsule.

The weight of each sample was recorded in the sample table which is contained in the Eager Experience Software which calculates and records the data as obtained from the CN analyzer. The flash elemental analyzer system completely oxidizes the sample with a catalyst through combustion. It is then further reduced to $CO_2$, $N_2$ and $H_2O$ under high temperature reactor chambers. The solid sample was wrapped inside a tin capsule and placed into a steel column through an auto sampler. The tin capsule containing the sample was burned in a pure oxygen environment. The carbon in the sample was converted into carbon dioxide, nitrogen into free air or oxides and hydrogen to water. A stream of helium gas carried those gases into a quartz column (which carries the reduction processes) filled with copper that reduced the nitrogen oxides to nitrogen and removes excess oxygen. The gas stream then flowed through a magnesium perchlorate trap (adsorption filter) which removed water before $CO_2$ and $N_2$ went into a gas chromatograph (GC) column at room temperature. $N_2$ then flowed through the gas chromatograph column first (retention time -110 seconds) then $CO_2$ (retention time-190s) and the thermal detector (TD) was used to give the quantitative data. Helium is used as a carrier gas because it is chemically inert.

### 3.8.3. Determination of Soil Available Nitrogen ($NH_4^+$ +$NO_3^-$)

Soil mineral nitrogen ($NH4^+$ +$NO3^-$) was determined using the flow injection method using the Flow Injection Analyzer (FIA). The method uses cadmium reductor for nitrates and gas diffusion method for ammonium (Singh, 1988). Nitrates in the soil sample were extracted using 2M KCl solution. Five grams of air-dried soil was weighed into a 50ml polythene bottle and 25ml of 2M KCl was added and mechanically shaken for one hour. The suspension was centrifuged and filtered through Whatman No.1 filter paper and the filtrate was then introduced into the flow injection system.

The procedure for determination of nitrates is reduction to nitrite in a cadmium reductor. (Nitrates are reduced into nitrites because nitrates cannot react with sulphanilamide). The nitrites reacted with sulphanilamide to form a diazo-compound which further reacted with NED to form an Azo dye (pink in colour) whose absorbance was read at 540nm. The intensity of the colour corresponds to the amount of nitrates in the soil extract. The results obtained were expressed in ppm units. To obtain ppm in the soil, the following formula was used:

w= (CxV)/W

Where: w= mg $NO_3^-$-N/kg soil; C= concentration nitrate as mg/l $NO_3^-$ -N;

V= volume of the extract in ml; W= weight of the sample in g.

For ammonium, the soil was also extracted by 2M KCl solution. Five grams of air-dried soil was weighed in 50ml polythene bottle and 25ml of 2M KCl was added and shaken mechanically for one hour. The suspension was then transferred into centrifuge tubes and centrifuged for 5 minutes then filtered through Whatman No. 1 filter paper to obtain a clear filtrate. The filtrate was then introduced into the flow injection system. The soil sample extract was injected into a carrier stream which is merged with sodium hydroxide stream. In the resulting alkaline stream gaseous ammonia is formed which diffused through a gas permeable membrane into an indicator stream. The indicator stream which comprises of a mixture of acid-base indicators reacted with ammonia gas. A colour shift resulted which was measured photometrically at 590nm. The results were expressed in mg $NH4^+$-N mg/kg (ppm) sample using the following formula:

w= (cxv)/W

Where: w= mg $NH_4^+$-N/kg soil (ppm); c= concentration ammonium as mg/l $NH_4^+$-N;

v= volume of the extract in ml; W= weight of soil sample in g.

### 3.8.4. Determination of Available P in Soil

The Mehlich1 double acid extraction method was used for the determination of available P (Savoy, 2009). The dried soil was extracted in 1:5 ratios (w/v) with a mixture of 0.1N

HCl and 0.025N $H_2SO_4$ solutions. The hydrochloric acid serves to replace the bulk exchangeable metal cations. The sulphate ions in the acid medium fulfils the replacement of the soluble P available to plants which is held in exchangeable form.

Five grams of dried soil was weighed in 50ml polythene bottle and 25ml of extracting solution was added. The suspension was shaken mechanically for one hour and then transferred into centrifuge tubes and centrifuged for 5 minutes which was then filtered through Whatman No.1 filter paper to obtain a clear filtrate. Five milliliters of working standard series, soil extract and blank were pipetted into test tubes. One milliliter of ammonium vanadate-molybdate mixture was added and mixed well and its optical density read on the UV-Visible spectrophotometer after one hour at 430nm. To obtain the concentration of P in the soil (ppm), the ppm in solution obtained from the UV-Visible spectrophotometer was multiplied by the dilution factor, which is the ratio of soil sample in grams to the extracting solution which in this case was the ratio 1:5 obtained from 5g of soil sample in 25ml extracting solution.

### 3.8.5. Determination of Magnesium in the Soil

Measurement of the level of magnesium in the soil was done at the beginning and at the end of the experiment. The content of magnesium in the soil was determined using the Mehlich1 double acid extraction method ( Savoy, 2009). Five grams of dried soil was weighed in 50ml polythene bottles and 25ml of extracting solution (0.1N HCl and 0.025N $H_2SO_4$) was added.

The suspension was then shaken mechanically for one hour and transferred to centrifuge tubes where it was centrifuged for 5 minutes and then filtered through Whatman No.1

filter paper to obtain a clear filtrate. One milliliter of the extract was then pipetted into test tubes. Five milliliters of magnesium compensating solution was added, followed by 2ml titan yellow and 2ml sodium hydroxide mixing after each addition. The optical density was then read on the UV-Visible spectrophotometer after one hour at 540nm.

### 3.8.6. Determination of Ca, K and Na in Soil

To assess the fertility of the soil, Ca, Na and K were determined at the beginning and at the end of the experiment. The method used was the Mehlich1 double acid extraction method (Savoy, 2009). Five grams of soil sample was weighed into 50ml polythene bottle and 25ml extracting solution was added (0.1N HCl and 0.025N $H_2SO_4$). The suspension was mechanically shaken for one hour and then transferred to centrifuge tubes where it was centrifuged for 5 minutes and then filtered through Whatman No.1 filter paper to obtain a clear filtrate. The concentrations of the cations in the soil extract were then measured using the flame photometer. A calibration graph was obtained from the working standard series against elements (Ca, K and Na) concentrations (in meq/100g soil) from which the concentrations of cations were read.

### 3.8.7. Determination of Exchangeable Acidity in Soil

The determination of exchangeable acidity ($H^+$ and $Al^{3+}$) was done by weighing 5g of soil sample which was leached using potassium chloride ($K^+$ ions replace exchangeable $H^+$ and $Al^{3+}$ held against permanent negative charges of the exchange complex). The total exchangeable acidity was determined by titrating with NaOH. The amount in milliliters of NaOH needed to bring the potassium chloride back to its original pH is equivalent to the amount in milligram-equivalent (meq) of hydrogen and aluminium exchanged.

Seventy five milliliters of 1M KCl solution was used for leaching. To the filtrate, 2-3 drops of phenolphthalein indicator were added and filtrate was titrated with 0.05N NaOH until the colour changed from colourless to pink. The amount of NaOH used for reaction, that is bringing back to original pH was equivalent to amount of $H^+$ and $Al^{3+}$ exchanged and was calculated. Each ml of NaOH used is equivalent to milliequivalent per 100g of soil.

### 3.8.8. Effective Cation Exchange Capacity (ECEC)

Effective cation exchange capacity was determined by the sum of exchangeable bases ($Ca2^+$, $Mg2^+$, $K^+$ and $Na^+$) and exchangeable acidity ($Al3^+ + H^+$).

### 3.8.9. Soil Texture Size Determination

The soil texture was determined by the Hydrometer method as outlined by Okalebo et al.,(2002). Approximately 40 g of soil was weighed into 250 ml beaker and oven dried at 105 0C over night. The sample was removed from the oven and then placed in a desiccator to cool, after, which it was weighed and the oven dry weight taken. A 100 ml of dispersing agent commonly known as Calgon (Sodium Bicarbonate and Sodium Hexa-metaphosphate) was measured and added to the soil. It was then placed on a hot plate and heated until the first sign of boiling was observed. The content in the beaker was washed completely into a shaking cup and then fitted to a shaking machine and shaken for 5 minutes. The sample was sieved through a 50 microns sieve mesh into a 1.0 L cylinder. The sand portion was separated by this method while the silt and clay went through the sieve into the cylinder. The sand portion was dried and further separated using graded sieves of varying sizes into coarse, medium and fine sand. These were weighed and their weights taken.

The 1.0 L cylinder containing the dispersed sample was placed on a vibration-less bench and then filled to the mark. It was covered with a watch glass and allowed to stand overnight. The Hydrometer method was used to determine the silt and the clay contents. The cylinder with its content was agitated to allow the particles to be in suspension, it was then placed on the bench and hydrometer readings taken at 30 seconds, 4 minutes, 1 hour, 4 hours and 24 hours intervals. At each hydrometer reading the temperature was also taken. Coarse silt, medium silt, fine silt and clay portions were then calculated graphically. The various portions were expressed in percentage and using the textural triangle the texture was determined.

### 3.8.10. Bulk Density

Bulk densities of the soil profile, at each site from 0 – 20 cm and 20 – 40 cm depths were determined by the core ring method. An undisturbed soil core was taken from the field by a core sampler and dried in a hot air oven at $105^0$C to a constant weight. The weight of the soil per unit volume was then calculated from the known volume of the core sampler.

Calculation:

$$\mathrm{Bd} = \frac{Ms}{Vt}\ g/cm3$$

Where:

$B_d$= bulk density, g/cm$^3$; $M_s$ = mass of oven dry soil core, g; $V_t$ = volume of soil core, cm$^3$.

### 3.8.11. Determination of Microbial Population in Soil

The measurement of bacteria and fungi was done at the beginning and at the end of the experiment. Both bacteria and fungi in the soil samples were determined using the dilution plate counting method (Ogunmwoyi et al., 2008).

Nutrient agar (NA) and potato dextrose agar (PDA) was prepared and poured into sterile petri dishes. The mixture was allowed to solidify and then labeled. 0.1gm of a broad–spectrum antibiotic e.g. chloramphenicol was added to a liter of PDA before dispensing to inhibit growth of bacteria. Nine ml sterile dilution blanks was made with water in test tubes and labeled as $10^{-1}$, $10^{-2}$,….$10^{-5}$. 1gm of well mixed soil sample was taken and suspended it in the first ($10^{-1}$) 9ml water blank to effect the first diluents and shaken well to mix. Serially, the diluted soil suspension was made in water using the dilution tubes by transferring 1ml from first diluents ($10^{-1}$) to the second water blank to effect the $10^{-2}$diluent. The same serial dilution was repeated up to the desired dilution. Aseptically, 0.1 ml inoculums of $10^{-1}$and $10^{-3}$ dilutions was transferred and spread on plates of PDA and NA plates, respectively. NA plates were incubated at $37^0$C for approximate 18hrs and PDA at room temperatures for 24-72 hrs after which the plates were observed every day.

The colony forming units were counted in the plates using a colony counter and the number of bacteria and fungi present was calculated in a gram of soil, taking into consideration the inoculums amount and dilution factors.

## 3.9. Plant Analyses

### 3.9.1. Plant Sampling and Preparation

At harvest, maize grain and stover parts were sampled. The samples were kept in paper bags and oven-dried at 60 $^0$C for 48 hours after which they were milled to pass through 20 mesh sieve.

### 3.9.2. Analysis of Total N

The method used for the determination of total N in plant tissues was the flash combustion method using CN Elemental Analyzer.

Five milligrams of dried and milled plant tissue sample was weighed into a tin capsule which was then folded and its weight recorded using tweezers to avoid contamination using hands. The samples were then placed into a steel column using an auto sampler. The tin capsule containing the plant sample was then burned in a pure oxygen environment. (The flash elemental analyzer completely oxidizes the sample with a catalyst through combustion and further reduced to produce $CO_2$, $N_2$ and $H_2O$ under high temperature reactor chambers). The rest of the procedures are as described in section 3.8.2.

### 3.9.3. Determination of Phosphorus

Phosphorus was determined in plant ash using the Vanado-Molybdenum method as outlined by Okalebo et al.,(2002). Approximately 0.5 g of the grind plant material was weighed into a porcelain crucible and ashed in a muffle oven at a temperature of 450 – 500 $^0$C. The ashed sample were removed from the oven after cooling then made wet with

1–2 drops of distilled water and 10 ml of 1:2 dilute $HNO_3$ added. The crucible was then heated on a water bath until the first sign of boiling was observed.

The crucible was removed and allowed to cool. The content was filtered into a 100 ml volumetric flask using a No. 540 filter paper. The crucible was washed two times with about 5 ml distilled water followed by the filter which was also washed two times with about 20 ml distilled water. After 10 ml each of ammonium vanadate and ammonium molybdate solutions were added and shaken thoroughly. The solution was allowed to stand for 10 minutes for full colour development and then filled to the 100 ml mark. A standard curve was also developed concurrently with P concentrations ranging from 0, 1, 2, 5, 10, and 15 to 20 μg P per milliliter of solution. The absorbance of the sample and standard solutions were read on the spectrophotometer (spectronic 21D) at a wavelength of 470 nm. A standard curve was obtained by plotting the absorbance values of the standard solutions against their concentrations. Phosphorus concentration of the samples was determined from the standard curve.

### 3.10. Nitrogen and Phosphorus Uptake

Nutrient uptake was determined for maize stover and grain. This was calculated from the nutrient concentrations obtained from the tissue analysis and oven-dry matter weight expressed in kg/ha.

### 3.11. Determination of Nutrient Use Efficiency

Agronomic nutrient use efficiency was determined to assess the efficiency of maize in utilizing nutrients. The formula used to determine Agronomic Efficiency (AE) was as described by Rajendra (2009).

$$AE = \frac{(\mathrm{yf} - \mathrm{yc})}{\mathrm{Na}}$$

Where: yf= yields in fertilized plots (kg/ha); yc= yields in control plots (kg/ha);

Na= amount of nutrient applied (kg/ha)

AE= is the same as crop response ratio or Agronomic Efficiency

### 3.12. Statistical Analysis

All data were subjected to statistical analysis. The statistical package used was SAS version 8. Treatment differences were separated using Least Significant Differences (LSD) Test. Regression analyses were carried out to establish the relationships between parameters measured for predictive purposes.

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

This chapter presents the findings from two experimental fields, Rubona and Karama, which were carried out in the season A of 2013. The results are presented as follows: 4.1 effect of treatments on grain yield and yield of other maize components; 4.2 effect of treatments on nutrient uptake and nutrient use efficiency and 4.3 effect of treatments on bio-chemical soil properties.

## 4.1 Grain Yield and Yield Components

### 4.1.1 Effect of Treatments on Maize Grain Yield at Rubona and Karama

#### 4.1.1.1 An Overview of Effects of Various Treatments and their Interactions on Maize Grain Yield and Maize Yield Components

The fertilizer treatments had a significant effect on the grain yield and yield components. The results showed that grain yield, ear length, ear girth, weight of 1000 grains and stover yield were influenced significantly($P<0.05$) by the application of farmyard manure and inorganic fertilizers (Tables 5 and 6).

The combined treatments produced yields which were significantly higher than those produced by organic and inorganic fertilizers applied separately. Treatments 100 Kg N +50 Kg P+10TM and 100 Kg N+25 Kg P+ 10TM produced 8.92 and 8.72 t/ha$^{-1}$ of maize grain, respectively, at Rubona site (Table 5) and 7.11and 6.99 t/ha$^{-1}$,respectively at Karama site ( Table 6). The control (T1) plot gave minimum yield (4.61 and 3.23 t/ha$^{-1}$) at Rubona and Karama site,s respectively.

**Table 5: Effect of FYM and mineral fertilizers on the grain yield and yield components of maize (Rubona site)**

| Treatments | Ear Length(cm) | Ear Girth(cm) | Weight of 1000grain(g) | Grain Yield(t ha) | Stover yield (t ha) |
|---|---|---|---|---|---|
| **Control** | 12.97g | 4.33g | 338.62h | 4.61g | 5.79g |
| **0KgN+0KgP+10TM** | 14.00fg | 4.61cde | 353.97gh | 5.63ef | 8.10ef |
| **0KgN+25KgP+0TM** | 13.80fg | 4.50defg | 340.85h | 5.34f | 7.59ef |
| **0KgN+25KgP+10TM** | 13.91fg | 4.62cdef | 364.88fgh | 5.62ef | 7.08fg |
| **0KgN+50KgP+0TM** | 14.22fg | 4.50defg | 364.89fgh | 5.43ef | 8.09ef |
| **0KgN+50KgP+10TM** | 15.33ef | 4.78bcd | 371.34efgh | 6.12de | 7.53ef |
| **50KgN+0KgP+0TM** | 16.47cde | 4.71bcde | 388.54cdefg | 7.04c | 8.99de |
| **50KgN+0KgP+10TM** | 16.69cde | 4.85abc | 375.31efgh | 6.97c | 8.91de |
| **50KgN+25KgP+0TM** | 16.11de | 4.84abc | 380.45defgh | 6.69cd | 8.20ef |
| **50KgN+25KgP+10TM** | 16.58cde | 4.61cdef | 375.93defgh | 7.20c | 10.39bcd |
| **50KgN+50KgP+0TM** | 17.94abc | 4.73bcde | 397.77bcdefg | 7.20c | 10.27bcd |
| **50KgN+50KgP+10TM** | 16.67cde | 4.37fg | 412.21abcde | 7.35c | 10.11cd |
| **100KgN+0KgP+0TM** | 17.19bcd | 4.79bcd | 407.47bcdef | 8.26ab | 10.13cd |
| **100KgN+0KgP+10TM** | 18.14abc | 4.92ab | 435.31ab | 8.09b | 11.63abc |
| **100KgN+25KgP+0TM** | 18.08abc | 4.84abc | 419.76abcd | 8.08b | 11.51abc |
| **100KgN+25KgP+10TM** | 19.55a | 4.95ab | 431.46abc | 8.72ab | 11.45abc |
| **100KgN+50KgP+0TM** | 18.64ab | 4.94ab | 396.35bcdefg | 8.42ab | 11.79ab |
| **100KgN+50KgP+10TM** | 19.19a | 5.08a | 455.02a | 8.92a | 12.36a |
| **LSD** | 1.7471 | 0.251 | 44.111 | 0.6924 | 1.542 |

Means with the same letter in each column are not significantly different at $p<0.05$

### Table 6: Effect of FYM and mineral fertilizers on the grain yield and yield components of maize (Karama site)

| **Treatments** | **Ear Length(cm)** | **Ear Girth(cm)** | **Weight of 1000grain(g)** | **Grain Yield(t ha)** | **Stover yield (t ha)** |
|---|---|---|---|---|---|
| **Control** | 11.15d | 4.18h | 279.70h | 3.23f | 5.62f |
| **0KgN+0KgP+10TM** | 12.22d | 4.19gh | 303.85fgh | 3.99e | 7.36ef |
| **0KgN+25KgP+0TM** | 12.41d | 4.34efgh | 292.60gh | 3.62ef | 7.92de |
| **0KgN+25KgP+10TM** | 11.85d | 4.21gh | 303.85fgh | 3.66ef | 7.16ef |
| **0KgN+50KgP+0TM** | 12.38d | 4.19gh | 297.48fgh | 3.81ef | 8.34ed |
| **0KgN+50KgP+10TM** | 12.50d | 4.22hg | 292.60gh | 3.87e | 7.94ed |
| **50KgN+0KgP+0TM** | 14.22c | 4.25fgh | 326.35ef | 5.47bcd | 8.30ed |
| **50KgN+0KgP+10TM** | 14.44c | 4.52bcde | 321.60efg | 5.07cd | 7.48def |
| **50KgN+25KgP+0TM** | 14.28c | 4.43defg | 337.54e | 5.43bcd | 8.79cde |
| **50KgN+25KgP+10TM** | 14.77bc | 4.29efgh | 338.97de | 5.02d | 9.41bcd |
| **50KgN+50KgP+0TM** | 15.61abc | 4.65abcd | 347.32cde | 5.85b | 9.07bcde |
| **50KgN+50KgP+10M** | 15.48abc | 4.40efgh | 350.85bcde | 5.64bc | 9.33bcd |
| **100KgN+0KgP+0TM** | 15.66abc | 4.75ab | 377.78abc | 6.74a | 9.40bcd |
| **100KgN+0KgP+10TM** | 16.05ab | 4.67abc | 382.60ab | 6.89a | 10.45abc |
| **100KgN+25KgP+0TM** | 16.25ab | 4.73ab | 385.78a | 6.59a | 10.90ab |
| **100KgN+25KgP+10TM** | 16.25ab | 4.66abcd | 371.32abcd | 6.99a | 10.61abc |
| **100KgN+50KgP+0TM** | 15.61abc | 4.47cdef | 371.36abcd | 6.63a | 10.82ab |
| **100KgN+50KgP+10TM** | 16.53a | 4.78a | 392.59a | 7.11a | 11.56a |
| **LSD** | 1.5913 | 0.2423 | 1.2214 | 0.6037 | 1.9298 |

Means with the same letter in each column are not significantly different at $p<0.05$

This observation is in agreement with the finding of many researchers (Swift,1997; Mutegi,2012; Das et al.,1992; Tamayo et al.,1997 and Jate 2012), who observed that the combined use of organic and inorganic inputs resulted in higher yields than either source used alone. Boateng and Oppong (1995) also confirmed the superiority of the combined organic and inorganic inputs over the organic or inorganic inputs in their studies on the effect of farmyard manure and method of land clearing on soil properties and maize yield. They reported that the plots treated with poultry manure and NPK (20-20-0) gave the best yield.

The highest stover yields of 12.36 and 11.56 tons ha$^{-1}$ were produced by treatment 100 kgN+50 kgP+10 T M at Rubona and Karama sites, respectively. The control of this study recorded the lowest stover yields of 5.79 and 5.62 tons ha$^{-1}$,at Rubona and Karama sites, respectively. The combined effect of mineral fertilizers (nitrogen and phosphorus) at 100kg of N and 50kg of P at both sites (Rubona and Karama) gave higher grain yield of 8.42 tons ha$^{-1}$ and 6.63 tons ha$^{-1,}$ respectively, than those produced by organic and inorganic fertilizers separately and the control. However, these yields were slightly lower than those produced by both combined organic and inorganic fertilizers (Tables 5 and 6).

Concerning the seed weight, the results showed significant differences ($p<0.05$) among the 1000 seed weight of the treatments (Tables 5 and 6). The highest 1000 seed weight of 445.02 g and 392.59 g at Rubona and Karama, respectively, were obtained by treatment 100 Kg N+50Kg P+10T M while the lowest 1000 seed weight of 338.62 g and 279.70 g at Rubona and Karama, respectively, were obtained at the control treatment.

These results are similar to the findings of others (Rutunga *et al*.,1998 and Sevaram *et al*.,1998 ).There were significant differences in ear lengths among the treatments (Table 5 and 6).

The highest ear lengths measured 19.19 cm and 16.53 cm at Rubona and karama sites, respectively, which were recorded in treatment 100 Kg N+50 Kg P+10 T M. The control plot had the lowest ear lengths(4.3cm and 4.1cm) for Rubona and Karama sites, respectively as shown in Tables 5 and 6.

#### 4.1.1.2 Maize Grain Yield Response to N and P Fertilizers

The response results of N and P fertilizers application are shown in Figures 3 and 4 for Karama and Rubona,respectively. Rates applied for nitrogen were 0, 50 and 100 kg/ha while those for phosphorus were 0, 25 and 50 kg/ha. This is according to the current trends of fertilizer application in Rwanda.

While maize grain yields responded to both fertilizers, the response to N was higher than that of P in the two sites (Figs. 3 and 4 ). The response curves for P almost leveled at 50 kg rate while that of N was fairly straight even at 100kg/ha, suggesting that even higher rates of N could be applied for higher yield increases. Similar findings have been reported by various researchers (Zentner *et al*., 1987; Stewart, 2003; Kogbe and Adediran, 2003 and Tayebeh *et al*., 2010).

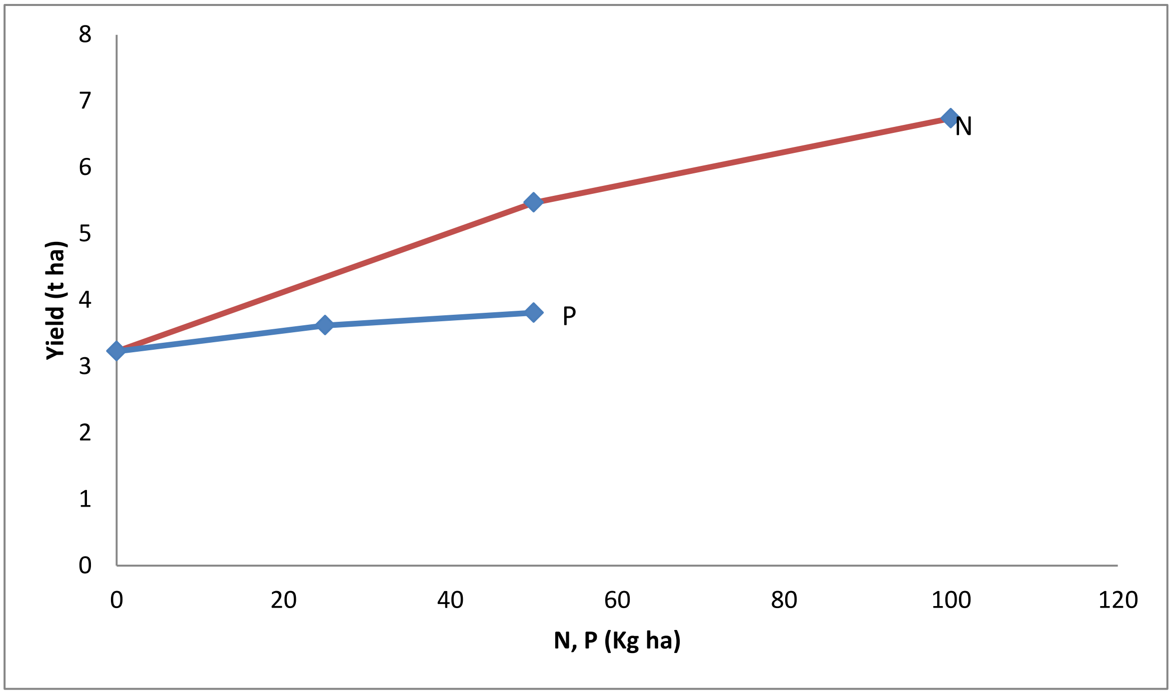

**Figure 3: Maize grain yield response to N and P ( Karama Site)**

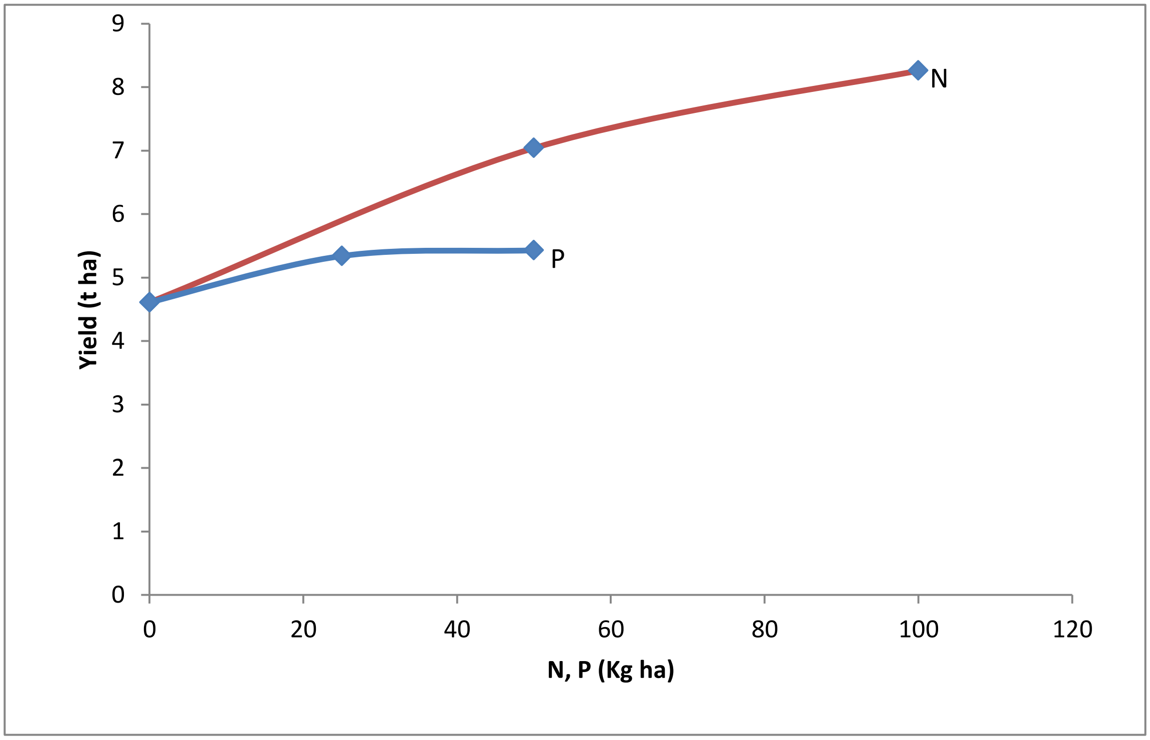

**Figure 4: Maize grain yield response to N and P ( Rubona Site)**

### 4.1.1.3 Effect of Manure on Maize Grain Yield

On the effect of manure on maize grain yield, manure at the dose of 10t ha$^{-1}$ had a significant ($p<0.05$) effect on grain yield with a yield increase of 22.1% above the control in Rubona and 23.5 % in Karama. In relation to mineral fertilizers at higher doses combined, the grain yield above that due to manure was 49.5% for Rubona and 66.1% for Karama.This indicates the importance of mineral fertilizer in maize production in the two areas.The control (0 t ha$^{-1}$) plots gave minimum grain yield (4.61 t ha$^{-1}$ and 3.23 t ha$^{-1}$), respectively at Rubona and Karama sites (Tables 5 and 6) while application of 10 t ha$^{-1}$ alone produced maize grain yield of 5.63 th$^{-1}$ and 3.99 t ha$^{-1}$ at Rubona and Karama, respectively. The high crop improvements with manure than those obtained with the control was probably attributed to the improvement of the physical conditions and biological activity of the soil (Chang *et al.*, 1990). In general, therefore, the yields realized with manure alone were lower than those obtained by sole mineral fertilizer and even with the combination of manure and mineral fertilizer (Tables 5 and 6). Similar findings were reported by Mochoge *et al.*,(1997) who recorded maize yield of between 370 and 940 kg/ha from unfertilized plots, between 900 and 2010 kg/ha from NP fertilized plots, 700 and 1720kg/ha from manure applied plots and between 1000 and 2280kg/ha in plots where NP fertilizers combined with manure were applied.

On the basis of these experimental findings, it seems that use of organic and inorganic fertilizers in proper combination can give higher yields than the sole application of either of the fertilizer or manure.

### 4.1.1.4 Comparison of Yields Performance at Rubona and Karama

Figure 5 shows the mean maize grain yields and their standard deviations as affected by the applied treatments at Rubona and karama sites. The comparison (Fig.5) clearly shows that the grains yield of maize was lower in Karama than Rubona in all the treatments.

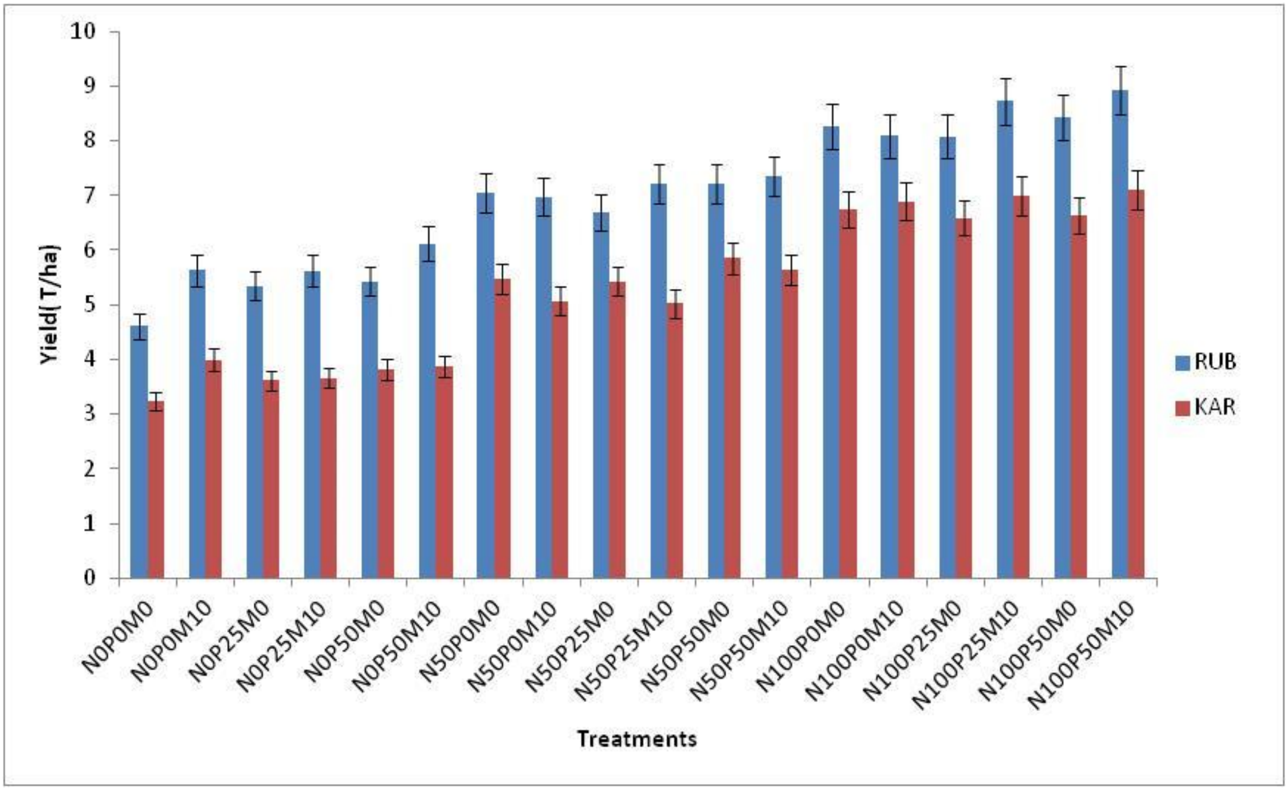

**Figure 5: Comparison of yields in Rubona (RUB) and Karama (KAR)**

Lower moisture regime characterized the 2013 A season in Bugesera (Karama site) might have been responsible for lower maize grain yield compared to Rubona site. The rainfall patterns for the two sites are shown on Table 3 and indicate clearly the difference rainfall regimes and patterns in the season at the two sites.

The low rainfall and its poor distribution at Karama site compared to that at Rubona, might have influenced soil moisture contents and nutrients uptake more at Karama than at

Rubona because nutrients are taken up ionic form in solution by plants (Mutegi *et al*. 2012). Soil moisture content influences N mineralization and availability and subsequent maize growth and uptake. Vanlauwe *et al*. (2002) noted that variability in climatic factors such as rainfall and temperature make the synchrony between nutrient release from tree litter and crop uptake an elusive goal to achieve in practical terms. Insufficient moisture in soils has also been reported to limit the response of crop to nutrients (Jama *et al*. 1997).

#### 4.1.1.5 Relationships of Maize Yield Components, N Uptake and Maize Grain

The correlation and regression analyses revealed significant positive relationships between the grain yield and yield components, and between the grain yield and N uptake. A very close positive correlation ($P<0.0001$) was found between the grain yield and the values of weight of 1000 grains, ear length, ear girth and stover weight at Rubona and Karama sites (Figures 6,7,8,9,10,11 and 13). The results showed that N grain uptake and maize grain yield are positively correlated ( $P<0.0006$ and $P<0.0001$) respectively, at Rubona and Karama sites ( Figures 14 and 15).

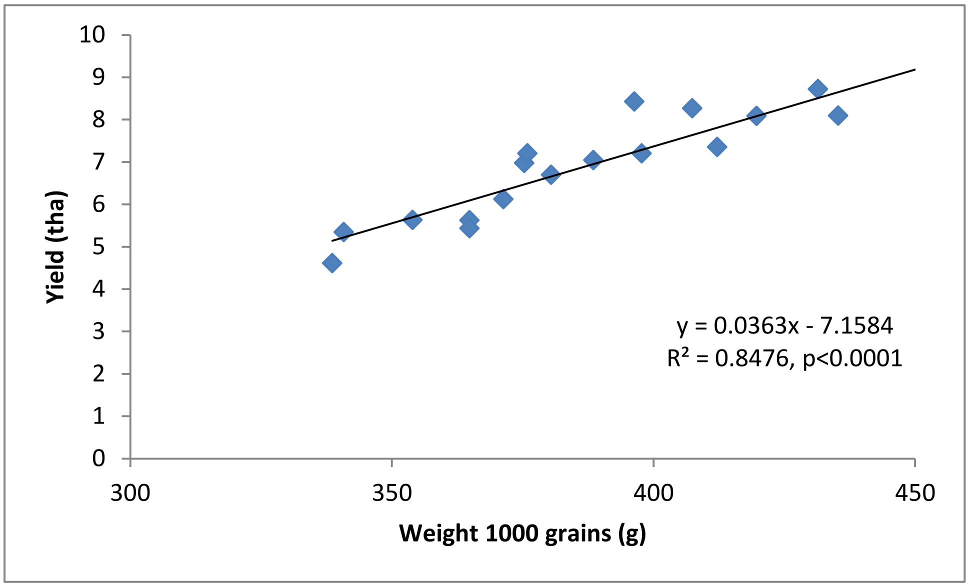

Figure 6: Relationship between 1000 seed weight and maize grain yield at Rubona site

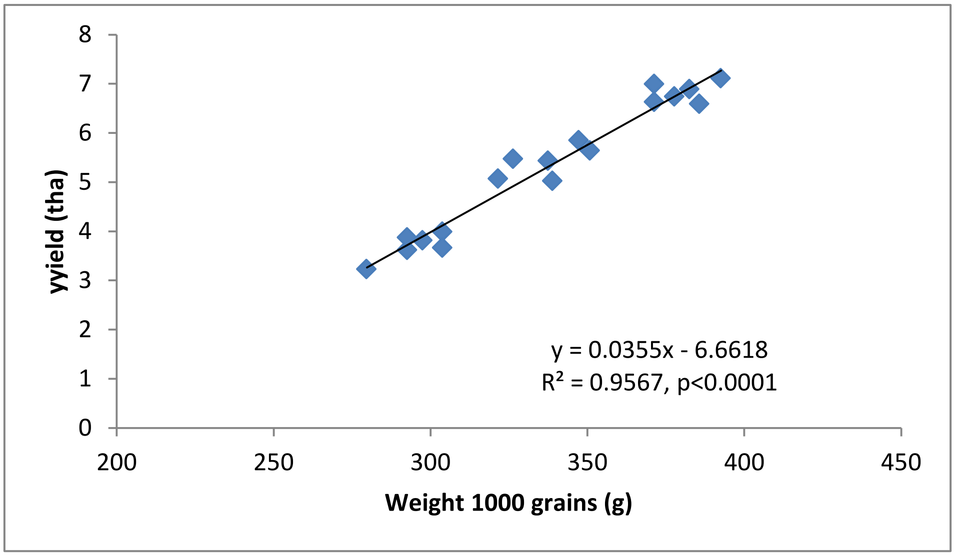

Figure7: Relationship between 1000 seed weight and maize grain yield at Karama site

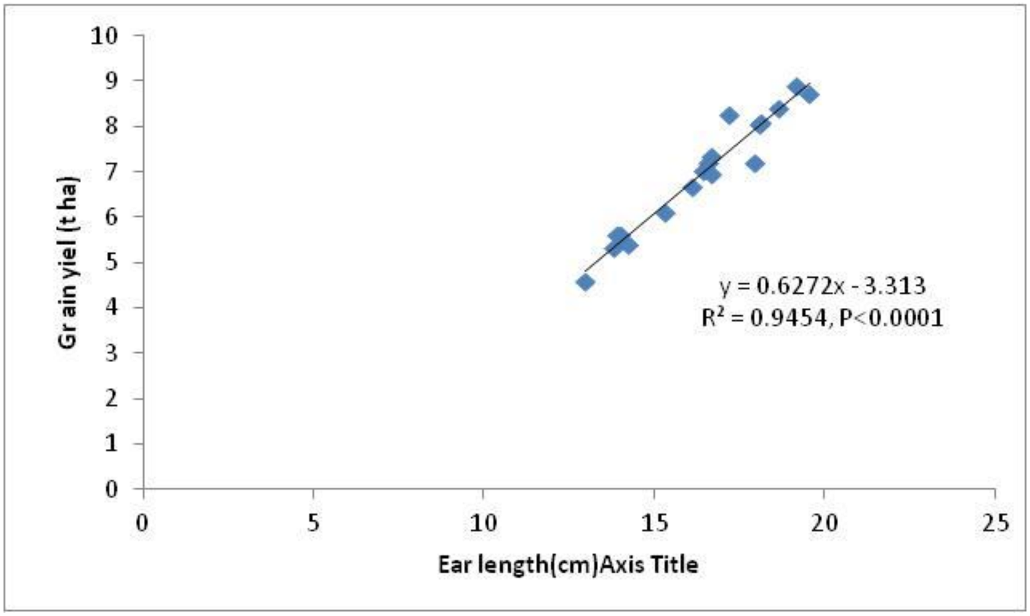

Figure 8: Relationship between ear length and maize grain yield at Rubona site

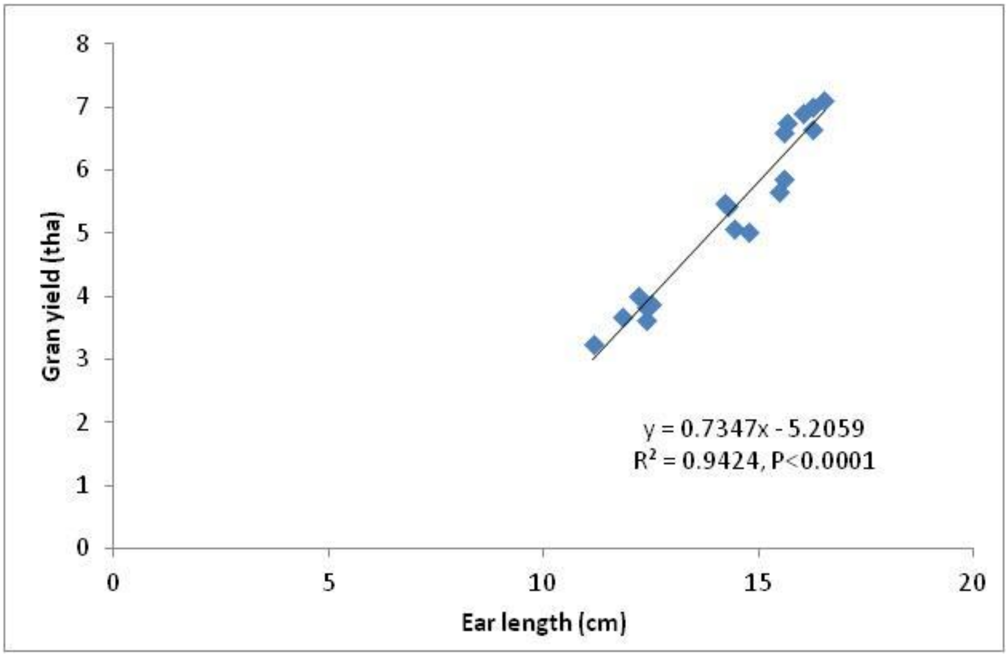

Figure 9: Relationship between ear length and maize grain yield at Karama site

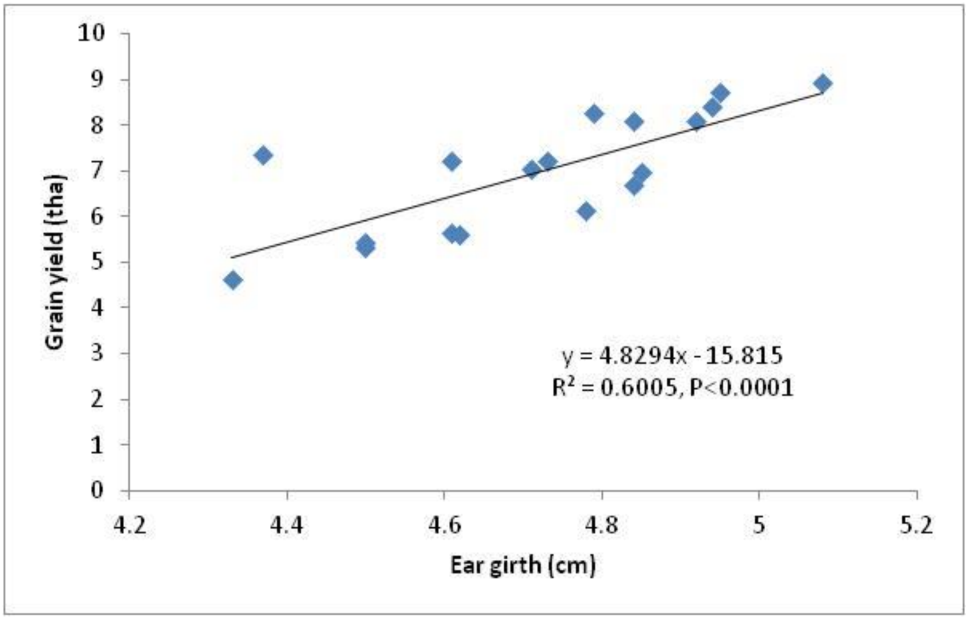

**Figure 10 : Relationship between ear girth and maize grain yield at Rubona site**

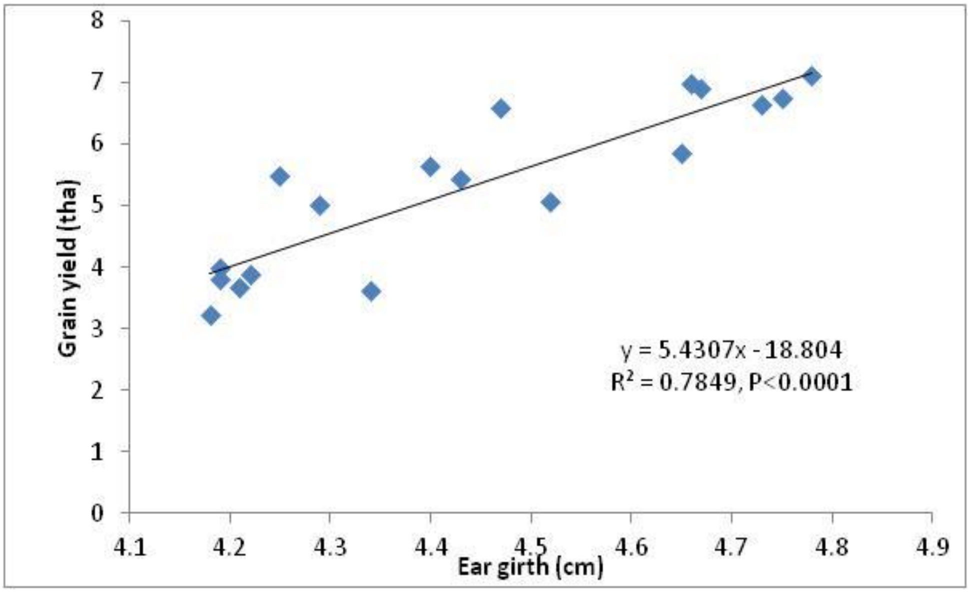

**Figure 11: Relationship between ear girth and maize grain yield at Karama site**

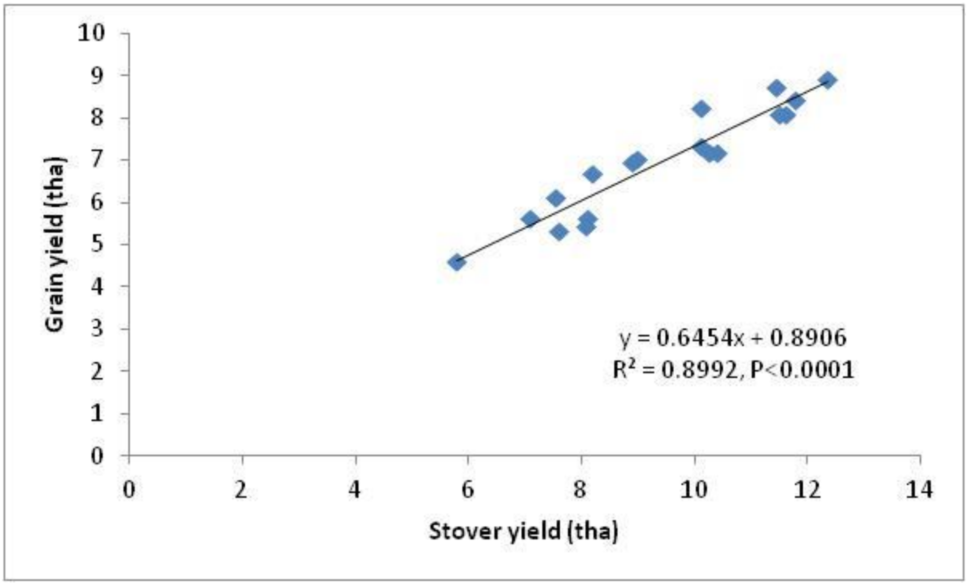

**Figure 12: Relationship between stover yield and maize grain yield at Rubona site**

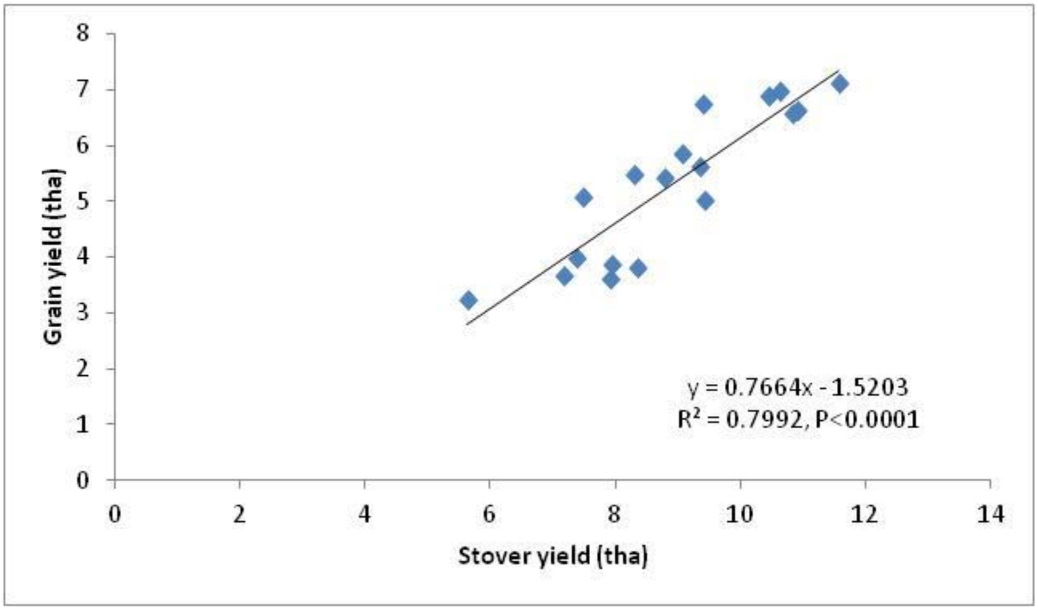

**Figure 13: Relationship between stover yield and maize grain yield at Karama site**

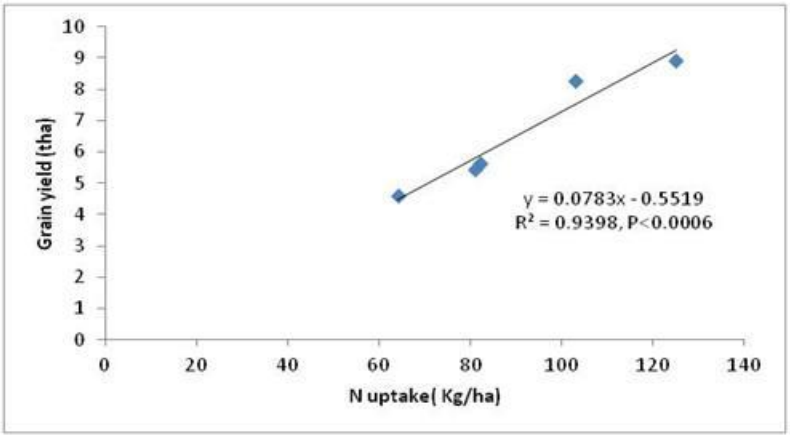

**Figure 14: Relationship between grain N uptake and Maize grain yield (Rubona site)**

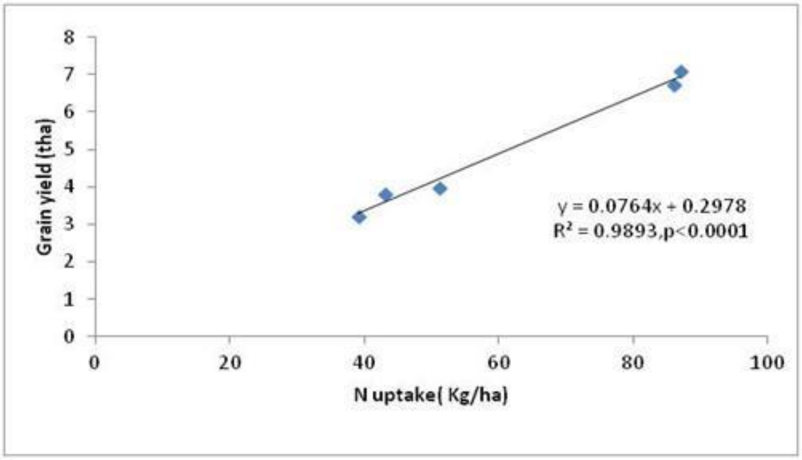

**Figure 15: Relationship between grain N uptake and Maize grain yield (Karama site)**

## 4.2. Effect of FYM and Mineral Fertilizers on Nutrient Uptake by Maize Crop.

### 4.2.1 The N and P Contents in Maize Grain and Stover

The mean nutrient contents of N and P in maize grain and stover for a few selected treatments are presented in Tables 7 and Table 8.

**Table 7: N and P content (%) in maize grain and stover**

| Treatments | Rubona site | | | | Karama site | | | |
|---|---|---|---|---|---|---|---|---|
| | Grain | | Stover | | Grain | | Stover | |
| | N(%) | P(%) | N(%) | P(%) | N(%) | P(%) | N(%) | P(%) |
| **Control** | 1.16a | 0.07a | 1.58b | 0.10a | 1.12a | 0.08a | 1.65c | 0.09a |
| **0KgN+0KgP+10TM** | 1.44a | 0.09a | 1.71ab | 0.12a | 1.20a | 0.08a | 1.75bc | 0.09a |
| **0KgN+50KgP+0TM** | 1.36a | 0.09a | 1.70ab | 0.11a | 1.20a | 0.09a | 1.71bc | 0.10a |
| **100KgN+0KgP+0TM** | 1.48a | 0.10a | 1.78a | 0.12a | 1.28a | 0.10a | 1.81ab | 0.11a |
| **100KgN+50KgP+10TM** | 1.52a | 0.10a | 1.82a | 0.14a | 1.28a | 0.11a | 1.90a | 0.11a |
| **LSD** | 0.5527 | 0.026 | 0.298 | 0.0389 | 0.4757 | 0.0356 | 0.4668 | 0.0225 |

Means with the same letter in each column are not significantly different at $p<0.05$

The results (Table 7) showed that even though the values obtained for N and P in the maize grain were not significantly different ($P > 0.05$) with treatments in the two sites (Rubona and Karama), the percentage content obtained in treatment 100KgN+50KgP +10TM (a combined treatment of N,P +manure) at both sites, were generally higher than other treatments, and more especially to those which received either organic and inorganic inputs separately . Nitrogen content in the maize grain at Rubona ranged between 1.16 and 1.52% and at Karama between 1.12 and 1.28% for the control and treatment 100KgN+50KgP+10TM ,respectively.

Similarly, the trend of N % content in stover was like that in the grain but with higher values than in the grain. The results showed that the values obtained for N in maize stover were significantly different ($P<0.05$) in Rubona and Karama Site. The nitrogen content percentage ranged between 1.58 and 1.82 % at Rubona and between 1.65 and 1.90% at Karama with respect to control and 100KgN+50KgP+10TM at both sites.

The highest and lowest P values were recorded in treatments 100KgN+50KgP+10TM and the control,respectively. Phosphorus content of the maize stover ranged from 0.09 to 0.11% at Karama and from 0.10 to 0.14% at Rubona site. The higher values observed in the combined treatments could be attributed to the combined treatments' effects such as improved soil environment for nutrient uptake (Marschner 1995). Guo *et al*. (2007) noted that inorganic fertilizers released their nutrient rather fast for the plants to utilize. This accounts for the observed high value of the N and P content of crops fertilized with inorganic fertilizer.

In terms of Total Nutrient Uptake as shown in Table 8, nutrient uptake under the various treatments was significantly different ($P < 0.05$) from one another, except for P uptake in the grain. Nitrogen uptake in maize grain ranged between 39 and 64 kg ha$^{-1}$ in the control to 87 and 125 kg ha$^{-1}$ in treatment 100KgN+50KgP+10TM, respectively, at karama and Rubona sites, while with maize stover the range was between 99 Kgha$^{-1}$ (control) to 190 Kg ha$^{-1}$ and 193 Kg ha$^{-1}$ (100KgN+50KgP+10TM), respectively at Karama and Rubona sites. The P uptake ranged from 3.05 and 4.63 kg p ha$^{-1}$ (control) to 7.54 and 7.70 kg Pha$^{-1}$ (100KgN+50KgP+10TM ) at Karama and Rubona, respectively, in maize grain. P uptake in maize stover ranged from 6.07 and 7.08 kgPha$^{-1}$ (control), respectively at Karama and Rubona to 10.90 and 12.54 kg P ha$^{-1}$(100KgN+50KgP+10TM ), respectively, at Karama and Rubona sites (Table 8).

**Table 8: Effect of FYM and mineral fertilizers on N and P uptake in maize grain and stover ( Kg/ha)**

| Treatments | Rubona site | | | | Karama site | | | |
|---|---|---|---|---|---|---|---|---|
| | Grain nutrient uptake(kg/ha) | | Stover nutrient uptake(kg/ha) | | Grain nutrient uptake(kg/ha) | | Stover nutrient uptake(kg/ha) | |
| | N | P | N | P | N | P | N | P |
| **Control** | 64c | 4.63a | 99c | 7.08b | 39b | 3.05c | 99c | 6.07b |
| **0KgN+0KgP+10TM** | 82bc | 5.29a | 144b | 10.48a | 51b | 3.16c | 143b | 6.76ab |
| **0KgN+50KgP+0TM** | 81bc | 5.43a | 128b | 9.73ab | 43b | 3.51bc | 140b | 8.25ab |
| **100KgN+0KgP+0TM** | 103ab | 6.61a | 183a | 11.36a | 86a | 5.39b | 164ab | 9.99ab |
| **100KgN+50KgP+10TM** | 125a | 7.70a | 193a | 12.54a | 87a | 7.54a | 190a | 10.90a |
| **LSD** | 0.0315 | 0.0022 | 0.0406 | 0.0029 | 0.0245 | 0.002 | 0.076 | 0.0042 |

Means with the same letter in each column are not significantly different at $p<0.05$

Generally, Uptake of N and P fertilizers was better with the combined application of organic and inorganic fertilizers. The combined organic and mineral fertilizers of 100KgN+50KgP+10TM improved nutrients uptake and their contents in both the grain and stover than the sole organic or inorganic treatments. Jones and Jacobsen (2001) had earlier highlighted that nutrient uptake by roots was dependent on both the ability of the roots to absorb nutrient and the concentration at the surface of the roots. This explains the increased N uptake with increased N application in this study (Table 8). Comparing the N and P nutrient contents in stover and grain of the two sites,Rubona and Karama, the contents at Rubona were higher than those of Karama (Table 8). This difference could be due to differences in soil moisture regimes (Jones *et al*., 2011). As seen on Table 3, the rainfall at Karama was low (516mm) and poorly distributed compared to that of Rubona ( 854.4mm). Plants have been reported to have difficulty in absorbing nutrients in dry soils(Jones et al.,2011). This might have been the case in Karama which recorded low nutrients accumulation in the maize tissues.

### 4.2.2 Effect of FYM Manure and Mineral Fertilizers on Nutrient Use Efficiency of Crop

Agronomic fertilizer use efficiency was determined to assess the efficiency of maize in utilizing nitrogen and phosphorus for grain production. Nitrogen use efficiency (NUE) was 48.6 and 36.5 kg of maize grain for each kilogram of N applied with respect to the application of 50 and 100kg/ha N at Rubona, while at karama, nitrogen use efficiency was 44.8 and 35.1 kg of maize grain for every kilogram of nitrogen applied at 50 and 100kg/ha N, respectively (Table 9).

Phosphorus use efficiency (PUE) was generally lower than that of nitrogen at bothe sites. At Rubona the P efficiency averaged 29.2 and 16.4 kilogram of P applied at 25 and 50 kg/ha P, while at Karama, the values of PUE were even lower than those of nitrogen with its PUE averaging 15.6 and 11.6 kilogram of maize grain for each kg of P applied at 25 and 50 kg/ha P, respectively (Table 9). In each case of nutrient application, the lower doses exhibited higher nutrient efficiencies than higher doses, an indication of better use efficiency of nutrients at low doses.

The results of this study concur with the research done by other researchers (Kayuki et al.,2012; Kogbe et al.,2003; Maranville *et al*., 2002). Kayuki et al. (2012) reported that at very high N application rate the NUE declined despite the slight increase in grain yield. Similar observation had earlier been reported by Kogbe *et al*. (2003). Maranville *et al*. (2002) added that nitrogen use efficiency (grain weight per unit of N supplied from soil and/or fertilizer) is reduced due to poor crop cultural practices, sub-optimal yields and N losses or deficiency of other nutrients. Kogbe and Adediran (2003) reported that PUE increased until 40kg/ha but declined with increase in P application in the soil. Jate (2012) reports that the highest FUE of N and P is achieved when combined FYM and mineral NP fertilizers are applied , because then nutrient supply for crop demand is balanced.

**Table 9:Agronomic Nutrient Use Efficiency of maize at Rubona and Karama (kg grain/ kg of fertilizer applied)**

| Attribute | NUE(Kg grain) | | PUE (Kg grain) | |
|---|---|---|---|---|
| Fertilizer Rates(Kg/Ha) | Rubona | Karama | Rubona | Karama |
| 25 | | | 29.2 | 15.6 |
| 50 | 48.6 | 44.8 | 16.4 | 11.6 |
| 100 | 36.5 | 35.1 | | |

## 4.3. Effect of Farmyard Manure and Mineral Fertilizers on Bio-Chemical Soil Properties

The third objective of the study was to determine the influence of the various organic and mineral fertilizers on soil biochemical properties. The general soil fertility parameters changed with the application of the various organic and mineral fertilizers as shown in Tables 10-23.

### 4.3.1 Effect of Treatments on Soil pH

The soil pH increased fairly significant in the plots treated with organic and inorganic fertilizers as compared to those that received N and P fertilizers and the control, where pH levels showed a marginal decrease. Both treatments had received 10 tons of FYM meaning, an indication that high manure in soil has the capacity to absorb or bind hydrogen ions in its humic forms while application of N fertilizers add hydrogen ions to the soil, hence, high acidity. These results agrees with Kang (1993) and Mugendi *et al*. (1999) who reported a general reduction in acidity after organic and mineral fertilizers application. The slight increase in pH in the combined treatments( organics and mineral fertilizers) compared to the sole application of organic inputs could be as a result of the $H^+$ ions, which are absorbed from the soil solution by humic substances (Tisdale *et al*. 1993).

**Table10: Effect of FYM and mineral fertilizers on soil pH at Rubona**

| Treatment | Initial | End of experiment | Difference |
|---|---|---|---|
| **Control** | 5.7 | 5.5bc | +0.20 |
| **10 TM** | 5.7 | 6.0a | -0.30 |
| **50 kg P** | 5.7 | 5.7b | 0.00 |
| **100 kg N** | 5.7 | 5.4c | +0.30 |
| **100kgN+50kgP+10TM** | 5.7 | 6.1a | -0.40 |
| **LSD** | | 0.2917 | |

Means with the same letter in each column are not significantly different at $p<0.05$

**Table11: Effect of FYM and mineral fertilizers on soil pH at Karama**

| Treatment | Initial | End of experiment | Difference |
|---|---|---|---|
| **Control** | 5.8 | 5.50b | +0.30 |
| **10 TM** | 5.8 | 6.60a | -0.80 |
| **50 kg P** | 5.8 | 6.50b | -0.7 |
| **100 kg N** | 5.8 | 6.00c | -0.2 |
| **100kgN+50kgP+10TM** | 5.8 | 6.57a | -0.77 |
| **LSD** | | 0.0486 | |

Means with the same letter in each column are not significantly different at $p<0.05$

### 4.3.2 Effect of Treatments on Soil Organic Carbon

At the end of the experiment, the highest levels of OC of 3.34% and 1.87%, respectively, in Rubona and Karama soils were obtained in treatment 100KgN+50KgP+10TM (Table 12). The higher OC levels observed in organic materials- amended plots could be attributed to the FYM addition and to P nutrient availability for microbial activity than where only FYM alone was applied (Antill. *et al.*,2001).

**Table 12: Effect of FYM and mineral fertilizers on soil Organic C (%)**

| Treatment | Rubona | | | Karama | | |
|---|---|---|---|---|---|---|
| | Initial | End | Change | Initial | End | Change |
| **Control** | 3.08 | 2.35e | -0.73 | 1.71 | 1.47d | -0.24 |
| **10 TM** | 3.08 | 2.99b | -0.09 | 1.71 | 1.29e | -0.42 |
| **50 kg P** | 3.08 | 2.37d | -0.71 | 1.71 | 1.58c | -0.13 |
| **100 kg N** | 3.08 | 2.50c | -0.58 | 1.71 | 1.62b | -0.09 |
| **100kgN+50kgP+10TM** | 3.08 | 3.34a | 0.26 | 1.71 | 1.87a | 0.16 |
| **LSD** | | 0.0084 | | | 0.0049 | |

Means with the same letter in each column are not significantly different at $p<0.05$

### 4.3.3 Effect of Treatments on Soil Total N

Total Nitrogen at the of experiment ranged from 0.38% to 0.25% and 0.35% with respect to control and 100KgN+50KgP+10TM treatments at Rubona site (Table 13). At Karama site, total N decreased from 0.28% to 0.23% and 0.25% respectively on the control and T18 (table 13). Generally, as a result of nutrient uptake by the maize, soil total nitrogen content decreased in all the treatments after harvest. Hanway (1971) observed that N tends to be depleted rapidly from the soil with cash grain farming such as maize.

**Table 13: Effect of FYM and mineral fertilizers on soil total N (%)**

| Treatment | Rubona | | | Karama | | |
|---|---|---|---|---|---|---|
| | Initial | End | Change | Initial | End | Change |
| **Control** | 0.38 | 0.25c | -0.13 | 0.28 | 0.23a | -0.05 |
| **10 TM** | 0.38 | 0.28b | -0.1 | 0.28 | 0.25a | -0.03 |
| **50 kg P** | 0.38 | 0.25c | -0.13 | 0.28 | 0.24a | -0.04 |
| **100 kg N** | 0.38 | 0.35a | -0.03 | 0.28 | 0.25a | -0.03 |
| **100kgN+50kgP+10TM** | 0.38 | 0.35a | -0.03 | 0.28 | 0.25a | -0.03 |
| **LSD** | | 0.0129 | | | 0.022 | |

Means with the same letter in each column are not significantly different at $p<0.05$

### 4.3.4 Effect of Treatments on Soil Available P

Table 14 shows available P levels in the soil during the growing season of maize as influenced by the various treatments applied. Soil available phosphorus after the experiment was increased in the plots treated with phosphorus and manure (Table14). Increases from 7.62 mgkg$^{-1}$ to 11.18 mgkg$^{-1}$ and 3.22 mgkg$^{-1}$ to 4.31 mgkg$^{-1}$ respectively at Rubona and Karama sites were observed under treatment 100kgN+50KgP+10TM (Table 14). The use of manure has been shown to increase the amount of soluble organic matter which are mainly organic acids that increase the rate of desorption of phosphate and thus improves the available P content in the soil (Zsolnay *et al*., 1994). Changes in available P were generally low in all plots because P is relatively immobile and strongly adsorbed by soil particles (Ige *et al*., 2005).

**Table** 14**: Effect of FYM and mineral fertilizers on soil Available P (mgkg-1**)

| Treatment | Rubona | | | Karama | | |
|---|---|---|---|---|---|---|
| | Initial | End | Change | Initial | End | Change |
| **Control** | 7.62 | 5.73d | -1.89 | 3.22 | 2.12d | -1.1 |
| **10 TM** | 7.62 | 5.08e | -2.54 | 3.22 | 2.29c | -0.93 |
| **50 kg P** | 7.62 | 8.90b | 1.28 | 3.22 | 3.57b | 0.35 |
| **100 kg N** | 7.62 | 8.13c | 0.51 | 3.22 | 3.56b | 0.34 |
| **100kgN+50kgP+10TM** | 7.62 | 11.18a | 3.56 | 3.22 | 4.31a | 1.09 |
| **LSD** | | 0.0479 | | | 0.0209 | |

Means with the same letter in each column are not significantly different at $p<0.05$

### 4.3.5 Effect of Treatments on Available Soil N ($NO_3^-$ & $NH_4^+$)

Tables 15 and 16 show the concentration of available nitrogen ($NO_3^-$ N and $NH_4^+$ N) in soil during the growing period of maize as influenced by the various treatments applied. The amount of $NH_4^+$ was different in the two sites (Table15). Ammonium-N concentration in the soil was significantly higher ($p<0.05$) in the plots treated with organic and mineral fertilizers than the control. Treatment 100KgN+50KgP+10TM gave rise to highest concentration of $NH_4^+$ in the two sites but with much higher concentration at Karama (Table15).

**Table 15: Effect of FYM and mineral fertilizers on soil $NH_4^+$(mg/kg$^{-1}$)**

| **Treatment** | **Rubona** | | | **Karama** | | |
|---|---|---|---|---|---|---|
| | **Initial** | **End** | **Change** | **Initial** | **End** | **Change** |
| **Control** | 25.93 | 21.00d | -4.93 | 24.00 | 21.03e | -2.97 |
| **10 TM** | 25.93 | 30.63b | 4.7 | 24.00 | 35.10c | 11.1 |
| **50 kg P** | 25.93 | 27.37c | 1.44 | 24.00 | 23.70d | -0.3 |
| **100 kg N** | 25.93 | 30.70b | 4.77 | 24.00 | 40.53b | 16.53 |
| **100kgN+50kgP+10TM** | 25.93 | 35.00a | 9.07 | 24.00 | 54.07a | 30.07 |
| **LSD** | | 0.4321 | | | 0.2004 | |

Means with the same letter in each column are not significantly different at $p<0.05$

Similarly, the amount of $NO_3^-$ was different in the two sites and reflected the treatments. In general, lower levels were found in the control and the highest amount of $NO3^-$ was observed in treatment 100KgN+50KgP+10TM (Table16). The high level of $NO_3^-$ accumulation in the organic combined with mineral fertilizers treatments could have favoured $NO_3$-production process, namely nitrification (Burger and Jackson 2003). The observed higher concentrations of available N in soils after nitrogen dose has also been emphasized by Dubey *et al*. (2012) who reported that continuous use of nitrogenous fertilizers generally increased the available N status of the soil.

**Table 16: Effect of FYM and mineral fertilizers on soil $NO_3^-$ (mg/kg$^{-1}$)**

| **Treatment** | **Rubona** | | | **Karama** | | |
|---|---|---|---|---|---|---|
| | **Initial** | **End** | **Change** | **Initial** | **End** | **Change** |
| **Control** | 19.83 | 20.37e | 0.54 | 17.33 | 20.23e | 2.9 |
| **10 TM** | 19.83 | 26.70c | 6.87 | 17.33 | 25.50c | 8.17 |
| **50 kg P** | 19.83 | 22.60d | 2.77 | 17.33 | 20.90d | 3.57 |
| **100 kg N** | 19.83 | 28.23b | 8.4 | 17.33 | 30.13b | 12.8 |
| **100kgN+50kgP+10TM** | 19.83 | 29.60a | 9.77 | 17.33 | 33.87a | 16.54 |
| **LSD** | | 0.4321 | | | 0.2004 | |

Means with the same letter in each column are not significantly different at $p<0.05$

### 4.3.6 Effect of Treatments on Cation Exchange Capacity (CEC)

Table 17 presents the soil cation exchange capacity (CEC) as influenced by experimental treatments. The 100KgN+50KgP+10TM treatment gave the highest CEC values of 18.84cmolkg$^{-1}$ and 13.83cmolkg$^{-1}$, respectively in Rubona and karama sites at the end of experiment (table17). The control gave the lowest CEC values of 12.64cmolkg$^{-1}$ and 11.49cmolkg$^{-1}$, respectively in Rubona and Karama sites (Table17).Unlike in Rubona where the rest of other treatments did not affect the CEC, in Karama site, all the treatments increased the CEC of the soil. This behavior is rather strange and unexpected with Karama soils which had low organic carbon. However, addition of organic matter into soils in most cases increases CEC due to its humic acids which increase the negative charge (Norman *et al*.,2000; Lifeng *et al*.,2006).

**Table 17: Effect of FYM and mineral fertilizers in soil CEC(cmolkg-1)**

| **Treatment** | **Rubona** | | | **Karama** | | |
|---|---|---|---|---|---|---|
| | **Initial** | **End** | **Change** | **Initial** | **End** | **Change** |
| **Control** | 17.06 | 12.64e | -4.42 | 10.82 | 11.49e | 0.67 |
| **10 TM** | 17.06 | 17.27b | 0.21 | 10.82 | 12.92c | 2.1 |
| **50 kg P** | 17.06 | 14.31d | -2.75 | 10.82 | 12.31d | 1.49 |
| **100 kg N** | 17.06 | 15.50c | -1.56 | 10.82 | 13.50b | 2.68 |
| **100kgN+50kgP+10TM** | 17.06 | 18.84a | 1.78 | 10.82 | 13.83a | 3.01 |
| **LSD** | | 0.0146 | | | 0.0131 | |

Means with the same letter in each column are not significantly different at $p<0.05$

### 4.3.7 Effect of Treatments on Exchangeable K, Ca and Mg

Generally, exchangeable K decreased in all the plots of fertilizer type (Table18). Exchangeable Ca increased in plots treated with organic fertilizer after harvest but it reduced in all other plots (Table19). The increases in exchangeable Mg was more under plots treated with organic and inorganic fertilizers compared with any other treatment including the control (Table20).

**Table18: Changes on soil Exchangeable K (cmolkg$^{-1}$) under different fertilizers**

| **Treatment** | **Rubona** | | | **Karama** | | |
|---|---|---|---|---|---|---|
| | **Initial** | **End** | **Change** | **Initial** | **End** | **Change** |
| **Control** | 0.58 | 0.18c | -0.4 | 0.75 | 0.55c | -0.2 |
| **10 TM** | 0.58 | 0.30b | -0.28 | 0.75 | 0.61b | -0.14 |
| **50 kg P** | 0.58 | 0.30b | -0.28 | 0.75 | 0.55c | -0.2 |
| **100 kg N** | 0.58 | 0.30b | -0.28 | 0.75 | 0.61b | -0.14 |
| **100kgN+50kgP+10TM** | 0.58 | 0.55a | -0.03 | 0.75 | 0.78a | 0.03 |
| **LSD** | | 0.0073 | | | 0.0069 | |

Means with the same letter in each column are not significantly different at $p<0.05$

**Table19: Changes on soil Exchangeable Ca(cmolkg$^{-1}$) under different fertilizers**

| **Treatment** | **Rubona** | | | **Karama** | | |
|---|---|---|---|---|---|---|
| | **Initial** | **End** | **Change** | **Initial** | **End** | **Change** |
| **Control** | 3.07 | 2.00e | -1.07 | 2.33 | 2.16c | -0.17 |
| **10 TM** | 3.07 | 2.63b | -0.44 | 2.33 | 2.24d | -0.09 |
| **50 kg P** | 3.07 | 2.08d | -0.99 | 2.33 | 2.28c | -0.05 |
| **100 kg N** | 3.07 | 2.40c | -0.67 | 2.33 | 2.64b | 0.31 |
| **100kgN+50kgP+10TM** | 3.07 | 2.91a | -0.16 | 2.33 | 2.80a | 0.47 |
| **LSD** | | 0.0158 | | | 0.0084 | |

Means with the same letter in each column are not significantly different at $p<0.05$

**Table 20: Changes on soil Exchangeable Mg (cmolkg$^{-1}$) under different fertilizers**

| **Treatment** | **Rubona** | | | **Karama** | | |
|---|---|---|---|---|---|---|
| | **Initial** | **End** | **Change** | **Initial** | **End** | **Change** |
| **Control** | 0.15 | 0.31c | 0.16 | 0.32 | 0.36e | 0.04 |
| **10 TM** | 0.15 | 0.46a | 0.31 | 0.32 | 0.44b | 0.12 |
| **50 kg P** | 0.15 | 0.37b | 0.22 | 0.32 | 0.39d | 0.07 |
| **100 kg N** | 0.15 | 0.38b | 0.23 | 0.32 | 0.41c | 0.09 |
| **100kgN+50kgP+10TM** | 0.15 | 0.47a | 0.32 | 0.32 | 0.60a | 0.28 |
| **LSD** | | 0.0091 | | | 0.0049 | |

Means with the same letter in each column are not significantly different at $p<0.05$

### 4.3.8 Effect of Treatments on Effective Cation Exchange Capacity (ECEC)

Addition of organic fertilizer increased Effective Cation Exchange Capacity (ECEC) (Ttable 21). It has been recorded that crops take up more nutrients when mineral fertilizer was added in what is known as “luxury consumption” probably because nutrients from this source are readily available (Howeler *et al.*,1983). It has also been observed that addition of manure increases water holding capacity and this means that nutrient would be made available to crops where manure has been added to the soil (Costa *et al.*,1991). The rate of depletion of ECEC was least where inorganic + organic was added showing that nutrients were conserved better than inorganic fertilizer treatment. Uphoof (2002) encouraged the use of organic amendments since chemical fertilizers do not contribute much overtime to soil quality. Integration of mineral with organic fertilizer increases soil fertility through improvement of physical and chemical properties of soil. Improvement of soil organic matter improves soil physical properties and it increases nutrient availability (Onemli, 2004).

Application of FYM plus mineral fertilizer improved soil fertility through improvement of organic matter and nutrient content of the soil. Fertilizer application significantly increased the concentrations of N, P, and organic carbon in the plough layer of soil. The similar results were observed by (Ishaq *et al.*, 2002).

**Table 21: Changes in Soil ECEC (cmolkg$^{-1}$) under different fertilizers**

| **Treatment** | **Rubona** | | | **Karama** | | |
|---|---|---|---|---|---|---|
| | **Initial** | **End** | **Change** | **Initial** | **End** | **Change** |
| **Control** | 4.31 | 3.37e | -0.94 | 3.79 | 3.51e | -0.28 |
| **10 TM** | 4.31 | 4.31b | 0 | 3.79 | 4.21b | 0.42 |
| **50 kg P** | 4.31 | 3.46d | -0.85 | 3.79 | 3.70d | -0.09 |
| **100 kg N** | 4.31 | 4.01c | -0.3 | 3.79 | 4.02c | 0.23 |
| **100kgN+50kgP+10TM** | 4.31 | 5.23a | 0.92 | 3.79 | 4.73a | 0.94 |
| **LSD** | | 0.0175 | | | 0.01 | |

Means with the same letter in each column are not significantly different at $p<0.05$

### 4.3.9 Changes in Soil Biological Properties under Different Fertilizers

The results on effect of organic manure and mineral fertilizers on biological properties of the soil observed during initial and final stages of the experiment were given in table 22 and 23. The results showed that the microbial load was found to be well flourished. The recorded fungal count value in the initial stage (before the experiment) was 5.13x$10^3$ cfu/gm at Rubona site. The fungal count value in the initial stage at Karama site was 6.57 x$10^3$cfu. At harvest, the maximum fungal count was recorded in T18 (100KgN+50KgP+10TM) followed by T2 (0KgN+0KgP+10TM) in two sites. Their respective value was 6.10x$10^3$cfu/gm and 5.23x$10^3$cfu/gm in Rubona site , and the fungal count value recorded in Karama Site was 6.63x$10^3$cfu/gm and 5.7x$10^3$cfu/gm respectively in T18 and T2. The minimum fungal count value was recorded in T1(Control) in the two sites (table 22).

**Table 22: Effect of organic manure and mineral fertilizers on soil fungi (cfu/$10^3$)**

| Treatment | Rubona | | Karama | |
|---|---|---|---|---|
| | Initial | Harvest | Initial | Harvest |
| **Control** | 5.13 | 3.57d | 6.57 | 3.90d |
| **10 t/ha manure** | 5.13 | 5.23b | 6.57 | 5.17b |
| **50 kg P** | 5.13 | 4.37c | 6.57 | 3.97d |
| **100 kg N** | 5.13 | 5.10b | 6.57 | 4.60c |
| **100kgN+50kgP+10TM** | 5.13 | 6.10a | 6.57 | 6.63a |
| **LSD** | | 2.991 | | 2.7513 |

Means with the same letter in each column are not significantly different at $p<0.05$

The T18 (100KgN+50KgP+10TM) applied plot was noticed with maximum bacteria at the harvest in two sites. The value was 1.61x$10^6$cfu/gm and1.68x$10^6$cfu/gm respectively in Rubona and Karama sites . The initial stage value was $0.95 \times 10^6$cfu/gm and $0.65 \times 10^6$cfu/gm respectively in Rubona and Karama sites . The control recorded the minimum bacterial count at the end on experiment. The value was$1.08 \times 10^6$cfu/gm and $0.72 \times 10^6$cfu/gm respectively in Rubona and Karama site (Table 23).

**Table 23: Effect of organic manure and mineral fertilizers on soil bacteria (cfu/$10^6$)**

| **Treatment** | **Rubona** | | **Karama** | |
|---|---|---|---|---|
| | **Initial** | **Harvest** | **Initial** | **Harvest** |
| **Control** | 0.95 | 1.08a | 0.65 | 0.72b |
| **10 t/ha manure** | 0.95 | 1.26a | 0.65 | 0.95b |
| **50 kg P** | 0.95 | 1.15a | 0.65 | 0.75b |
| **100 kg N** | 0.95 | 1.18a | 0.65 | 1.55a |
| **100kgN+50kgP+10TM** | 0.95 | 1.61a | 0.65 | 1.68a |
| **LSD** | | 0.9878 | | 1.5447 |

Means with the same letter in each column are not significantly different at $p<0.05$

The application of mineral fertilizer and farmyard manure had increased both fungal and bacterial communities. Similar results were reported by Somasundaram (2003) and Musyoki (2011). Sole application of mineral fertilizers (N and P) negatively affected microbial communities.. Application of organic inputs alone had a lower diversity of microbial communities compared to combination of both organic and mineral fertilizers though a relatively higher diversity was noted compared to sole application of mineral fertilizers.

The microbial community composition at the experimental sites was dominated by bacteria, while fungal biomass was lower, as it is typical of intensively cultivated agricultural soils (Bardgett 2005). Bacteria were also the most sensitive microbial group to the different fertilizers; this seems reasonable, as bacteria have a much shorter turnover time than fungi and can react faster to the environmental changes in soil. Bacteria growth is often limited by the lack of readily available C substrates, even in soil with a high C/N ration, and comprised the first group of microorganisms to assimilate most of the readily available organic substrates after they are added to the soil (Demoling *et al*.2007; Kuzyakov 2010).

# CHAPTER FIVE

## 5.0 CONCLUSION AND RECOMMENDATIONS

### 5.1 Conclusion

The main aim of this study was to evaluate the effect of farmyard manure and inorganic fertilizer on maize grain yields and soil properties in two Districts of Rwanda. The results obtained in this study show that:

- Yields were significantly affected by the various treatments
- Organic and mineral fertilizers produced yields which were significantly higher than the values obtained by organic or inorganic fertilizers separately.
- The highest grain and stover yield in Rubona and Karama sites were obtained by 100kg N+50kgP+10TM treatment while the control obtained the lowest grain and stover yields.
- Maize grain yields responded better to N than P in the two sites
- The combined treatments of 100kg N+50kgP+10TM indicated significantly higher nutrient uptake values than the control.
- Most soil properties were not much affected by the treatments in this one season crop. However, soil pH, organic carbon and microbial populations (bacteria and fungi) significantly increased due to FYM application while soil total N was decreased in all the treatments.

## 5.2 Recommendations

- The combined application of organic and inorganic fertilizers at 100Kg N ha$^{-1}$+ 50 kg P ha$^{-1}$+10TM ha$^{-1}$ can be recommended.

- Long term studies of the treatments used in this study should be carried out to further ascertain their effects on physical properties of the soil.

- Further research to be conducted for a longer period using different rates of FYM and inorganic fertilizer in the different ecological zones of Rwanda in order to come up with a robust figure on the optimum rates for increased maize production.

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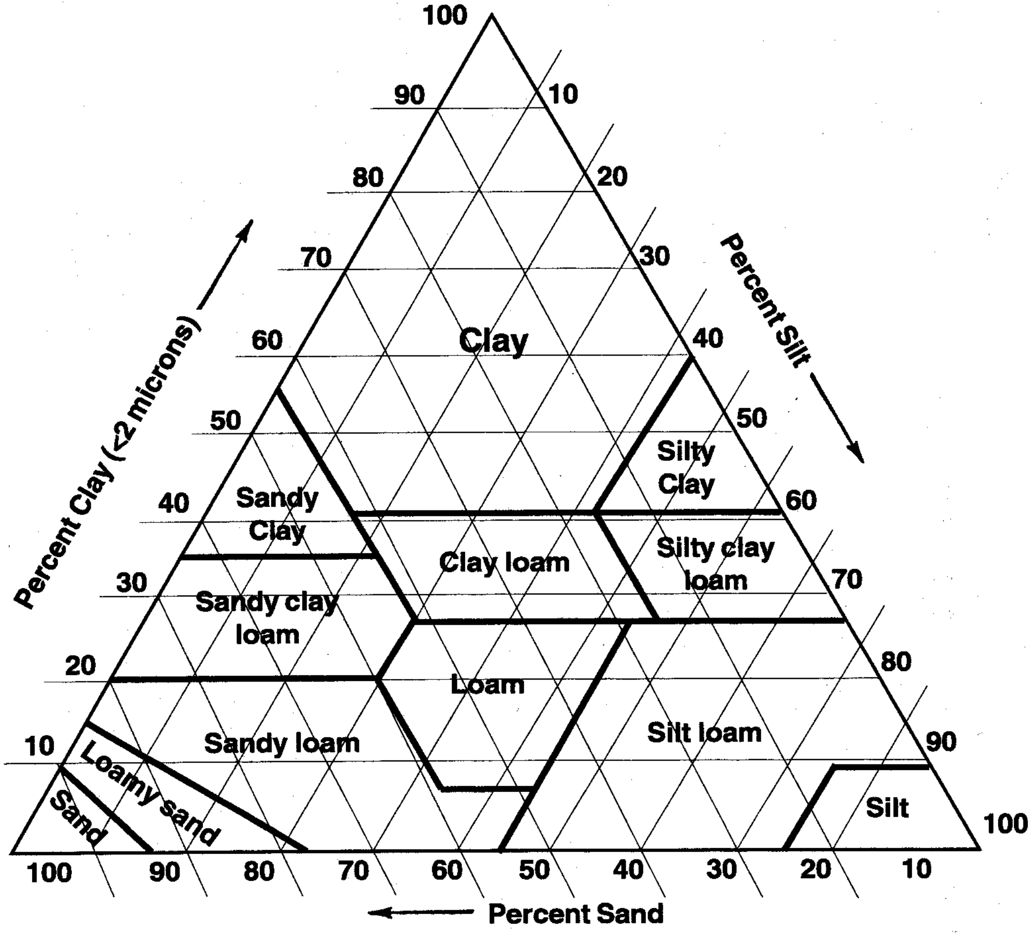
# APPENDICES

## APPENDIX 1: TREATMENTS AND THEIR RANDOMIZATION

**EXPERIMENT FIELD LAYOUT**
**PLOT SIZE: 4.5X4.5m**

| BLOCK1 | BLOCK2 | BLOCK3 |
|---|---|---|
| TRT | TRT | TRT |
| T4 | T2 | T12 |
| T11 | T17 | T14 |
| T3 | T10 | T1 |
| T18 | T8 | T4 |
| T14 | T13 | T5 |
| T6 | T12 | T3 |
| T7 | T1 | T17 |
| T10 | T3 | T8 |
| T9 | T18 | T10 |
| T5 | T6 | T11 |
| T17 | T7 | T16 |
| T12 | T9 | T6 |
| T2 | T5 | T15 |
| T1 | T4 | T2 |
| T13 | T11 | T18 |
| T8 | T16 | T9 |
| T15 | 14 | T13 |
| T16 | 15 | T7 |

## APPENDIX 2: SOIL TEXTURAL TRIANGLE



# APPENDIX 3: ANOVA RESULTS

## a. Maize yield

### Ear Length at Rubona site

```
         Source                      DF         Anova SS     Mean Square    F Value    Pr > F

         Trt                         17      204.8680833      12.0510637      10.87    <.0001
         Blk                          2        4.3592333       2.1796167       1.97    0.1556
```

### Ear Girth at Rubona site

```
         Source                      DF         Anova SS     Mean Square    F Value    Pr > F

         Trt                         17       2.10627593      0.12389858       5.42    <.0001
         Blk                          2       0.03974815      0.01987407       0.87    0.4286
```

### Weight of 1000grains at Rubona site

```
Source                      DF         Anova SS     Mean Square    F Value    Pr > F

         Trt                         17      54748.97596      3220.52800       4.56    <.0001
         Blk                          2       1438.50334       719.25167       1.02    0.3721
```

### Grain yields at Rubona site

```
         Source                      DF         Anova SS     Mean Square    F Value    Pr > F

         Trt                         17      85.22814259      5.01342015      28.79    <.0001
         Blk                          2       1.35707037      0.67853519       3.90    0.0300
```

### Stover yields at Rubona site

```
         Source                      DF         Anova SS     Mean Square    F Value    Pr > F

         Trt                         17      183.9178593      10.8186976      12.53    <.0001
         Blk                          2        0.0936704       0.0468352       0.05    0.9473
```

### Ear Length at Karama site

```
         Source                      DF         Anova SS     Mean Square    F Value    Pr > F

         Trt                         17      159.7679704       9.3981159      10.22    <.0001
         Blk                          2        2.0798259       1.0399130       1.13    0.3346
```

### Ear Girth at Karama site

```
         Source                      DF         Anova SS     Mean Square    F Value    Pr > F

         Trt                         17       2.44600000      0.14388235       6.75    <.0001
         Blk                          2       0.05841111      0.02920556       1.37    0.2678
```

Weight of 1000 grains  at Karama site

```
Source                      DF       Anova SS     Mean Square    F Value    Pr > F

Trt                         17    69615.42765      4095.02516      10.36    <.0001
Blk                          2      337.14820       168.57410       0.43    0.6563
```

Grain yields at Karama site

```
Source                      DF       Anova SS     Mean Square    F Value    Pr > F

Trt                         17    91.63148148      5.39008715      40.72    <.0001
Blk                          2     0.11124815      0.05562407       0.42    0.6603
```

Stover yields at Karama site

```
Source                      DF       Anova SS     Mean Square    F Value    Pr > F

Trt                         17    124.6985704       7.3352100       5.42    <.0001
Blk                          2      8.0936704       4.0468352       2.99    0.0635
```

## **b.Soil and plant chemical results**

The concentration of Nitrogen in grains of Rubona site

```
Source                      DF       Anova SS     Mean Square    F Value    Pr > F

Blk                          2     0.21312000      0.10656000       1.24    0.3404
trt                          4     0.24384000      0.06096000       0.71    0.6090
```

The concentration of Posphorous in grains of Rubona site

```
Source                      DF       Anova SS     Mean Square    F Value    Pr > F

Blk                          2     0.00028000      0.00014000       0.74    0.5085
trt                          4     0.00144000      0.00036000       1.89    0.2048
```

N stover concentration at  Rubona site

```
Source                      DF       Anova SS     Mean Square    F Value    Pr > F

Blk                          2     0.09829333      0.04914667       1.96    0.2026
trt                          4     4.30942667      1.07735667      43.01    <.0001
```

P stover concentration at  Rubona site

```
Source                      DF       Anova SS     Mean Square    F Value    Pr > F

Blk                          2     0.00085333      0.00042667       1.00    0.4096
trt                          4     0.00230667      0.00057667       1.35    0.3313
```

Grain N uptake   at  Rubona site

```
Source                      DF       Anova SS     Mean Square    F Value    Pr > F

Blk                          2     0.00129540      0.00064770       2.31    0.1615
trt                          4     0.00686229      0.00171557       6.12    0.0148
```

Grain P uptake   at  Rubona site

```
 Source                      DF        Anova SS     Mean Square    F Value    Pr > F

 Blk                          2      0.00000487      0.00000243       1.82    0.2228
 trt                          4      0.00001778      0.00000444       3.33    0.0696
```

Stover N uptake   at  Rubona site

```
 Source                      DF        Anova SS     Mean Square    F Value    Pr > F

 Blk                          2      0.00055544      0.00027772       0.60    0.5738
 trt                          4      0.11453257      0.02863314      61.44    <.0001
```

Stover P uptake   at  Rubona site

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

 Blk                          2      0.00001650      0.00000825       3.40    0.0854
 trt                          4      0.00005055      0.00001264       5.21    0.0231
```

The concentration of Nitrogen in grains of Karama site

```
 Source                      DF        Anova SS     Mean Square    F Value    Pr > F

 Blk                          2      0.23808000      0.11904000       1.86    0.2164
 trt                          4      0.05376000      0.01344000       0.21    0.9254
```

The concentration of Phosphorous in grains of Karama site

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

 Blk                          2      0.00101333      0.00050667       1.42    0.2965
 trt                          4      0.00182667      0.00045667       1.28    0.3539
```

N stover concentration at Karama site

```
 Source                      DF        Anova SS     Mean Square    F Value    Pr > F

 Blk                          2      0.17721333      0.08860667       1.44    0.2920
 trt                          4      0.32484000      0.08121000       1.32    0.3407
```

P stover concentration at Karama site

```
 Source                      DF        Anova SS     Mean Square    F Value    Pr > F

 Blk                          2      0.00345333      0.00172667      12.05    0.0039
 trt                          4      0.00069333      0.00017333       1.21    0.3782
```

Grain N uptake   at Karama site

```
 Source                      DF        Anova SS     Mean Square    F Value    Pr > F

 Blk                          2      0.00110970      0.00055485       3.27    0.0917
 trt                          4      0.00659918      0.00164980       9.72    0.0037
```

Grain P uptake   at Karama site

```
 Source                      DF        Anova SS     Mean Square    F Value    Pr > F

 Blk                          2      0.00000145      0.00000072       0.63    0.5589
 trt                          4      0.00004479      0.00001120       9.69    0.0037
```

Stover N uptake   at Karama site

```
         Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Blk                          2     0.00025681      0.00012841       0.08    0.9250
         trt                          4     0.03235280      0.00808820       4.96    0.0263
```

Stover P uptake   at Karama site

```
         Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Blk                          2     0.00001230      0.00000615       1.25    0.3366
         trt                          4     0.00005074      0.00001269       2.58    0.1182
```

Soil pH 0-20Cm at Rubona site at harvest

```
         Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Trt                          4     1.11600000      0.27900000      11.63    0.0020
         Blk                          2     0.04800000      0.02400000       1.00    0.4096
```

Soil OC 0-20Cm at Rubona site at harvest

```
         Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Trt                          4     2.29924000      0.57481000    28740.5    <.0001
         Blk                          2     0.00004000      0.00002000       1.00    0.4096
```

Soil Total N 0-20Cm at Rubona site at harvest

```
         Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Trt                          4     0.03066667     0.00766667     164.29     <.0001
         Blk                          2     0.00009333     0.00004667       1.00     0.4096
```

Soil NH$^4$ 0-20Cm at Rubona site at harvest

```
         Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Tr                           4    324.6226667      81.1556667    1540.93    <.0001
         Blk                          2      0.2520000       0.1260000       2.39    0.1533
```

Soil NO$_3$ 0-20Cm at Rubona site at harvest

```
  Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Tr                           4    181.4466667      45.3616667     861.30    <.0001
         Blk                          2      0.2520000       0.1260000       2.39    0.1533
```

Soil Av.P 0-20Cm at Rubona site at harvest

```
         Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Trt                          4    73.28613333     18.32153333    28259.4    <.0001
         Blk                          2     0.00161333      0.00080667       1.24    0.3385
```

Soil Ca 0-20Cm at Rubona site at harvest

```
         Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Trt                          4     7.15044000      1.78761000    25537.3    <.0001
         Blk                          2     0.00004000      0.00002000       0.29    0.7588
```

Soil Mg 0-20Cm at Rubona site at harvest

```
         Source                      DF       Anova SS     Mean Square    F Value    Pr > F

         Trt                          4     0.05209333      0.01302333     558.14    <.0001
         Blk                          2     0.00021333      0.00010667       4.57    0.0474
```

### Soil K 0-20Cm at Rubona site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.21664000      0.05416000    3610.67    <.0001
Blk                          2      0.00001333      0.00000667       0.44    0.6561
```

### Soil Na 0-20Cm at Rubona site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.00149333      0.00037333    16.00      0.0007
Blk                          2      0.00001333      0.00000667     0.29      0.7588
```

### Soil CEC 0-20Cm at Rubona site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4     70.98160000     17.74540000     295757    <.0001
Blk                         2      0.00025333      0.00012667       2.11    0.1836
```

### Soil H$^+$ 0-20Cm at Rubona site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.58750667      0.14687667    4005.73    <.0001
Blk_                         2      0.00004000      0.00002000       0.55    0.5997
```

### Soil ECEC 0-20Cm at Rubona site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      6.80890667      1.70222667    19641.1    <.0001
Blk                          2      0.00084000      0.00042000       4.85    0.0418
```

### Soil pH 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.72666667      0.18166667     272.50    <.0001
Blk                          2      0.00133333      0.00066667       1.00    0.4096
```

### Soil OC 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.54470667      0.13617667    20426.5    <.0001
Blk                          2      0.00001333      0.00000667       1.00    0.4096
```

### Soil Total N 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4        0.00070667   0.00017667     1.29       0.3499
Blk                          2        0.00064000   0.00032000     2.34       0.1583
```

### Soil NH$^4$ 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4     2150.577333      537.644333    47439.2    <.0001
Blk                          2        0.089333        0.044667       3.94    0.0644
```

### Soil NO$_3$ 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4     415.2093333     103.8023333    9159.03    <.0001
Blk                          2       0.0893333       0.0446667       3.94    0.0644
```

Soil Av.P 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4     10.48849333      2.62212333    21260.5    <.0001
Blk                          2      0.00001333      0.00000667       0.05    0.9477
```

Soil Ca 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.93924000      0.23481000    11740.5    <.0001
Blk                          2      0.00004000      0.00002000       1.00    0.4096
```

Soil Mg 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.10722667      0.02680667    4021.00    <.0001
Blk                          2      0.00001333      0.00000667       1.00    0.4096
```

Soil K 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.11169333      0.02792333    2094.25    <.0001
Blk                          2      0.00009333      0.00004667       3.50    0.0809
```

Soil Na 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.00140000      0.00035000    8.75       0.0051
Blk                          2      0.00001333      0.00000667    0.17       0.8493
```

Soil CEC 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4     10.58613333      2.64653333    54755.9    <.0001
Blk                          2      0.00028000      0.00014000       2.90    0.1132
```

Soil $H^+$ 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.91956000      0.22989000    3.31E16    <.0001
Blk                          2      0.00000000      0.00000000       0.00    1.0000
```

Soil ECEC 0-20Cm at Karama site at harvest

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      2.70897333      0.67724333    23902.7    <.0001
Blk                          2      0.00037333      0.00018667       6.59    0.0204
```

### c. Soil microbial results

Soil bacteria 0-20 cm at Rubona site

```
Source                      DF        Anova SS     Mean Square    F Value    Pr > F

Trt                          4      0.52344000      0.13086000       0.48    0.7534
Blk                          2      1.35033333      0.67516667       2.45    0.1476
```

### Soil fungi 0-20 cm at Rubona site

```
Source                      DF       Anova SS    Mean Square   F Value   Pr > F

Trt                          4     5.38733333     1.34683333      0.53   0.7154
Blk                          2     6.63633333     3.31816667      1.31   0.3208
```

### Soil bacteria 0-20 cm at Karama site

```
Source                      DF       Anova SS    Mean Square   F Value   Pr > F

Trt                          4     2.46024000     0.61506000      0.91   0.5004
Blk                          2     0.98896000     0.49448000      0.73   0.5094
```

### Soil fungi 0-20 cm at Karama site

```
Source                      DF       Anova SS    Mean Square   F Value   Pr > F

Trt                          4    12.99066667     3.24766667      3.75   0.0527
Blk                          2     4.96533333     2.48266667      2.87   0.1150
```