ASSESSMENT OF THE NITROGEN AND PHOSPHORUS NEEDS AND USE EFFICIENCIES FOR ENHANCED MAIZE YIELDS IN MBOZI DISTRICT OF TANZANIA

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A DISSERTATION SUBMITTED IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE IN SOIL SCIENCE AND LAND MANAGEMENT OF SOKOINE UNIVERSITY OF AGRICULTURE. MOROGORO, TANZANIA

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ABSTRACT

A study was conducted in Lumbila, Senjele, Mbimba and Ihowa villages of Mbozi district, Tanzania during 2012 – 2013 cropping season to assess the fertility status of the soils and response of maize to N and P as a strategy for enhanced and sustainable maize production. This study was triggered by the low maize yield in Tanzania due to many factors which include declining soil fertility, soil N and P being the major constraints to maize production. The search for the most appropriate rate of N and P fertilizers in relation to maize that would result in optimum yields prompted this research to be conducted. The experiment was laid as Randomized Complete Block Design with three replications. Maize variety used was "UH 615" with fertilizer treatments of Urea (46%N) and TSP (46% P_2O_5). Based on the soils analytical data, the major soil limitations for increased and sustainable maize production at the study areas include the deficiencies of N, P, Ca, Zn and low in OM. Application of 80 kg N ha^{-1} + 20 kg P ha^{-1} and 120kg N ha^{-1} + 20 kg P ha^{-1} significantly ($P \leq 0.05$) enhanced maize growth and yield more than other treatments, however, the effect was insignificant on harvest index of maize. Application of N at the rates of 40, 80 and 120 kg ha^{-1} and combining each rate with 20, 40 and 60 kg P ha^{-1} reduced NUE while increased PUE of maize in all experimental sites. These findings suggest that as NUE decreased the PUE is increased. This could be related to the increase in N and P imbalances in soils as the rates of N applied increased. Results also indicated an inverse relationship between the higher doses of fertilizer application and benefit cost ratio. Application of 80 kg N ha^{-1} + 20 kg P ha^{-1} and 120kg N ha^{-1} + 20 kg P ha^{-1} produced the highest maize yields equivalent to 4.4 and 4.2 t ha^{-1} with the gross return of 2,112,000/= TSh and 2,020,800/= Tsh ha^{-1} with respect to BCR, respectively. This study further confirmed the role of N and P fertilizers in increasing growth and grain yield in maize production. From these results application of 120kg N ha^{-1} + 20 kg P ha^{-1} may be recommended for increasing maize yields particularly in the study areas. However, application of 80 N ha^{-1} + 20 kg P ha^{-1} can also increase in the yield of maize. This will greatly benefit farmers in Mbozi district where the supply of N fertilizer is low and cases where farmers cannot afford the cost of high fertilizer input. It is also recommended that while there is a wide-scale adoption of blanket fertilizer recommendation there is a need for site-specific nutrient management for balanced fertilization.

DECLARATION

I, Lusungu Liduke, do hereby declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor concurrently submitted for a degree award in any other institution.

Lusungu Liduke Date
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The above declaration is confirmed by;

Prof. P. Mrema Date
(Supervisor)

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(Supervisor)

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DEDICATION

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LIST OF SYMBOLS AND ABREVIATIONS

ADP	Adenosine Di Phosphate
AMP	Adenosine Mono Phosphate
APRE	Apparent Nutrient Recovery Efficiency
ARI	Agricultural Research Institute
ARN	Agronomic Recovery of Nitrogen
ARP	Agronomic Recovery of Phosphorus
ATP	Adenosine Tri Phosphate
AUE	Agronomic Nutrient Use Efficiency
BCR	Benefit Cost Ratio
BNF	Biological Nitrogen Fixation
C:N	Carbon to Nitrogen Ratio
CBA	Cost Benefit Analysis
CEC	Cation Exchange Capacity
cmol/kg	centimol per kilogram
CRBD	Completely Randomized Block Design
CV	Coefficient of Variation
CVR	Cost Value Ratio
DAP	Days After Planting
DM	Dry Matter
DMRT	Duncan Multiple Range Test
EPINAV	Enhancing Pro – poor Innovation in Natural Resources and Agricultural Value Chains
FC	Field Capacity
HI	Harvest Index

IITA	International Institute of Tropical Agriculture
IRR	Internal Rate of Return
LA	Leaf Area
LAI	Leaf Area Index
LISF	Local Indicators of Soil Fertility
MAFC	Ministry of Agriculture, Food Security and Cooperatives
masl	metre above sea level
MVP	Marginal Value Product
NPV	Net Present Value
ns	not significant
NUE	Nutrient Use Efficiency
NUE	Nitrogen Use Efficiency
PPUE	Physiological Phosphorus Use Efficiency
PUE	Phosphorus Use Efficiency
RCBD	Randomized Complete Block Design
SOM	Soil Organic Matter
SSA	Sub Saharan Africa
SUA	Sokoine University of Agriculture
TISF	Technical Indicators of Soil Fertility
TSP	Triple Super Phosphate
USA	United State of America
VC	Variable Cost

CHAPTER ONE

1.0 INTRODUCTION

Maize (*Zea mays* L.) is the main staple cereal crop in Tanzania (Amani, 2004), and serves as food for over 80% of the population of Tanzania (Bisanda and Mwangi, 1996), Tanzania is currently one of the twenty major producers of maize in the word (FAO, 2012), and is among the top three maize producing countries in Sub – Saharan Africa (SSA) after South Africa and Zimbabwe which together account for more than 70% of maize produced in the SSA (Magenya *et al*., 2008). Further, maize is food crop for more than 100 million people (Magenya *et al*., 2008). The average consumption of maize in Tanzania is estimated at 113 kg per person per year and contributes to 60% of the total energy in the diets of Tanzanians (Hugo *et al*., 2002). The maize consumption in Tanzania amounts to 3.0 million tons annually (Katinila *et al*., 1998) while the production level is 2.7 million tons hence a deficit about 0.3million tons, which have to be imported to offset the deficit. Of recent, maize production levels have been fluctuating due to various reasons, including declining soil fertility under continuous maize cultivation and erratic and inadequate rainfall.

In Tanzania maize is grown in all the agro-ecological zones, the Southern Highlands being the major producer and Southern zone being the least producer (Nsami *et al*., 2002). The production levels according to zonation are of the order: Southern Highlands (44.8%), Lake (19.7%), Northern (11.0%), Western (9.7%), Eastern (8.4%), Central (3.8%) and Southern zones (2.6%) (Nsami *et al*., 2002) of the total maize production in Tanzania.

In Tanzania maize is produced mainly under rain fed agriculture over a wide range of altitudes, from near sea level to about 2400m above sea level (Mbwaga *et al*., 2000).

Maize is cultivated on an average of two million hectares which is about 45% of the arable land area in Tanzania (Mbwaga *et al*., 2000). About 85% of the maize in Tanzania is produced by small-scale farmers with minimum utilization of inputs production technologies and practices (Aloyce *et al.,* 1998). Maize production in Tanzania is limited by both abiotic and biotic factors such as low soil fertility, crop pests and diseases, the use of low yielding varieties (Msaky *et al*., 2010). low maize prices immediately after harvesting and high storage costs and losses.

Soil fertility is considered as one of the major limitation in maize production in Tanzania as evidenced by very low maize yields ranging between 0.9 to 1.4 t ha^{-1} compared to the potential of most released varieties of about 4 to 5 t ha^{-1} (FAO, 2002). The fertility status of the soils in many areas in Tanzania has not been assessed and monitored, so the amounts of nutrient supplements needed per ha to replenish the nutrients lost through various processes like uptake by plants are not known leading farmers to rely on their experiences to estimate the amounts of fertilizers to apply, particularly on maize. Only about 0.7% of farmers in Tanzania use an average of 8 kg ha^{-1} of inorganic fertilizers in maize production (MAFC, 2009). Fertilizer recommendations, where utilized, are blanket and have been released over 30 years ago, hence lead to low maize yields culminating into small scale farmers remaining in the vicious circle of food insecurity. Nitrogen (N) and phosphorus (P) are the major limiting plant nutrients in most of the soils under maize cultivation in the Southern Highlands (Bisanda *et al*., 1998). The deficiencies of N and P have been attributed to the mining of nutrients through crops harvest. For instance, a crop of maize that produces 5-6 t ha^{-1} would remove up to 100-150 kg N ha^{-1} and 17-26 kg P ha^{-1} per cropping season from the soil through harvest (Bisanda *et al*., 1998). The deficiencies of N and P in soils have also been attributed to inherent low levels of N and P in the soil parent materials (Masood *et al*., 2011). Losses and transformations of N and P in soils, respectively further affect the levels of plant available N and P. The solution to this problem would be the application of N and P fertilizer as well as other nutrients in crop production, maize inclusive and the adoption of the appropriate agronomic practices.

Therefore, understanding the soil characteristics, amounts and forms of N and P in the soils would assist in the establishment of the amounts of N and P that have to be applied to the soils for enhanced crop growth and hence increase in yields and consequently attainment of food security and increase in farmer's income and subsequently improved livelihoods.

The general objective of this study is to assess the fertility status of the soils with respect to N and P so as to chart out strategies for enhanced and sustainable maize production in Lumbila, Senjele, Mbimba and Ihowa villages of Mbozi district, Tanzania.

The above mentioned general objective was addressed through the following specific objectives:-

i. Evaluation of the fertility status of the soils in the study areas using both local indicators of soil fertility (LISF) and technical indicators of soil fertility (TISF)
ii. Evaluation of the response of maize to N and P on maize yields.
iii. Evaluation of the N and P use efficiencies in the study areas so as to chart out the appropriate N and P fertilizer application strategies, and
iv. Establishment of the benefit cost ratio (BCR) of maize production for the economic sustainability of maize production in Mbozi district.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Origin of Maize

Maize (*Zea mays* L.) or corn as it is called in the USA was first domesticated in Mexico for use as a cereal food crop. The crop was extensively cultivated in Mexico as early as 5000 years ago (Manglesdorf, 1974). With the time maize became the cornerstone of agriculture worldwide and was called the golden crop (Jayne and Jones, 1997). Maize was not known outside the Americas until 16th century when explorers introduced maize seed grain to Europe and Africa (Marvin, 1965). Maize was introduced in Africa from Mexico at the beginning of 16th century by the Portuguese (Bisanda *et al*., 1998). Currently, maize is grown all over Africa particularly the SSA countries (Wambugu and Wafula, 1999).

2.2 Maize as a Staple Food

Maize is the main staple food crop in Tanzania (FAO, 2012) and over 80% of the population of Tanzania depends on maize for food (Bisanda and Mwangi, 1996). It is estimated that the annual per capita consumption of maize in Tanzania is 112.5 kg, translating to about three million tons per year (Msaky *et al*., 2010). It has been reported that maize contributes about 60% of the dietary calories to Tanzanian consumers (Bisanda *et al*., 1998). Maize provides more carbohydrates than wheat and sorghum, and it is a good source of phosphorus and contains small amounts of calcium, iron, thiamine, niacin and fats (Brandes, 1992). Also maize contains appreciable levels of proteins with high levels of the essential amino acids like lysine, isoleucine, methionine and threonine (Adeyemo, 1984).

2.3 Maize Production Systems in Sub-Saharan Africa (SSA)

The cropping systems of maize production in SSA include sole cropping, mixed cropping, intercropping and alley cropping. Mixed cropping is a common practice in most of the small scale farming systems of SSA, including Tanzania inclusive (Dixon *et al* 2001). Crops intercropped with maize include legumes like beans (*Phaseolus vulgaris*), cowpeas (*Vigna unguiculata*) and soybeans (*Glycine max*); root crops such as sweet- potato (*Ipomoea batatas*), Irish potato (*Solanum tuberosum*) and horticultural crops like watermelon (*Citrullus lanatus*) (Tuaeli *et al*., 2003). In Northern Tanzania, the most common practice is maize - beans mixed cropping system. Beans are intercropped or mixed with maize because it is used as a complement in most local dishes. Other reasons for mixed cropping include maximizing land use, spreading economic and climatic risks and improving soil productivity through biological nitrogen fixation and biomass production (Tuaeli *et al*., 2003).

Intercropping of maize and cowpeas (*Vigna unguiculata*) is especially beneficial in soil will low nitrogen content (Vesterager *et al*. 2008). As cowpeas make use of the N in the atmospheric through the process of biological N-fixation (BNF), they do not vigorously compete with maize and other crops for the nitrogen in soils. Intercropping of maize and cowpeas is more economical than maize monocropping when phosphate fertilizers are not applied as compared to applications of 30 or 60 kg P ha^{-1} (Mongi *et al*., 1976). Mongi *et al*. (1976) found alternate row intercropping maize and cowpeas to give 34% more monetary return than monocropped maize, while maize and cowpea planted in the same hills had an increase of 29% in monetary returns. Growing of cowpeas in the maize field provides an important protein source for humans and livestock; improves soil fertility, suppresses weeds and insurance against total crop failure when one crop fails (Mongi *et al*., 1976).

Maize and sweet potato are a common intercropping combination in the semi-arid Rift Valley of East Africa. Using an early maturing variety of maize would increase total yield over several years as compared to a mid-late maturing variety (Amede *et al*., 2001). Sweet potato yield was significantly reduced in dry years due to inability to tuberise. But intercropping did not reduce sweet potato vines production. Sweet potato vines are commonly used as fodder for livestock. Since the vines are not included in the land equivalent ratio calculations, their use significantly increases the benefits of intercropping maize and sweet potato (Amede *et al*., 2001).

Qureshi (1990) reported maize yields of about 6 t ha^{-1} that were realized when mixed with soybean compared to the yields of 5.1t ha^{-1} in pure stand as reported by Akhtar *et al*, (2010). According to Akhtar *et al.* (2010), mixed cropping of a cereal crop with legumes and incorporation of the legume crop residues improved soil fertility attlibuted to the increase in soil organic carbon in addition to other plant nutrients for the subsequent cropping seasons.

2.4 Importance of Maize in Africa

According to Rosegrant *et al.* (2001), demand for maize as a staple food in SSA is projected to increase nearly two-fold by the year 2020. The popularity of maize in Africa has been on the increase to the extent of replacing the traditional crops such as sorghum and millet (Pratt *et al.,* 2003). An estimate of 90% of the maize produced in Africa is consumed as food and accounts for 60% of dietary calories and more than 50% of utilizable proteins to consumers (Katinila *et al*., 1998). Maize serves as a bulk of raw materials for the livestock and many agro-allied industries in the world (Bello *et al*., 2012). According to Pratt *et al.* (2003), per capital maize consumption is the highest in the eastern and southern Africa region with an average of over 100 kg per year in Kenya, Tanzania, Malawi, Zimbabwe and Swaziland giving maize similar position in terms of dietary importance as it is for rice in Asia.

According to Makundi *et al.* (2010), maize in Tanzania is important in improving food security and livelihoods of the resource poor farmers' communities. Maize is a dual purpose crop with high potential of alleviating hunger throughout the country (Gibson, 2005). About 85% of the population in Tanzania depends largely on maize for their food needs and income realization through the sale of the surplus grain. This indicates that any factor that will undermine maize production is a threat to the food security and national economy (Wambugu and Wafula, 1999).

2.5 Maize Production in Tanzania

The maize crop in Africa is produced in diverse environments by resource limited small holder farmers who cultivate /grow self open pollinated seed from one season to the next (Bigirwa *et al*., 2001). Maize in Tanzania is grown almost in all parts of the country, mainly by smallholder farmers contributing to about 85% of the total maize produced (Aloyce *et al.,* 1998). The crop is produced over a wide range of altitudes, from near sea level to about 2400 m above sea level. The crop is produced in almost all ecological zones like Lake, Western, Northern, Southern, Central, Southern highland and Eastern zones. The Southern Highlands alone with land area of about 28% of mainland, Tanzania accounts for more than 50% of total national maize production (Mdadila, 1995). The Ministry of Agriculture/National Bureau of Statistics Report (2003) provided the trends of the maize production in Tanzania for the period 1994 to 2002 which showed that maize production increased rapidly from 1.5 in 1994 to nearly 3 million tons in 1995 and thereafter decreased to about 2 million tons in 1998. The trend then seemed to increase gradually in all years as from 2000 to 2002 as presented in Fig. 1.

Figure 1: Maize Production Trends in Tanzania (1994 - 2002)

Source: Ministry of Agriculture and food security (MAFC)(2009)

2.6 Maize Production Constraints

Currently, maize production is rapidly spreading into marginal areas, where the soils have low fertility status. This situation has expanded the area of cultivation to marginal maize growing areas/lands with consequent increased risks in maize production (Bigirwa *et al*., 2001) with consequent soil/land degradation.

2.7 Soil, Nutrients and Environmental Requirements of Maize

Maize is primarily a warm weather crop hence grown in a wide range of climatic conditions (ICAR, 2006). Maize can successfully be grown in areas receiving an annual rainfall of 600 mm, which should be well distributed throughout its active growing stages. Maize needs more than 50% of its total water requirements in about 30 to 35 days after tasseling and inadequate soil moisture at grain filling stage results in poor yields and shriveled grains. Maize cannot withstand frost at any stage and prolonged cloudy period is harmful for the crop but intermittent sunlight, cloud and rain are the most ideal for its growth (ICAR, 2006). Maize needs bright sunny days for its accelerated photosynthetic activity and rapid growth (Tripathi *et al*., 2011). Soil texture is the foremost important requirement as it controls moisture and nutrient retention capacities of soils. Loamy or silt loamy surface soils and brown silt clay loams with fairly permeable sub-soils are the ideal soil types for maize cultivation (Tuaeli *et al.,* 2003). Although maize grows on a wide range of soils, it does not perform well on soils of low fertility status, except with heavy application of fertilizers (Sanchez *et al.,* 2002) and other soil amendments.

Maize can be grown successfully on soils with pH ranging from 5.0 to 7.0 but a moderately acid soil environment of pH 6.0 – 6.9 is optimum (Zhang *et al*., 2004). Soils with pH below 6.0 or above 6.9 would result in the manifestation of some nutrient deficiency symptoms and mineral toxicities of certain plant nutrients, like for example chlorosis, necrosis and stunted growth (Zhang *et al*., 2004). In strongly and very strongly acid soils (pH < 5), liming is mandatory for optimum maize production (Heisey and Mwangi, 1996). The maize crop has high nutrient requirements and high yielding maize varieties like hybrids have been reported to have high N (310 kg N ha^{-1}), P (40 kg P ha^{-1}) and K (210 kg K ha^{-1}) requirements (Birch *et al*., 2003).

The optimum temperature for the growth and development of maize ranges from 30 to 34°C. The cool conditions at high altitudes lengthen the growth cycle or period. Temperatures below 5 °C and above 45 °C result in poor growth and sometimes death of the maize plants (Rasheed *et al*., 2004). Generally, the temperatures in Tanzania are favorable for maize production as long as the appropriate varieties are grown in areas for which they were bred or adapted (Zhang *et al*., 2004). FAO (2012) reported that maize is an efficient user of water in terms of total dry matter production and among the cereals it is potentially the highest yielding grain crop. For optimal production, maize requires between 500 and 800 mm of rainfall per annum or growing season other climatic variables being optimal.

2.8 Fertilizer Use in Maize Production in SSA

In most parts of the world, chemical fertilizers are used in maintaining or increasing and sustaining soil fertility. However, farmers in SSA use very small amounts of chemical fertilizer as well as organic soil amendments. Kisetu and Mtakimwa, (2013), reported that the average fertilizer application in SSA is 7 kg of fertilizer nutrients per hectare of arable land. It has been reported that the use of inorganic fertilizers is relatively higher in some countries of southern Africa notably Zimbabwe, Zambia, and Malawi where the commercial farming sector is relatively well developed (Heisey and Mwangi, 1996) than the rest of SSA. For example, the fertilizer application rate in Zambia for maize is 70 kg per hectare, 55 kg in Zimbabwe, and 26 kg in Malawi (Heisey and Mwangi, 1996). Nevertheless, these levels are well below the requirements for the maize crops and maintenance of nutrient levels in soils is likely to remain so for a long time (Kisetu and Mtakimwa, 2013).The reasons for the low use of fertilizers in SSA include inadequate knowledge on the nutrient requirement by maize, ignorance on the benefits of using fertilizers in crop production, low crop prices and high costs of the fertilizers.

2.9 Effect of Nitrogen on Maize

Nitrogen (N) is a crucial nutrient element to maize for growth and development (Gallais and Hirel, 2004). Nitrogen is a plant nutrient that is required in larger quantities than others nutrients especially for cereal crops (Amuri, 2003). Many field studies have shown that N is the most important growth-limiting factor because it acts as the motor for maize growth and accounts for 1 to 4 percent of the dry matter of the maize plants (Rasheed *et al*., 2004). Rasheed *et al*. (2004) reported that, N imparts dark-green colour and guarantees optimal chlorophyll synthesis for photosynthetic activity. The dynamics of N in soils is controlled by processes like mineralization, nitrification, denitrification, immobilization, soil erosion, leaching, volatilization and hydrolysis as presented in Fig. 2.

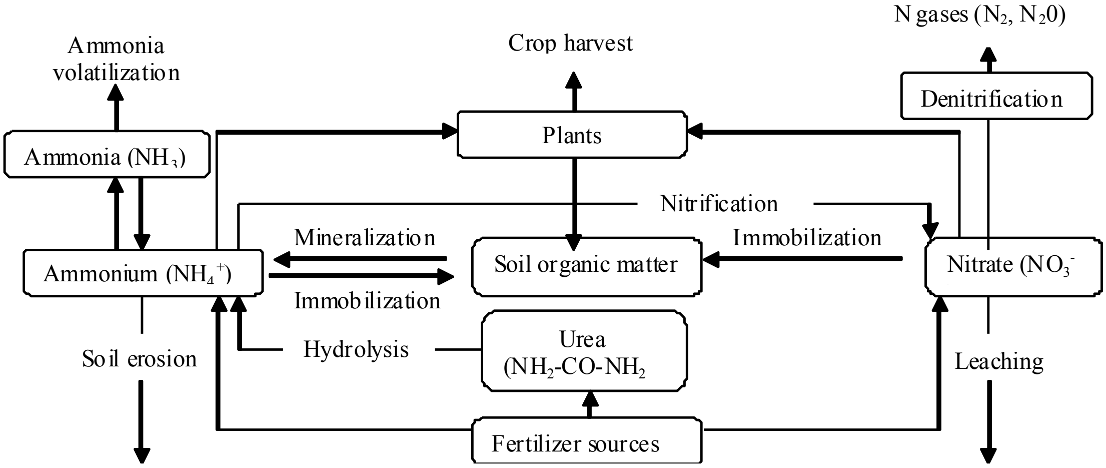


Figure 2: The Dynamics of N in soils

Source; (Hart *et al.,*(1994)

The plant-available soil nitrogen is in the inorganic forms, namely NH_4^+ and NO_3^- forms (Kalumuna, 2005). Nitrogen application is one of the important soil management practices aimed at improving the growth and yields of maize (Hammad *et al.*, 2011). Spatial N availability is largely determined by maize root distribution in the soil. A typical response of maize plants to low levels of available soil N supply is attributed to increased root to shoot ratio resulting from relatively more assimilates translocated from shoots to roots.

The elongation of the maize axial and lateral roots is enhanced at relatively low N supply (Chun *et al.*, 2005a) but lateral root elongation is inhibited if the N supply is extremely low (Chun *et al.*, 2005b). Low N uptake induces N translocation from older to younger leaves and from vegetative to generative organs (Mehrzad *et al.*, 2011). This retranslocation of N results in chlorophyll degradation in older leaves which makes them appear yellow, a typical N deficiency symptom (Guohua *et al*., 2003). However, under field conditions, this may be confused with maize plants which keep a relatively homeostatic N concentration in the leaves by reducing leaf expansion at the seedling stage (Singletary and Below, 1990). It is only at anthesis and kernel-filling stages that a dramatic N retranslocation from vegetative organs to ears occurs and old leaves therefore show typical symptoms of chlorosis (Mehrzad *et al*., 2011). Ear and grain development are severely inhibited by N deficiency (Guohua *et al*., 2003). It has been reported and established that yield reductions at low N stress is largely due to increased kernel abortion and fewer kernels per ear (Guohua *et al*., 2003). It therefore, appears that N metabolism in kernels has a direct effect on the development and productivity of maize. Provision of N to maize plants at the development stage would increase their capacity to synthesize protein and to utilize sugars for the biosynthesis of starch (Singletary and Below, 1990).

2.10 Sources of Nitrogen in Soils

The total N content in soils ranges from very low (<0.1%), low (0.1 – 0.2 %), medium (0.2 - 0.5 %) to high (>0.5 %) (Landon, 1991). Nitrogen is present in soils both in organic and inorganic forms. There is a wide variation in the types of organic compounds that contain N (Landon, 1991). Organic N is contained in the soil organic matter, the major storehouse for many plant nutrients in the soil, and inorganic N is contained in the soil solution and on soil exchange sites (James, 2001). Organic N constitutes between 95 and 99% of soil N and inorganic N constitutes between 1 to 5% (Brady and Weil, 2000). Nitrogen is taken by plants in the inorganic forms mainly as NH_4^+ and NO_3^-. In order for the organic N to be available and taken up by plants, various transformation processes must take place to convert it into inorganic forms, like the mineralization process (Brady and Weil, 2000). During mineralization, complex and large organic molecules containing nitrogen are broken down into simpler and smaller molecules (compounds) and then into NH_4^+. The mineralization process is a two-stage process namely aminization and amonification (James, 2001) as shown below:

$$\begin{array}{c}\text{Complex organic}\\ \text{N compound}\end{array} \xleftarrow{\text{Aminization}} \begin{array}{c}\text{Amino}\\ \text{N}\end{array} \xleftarrow{\text{Ammonification}} \begin{array}{c}\text{Ammonium}\\ \text{N}\end{array} \cdots\cdots\cdots \quad (\text{ i })$$

Mineralization is a process of converting organic N into inorganic form which is available for plant uptake. When organic materials are added to the soil; soil microorganisms decompose the plant residues. Soil microbes convert organic N to ammonium (NH_4^+) and then to nitrate (NO_3^-) compounds, the forms of N that plant roots assimilate (Brady and Weil, 2000).

2.11 Soil Nitrogen Losses

Nitrogen can be lost from the soil in various ways including leaching, denitrification, and nutrient transfer by crop harvest (soil mining) as well as erosion (Brady and Weil, 2000). Nitrogen in the form of NO_3^- may be lost through leaching because of its high mobility especially in soil with low water holding capacity and low anion exchange capacity (Brady and Weil, 2000). Gaseous losses of N in the form of NO, NO_2, N_2O and N_2 range from 0 to 69% of the total N applied, and these losses depend much on soil pH, soil moisture as well as soil temperature status (Bai *et al.*, 2012). Leaching losses vary between cropping systems and crop types depending on root vigour and depth and soil solution percolate down the soil profile. In West Africa, losses ranging from 0.3 to 0.7 kg ha^{-1} were reported under cereal crops and as high as 25 kg ha^{-1} under groundnuts (Pieri, 1995). Leaching is much greater in course textured soils than clay soils. In Sweden and Denmark, leaching of up to 40 kg N ha^{-1}per season was observed in sandy soil (Hansen and Djurhuus, 1997). Studies have shown that erosion losses through sediment transport can account for >95% of N losses. In Minnesota (USA), erosion losses accounting for 50-110 kg N ha^{-1} per year have been reported (Power, 1983). Soil N can also be lost through crop harvests that are not returned to the soil or field.

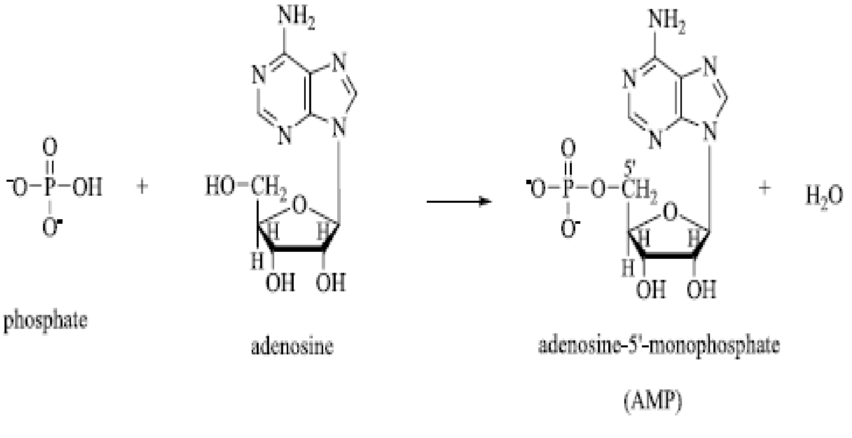
According to Stoovogel *et al*. (1993), the N loss range from 20 to 40 kg N ha^{-1} per year in Tanzania through crop harvests. Due to these losses and the dynamic nature of N in soils, management of this nutrient needs much attention in order to optimize its availability to a growing crop hence its use efficiency.

2.12 Effect of Phosphorus on Maize Yields

Phosphorus is the second most important nutrient required by plants. It is an essential component of nucleic acids, phosphorylated sugars, lipids and proteins, which control all life processes (Mehrzad *et al*., 2011). Mehrzad *et al*. (2011) reported that phosphorus forms high-energy phosphate bonds with adenine, guanine and uridine, which act as carriers of energy for many biological reactions. Phosphate ion reacts with the –OH groups on the sugar residue of a nucleoside to form a phosphate monoester with the consequent formation of a nucleotide. This commonly occurs at the OH attached at the 5′ carbon.

$$\text{Phosphate(s)} + \text{Nucleoside} \longrightarrow \text{Nucleotide} \;\ldots\ldots\ldots\ldots\ldots\ldots\; \text{(ii)}$$

The formation of a nucleotide from a nucleoside and a phosphate is as shown below:



………………… (iii)

So, P is a master key to agriculture because it is directly involved in most of the life processes and is a component of every living cell (Jones, 1982). Low crop production is often associated with the lack of P than to the deficiency of other nutrient elements except nitrogen (Thompson and Troeh, 1993). Phosphorus is required in the breakdown of carbohydrates, mitotic cell division, early root growth and development, hastening maturity and stimulation of fruits and seed production (Eliuth, 2004). It is also essential in a number of enzymatic reactions, transfer of energy for biochemical processes (ATP, ADP and AMP) which supply energy for various reactions and it is a constituent of nucleic acids (Dioxyribonucleic acid and Ribonucleic acid). Furthermore, P is required in the formation of hormones and also is involved in photosynthetic reactions (Pillai, 1964). Phosphorus deficient plants show stunted growth; leaves develop dark-blue characteristic and sometimes-purplish appearance caused by the high mobility of phosphorus within plants, older leaves become chlorotic as compared to younger leaves in instances of P deficiency in soils (Mehrzad *et al*., 2011). Leaf shape may be distorted and also leads to reduction in the number of leaves (Lynch *et al*., 1991) hence low leaf area index (LAI). This reduces the amount of photosynthetically active radiation absorbed by the canopy, leading ultimately to low biomass accumulation (Pellerin *et al.,* 2000). The negative effect of phosphorus deficiency on LAI also adversely affects adventitious root emergence and therefore further exacerbating P uptake (Pellerin *et al.,* 2000). There is no soil that can sustain high yields if it is deficient in P (Tandon, 1987).

2.13 Response of Maize to N and P Containing Fertilizers

Decline in soil fertility is considered as a major limiting factor to achieving household food sufficiency in the majority of smallholder farming systems in SSA (Okalebo *et al*., 2007). Declining maize productivity is partly attributed to low plant populations, higher incidences of pest and disease pathogens, weed infestations which are correlated to a number of soil related bio-physical limitations (Jama *et al*., 1997). Continental, district (Smaling *et al*., 1997) and farm (Shepherd *et al*., 1996) scale studies showed widespread deterioration in soil chemical, biological and physical properties in most smallholder cropping environments. These studies further revealed negative nutrient balances such as N > 46 kg ha^{-1} and P > 3 kg ha^{-1} in most countries in SSA, with average N mining in some parts of western Kenya estimated at up to 112 kg N ha^{-1} (Bekunda *et al*., 1997).

Despite numerous studies that gave positive maize crop yield responses to mineral N and P containing fertilizer additions, fertilizer costs versus revenue from maize sales prohibit their use in smallholder cropping systems which are largely subsistence (Odendo *et al*., 2007). However, integration of modest amounts of inorganic fertilizers with organic amendments such as manures or nutrient rich legume residues, offers a strategy to meet smallholder maize crop nutrient requirements (Jama *et al*., 1997).

2.14 Factors that Determine Maize Response to N Fertilizers

The uptake of N per day per kg of maize plant biomass is at maximum when the plant is young and gradually declines with age. Therefore, N constitutes a significant percentage of the dry weight in younger than in older plants (Thompson and Troeh, 1993). Carefulness, on the correct amount of N to be applied, timing and placement of each gram of nitrogen used by maize per year should be kept in mind to overcome losses through leaching and immobilization.

2.14.1 Time of application of N

Response to fertilizer N by maize is affected by time of application in relation to the stage of plant growth and form of fertilizer applied (Rasheed *at el*., 2004). Maximum N use efficiency by maize is attained during the vegetative phase to grain filling stage, as this stage permit maximum utilization of fertilizer N (Tisdale *et al.,* 1993). On soils with high potential for N loss (leaching or denitrification), application close to optimum crop uptake is important to minimize losses and to increase the crop response to fertilizer N (Tisdale *et al.,* 1993). Early applications, especially for fertilizers containing the nitrate form of fertilizer should be avoided so as to minimize losses through leaching (Tisdale *et al.,* 1993). To reduce losses due to denitrification and leaching, N fertilizers should be applied to a maize crop at the time of active vegetative growth.

2.14.2 Method of application

Broadcasting and banding are the most common methods used by farmers when applying N fertilizers. Effectiveness of the method varies with cropping system and the forms in which fertilizer N is applied (Patrick, 2006). In banding, N fertilizers are placed 5 – 8 cm away from the maize plant to avoid plant injury and fertilizer losses especially for ammonium and nitrate fertilizers which are susceptible to leaching and denitrification (Tisdale *et al.,* 1993). Banding method is used for wide spaced grown crops like maize so as to make it easily available for crop uptake (Tisdale *et al.,* 1993). Broadcasting method refers to spreading the fertilizers uniformly all over the field and most appropriate for the close spaced crops, like rice and sorghum. With broadcasting the plants permeate the whole volume of the soil. However large doses of fertilizers are to be applied.

2.15 Factors that Determine Maize Response to Phosphate Fertilizers

Although the dissolution of P fertilizer in soil is a prerequisite for plant uptake, dissolution alone should not be used as an indicator of P availability to plants because a number of soil factors are involved in the uptake of P (Eliuth, 2004). Soil type, soil pH, type and amount of clay minerals, hydrous oxides of Al and Fe, temperature and exchangeable Ca and $CaCO_3$ influence the availability of the added P to the maize crop (Eliuth, 2004). Also, the rate of plant uptake of P is partly dependent on the availability of N (Akram *et al*., 2007). It has been found that small amounts of N included in P fertilizers make it more effective due to synergist effect, thus suggesting the importance of balanced fertilization of these two elements in maize nutrition (Thompson and Troeh, 1993). Organic P becomes available after mineralization, a process mediated by microorganism like *Bacillus* and *Streptomyces* species.

Microorganisms can enhance the capacity of plants to acquire P from soil through various mechanisms namely: (1) increased root growth through either an extension of existing root systems (e.g. mycorrhizal associations or by hormonal stimulation of root growth, branching, or root hair development (phytostimulation: e.g. production of indole-3-acetic acid, GAs, or enzymes that alter plant ethylene precursors, such as 1-aminocyclopropane-1-carboxylate deaminase (Richardson *et al*., 2009; Hayat *et al*., 2010)); (2) alteration of sorption equilibria that may result in increased net transfer of orthophosphate ions into soil solution or facilitate the mobility of organic P either directly or indirectly through microbial turnover (Seeling and Zasoski, 1993); and (3) through induction of metabolic processes that induce/enhance the solubilizing and mineralizing P from sparingly available forms of soil inorganic and organic P (Figure 3) (Richardson *et al*., 2009). This includes the efflux of protons and organic anions, production of siderophores and release of phosphatase and cellulolytic enzymes required for the hydrolysis of organic P or mineralization of organic residues and organic matter, respectively (Ryan *et al.*, 2001). Organic anions and protons are particularly effective in solubilizing precipitated forms of P (e.g. Ca-phosphates under alkaline conditions), and chelating metal ions that are commonly associated with complexed forms of soil P (as it is for the role of siderophores in mediating Fe availability), or by facilitating the release of adsorbed orthophosphate or organic P through ligand-exchange reactions (Ryan *et al.*, 2001).

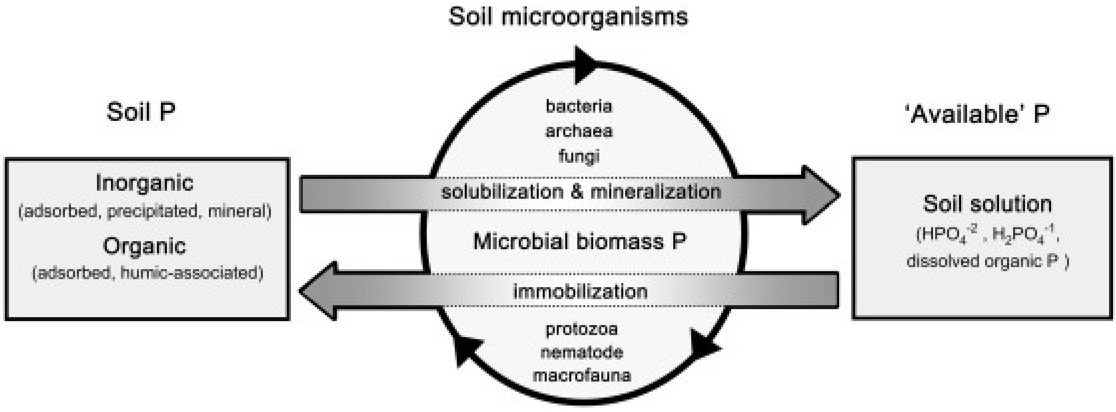


Figure 3: Dynamics of Organic and Inorganic P Forms in the Soil Ecosystem. Source: (Richardson *et al.*, 2009)

Plant P uptake is largely governed by three factors namely the type of plant, the stage of growth and competition between the plant roots and soil components for soil and fertilizer P (Jones, 1982). Root development of such crops usually allow adequate uptake of soil P for later growth of the maize crop. Maize is quite efficient in the utilization of P compared with small grains (Jones, 1982).

2.16 Nitrogen and Phosphorus Use Efficiency

Gallais and Hirel (2004) defined nutrient use efficiency (NUE) as the grain yield or biomass per unit of available nutrient in the soil including the residual mineral nutrients present in the soil and those provided by fertilization. The NUE can be expressed as:

$$\text{NUE (\%)} = \frac{\text{Nutrients uptake in treated unit} - \text{Nutrient uptake in control}}{\text{Amount of nutrients applied}} \times 100 \quad \ldots.\text{(iv)}$$

The NUE entails two components namely: uptake efficiency, that is, the ability of plants to take up a given mineral nutrient from the soil and utilization efficiency, that is, the ability of plants to use the mineral nutrient to produce biomass and grains (seeds) (Gallais and Hirel, 2004).

NUE is also becoming much more important in the market oriented /based economy of agricultural products, thus moving away from the traditional and rather static “soil dependent” agriculture to dynamic “fertilizer dependent” agriculture (BARC, 2005). Currently, fertilizers are very costly and scarce inputs to the agricultural system. The crop production system with high yield target cannot be sustained unless nutrient inputs to soils like fertilizers and manures and other soil amendments are at least balanced against nutrient removed by crops from the soil ecosystem (Rijpma and Jahiruddin, 2004).

Excessive applications of N fertilizers in intensive agricultural systems is causing serious environmental problems such as nitrate leaching and nitrous oxide emissions, in areas with high rainfall during the maize growing seasons (Fan *et al.,* 2010). Improving N and P fertilizers application techniques (like side dressing for N and banding for P) can greatly increase N and P use efficiency. Developing N and P use efficient cultivars provides an alternative strategy for increased and sustainable maize production. Knowledge on the physiology and genetics of N and P uptake and utilization is crucial to the development of an N and P efficient cultivar. The response of maize plants to N and P stress and the possible physiological and genetic mechanisms determine N and P use efficiency. The NUE therefore tends to increase with decreasing N and P fertilizer input (Moll *et al*., 1982).

2.17 Cost -Benefit Analysis (CBA)

Cost benefit analysis (CBA) systematically analyses the economic justification of a potential investment decision. It involves identifying, measuring and placing monetary value on inputs and outputs of a particular production system/enterprise and then comparing these costs and benefit as an aid for decision-making (Gittinger, 2001). The CBA is also addresses the identification, quantification and valuation of information about benefits and costs in order to determine the worthiness of an enterprise (Gittinger, 2001).

The CBA has a great potential as a tool for analyzing agricultural enterprises or ventures. Its advantages include its wide acceptability, use of a common unit of currency (money) and the potential to quantify and compare a broad range of factors that is inputs and outputs (Senkondo, 1992). The CBA, however, has its shortcomings and in particular in accommodating social and environmental tangible issues and its assumption that a favourable income distribution does exists (Senkondo, 1992).

The CBA discount can also be used to measure Benefit Cost Ratio (BCR), Net Present Value (NPV) and Internal Rate of Return (IRR). These are the principal measures of project worthness. However, important consideration in this analysis will involve only the identification of costs and benefits (Gittinger, 2001).

2.18 Benefit - Cost Ratio

Benefit- Cost ratio (B/C) is the ratio of project benefit (over control) to added project cost (over control) according to Rahman *et al.,* (2011). The ratio is one of the most popular criteria used in project appraisal and evaluation especially for economic analysis. Benefits and costs are counted at the time they are earned or spent and the cash flow is extended over a period of several years. Usually the number of years is assumed to be the useful economic life of the proposed project. Since project life extends over several years, the cash flow must be discounted to compansate for the time value of money. The desicion rule in the benefit-cost analysis is to accept all projects with benefit- cost ratios greater than one when discounted at the selected opportunity costs of capital (Kay, 1981). It is useful to think of partial budgeting as a type of marginal analysis as it is best adapted to analyzing relatively small changes in the whole farm plan (Kay, 1981). To compare different treatments combination with one control treatment the following equation should be adopted;

$$\text{BCR (over control)} = \frac{\text{Gross return (Ti) - Gross return (T0)}}{\text{VC (Ti) – VC (T0)}} \quad \text{or} \ldots\ldots\ldots\ldots\ldots\ldots \text{(v)}$$

$$= \frac{\text{Added benefit (over control)}}{\text{Added cost (over control)}}$$

Where, Ti = T1 ------- T16 = Treatment combinations

T0 = Control treatment.

VC= Variable cost.

Gross return = Yield x price

The BCR expresses the benefit generated per unit of cost and it is interpreted as follow:

i. BCR > 1: present value of benefits exceeds the present value of costs
ii. BCR = 1: present value of benefits equals present value of costs
iii. BCR < 1 the present value of costs exceeds the present value of benefits

Therefore, projects with a BCR of 1 or greater are economically viable when the costs and benefit streams are discounted at the opportunity cost of the capital (Kay, 1981). The absolute value of the BCR varies depending on the discount rate chosen; the higher the discount rate, the smaller the BCR.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1 Location and Description of the Study Area

The study was conducted in Mbozi district at Lumbila (08.97756° S and 33.10844° E at 1584 masl), Senjele (08.96982° S and 33.15833° E at 1543 masl), Mbimba (09.04636° S and 32.95720° E at 1692 masl) and Ihowa (09.05823° S and 33.1174° E at 1712masl) villages. The study area has temperatures ranging from 15^{o}C to 25^{o}C and rainfall ranging from 600 to 2500 mm per annum. The villages receive a unimodal rainfall pattern with a growing season of 8 months, as from November to June. Maize production in the study area is normally rain-fed.

3.2 Evaluation of the Fertility Status of the Soils in the Study Areas

Composite soil samples from the field experimental sites were sampled at 0 - 30 cm depth by using soil auger 2 month before planting. Soil samples were obtained randomly in the experimental field using the method described by Kimaro (2009) and each composite soil samples was prepared from 20 point samples from each site. The area of each field was 1296 m^2. The composite samples were packed, labeled and taken to the Department of Soil Science Laboratory at SUA for physical and chemical analysis. Soil samples were air-dried, ground, sieved through 2 mm sieve and analyzed for particle size distribution, pH, total Nitrogen (N), available P, plant available Sulphur, Cation Exchange Capacity (CEC), Exchangeable Bases (Ca, Mg, K and Na), extractable micronutrients and Organic Carbon using the analytical methods as outlined in Table 1.

Table 1: Methods Used in Chemical and Physical Analysis of the Composite Soil Samples

PARAMETER	METHOD OF ANALYSIS	REFERENCES
Soil texture	Bouyocous hydrometer.	Gee and Bauder (1986)
pH	Electrometrically in 1:2.5, soil: 0.01M $CaCl_2$ suspensions.	Thomas (1996)
Organic Carbon	Wet oxidation by Black Walkley method.	Nelson and Sommers (1982)
Total Nitrogen	Micro Kjedahl method.	Bremner (1996).
Available Phosphorus	Bray 1 method.	Olsen and Somners (1982)
CEC	Saturation with buffered neutral 1M NH_4-Ac solution (CH_3COONH_4)	Rhodes (1982)
Exchangeable Bases (K^+, Mg^{2+}, Ca^{2+} and Na^+)	NH_4^+ displacement method and quantified by AAS.	Lindsay and Norvel (1978)
Extractable micronutrients (Fe, Cu, Zn and Mn)	DTPA extraction and quantified by AAS.	Lindsay and Norvel (1978)
Sulphate sulphur	Turbidimetric method	Okalebo (2002)

3.3 The Field Experiment

3.3.1 Land Preparation

Land ploughing and harrowing activities were done during the third week of December 2012. The condition was dry enough to hinder sprouting of many weeds prior to planting and for proper pulverization of the soil to get the seed bed fine enough for the establishment of maize crop.

The experimental design used was 4^2 factorial in a Randomized Complete Block Design (RCBD), with three (3) replications at each village and the gross plot areas were 4 m x 4 m. N and P were applied at 0, 40, 80,120 and 0, 20, 40 and 60 $kgha^{-1}$ respectively. N was applied as urea $CO(NH_2)_2$ and P as TSP. A total of 48 treatment plots per experimental site were used for the experiment with 1.0 m path between plots. Two seeds of maize variety UH 615 were sown at a depth of 3-5cm per stand and thinned to one seedling per stand 14 DAP. Plant spacing used was 75 cm between rows and 30 cm between plants giving a population of 71 plants per treatment plot equivalents to 44444 plants ha^{-1}.

3.3.2 Planting

Planting was done on 22nd, 23rd and 24th December 2012 at Ihowa, Lumbila and Mbimba sites, respectively and on 9th January 2013 at Senjele site. Two seeds were planted per hole, and thinned to one seedling seven days after emergence.

3.3.3 Fertilizer application

Nitrogen fertilizer (Urea) ($CO\ (NH_2)_2$) was applied in three splits: one third of each level of N rates and all the P as TSP were banded at planting. First dose of N was applied at planting and the second application of Urea was carried out immediately after the first weeding that is 33 days after planting (DAP) and the third application of Urea was done 62 DAP. The split application was done for effective utilization of N by plants to avoid excessive leaching.

3.3.4 Weed control

The land in Mbozi district is highly infested with different weeds like *Rhamphicarpa fistulosa, Oryza longistaminata, Cynodon dactylon* and *Striga asiatica* which grow vigorously and distributed by grazing animals such as cattle and goats which feed on crop residues. For this reason, two weeding operations were inevitably necessary. First weeding was 21 DAP and the second at ninth week after germination. All other agronomic practices were strictly adhered to as described by Kanyeka *et al*. (2007).

Maize stalk borers (*Buseola fusca* L.) were the major pests affecting the maize crop in this study as shown in (Fig. 4). Insecticide (*Thiodan*) was applied at the rate of 1 L ha^{-1} to control insect pests. Generally, the performance of maize crop was improved after the use of the insecticide (Fig. 5).

Figure 4a Figure 4b

Figure 4: Maize Crop Leaves Affected by Stalk borers

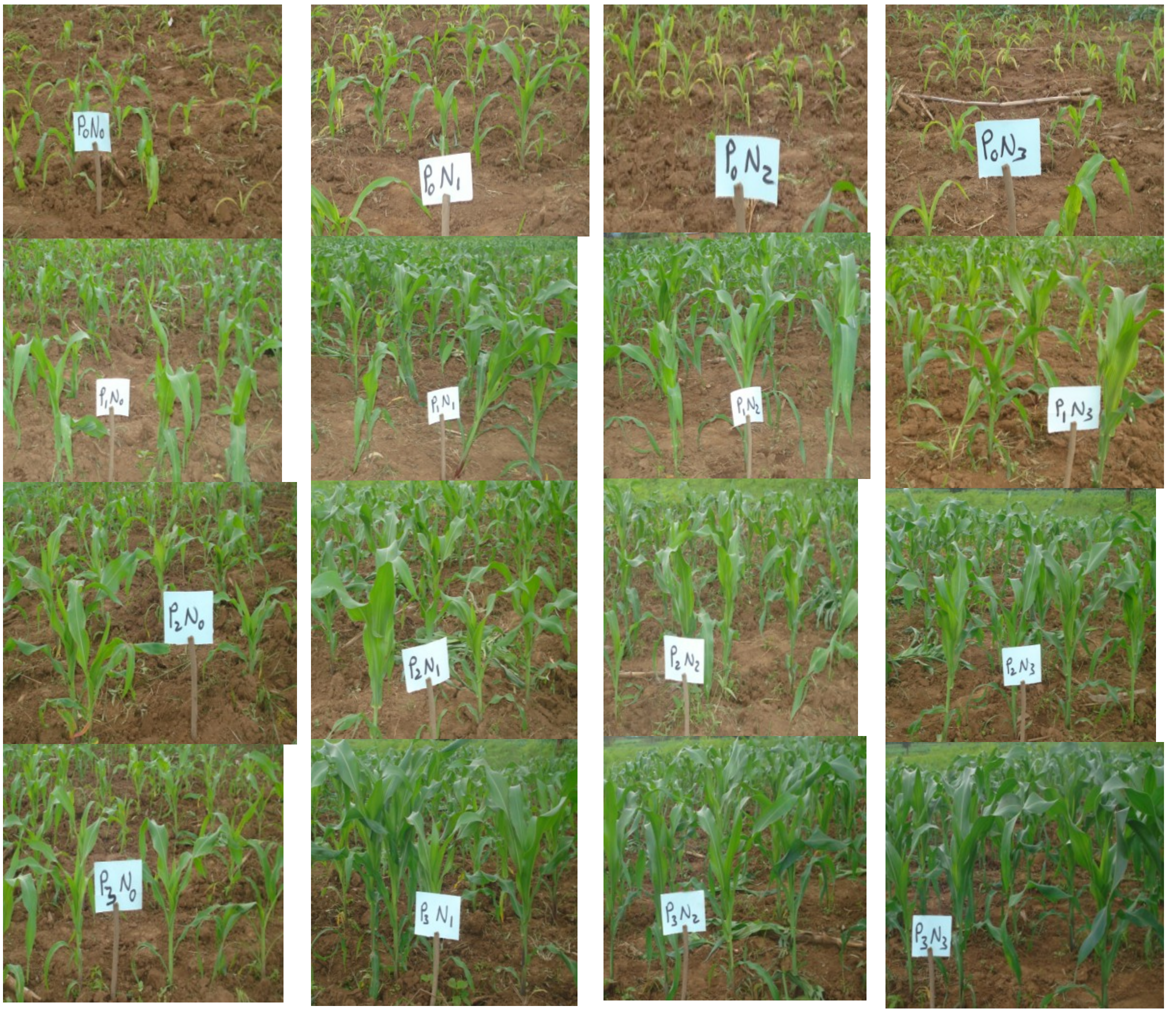


Figure 5: General Maize Performances Four Weeks after Planting

3.4 Sampling and Analysis of Plant Materials

Before tasselling that is at 76 DAP, 5 ear-leaves from inner rows per plot were randomly sampled and air-dried then oven-dried at 65° C to constant weights. The samples were then cut to small pieces and ground to pass through 0.5 mm sieve. Nitrogen contents in the maize plants leaves were determined by the micro – Kjeldahl digestion and distillation method (Bremner, 1996). Phosphorus contents in the maize leaves were determined by wet digestion with H_2SO_4 - H_2O_2, Phosphorus content from H_2SO_4 - H_2O_2 digests were quantified by calorimetric method.

3.5 Data Collection

3.5.1 Plant height

The heights of 10 randomly selected maize plants were measured from the ground level to the tip of the terminal leaf by using a tape measure when all the plants had tasseled (Fig. 6).

Figure 6a **Figure 6b**

Figure 6: Plant Height Measured at Tasselling Stage

3.5.2 Grain Yield

Maize yield were determined by harvesting and threshing maize after attaining maximum maturity. Ten maize cobs were harvested, sun-dried, threshed manually and grain yield were recorded. Maize grain yield were obtained at moisture content of 12% which were then converted into t ha^{-1} by using the following formula:

$$\text{Grain yield (t ha}^{-1}\text{)} = \frac{\text{Plot yield (kg) x } 10000 \text{ m}^2}{\text{Plot size (m}^2\text{) x } 1000 \text{ kg}} \quad \text{…….. ………………..(vi)}$$

3.5.3 Harvest Index (%)

Maize yield was determined by harvesting and threshing maize after attaining maximum maturity. The weights of total dry biomass and grain were determined by a spring balance and yield expressed in t ha^{-1}. The harvest index (HI) of the maize was then computed as the ratio of the maize grain yield to the biological yield as described by Asghar *et al.* (2010) and Kisetu and Mtakimwa. (2013) as expressed below:

$$\text{Harvest index (\%)} = \frac{\text{Maize grain yield (kg ha}^{-1}\text{)}}{\text{Biological yield (kg ha}^{-1}\text{)}}\text{x}100 \ldots\ldots\ldots\ldots\ldots\ldots\ldots \;\ldots\ldots\ldots\text{(vii)}$$

3.5.4 Nutrients N and P Use Efficiencies and their Recovery

Nutrient use efficiencies involved agronomic and physiological factors. Agronomic fertilizer use efficiency (FUE) is defined as the increase in yield of the harvested portion of the crop per unit of fertilizer applied or it is the grain to nutrient ratio. The beneficial effects pertaining to solely and combined use of urea and TSP on maize growth N and P uptakes were assessed accordingly. The apparent nutrient recovery (a proxy for nutrients N and P capture efficiency) from urea and TSP fertilizers was calculated by comparing nutrient uptake by maize between fertilized and the absolute control plots. Lija *et al.* (2014) regarded nutrient recovery as the fertilizer nutrient use efficiency (NUE), which is the ratio of the difference of the total nutrient uptake of fertilized plants and the total nutrient uptake of unfertilized plants (control plots), to the rate/amount of fertilizer nutrient applied. The apparent recovery of N and P in N alone, P alone and in NP treatments was calculated as described by Tittonell *et al.* (2008), Mujeeb *et al.* (2008) and Mengel and Kirkby. (2001) as follows:

$$\text{AR (N or P)(\%)} = \frac{\text{N or P uptake(F)} - \text{P or N uptake (C)}}{\text{Rate of N or P applied}}\text{x}100\ldots\ldots\ldots\ldots\ldots\ldots\ldots,,,,,,,,,,,,,,,,,,,,,,.\text{(viii)}$$

$$\text{PUE (N or P)(kg/kg)} = \frac{\text{Yield(F)} - \text{Yield (C)}}{\text{N or P uptake(F)} - \text{N or P uptake (C)}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(ix)}$$

$$\text{AUE (N or P)(kg/kg)} = \frac{\text{Yield(F)} - \text{Yield (C)}}{\text{Rateof N or P applied}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(x)}$$

Where F = Fertilizer applied, C = Control (without fertilizer), N = Fertilizer N, P = Fertilizer P, PUE = Physiological Use Efficiency, AR = Agronomic Recovery and AUE = Agronomic Use Efficiency.

3.6 Statistical Data Analysis

Data obtained from section 3.4 were subjected to statistical analysis based on the statistical model as described by Snedecor and Cochran (1989) where:

$$\mathbf{X_{ij} = \mu + T_i + B_j + e_{ij}} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\textbf{(xi)}$$

Where: μ= Overall mean,

T_i= treatment effect for the treatment i= 1, 2, 3……..t,

B_j= block effect for blocks j=1, 2, 3……..b,

e_{ij} = random error peculiar to each observation in i^{th} treatment and j^{th} block

The Genstat statistical computer package was used. Where significance existed, the New Duncan's Multiple Range Test (NDMRT) was used to separate the means at 5% level of significance.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Soil Fertility Evaluation

4.1.1 Some of the physical and chemical properties of soils

The soil separates, clay, silt and sand percentages ranged from 33 to 53%, 16 to 26% and 31 to 46%, respectively (Table 2). The textural classes of the soils ranged from clay loam to sand clay loam and clay (Table 2). Based on the textural classes of the soils, the soils would have good moisture retention capacities.

4.1.2 Soil pH

The soil pH values ranged from 5.29 to 6.29 (Table 2). Based on the categorization by Landon (1991), the soils are moderately acid in reaction. The optimal soil pH range for maize production is between 6 and 7 but also obtained in soil with pH values between 5.1 and 5.5 (Timbula, 2003). However, if proper management practices like supplementing fertilizers containing P and addition of organic materials can support maize production.

4.2.2 Organic Carbon

The organic carbon (OC) contents in soils ranged from 1.26 to 1.8% (Table 2) and categorized as very low (<1.5%) for Mbimba and Ihowa soils while it ranged from 1.5 to 4.5% and categorized as medium (Landon, 1991) for sites in Senjele and Lumbila villages. The low levels of OC in Mbimba and Ihowa soils is a reflection of low soil organic matter (O.M) that migtht be attributed by high rate of decomposition, mineralization and oxidation of organic residues (Landon, 1991).

Table 2: The Physical and Chemical Properties of the Soils at the Experimental Sites

	Sampled areas			
Parameter	**Ihowa**	**Lumbila**	**Mbimba**	**Senjele**
Particle size distribution (%)				
Clay	46	33	53	38
Silt	20	26	16	16
Sand	34	41	31	46
Textural class	Clay	Clay loam	Clay	Sandy clay
pH (1:2.5; soil : 0.01M $CaCl_2$ suspension)	5.96	5.91	5.29	6.29
Organic Carbon (%)	1.26	1.52	1.26	1.8
Soil Organic Matter (%)	2.17	2.62	2.17	3.10
Total Nitrogen (%)	0.12	0.11	0.13	0.11
Available P (mg kg^{-1})	0.68	1.0	0.60	1.27
CEC (cmol (+) kg^{-1})	21.5	15.5	23.2	19
Sulphate sulphur (mg kg^{-1})	10.55	12.18	16.05	9.73
Exchangeable Bases (cmol (+) kg^{-1})				
Ca	3.53	4.34	4.23	5.47
K	1.08	0.57	1.09	0.77
Mg	2.09	2.14	1.02	2.07
Na	0.17	0.46	0.12	0.17
PBS (%)	31.95	44.32	29.61	36.16
DTPA extractable micronutrients (mg kg^{-1})				
Fe	75.88	48.26	52.24	68.98
Cu	0.43	0.26	0.43	2.87
Zn	3.21	1.82	2.22	1.87
Mn	107.26	48.66	89.32	131.32

The low organic matter in the soils would likely affect their physical, chemical and biological properties. Physically, Organic Matter promotes aggregate stability and therefore water infiltration, percolation and retention. Its impacts on soil chemistry are by increasing Cation Exchange Capacity (CEC), soil buffer capacity and nutrient supply. Biologically, it stimulates the activity and diversity of microorganisms in soil. In order to increase the Organic Carbon contents of these soils for optimal crop production, application of organic soil amendments, like farmyard manure, compost, green manure and industrial wastes like waste tea, waste tobacco and incoporation of the crop residues to the soils need to be promoted.

4.2.3 Total Nitrogen

The total Nitrogen contents ranged from 0.11 to 0.13 % (Table 2). Based on the rating by Landon (1991), Mbimba, Ihowa Senjele and Lumbila soils had low total N. The low Nitrogen content could be attributed to the low organic matter content following higher rates of Organic Matter transformation in the respective soils. The transformation processes include, decomposition, mineralization and oxidation of the organic compounds, which normally takes place in tropical soils, at high rates because of the high temperatures and humidity, hence higher microbial activities (Timbula, 2003). The low level of N therefore can be hardly to support plant growth and development. Application of N fertilizers to these soils (organic/inorganic) for increased crop production is inevitable.

4.2.4 Phosphorus

The plant extractable P (Bray-1 P) for the soils ranged from 0.595 to 1.265 mg kg^{-1} soil (Table 2). According to Landon (1991), P less than 6 mg kg^{-1} is rated as very low. The very low available P was confirmed by P deficiency symptoms in the old leaves of the maize plants at their young stages of growth at the experimental sites in the absolute control plots (Fig. 7). The low levels of P in the soils could probably be due to low levels of P in the parent materials of the soils and conversion of soil P into forms not easily extractable by the Bray-1 reagents (Eliuth, 2004). Furthermore, P is deficient in most agricultural soils under subsistence and smallholder farming systems due to continuous uptake of the P by plants and lack or low rates application of P containing fertilizers (Kisetu and Honde, 2014). It could also be argued that the low contents of P might be one of the limiting factors for high maize production in the study areas. The need for P fertilization to increase and sustain maize production in the study areas is thus mandatory.

Figure 7a Figure 7b

Figure 7: Maize Crop Leaves Affected by P Deficiencies

4.2.5 Cation Exchange Capacity

The cation exchange capacities ranged from 15.5 to 23.2 cmol (+) kg^{-1} soil (Table 2). Based on Landon (1991) categolization all soils had medium Cation Exchange Capacities (CEC). Cation Exchange Capacity is the extent at which the soil can hold the positively charged ions in exchangeable forms. These cations are held on the negatively charged surfaces of the clay and organic matter particles in the soil through electrostatic forces.

4.2.6 Exchangeable Bases

4.2.6.1 Calcium

The exchangeable calcium varied from 3.53 to 5.47 cmol (+) kg^{-1} soil (Table 2). Based on the categorization by Landon (1991), the soil of Ihowa had low exchangeable Ca (3.53 cmol (+) kg^{-1} soil) while Senjele, Lumbila and Mbimba soils had medium exchangeable Ca ranged from 4.23 to 5.47 cmol (+) kg^{-1} soil.

4.2.6.2 Magnesium

The exchangeable Mg ranged from 1.09 to 2.09 cmol (+) kg^{-1} soil and it was in the order of Ihowa, Lumbila, Mbimba and Senjele, respectively (Table 2). Inferring to the categorization compiled by Landon (1991), exchangeable Mg levels in the study soils were high (> 1.09 cmol (+) kg^{-1} soil) suggesting that Mg is not one of the nutrients contributing to the low yields of maize in the study areas. However, nutrients imbalances might be contributing to the variations in the levels of the nutrient elements in the soils of the study areas.

4.2.6.3 Potassium

Potassium levels in the soils at the experimental sites ranged from 0.57 to 1.09 cmol (+) kg^{-1} soil (Table 2). Landon (1991) ranked Potassium levels in soils as <0.03 – 0.2; 0.2-0.4 and > 0.4 – 0.8 Cmol(+)kg^{-1}, low, medium and high, respectively. Based on this categorization by Landon (1991) all soils had high exchangeable K. Therefore K is not one of the nutrients contributing to the low yields of maize in the study areas.

4.2.6.4 Sodium

Sodium levels in the soils ranged from 0.17 to 0.46 cmol (+) kg^{-1} soil (Table 2). All soils had low levels of exchangeable Na (<1.0 cmol (+) kg^{-1} soil) based on the rating by Landon (1991).

4.2.7 Zinc

The DTPA extractable Zn ranged from 1.82 to 3.21 mg kg^{-1}(Table 2), which was low to adequate (Tisdale *et al.,* 1985). The soils at the experimental sites had low amounts of extractable Zn, which might be attributed to the nature of the parent materials and the low solubility of Zn minerals or Zinc containing minerals in the moderately acid soils. Landon (1991) reported that the level of Zn under acidic conditions could attain high values or reaching the toxic level. The soil analysis results showed that the levels of Zn were all below the toxic levels. This could be attributed to low level of micronutrients in the parent materials hence low amounts released to the soil solution.

4.2.8 Copper

The amounts of DTPA extractable Cu ranged from 0.26 to 2.87 mg kg^{-1} (Table 2), which were high (> 0.26) (Landon, 1991). These levels of Cu might have been influenced by low soil pH. The solubility of Cu in soils decreases slowly with increasing soil pH. High levels of Cu can also induce deficiency of Fe and Zn, conversely, high levels of Fe and Zn have been found to induce Cu deficiencies (Landon, 1991).

4.2.9 Iron

Iron levels in the soils of the study areas ranged from 48.26 to 75.88 mg kg^{-1} (Table 2). According to Tisdale *et al.* (1985), these Fe levels could be categorized as high above the critical level of 0.6 mg kg^{-1}. However, the availability of Fe to plants is influenced mainly by the soil pH and the redox equilibria (potential) between Fe^{2+} and Fe^{3+} compounds whose solubility decreases with increasing pH. Deficiencies of Fe are mostly encountered in calcareous soils and in soils following heavy application of lime, where Fe is precipitated as insoluble ferric oxides (Landon, 1991).

4.3 Response of maize to N and P

4.3.1 Dry matter yields

The response of maize to N and P applications to the Ihowa, Lumbila, Mbimba and Senjele soils are presented in Table 3. There was very highly significant ($P< 0.001$) increase in dry matter yield due to the application of N and P compared with the dry matter yield obtained from the absolute control. The maize from the control plots gave the lowest dry matter yield. An application of N and P containing fertilizers in combination gave relatively higher responses than an application of each nutrient singly. Application of 120 kg N ha^{-1} and 60 kg P ha^{-1} resulted to the highest dry matter yields of 7.7 and 9.38 t ha^{-1} at Ihowa and Senjele sites, respectively and the highest dry matter yields of 8.7 and 7.3 t ha^{-1} were obtained at Lumbila and Mbimba sites at rate of 120 kg N ha^{-1} and 20 kg P ha^{-1} respectively.

The significant response of maize to the application of N and P indicates that these nutrients were deficient in the soils of the study areas. The low dry matter yields obtained in the control plots (Table 3) reflects the inability of the study soils to supply adequate amounts of N and P, hence the low fertility status of these soils. The low dry matter yields and high responses of N and P applications also support the low levels of total N and available P in the study areas (Tables 2 and 3). Therefore, the yield responses obtained by an application of N and P to Ihowa, Lumbila, Mbimba and Senjele soils are consistent with the low levels of the N and P in the soils.

Table 3: Dry Matter (tons/ha) as Influenced by Different Levels of P and N

	Dry matter (tons/ha)			
Treatment	**Ihowa**	**Lumbila**	**Mbimba**	**Senjele**
Control	2.893 a	3.822 ab	2.963 ab	3.36 a
P_0N_{40}	3.71 ab	4.756 abc	3.793 abc	4.31 ab
P_0N_{80}	4.573 abc	6.044 cde	4.385 abcd	5.53 bcd
P_0N_{120}	4.573 abc	6.667 cde	4.741 bcd	5.58 bcd
$P_{20}N_0$	3.943 ab	5.956 cde	2.548 a	5.71 bcd
$P_{20}N_{40}$	4.877 bc	6.089 cde	4.267 abcd	6.21 cdef
$P_{20}N_{80}$	6.09 cd	7.289 def	5.63 cde	6.62 def
$P_{20}N_{120}$	7.21 d	8.711 f	7.348 e	8.39 gh
$P_{40}N_0$	3.803 ab	3.644 a	3.437 ab	4.76 abc
$P_{40}N_{40}$	4.923 bc	4.667 abc	4.741 bcd	5.94 bcde
$P_{40}N_{80}$	6.02 cd	5.689 bcd	4.978 bcd	6.98 defg
$P_{40}N_{120}$	6.79 d	6.356 cde	5.985 de	7.71 fg
$P_{60}N_0$	4.34 abc	5.467 abcd	2.37 a	5.85 bcde
$P_{60}N_{40}$	5.95 cd	5.911 cde	3.793 abc	6.30 cdef
$P_{60}N_{80}$	7.233 d	6.667 cde	5.57 cde	7.48 efg
$P_{60}N_{120}$	7.7 d	7.867ef	5.57 cde	9.38 h
Grand mean	5.29	5.97	4.51	6.26
CV (%)	18.4	17.3	24.1	14.1
LSD	1.622	1.725	1.814	1.47
F stat.	***	***	***	***

N.B; *** Very highly significant ($P<0.001$).

The means in the same column followed by the similar letter(s) are not statistically different at 5% level of significance following Duncan's Multiple range Test

4.3.2 Plant Height

Table 4 showed Plant height were increased with the increase of levels of N and P applied. Plant height ranged from 1.94 m to 3.37 m in all experimental sites. Results of plant height (Table 4) showed significant ($p<0.001$) variation with respect to the treatments used in Ihowa, Lumbila, Mbimba and Senjele from the absolute control. These results also revealed that the highest plant heights recorded were in the order Lumbila (3.19 m) > Ihowa (2.94 m) > Senjele and Mbimba (2.81 m) at the rate of 40 kg P ha^{-1} + 120 kg N ha^{-1}. The findings of this study indicated that the highest plant height recorded for maize from different sites was attributed to the application of high levels of N.

Table 4: Plant Height (m) as Influenced by Different Levels of P and N

	Plant height (m)			
Treatment	**Ihowa**	**Lumbila**	**Mbimba**	**Senjele**
Control	2.17 a	2.46 a	1.944 a	2.25 ab
P_0N_{40}	2.2 ab	2.57 ab	1.985 a	2.42 bcd
P_0N_{80}	2.48 abcd	2.68 bc	2.004 a	2.49 cdef
P_0N_{120}	2.35 abc	2.85 cdef	2.101 ab	2.66 defg
$P_{20}N_0$	2.4 abc	2.79 cde	2.269 ab	2.35 abc
$P_{20}N_{40}$	2.6 abcd	3 efgh	2.345 ab	2.52 cdef
$P_{20}N_{80}$	2.62 abcd	3.043 fghi	2.473 ab	2.65 defg
$P_{20}N_{120}$	2.51 abcd	3.19 hij	2.283 ab	2.77 g
$P_{40}N_0$	2.69 abcd	2.76 bcd	2.448 ab	2.16 a
$P_{40}N_{40}$	2.82 cd	2.90 def	2.81 b	2.47 bcde
$P_{40}N_{80}$	2.94 d	3.23ij	2.786 b	2.73 fg
$P_{40}N_{120}$	2.95 d	3.37 j	2.542 ab	3.04 h
$P_{60}N_0$	2.67 abcd	2.95 defg	2.538 ab	2.52 cdef
$P_{60}N_{40}$	2.82 cd	2.88 cdef	2.354 ab	2.47 bcde
$P_{60}N_{80}$	2.94 d	3.11 ghi	2.514 ab	2.68 efg
$P_{60}N_{120}$	2.72 bcd	3.19 hij	2.664 ab	2.81 g
Grand mean	2.62	2.94	2.38	2.56
CV (%)	10.5	3.7	16.2	4.9
LSD	45.814	0.183	0.642	0.21
F stat.	*	***	Ns	***

N.B; ns - not significant, Significant ($P<0.05$) and *** Very highly significant ($P<0.001$).
The means in the same column followed by the similar letter(s) are not statistically different at 5% level of significance following Duncan's New Multiple range Test.

Similar results have been reported by Mohamed *et al.* (2008) that an increase in N levels from 0 to 200 kg ha^{-1} significantly increased plant height, LAI and dry matter production of irrigated maize in sandy clay loam soil of Coimbatore in India. Similar trends were observed for absolute controls in the order of Lumbila (2.46 m) > Ihowa (2.17 m) > Senjele (2.25 m) and Mbimba (1.94 m). The highest significant plant height was obtained with the application of 40 kg P ha^{-1} + 120 kg N ha^{-1} which was very closely followed by an application of 40 kg P ha^{-1} + 80 kg N ha^{-1} and 60 kg P ha^{-1} + 80 kg N ha^{-1} (Table 4) and there were no significant differences among treatments observed in absolute control and in exclusive applications of 40 kg N ha^{-1}, 120 kg N ha^{-1}, 20kg P ha^{-1} at Senjele experimental site. In other words, the control plot gave the smallest plant height although this was not significantly different from the rest of treatments combinations apart from 40 kg P ha^{-1} + 120 kg N ha^{-1}, 40 kg P ha^{-1} + 80 kg N ha^{-1} and

60 kg P ha^{-1} + 80 kg N ha^{-1} (Table 4). Plant height varied from 2.17 m in the control plot to 2.95 m in a plot treated with 40 kg P ha^{-1} + 120 kg N ha^{-1}. The plant height ranged from 2.46 m in the control plot to 3.37 m in a plot treated with 40 kg P ha^{-1} + 120 kg N ha^{-1}. Paradkar and Sharma (1993) reported that plant height increased as N rate increased from low to higher levels. Gasim, (2001) indicated that the increase in plant height with nitrogen fertilizer is due to the fact that nitrogen promotes plant growth, increases the number of internodes and length of the internodes which results in progressive increase in plant height. Koul, 1997 reported similar results. Nitrogen fertilization increased number of leaves per plant and leaf area (El Noeman *et al*., 1990 and Gasim, 2001) noted that the addition of nitrogen increased stem diameter. Koul (1997) recorded that nitrogen application resulted in greater values of plant height, leaf area, number of leaves and stem diameter of fodder maize, fresh and dry forage yield were also increased due to addition of nitrogen

4.3.3 Grain Yields

Grain yield per cob and grain yield per hectare increased with increasing in the levels of N and P. Results of maize grain yields (Table 5 and 6) showed significant ($P<0.01$) different from absolute control. On the other hand, the lowest yields of maize were obtained from sole application of each Nutrient, where P_0N_{40} and $P_{40}N_0$ did not differ statistically from the absolute control. The grain weight per cob ranged from 25.83 to 102.75g per cob, where the grain yield ranged from 1.15 to 4.03tonha^{-1} in all experimental sites. Grain yields recorded in plots with application of N and P fertilizers were observed to be different compared to absolute control (no fertilizer added), hence there were significant differences at P (0.001) in maize grain yields among the treatments in all sites. Tejada and Gonzalez (2003) also reported that increasing N fertilizer rate resulted in higher grain yields compared with their absolute controls.

Table 5: Maize Grain Yield per Cob as Influenced by Different Levels of N and P

	Grain yield per cob (g)			
Treatment	**Ihowa**	**Lumbila**	**Mbimba**	**Senjele**
Control	25.83 a	26.22 a	25.87 a	31.19 a
P_0N_{40}	30.56 ab	35.78 ab	40.96 abcd	42.17 ab
P_0N_{80}	36.64 abc	51.32 bcd	51.96 cdef	59.85 bcd
P_0N_{120}	49.12 bcd	64.01 cdef	53.99 def	73.14 cdef
$P_{20}N_0$	27.53 ab	61.82 cdef	32.89 ab	69.32 cde
$P_{20}N_{40}$	54.77 cde	71.21 defgh	49.54 bcdef	80.94 defgh
$P_{20}N_{80}$	67.47 def	87 gh	62.51 f	99.07 gh
$P_{20}N_{120}$	67.77 def	81.6 fgh	77.95 g	94.74 fgh
$P_{40}N_0$	35.2 abc	46.52 abc	30.16 a	52.67 abc
$P_{40}N_{40}$	65.47 def	60.63 cdef	41.48 abcde	68.85 cde
$P_{40}N_{80}$	75.52 ef	68.51 cdefgh	56.85 def	78.73 defgh
$P_{40}N_{120}$	80.17 f	77.89 fgh	60.88 f	89.16 efgh
$P_{60}N_0$	29.55 ab	52.63 bcde	34.99 abc	58.39 bcd
$P_{60}N_{40}$	64 def	66.76 cdefg	39.71 abcd	75.25 cdefg
$P_{60}N_{80}$	82.57 f	74.36 efgh	58.2 ef	85.12 efgh
$P_{60}N_{120}$	76.31 ef	90.7 h	59.4 f	102.75 h
Grand mean	54.3	63.56	48.58	72.6
CV (%)	21.8	18.5	18.7	17.7
LSD	19.71	19.624	15.116	21.46
F stat.	***	***	***	***

N.B; *The means in the same column followed by the similar letter(s) are not statistically different at 5% level of significance following Duncan's NewvMultiple Range Test* and *** Very highly significant ($P<0.001$).

A slight decline in yield was observed when rates of 40 kgPha^{-1} and 60kgPha^{-1} were applied singly, this may be due to increase in P rate from 40kg/ha to 60kg/ha. Adepetu (1970) reported that, application of high rates of P caused nutrient imbalance and consequently yield depression of maize. A Similar observation were reported by Adediran and Banjoko (1995) on the response of maize to low and high rates of P. On the other hand, the lowest yields of maize were also obtained from sole application of each treatment. The existence of high variation among these treatments could be unveiled by large values of coefficient of variation (C.V. > 18%) obtained for some variables in this study. Similar observations have also been reported by Phiri *et al.* (2010).

Table 6: Maize Grain Yield tonha^{-1} as Influenced by Different Levels of N and P

	Grain yield (tonha^{-1})			
Treatment	**Ihowa**	**Lumbila**	**Mbimba**	**Senjele**
Control	1.148 a	1.165 a	1.15 a	1.39 a
P_0N_{40}	1.358 ab	1.59 ab	1.82 abcd	1.87 ab
P_0N_{80}	1.629 abc	2.281 bcd	2.31 cdef	2.66 bcd
P_0N_{120}	2.183 bcd	2.845 cdef	2.373 def	3.25 cdef
$P_{20}N_0$	1.223 ab	2.747 cdef	1.462 ab	3.08 cde
$P_{20}N_{40}$	2.434 cde	3.165 defgh	2.202 bcdef	3.60 defgh
$P_{20}N_{80}$	2.999 def	3.867 gh	2.778 f	4.40 gh
$P_{20}N_{120}$	3.012 def	3.627 fgh	3.465 g	4.21 fgh
$P_{40}N_0$	1.564 abc	2.067 abc	1.34 a	2.34 abc
$P_{40}N_{40}$	2.91 def	2.694 cdef	1.844 abcde	3.06 cde
$P_{40}N_{80}$	3.356 ef	3.045 cdefgh	2.526 def	3.50 defgh
$P_{40}N_{120}$	3.563 f	3.462 fgh	2.706 f	3.96 efgh
$P_{60}N_0$	1.313 ab	2.339 bcde	1.555 abc	2.60 bcd
$P_{60}N_{40}$	2.845 def	2.967 cdefg	1.765 abcd	3.35 cdefg
$P_{60}N_{80}$	3.337 ef	3.305 efgh	2.587 ef	3.78 efgh
$P_{60}N_{120}$	3.391 ef	4.031 h	2.64 f	4.57 h
Grand mean	2.392	2.82	2.16	3.23
CV (%)	21.8	18.5	18.7	17.7
LSD	0.8708	0.872	0.673	0.95
F stat.	***	***	***	***

N.B; *The means in the same column followed by the similar letter(s) are not statistically different at 5% level of significance following Duncan's New Multiple Range Test and* *** Very highly significant ($P<0.001$).

4.4 Harvest index (%) as Influenced by Different Levels of N and P

4.4.1 Effects of N rates on Harvest Index (HI) of Maize

The effects of N rates on the harvest index (HI) of maize in the four experimental sites are presented in Table 7. The results indicated that application of N alone at rates of 40, 80 and 120 kg ha^{-1} insignificantly increased harvest indices (HI) of maize from 34% to 44%, 44% to 58%, 36% to 48%, and 48% to 53%, for the Lumbila, Senjele, Ihowa and Mbimba soils, respectively. Contrary to the trends of HI observed in other soils, the increase in HI for the maize which was grown in Ihowa site was at 40 and 80 kg N ha^{-1} applied, which decreased to 51% at an application of 120 kg N ha^{-1}. However, these values of HI in maize for each site at different rates of N applied were relatively larger than their corresponding absolute control. HI was 31%, 43%, and 40% for Lumbila, Senjele, and Mbimba,villages respectively. Exceptional was also observed for the Ihowa site which recorded relatively larger HI (41%) in the absolute control than those obtained with an application of N at the rates of 40 and 80 kg ha^{-1} which had low HI of 36%. These results also revealed that at the highest rate of N applied (120 kg N ha^{-1}) the increase in HI of maize was in the order of Senjele > Mbimba > Ihowa > Lumbila. The findings of this study indicated that the highest HI recorded for maize from different sites was attributed to the low total dry biomass of maize after harvest. In addition, the high HI obtained at an application of N indicates that nutrients were converted to yield at the expense of total dry biomass production. These findings are in close agreement with the findings of Wasaya et al., (2012) who reported an insignificant effect of applied N on HI.

Table 7: Harvest Index (%) as Influenced by Different Levels of N and P

	Harvest Index (%)			
Treatment	**Ihowa**	**Lumbila**	**Mbimba**	**Senjele**
Control	41.19 ab	30.7 a	40.16 a	42.65 a
P_0N_{40}	36.44 ab	33.69 ab	48.46 ab	43.62 a
P_0N_{80}	36.06 ab	39.09 ab	53 abc	48.26 a
P_0 N_{120}	47.73 ab	44.14 ab	51.19 abc	58.39 a
$P_{20}N_0$	32.42 a	46.04 ab	60.35 bc	57.3 a
P_{20} N_{40}	50 ab	52.36 ab	53.03 abc	59.12 a
P_{20} N_{80}	54.09 ab	53.98 ab	49.38 abc	68.26 a
P_{20} N_{120}	43.08 ab	41.84 ab	47.4 ab	53.31 a
$P_{40}N_0$	42.12 ab	56.67 b	41.98 ab	54.89 a
P_{40} N_{40}	61.26 b	59.02 b	40.32 a	55.33 a
P_{40} N_{80}	60.88 b	54.49 ab	51.63 abc	52.48 a
P_{40} N_{120}	54.6 ab	57.76 b	44.84 ab	52.26 a
$P_{60}N_0$	30.17 a	46.24 ab	68.07 c	44.61 a
P_{60} N_{40}	48.1 ab	50.76 ab	47.03 ab	54.21 a
P_{60} N_{80}	52.69 ab	51.39 ab	47.09 ab	51.17 a
P_{60} N_{120}	48.05 ab	52.53 ab	51.81 abc	51.31 a
Grand mean	46.2	48.17	49.73	52.9
CV (%)	28.9	26.6	20	25.6
P (0.05)	ns	ns	ns	ns
LSD	22.24	21.384	16.549	22.56

N.B; ns - not significant

The means in the same column followed by the similar letter(s) are not statistically different at 5% level of significance following Duncan's New Multiple Range Test.

The trends of HI observed in this study at different rates of N applied could be attributed to the re-translocation of N in maize plant tissues. This indicates that low N stress induces N translocation from older to younger leaves and from vegetative to generative organs. Below (1996) reported that at anthesis and kernel-filling stages there is a dramatic N re-translocation from vegetative organs to ears under field conditions. The reason given for this is that maize plants tend to keep a relatively homeostatic N concentration in the leaves by reducing leaf expansion at the seedling stage.

4.4.2 Effects of N - P Combinations on HI of Maize

The effects of N and P combinations on the HI of maize at the four experimental sites are as presented in Table 7. Results indicate that application of N at the rates of 40 and 80 kg ha^{-1} and combining each rate with 20 kg P ha^{-1} insignificantly increased the HI of maize from 52 to 54%, 59 to 62%, and 50 to 54% for the Lumbila, Senjele and Ihowa, respectively (Table 7), which then decreased to 42%, 57%, and 32% at $N_{120}P_{20}$ combination. The exception of the trend observed for HI was in maize which was grown in Mbimba because the HI decreased from 53 to 47% at different N rates used and combined with 20 kg P ha^{-1}. The findings of this study suggest that an application of 20 kg P ha^{-1} in combination with 40 and 80 kg N ha^{-1} favoured HI of maize in the order of Senjele > Lumbila > Ihowa > Mbimba sites. This trend was almost similar to that of HI observed when N was applied alone, indicating that Senjele soil is mostly deficient in N and P, apart from other essential nutrients for plant growth and development compared with Lumbila, Ihowa and Mbimba villages. In addition, the ability of maize to transform its dry matter into grains with an application of 40 and 80 kg N ha^{-1} combined with 20 kg P ha^{-1} is more favoured in Senjele soil. However, similar combination reversed HI for maize in Mbimba soil, which disrupted the trend observed when similar rates of N were applied without any P application.

Results of an application of N at the rates of 40 and 120 kg ha^{-1} and combining each rate with 40 kg P ha^{-1} insignificantly HI of maize from 59 to 57%, 55 to 52%, and 61 to 55%, which decreased at $N_{80}P_{40}$ combination to 54%, 52%, and 60% for the Lumbila, Senjele and Ihowa, respectively (Table 7). On the other hand, the trend was different for the HI which was obtained for maize which was grown in Mbimba because the HI increased from 40 to 45% at 40 and 120 kg N ha^{-1} applied and each combined with 40 kg P ha^{-1}. However the use of 80 kg N ha^{-1} and 40 kg P ha^{-1} at Mbimba site there was an increase in HI to 52%. The findings of this study suggest that an application of 40 kg P ha^{-1} in combination with 40 kg N ha^{-1} recorded high HI of maize grown in the studied sites in the order Ihowa > Lumbila > Senjele > Mbimba. These findings also suggest that P at 40 kg ha^{-1} in the study sites favoured the Ihowa site at 40kg P ha^{-1} + 40 kg N ha^{-1} and 40 kg P ha^{-1} + 80 kg N ha^{-1} which recorded the highest but statistically similar HI (Table 7). In addition, the HI recorded for the maize grown in the study sites indicated that in Lumbila, Senjele and Ihowa sites $P_{40}N_{40}$ combination is suitable in adjusting HI of maize except for the Mbimba site which is suited by $P_{40}N_{80}$ combination.

Results of an application of N at the rates of 40, 80 and 120 kg ha^{-1} and combining each rate with 60 kg P ha^{-1} insignificantly ($p > 0.05$) increased HI of maize from 51 to 53%, and 47 to 52% for Lumbila and Mbimba sites respectively (Table 7) but these values of HI were respectively larger and smaller than their corresponding absolute control that is Lumbila (46%) and Mbimba (68%). Results however indicated that the HI for the maize in absolute control plot and those were treated with 60 kg P ha^{-1} combined with 40, 80 and 120 kg N ha^{-1} did not differ significantly (Table 7) but significant differences were observed for the Mbimba site. On the other hand, the HI of maize decreased from 54% at $P_{60}N_{40}$ to 51% at $P_{60}N_{80}$ and $P_{60}N_{120}$ for Senjele site and from 53% at $P_{60}N_{80}$ to 48% at $P_{60}N_{40}$ and $P_{60}N_{120}$ for Ihowa site. However, these values of HI were larger than the values obtained for their respective absolute control that is 45% and 30% for the Senjele and Ihowa sites, respectively.

These findings suggest that the best PN combination which explained attainable HI of maize in the study sites is $P_{60}N_{40}$. This is attributed to high rate of P, which enhanced N utilization in plants. These findings also suggest that at higher rates of P application relatively low rates of N can be applied to maize in the study soils and promises higher HI probably associated with reduction of N losses in soils by TSP fertilizer through volatilization in form of ammonia (NH_3) or transformed into weak nitric acid (HNO_3) in soils as reported by Fan and Mackenzie (1993). Ahmed *et al.* (2009) also reported that in acid soils, triple superphosphate (TSP) has been used to reduce ammonia loss. Similar authors stressed that this process does not only reduce ammonia loss but it also helps in releasing ammonium ions slowly into the soil.

Similarly, Wasonga *et al.* (2008) reported that the lack of significant differences in maize HI due to P rates above 13 kg P ha^{-1} was attributed to simultaneity increases in grain and total dry matter production in addition to low plasticity within a variety in terms of dry matter partitioning to the grains within the P application range. The authors applied 44 kg P ha^{-1} and 60 kg N ha^{-1} to the maize crop grown on a Vertisol and obtained HI values ranging from 43 to 46%. Similar findings reported by Tittonell *et al.* (2008) that a maize crop requires 34.1 kg N ha^{-1}, 9.4 kg P ha^{-1} and 30.9 kg K ha^{-1} to produce 3 t ha^{-1} of above-ground biomass. This observation was based on the assumption that N, P and K conversion efficiencies under balanced nutrient uptake of 88, 319 and 97 kg of dry matter per kg of N, P or K taken up by the crop, respectively.

4.5 Nutrient Use Efficiency (NUE) as Influenced by Different Levels of N and P.

4.5.1 Nitrogen Use Efficiency

The effects of N rates on N use efficiency at the four experimental sites were as presented in Table 8. Results indicated that an application of N alone at rates of 40, 80 and 120 kgNha^{-1} very highly significantly ($p < 0.001$) increased N use efficiency (NUE) of maize from 11 to 14 kg kg^{-1}, 12 to 16 kg kg^{-1}, and 5 to 9 kg kg^{-1} for the Lumbila, Senjele, and Ihowa sites, respectively (Table 8). On the other hand, an application of similar rates of N to Mbimba site decreased NUE from 17 to 10 kg kg^{-1} (Table 8). Apart from differences in ecological characteristics of the study areas, the nutrient contents in the soils differed as well, which increased variation in the levels of N in the maize plants (Ademba, 2009).

4.5.2 Effects of NP Combinations on N and P Use Efficiency of Maize

Results indicated that an application of N at the rates of 40, 80 and 120 kg ha^{-1} and combining each rate with 20 kg P ha^{-1} reduced nitrogen use efficiency (NUE) of maize from 50 to 21 kg kg^{-1}, 55 to 24 kg kg^{-1}, 32 to 16 kg kg^{-1}, and 26 to 19 kg kg^{-1} for the Lumbila, Senjele, Ihowa and Mbimba sites, respectively (Table 8). In addition, the values of phosphorus use efficiency (PUE) increased from 100 to 135 kg kg^{-1} and from 111 to 151 kg kg^{-1} at $P_{20}N_{40}$ and $P_{20}N_{80}$ and then decreased to 123 and 141 kg kg^{-1} at $P_{20}N_{120}$ for the Lumbila and Senjele sites, respectively. However, the values of PUE of maize in the same soils when there is no N application were 79 and 85 kg kg^{-1}, respectively. On the other hand, PUE of maize in the Ihowa and Mbimba sites increased from 64 to 93 kg kg^{-1} and from 53 to 116 kg kg^{-1}, respectively.

Results of an application of N at the rates of 40, 80 and 120 kg ha^{-1} and combining each rate with 40 kg P ha^{-1} reduced NUE of maize from 38 to 19 kg kg^{-1}, 42 to 22 kg kg^{-1}, 44 to 19 kg kg^{-1}, and 17 to 12 kg kg^{-1} for the Lumbila, Senjele, Ihowa, and Mbimba sites respectively (Table 8). In addition, the values of PUE in the order of NUE increased from 38 to 57 kg kg^{-1}, 42 to 64 kg kg^{-1}, 44 to 60 kg kg^{-1}, and 17 to 39 kg kg^{-1}. Results also indicated that PUE of maize in the same order of these soils with application of 40 kg P ha^{-1} when there is no N application were 23, 24, 10 and 5 kg kg^{-1}, respectively. These findings suggest that as NUE decreased the PUE increased. This could be related to the increase in N and P imbalances in soils as the rates of N applied increased. Similar findings have been reported by Ademba (2009) were the N-P interaction resulted from complex biological, chemical and physical factors functioning in the fertilized zone of the soil and resulting in increased P absorption. Also Ademba (2009) reported that increased root growth into the fertilizer zone due to presence of N intimate to P fertilizer caused increased P uptake.

Table 8: Effects of N Rates and P Combinations on Agronomic Use Efficiency

Treatment	**Agronomic use Efficiency (AUE) (kg kg-1)**							
	Ihowa		**Lumbila**		**Mbimba**		**Senjele**	
	N	P	N	P	N	P	N	P
Control	NA	NA	NA	NA	NA	NA	NA	NA
$P_0 N_{40}$	5.26ab	NA	10.63ab	NA	16.77bc	NA	12.20ab	NA
$P_0 N_{80}$	6.01ab	NA	13.94bc	NA	14.5b	NA	15.92bc	NA
$P_0 N_{120}$	8.62abc	NA	14.00bc	NA	10.2ab	NA	15.54bc	NA
$P_{20}N_0$	NA	3.77a	NA	79.11de	NA	15.61abc	NA	84.72ef
$P_{20} N_{40}$	32.16def	64.32cd	50.00g	99.99ef	26.31c	52.61e	55.28g	110.55fg
$P_{20} N_{80}$	23.13bcde	92.53d	33.77def	135.07g	20.36bc	81.42e	37.71def	150.84h
$P_{20} N_{120}$	15.53abcd	93.21d	20.51bc	123.08fg	19.29bc	115.75e	23.53bcd	141.21gh
$P_{40} N_0$	NA	10.41ab	NA	22.56abc	NA	4.77ab	NA	23.86abc
$P_{40} N_{40}$	44.04f	44.04bc	38.23efg	38.23bc	17.35bc	17.35abcd	41.83efg	41.83cd
$P_{40} N_{80}$	27.6cdef	55.21cd	23.49bcd	46.99bcd	17.21bc	34.42cde	26.41bcd	52.82cde
$P_{40} N_{120}$	20.13abcd	60.38cd	19.14bc	57.41cd	12.97b	38.9de	21.47bc	64.41de
$P_{60} N_0$	NA	2.75a	NA	19.56ab	NA	6.76ab	NA	20.15abc
$P_{60} N_{40}$	42.42ef	28.28abc	45.05fg	30.03abc	15.38bc	10.25ab	23.53bcd	32.64abcd
$P_{60} N_{80}$	27.36cdef	36.48abc	26.74cde	35.66abc	17.96bc	23.95bcd	29.96cde	39.95acd
$P_{60} N_{120}$	18.7abcd	37.39abc	23.88bcd	47.77bcd	12.42b	24.84bcd	26.50bcd	53cde
$LSD_{(0.05)}$	18.09	34.43	11.73	32.66	9.807	19.78	12.96	35.36
CV (%)	64.1	62.5	35.2	42.6	46.9	44.5	35	41.6
F stat.	***	***	***	***	***	***	***	***

N.B; *The means along the same column bearing similar letter(s) do not differ statistically at 5% level based on New Duncan's Multiple Range Test (DNMRT) and* *** Very highly significant (P<0.001).

Results indicated that an application of N at the rates of 40, 80 and 120 kg ha^{-1} and combining each rate with 60 kg P ha^{-1} increased NUE of maize from 24 to 30 kg kg^{-1} and 15 to 18 kg kg^{-1} in Senjele and Mbimba sites respectively (Table 8). Results also indicated that at the same rates of N and P combinations the NUE by maize of Lumbila and Ihowa sites decreased from 45 to 24 and 42 to 19 kg kg^{-1}, respectively. However, the values of PUE in all soils indicated an increase from 30 to 48 kg kg^{-1}, 33 to 53 kg kg^{-1}, 28 to 37 kg kg^{-1}, and 10 to 25 kg kg^{-1}, for the soils of Lumbila, Senjele, Ihowa, and Mbimba sites respectively. In addition, under application of 60 kg P ha^{-1} + 0 kg N ha^{-1} application in all soils, the lower values of PUE were recorded that is 20, 3 and 7 kg kg^{-1} for the soils of Lumbila and Senjele, Ihowa, and Mbimba sites, respectively. These findings suggest that the best combination for balanced NUE and PUE of maize is 60 kg P ha^{-1} + 40 kg N ha^{-1} for Senjele and Mbimba soils and 60 kg P ha^{-1} + 80 kg N ha^{-1} for the Lumbila and Ihowa soils.

Results of the physiological use efficiency of N and P (Table 9) followed similar trend of the agronomic nutrient use efficiency (AUE) of N and P by maize that is NUE and PUE but the former are very small because of the higher values of N and P uptakes obtained in this study. The findings of this study suggest that for better N and P use efficiencies by maize in the study areas, the best N and P combination is $P_{20}N_{40}$ if only the rates of N are to be varied. This increases nutrient balance of N and P in the soil for optimum plant uptake. These findings also indicated obvious influence of N application to P use efficiency of maize as evidenced from the lowest values of P recorded in all soils when there is no N application. These findings are also similar to those of Lija *et al.* (2014) who reported that an application of $N_{60}P_{25}$ caused better N and P use efficiency in roots, stems and leaves.

Table 9: Effect of N Rates and P combinations on Physiological Use Efficiency of Maize.

	Physiological Use Efficiency of (PUE) (kg kg^{-1})							
	Ihowa		**Lumbila**		**Mbimba**		**Senjele**	
Treatment	**N**	**P**	**N**	**P**	**N**	**P**	**N**	**P**
Control	NA	NA	NA	NA	NA	NA	NA	NA
$P_0 N_{40}$	0.807a	NA	NA	13.52a	1.216ab	-233a	0.855abc	9.1ab
$P_0 N_{80}$	1.737a	12.8a	NA	23.37a	1.338ab	34.8ab	1.537abc	-408.2a
$P_0 N_{120}$	-12.255a	9.3a	NA	36.51ab	2.449ab	57.9ab	-4.661ab	577.8ab
$P_{20}N_0$	-2.456a	8a	0.1382ab	13.88a	0.198a	9.7ab	15.911bc	6.8ab
$P_{20} N_{40}$	-19.852a	21.1a	0.3545cd	28.76ab	3.449ab	73.5ab	14.832bc	43.7ab
$P_{20} N_{80}$	-5.246a	12041.2a	0.1642ab	18.49a	3.304ab	338.5ab	7.309abc	271.5ab
$P_{20} N_{120}$	4.441a	-583.3a	0.4209d	29.03ab	3.156ab	41ab	9.143abc	420.3ab
$P_{40} N_0$	1.386a	-256.4a	0.0665ab	47.55ab	14.962b	5ab	-2.877ab	-11.5ab
$P_{40} N_{40}$	-2.001a	35.7a	0.2123bc	18.44a	-0.167a	22.7ab	9.938abc	989.1b
$P_{40} N_{80}$	10.938a	665.2a	0.1565ab	31.62ab	5.309ab	51.1ab	1.795abc	-20.9ab
$P_{40} N_{120}$	-7.174a	105.6a	0.199bc	32.66ab	2.537ab	33.1ab	16.187bc	-40.8ab
$P_{60} N_0$	-1.649a	21.8a	0.0844ab	22.60a	-14.79a	9.7ab	-16.106a	139.4ab
$P_{60} N_{40}$	3.82a	27.6a	0.1097ab	117.29b	5.516ab	355.1ab	0.636abc	55ab
$P_{60} N_{80}$	-16.193a	-8.9a	0.1227ab	29.80ab	1.993ab	-27ab	27.018c	71.7ab
$P_{60} N_{120}$	6.246a	106a	0.1389ab	37.12ab	3.044ab	558.7b	14.613bc	-202a
$LSD_{(0.05)}$	27.28	8708.7	0.1579	77.36	11.69	509.4	24.16	913.8
CV (%)	699.0	680.7	69.9	148.3	334.9	367.3	241.1	461.2
F stat.	n.s	n.s	***	n.s	*	n.s	n.s	n.s

N.B; ns - not significant, * Significant ($P<0.05$) and *** Very highly significant ($P<0.001$).
The means along the same column bearing similar letter(s) do not differ statistically at 5% level based on New Duncan's Multiple Range Test

4.5.3 Effects of NP combination rates on N and P recovery by maize from soils

The effects of N and P combinations rates on N and P recovery by maize were/are as presented in Table 10 state the trends of N and P recovery. The study indicates that an application of N alone at rates of 40, 80 and 120 kg ha^{-1} significantly ($p \leq 0.01$) decreased the agronomic recovery of N (ARN) from soils from 1.5 to 0.7%, 1.6 to 0.34%, 0.99 to 0.34%, and 1.4 to 0.78%, for Lumbila, Senjele, Ihowa and Mbimba sites, respectively. In addition, the results indicated that an application of P_{20} with N_{40}, N_{80} and N_{120} decreased ARN from 1.8 to 0.92%, 0.55 to 0.28%, 0.5 to 0.32%, and 0.8 to 0.7% for the Lumbila, Senjele, Ihowa and Mbimba, respectively. On the other hand, results showed that with the same rates of N and P application the agronomic recovery of P

(ARP) varied from 0.16 to 0.42%, 0.08 to 0.25%, 0.04 to 0.13%, and 0.08 to 0.29% for Lumbila, Senjele, Ihowa and Mbimba, respectively. Furthermore, results indicated that an application of 20 kg P ha^{-1} alone had ARP of 0.13%, 0.014%, 0.014%, and 0.16%, for Lumbila and Senjele, Ihowa and Mbimba, respectively (Table 10).

Results indicated that an application of N alone at rates of 40, 80 and 120 kg ha^{-1} significantly ($p \leq 0.01$) decreased the agronomic recovery of N (ARN) from soils from 1.5 to 0.7%, 1.6 to 0.34%, 0.99 to 0.34%, and 1.4 to 0.78%, for Lumbila, Senjele, Ihowa and Mbimba, respectively. On the other hand, results showed that with the same rates of N and P application the agronomic recovery of P (ARP) varied from 0.16 to 0.42%, 0.08 to 0.25%, 0.04 to 0.13%, and 0.08 to 0.29% for Lumbila, Senjele,Ihowa and Mbimba, respectively. Furthermore, results indicated that an application of 20 kg P ha^{-1} alone had ARP of ranged from 0.014 to 0.16%, for all sites (Table 10).

These findings suggest that N and P recovery from soils by maize is dependent upon the interaction between the two nutrient elements. This is probably attributed to the synergistic association between N and P in their functions in plants. These findings are similar to those of Silva *et al.* (2012) who found that the P recovery increased from 6.98 to 17.25% with increase rates of N application, and decreased from 14.11 to 11.81% with increased P rates application. Other studies by Tittonell *et al.* (2008) indicated that the apparent recovery efficiencies varied between 0 and 70% for N, 0 and 15% for P, and 0 to 52% for K, which justify the findings of this study. Ahmed *et al.* (2009) found that an application of 74.34 g urea + 27.36 g TSP + 13.5 g zeolite in a 2.25 m^2 plot improved urea-N uptake efficiency compared to urea without other amendment. This suggests that urea amended with TSP has a potential of reducing ammonia loss from surface-applied urea, hence increase its ability of being recovered by the growing plant.

Table 10: **Effects of N rates and P combinations on N and P Recovery by Maize from Soils**

	Agronomic Recovery (AR) (%)							
	Ihowa		**Lumbila**		**Mbimba**		**Senjele**	
Treatment	**N**	**P**	**N**	**P**	**N**	**P**	**N**	**P**
Control	NA	NA	NA	NA	NA	NA	NA	NA
$P_0 N_{40}$	0.99b	NA	1.51de	NA	1.41c	NA	1.63c	NA
$P_0 N_{80}$	0.5ab	NA	1.08bcd	NA	1.20bc	NA	0.99b	NA
$P_0 N_{120}$	0.33ab	NA	0.66b	NA	0.78abc	NA	0.34ab	NA
$P_{20}N_0$	NA	0.01a	NA	0.14ab	NA	0.16c	NA	0.13ab
$P_{20} N_{40}$	0.5ab	0.04a	1.80e	0.35cd	0.8abc	0.08abc	0.55ab	0.25b
$P_{20} N_{80}$	0.32ab	0.09a	1.05bcd	0.16ab	0.75abc	0.13bc	0.57ab	0.09ab
$P_{20} N_{120}$	0.55ab	0.13a	0.92bc	0.42d	0.71abc	0.295c	0.28a	0.15ab
$P_{40} N_0$	NA	0.07a	NA	0.07ab	NA	0.16c	NA	0.60ab
$P_{40} N_{40}$	0.85b	0.08a	1.74e	0.21bc	0.28a	0.08abc	0.7ab	0.12ab
$P_{40} N_{80}$	0.32ab	0.05a	1.10bcd	0.16ab	0.62abc	0.07ab	0.16a	0.12ab
$P_{40} N_{120}$	0.31ab	0.09a	0.92bc	0.20bc	0.58abc	0.14bc	0.36ab	0.10ab
$P_{60} N_0$	NA	0.03a	NA	0.08ab	NA	0.08abc	NA	0.046ab
$P_{60} N_{40}$	1.03b	0.07a	1.25cd	0.11ab	0.25a	0.03a	0.47ab	0.09ab
$P_{60} N_{80}$	0.51ab	0.08a	1.18bcd	0.12ab	1.38c	0.01a	0.41ab	0.07ab
$P_{60} N_{120}$	0.35ab	0.07a	0.89bc	0.14ab	0.41ab	0.02a	0.24	0.06ab
$LSD_{(0.05)}$	0.63	0.17	0.46	0.16	0.72	0.08	0.60	0.19
CV (%)	92.2	195.5	31.6	69.9	76.3	59.6	85.5	139.8
F stat.	*	n.s	***	***	**	***	***	n.s

N.B; ns - not significant, * Significant ($P<0.05$), **highly significant ($P<0.01$), *** Very highly significant ($P<0.001$).

The means along the same column bearing similar letter(s) do not differ statistically at 5% level based on Duncan's New Multiple Range Test (DNMRT).

4.6 Benefit - Cost Analysis in Maize Production

The results of the benefit - cost (BCR) analysis for Ihowa and Mbimba sites were as presented in Table 11 and Appendices 3 and 4. The BCR was high in treatments combinations of 40 kg P ha^{-1} + 40 kg N ha^{-1} (2 .78) and 20 kg P ha^{-1} + 120 kg N ha^{-1} (2.4) for Ihowa and Mbimba sites, respectively. The BCR was less than one (<1) in some treatments, which indicates that not all treatments combinations could be used by farmers. This indicates that the present value of costs exceeds the present value of benefits (Kay, 1981). Also net present value was higher for 40 kg P ha^{-1} + 120 kg N ha^{-1}

(Tshs 1,708,800/=) and 20 kg P ha^{-1} + 120 kg N ha^{-1} (Tshs1665600/=) for Ihowa and Mbimba, respectively, and the lowest was for control (Tshs 552000/=) for both experimental sites.

Table 11: Economic Analysis of Maize at Ihowa, Lumbila, Mbimba and Senjele Experimental Sites

	Ihowa		Lumbila		Mbimba		Senjele	
Treatment	**Gross return (Tshs ha^{-1})**	**BCR**	**Gross return (Tshs ha^{-1})**	**BCR**	**Gross return (Tshs ha^{-1})**	**BCR**	**Gross return (Tshs ha^{-1})**	**BCR**
Control	552000		561,600		552000		667,200	
$P_0 N_{40}$	652800	0.58	763,200	1.16	873600	1.86	897,600	1.33
$P_0 N_{80}$	782400	0.81	1,094,400	1.86	1108800	1.95	1,276,800	2.13
$P_0 N_{120}$	1046400	1.24	1,368,000	2.02	1137600	1.47	1,560,000	2.24
$P_{20}N_0$	585600	0.27	1,320,000	6.06	700800	1.19	1,478,400	6.48
$P_{20} N_{40}$	1166400	2.58	1,521,600	4.03	1056000	2.11	1,728,000	4.45
$P_{20} N_{80}$	1440000	2.53	1,857,600	3.69	1334400	2.23	2,112,000	4.11
$P_{20} N_{120}$	1444800	1.92	1,742,400	2.54	1665600	2.4	2,020,800	2.91
$P_{40} N_0$	748800	1.03	993,600	2.27	643200	0.48	1,123,200	2.39
$P_{40} N_{40}$	1396800	2.78	1,291,200	2.40	885120	1.1	1,468,800	2.64
$P_{40} N_{80}$	1612800	2.55	1,464,000	2.17	1214400	1.59	1,680,000	2.43
$P_{40} N_{120}$	1708800	2.18	1,660,800	2.07	1300800	1.41	1,900,800	2.33
$P_{60} N_0$	628800	0.30	1,123,200	2.20	748800	0.77	1,248,000	2.28
$P_{60} N_{40}$	1368000	2.22	1,425,600	2.35	847200	0.80	1,608,000	2.56
$P_{60} N_{80}$	1603200	2.18	1,588,800	2.13	1243200	1.44	1,814,400	2.38
$P_{60} N_{120}$	1627200	1.81	1,934,400	2.31	1267200	1.20	2,193,600	2.57

The gross margin increased with increasing rates of N application from 0 kg N ha^{-1} to 120 kg N ha^{-1} in combination with all levels of P (0 kg P ha^{-1}, 20 kg N ha^{-1}, 40 kg N ha^{-1} and 60 kg N ha^{-1}) in Ihowa and Mbimba sites. The BCR was lower at an application of 120 kg N ha^{-1} in combination with all levels of P applied. The poor resource farmers in Senjele, Lumbila and Mbimba villages may opt to use 80 kg N ha^{-1} and those in Ihowa village may use 120 kg N ha^{-1}. In order to get additional benefits of Tshs 609,600/=, Tshs 532,800/=, Tshs 494,400/= and Tshs 556,800/= over control plots for the Senjele, Lumbila, Ihowa and Mbimba villages (Table 11 and appendices 3, 4, 5 and 6), respectively. However, the wealthy farmers who can invest more money for fertilizers and are interested in getting higher gross margin can adopt 60 kg P ha^{-1} and 120 kg Nha^{-1} for the Senjele, Lumbila and Ihowa villages and 40 kg P ha^{-1} and 120 kg N ha^{-1} for Mbimba to increase their gross margin profitably.

The main assumption in undertaking BCR is that prices reflect the value or can be estimated in that manner. The economic theory states that commodities have to be priced at their marginal value product (MVP) that is where the MPV of the commodity equals to its price (Senkondo, 1992). Alternatively, commodities are to be valued where the price of every goods and services is exactly equal to the value that the last unit utilized contributes to the production. Theoretically, pricing should be at the point where MVP, opportunity cost and price are equal. At this point no more transfer of resources could result in greater output or satisfaction.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMENDATIONS

5.1 Conclusions

Based on the information obtained from this research, the following conclusions were made:

i. Based on the soils analytical data, the major soil limitations for increased and sustainable maize production at the study areas include the deficiencies of N, P, Ca, Zn and low in OM in the soils.

ii. The results of the study showed that application of 80 kg N ha^{-1} + 20 kg P ha^{-1} and 120 kg N ha^{-1} + 20 kg P ha^{-1} significantly increased the maize growth and yield than other treatments. The application rate of 120 kg N ha^{-1} + 20 kg P ha^{-1} significantly ($P = 0.05$) enhanced grain yield, however, the effect was not statistically significant on HI of maize.

iii. Results of an application of N at the rates of 40, 80 and 120 kg ha^{-1} and combining each rate with 20, 40 and 60 kg P ha^{-1} reduced NUE while increased PUE of maize in all experimental sites. These findings suggest that as NUE decreased the PUE is increased. This could be related to the increase in N and P imbalances in soils as the rates of N applied increased.

iv. There was an inverse relationship between the higher dose of fertilizer application and BCR. Application of 80 kg N ha^{-1} + 20 kg P ha^{-1} and 120 kg N ha^{-1} + 20 kg P ha^{-1} P resulted the highest maize equivalent yield of 4.4 and 4.2 t ha^{-1} with the gross return of 2,112,000/= and 2,020,800/= Tshs ha^{-1} with respect to BCR, respectively. This study further confirms the role of nitrogen and phosphorus fertilizers in increasing maize growth and grain yields.

5.2 Recommendations

1. From the result of the study, application rate of 120 kg N ha^{-1} + 20 kg P ha^{-1} may be recommended for increasing maize yield particularly in the study areas. However, application of 80 N ha^{-1} + 20 kg P ha^{-1} can also bring about increase in the yield of maize. This will greatly benefit farmers in Mbozi district area where supply of nitrogen fertilizer is low and cases where farmers cannot afford the cost of high fertilizer input

2. It is recommended that N and P should be applied taking into account application time in relation to the stage of plant growth, form of fertilizer applied and method of application (broadcasting and banding). For long and medium terms, farmers should be educated on fertilizer behaviour, method and time of fertilizer application.

3. It is recommended that plant residues should be incorporated in the soil at the beginning of long rains at Mbozi district areas. This will enhance poor resource farmers with low purchasing ability of inorganic nitrogenous fertilizers to improve maize productivity.

4. It is recommended that while there is a wide-scale adoption of blanket fertilizer recommendation there is a need for site-specific nutrient management for balanced fertilization.

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APPENDICES

Appendix 1: Rates of N and P Fertilizer Applied in Field Experiment

P_0N_0 (Treatment control)	**$P_{20}N_0$**	**$P_{40}N_0$**	**$P_{60}N_0$**
P_0N_{40}	**$P_{20}N_{40}$**	**$P_{40}N_{40}$**	**$P_{60}N_{40}$**
P_0N_{80}	**$P_{20}N_{80}$**	**$P_{40}N_{80}$**	**$P_{60}N_{80}$**
P_0N_{120}	**$P_{20}N_{120}$**	**$P_{40}N_{120}$**	**$P_{60}N_{120}$**

The subscript numbers indicate the rates of the different nutrients that were applied $kgha^{-1}$

Appendix 2: Field Layout

	TREATMENTS															
BLOCKS	P_0 N_0	P_0 N_1	P_0 N_2	P_0 N_3	P_1 N_0	P_1 N_1	P_1 N_2	P_1 N_3	P_2 N_0	P_2 N_1	P_2 N_2	P_2 N_3	P_3 N_0	P_3 N_1	P_3 N_2	P_3 N_3
	P_1 N_3	P_1 N_2	P_1 N_1	P_1 N_0	P_0 N_3	P_0 N_2	P_0 N_1	P_0 N_0	P_3 N_3	P_3 N_2	P_3 N_1	P_3 N_0	P_2 N_3	P_2 N_2	P_2 N_1	P_2 N_0
	P_3 N_3	P_3 N_2	P_3 N_1	P_3 N_0	P_2 N_3	P_2 N_2	P_2 N_1	P_2 N_0	P_1 N_3	P_1 N_2	P_1 N_1	P_1 N_0	P_0 N_3	P_0 N_2	P_0 N_1	P_0 N_0

P_0 = 0 Kg P ha^{-1} (Control); P_1 = 20 Kg P ha^{-1}; P_2 = 40 Kg P ha^{-1}; P3 = 60 Kg P ha^{-1}
N_0 = 0 Kg N ha^{-1}(Control); N_1 = 40 Kg N ha^{-1}; N_2 = 80 Kg N ha^{-1}; N_3 = 120 Kg N ha^{-1}

Appendix 3: Economic Analysis of Maize at Ihowa Experimental Site

Treatment	Maize yield (t ha^{-1})	Gross return (ha^{-1})	Marginal gross margin(ha^{-1})	VC (ha^{-1})	TVC (ha^{-1})	BCR
Control	1.15	552000		350000		
$P_0 N_{40}$	1.36	652800	100800	523100	173100	0.58
$P_0 N_{80}$	1.63	782400	230400	636200	286200	0.81
$P_0 N_{120}$	2.18	1046400	494400	749300	399300	1.24
$P_{20} N_0$	1.22	585600	33600	475217	125217	0.27
$P_{20} N_{40}$	2.43	1166400	614400	588317	238317	2.58
$P_{20} N_{80}$	3.00	1440000	888000	701417	351417	2.53
$P_{20} N_{120}$	3.01	1444800	892800	814517	464517	1.92
$P_{40} N_0$	1.56	748800	196800	540500	190500	1.03
$P_{40} N_{40}$	2.91	1396800	844800	653600	303600	2.78
$P_{40} N_{80}$	3.36	1612800	1060800	766700	416700	2.55
$P_{40} N_{120}$	3.56	1708800	1156800	879800	529800	2.18
$P_{60} N_0$	1.31	628800	76800	605000	255000	0.30
$P_{60} N_{40}$	2.85	1368000	816000	718100	368100	2.22
$P_{60} N_{80}$	3.34	1603200	1051200	831200	481200	2.18
$P_{60} N_{120}$	3.39	1627200	1075200	944300	594300	1.81

Appendix 4: Economic Analysis of Maize at Mbimba Experimental Site

Treatment	Maize yield (t ha^{-1})	Gross return (ha^{-1})	Marginal gross margin (ha^{-1})	VC (ha^{-1})	TVC (ha^{-1})	BCR
Control	1.15	552000		350000		
Control	1.82	873600	585600	523100	173100	1.86
$P_0 N_{40}$	2.31	1108800	321600	636200	286200	1.95
$P_0 N_{80}$	2.37	1137600	556800	749300	399300	1.47
$P_0 N_{120}$	1.46	700800	148800	475217	125217	1.19
$P_{20} N_0$	2.2	1056000	504000	588317	238317	2.11
$P_{20} N_{40}$	2.78	1334400	782400	701417	351417	2.23
$P_{20} N_{80}$	3.47	1665600	1113600	814517	464517	2.4
$P_{20} N_{120}$	1.34	643200	91200	540500	190500	0.48
$P_{40} N_0$	1.84	885120	333120	653600	303600	1.1
$P_{40} N_{40}$	2.53	1214400	662400	766700	416700	1.59
$P_{40} N_{80}$	2.71	1300800	748800	879800	529800	1.41
$P_{40} N_{120}$	1.56	748800	196800	605000	255000	0.77
$P_{60} N_0$	1.77	847200	295200	718100	368100	0.80
$P_{60} N_{40}$	2.59	1243200	691200	831200	481200	1.44
$P_{60} N_{80}$	2.64	1267200	715200	944300	594300	1.20

Appendix 5: Economic Analysis of Maize at Senjele Experimental Site

Treatment	Maize yield (t ha-1)	Gross return (ha-1)	Marginal gross margin (ha-1)	VC (ha-1)	TVC (ha-1)	BCR
Control	1.39	667,200		350,000		
$P_0 N_{40}$	1.87	897,600	230,400	523,100	173,100	1.33
$P_0 N_{80}$	2.66	1,276,800	609,600	636,200	286,200	2.13
$P_0 N_{120}$	3.25	1,560,000	892,800	749,300	399,300	2.24
$P_{20} N_0$	3.08	1,478,400	811,200	475,217	125,217	6.48
$P_{20} N_{40}$	3.6	1,728,000	1,060,800	588,317	238,317	4.45
$P_{20} N_{80}$	4.4	2,112,000	1,444,800	701,417	351,417	4.11
$P_{20} N_{120}$	4.21	2,020,800	1,353,600	814,517	464,517	2.91
$P_{40} N_0$	2.34	1,123,200	456,000	540,500	190,500	2.39
$P_{40} N_{40}$	3.06	1,468,800	801,600	653,600	303,600	2.64
$P_{40} N_{80}$	3.5	1,680,000	1,012,800	766,700	416,700	2.43
$P_{40} N_{120}$	3.96	1,900,800	1,233,600	879,800	529,800	2.33
$P_{60} N_0$	2.6	1,248,000	580,800	605,000	255,000	2.28
$P_{60} N_{40}$	3.35	1,608,000	940,800	718,100	368,100	2.56
$P_{60} N_{80}$	3.78	1,814,400	1,147,200	831,200	481,200	2.38
$P_{60} N_{120}$	4.57	2,193,600	1,526,400	944,300	594,300	2.57

Appendix 6: Economic Analysis of Maize at Lumbila Experimental Site

Treatment	Maize yield (t ha^{-1})	Gross return (ha^{-1})	Marginal gross margin (ha^{-1})	VC (ha^{-1})	TVC (ha^{-1})	BCR
Control	1.17	561,600		350,000		
$P_0 N_{40}$	1.59	763,200	201,600	523,100	173,100	1.16
$P_0 N_{80}$	2.28	1,094,400	532,800	636,200	286,200	1.86
$P_0 N_{120}$	2.85	1,368,000	806,400	749,300	399,300	2.02
$P_{20} N_0$	2.75	1,320,000	758,400	475,217	125,217	6.06
$P_{20} N_{40}$	3.17	1,521,600	960,000	588,317	238,317	4.03
$P_{20} N_{80}$	3.87	1,857,600	1,296,000	701,417	351,417	3.69
$P_{20} N_{120}$	3.63	1,742,400	1,180,800	814,517	464,517	2.54
$P_{40} N_0$	2.07	993,600	432,000	540,500	190,500	2.27
$P_{40} N_{40}$	2.69	1,291,200	729,600	653,600	303,600	2.40
$P_{40} N_{80}$	3.05	1,464,000	902,400	766,700	416,700	2.17
$P_{40} N_{120}$	3.46	1,660,800	1,099,200	879,800	529,800	2.07
$P_{60} N_0$	2.34	1,123,200	561,600	605,000	255,000	2.20
$P_{60} N_{40}$	2.97	1,425,600	864,000	718,100	368,100	2.35
$P_{60} N_{80}$	3.31	1,588,800	1,027,200	831,200	481,200	2.13
$P_{60} N_{120}$	4.03	1,934,400	1,372,800	944,300	594,300	2.31