EFFECT OF COMBINING CATTLE MANURE AND INORGANIC P-ERTILIZER ON SOIL PROPERTIES AND MAIZE YIELD IN ACIDIC SOILS IN BEIRA CORRIDOR, MOZAMBIQUE

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DECLARATION

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Supervisors Approval

We confirm that the work reported in this thesis was carried out by the candidate under our supervision and has been submitted with our approval as university supervisors.

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DEDICATION

This work is dedicated to my beloved parents. It is also dedicated to Regina, Joaquina, Ivan, Edson, Henry, AM Junior, Rachael and Erick for their patience, encouragement and support throughout the period of studies.

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ABBREVIATIONS AND ACRONYMS

ASL	Above Sea Level
CBR	Cost Benefits Ratio
CEC	Cations Exchange Capacity
CM	Cattle Manure
DNSA	National Directorate for Agricultural Services
FAO	Food and Agriculture Organization
GDP	Gross Domestic Product
INAM	National Institute for Meteorology
ISFM	Integrated Soil Fertility Management
MINAG	Ministry of Agriculture
MBC	Mozambique Beira Corridor
MRs	Mineral resources
ORs	Organic resources
PAPA	Action Plan for Food Production
SETSAN	Technical Secretariat for Food Security and Nutrition
SOM	Soil Organic Matter
SSA	Sub-Saharan Africa

ABSTRACT

Mozambique lags behind all other Southern and Eastern African countries in maize production leading to maize imports. Soil nutrient depletion, lack of combination of organic resources with mineral resources coupled with high soil acidity has been identified as the main causes of the declining crop yields. Maize yield in smallholder systems in central Mozambique can be increased by optimum utilization of mineral fertilizers combined with cattle manure and other locally available organic resources. The aim of this study was to evaluate the effect of combining cattle manure and inorganic P-fertilizer on soil properties and maize yield in acidic soils along Beira Corridor, Mozambique. The objectives were to evaluate the effect of combined incorporation of cattle manure and mineral fertilisers on soil properties and maize yield; to determine the optimum rate of manure-inorganic fertiliser interactions for increased fertilizer use efficiency and to assess the profitability of combined application of cattle manure and mineral fertilisers for small scale farmers. The experiment consisted of combination of three levels of inorganic P-fertilizers (TSP) at 0; 25 and 50 kg ha^{-1} (P_2O_5) with three levels of cattle manure (0, 5 Mg/ha and 10 Mg/ha). The total treatments tested were nine and arranged in RCBD with four replications. Analysis of variance (ANOVA) was used for data analysis, and treatment means were compared at probability ($p<0.05$) using Least Significant Difference (LSD). Cattle manure at 10 Mg/ha combined with TSP at rate of 50 kg/ha gave higher maize grain yield of 4.87 $Mgha^{-1}$ compared to 0.55 $Mgha^{-1}$ of the control. Combination of mineral fertilizers with manure significantly increased phosphorus use efficiency by 98%; phosphorus agronomic efficiency by 87%; phosphorus recovery efficiency by 0.46 g kg^{-1} and utilization efficiency by 98%. Inorganic P-fertilizer use was cheapest when TSP as source of P was combined with manure at rate of 5 Mg ha^{-1} having Value Cost Ratio of 8.12 but P-fertilizer (as TSP) was most expensive when applied without manure, having VCR of 3.40. Advocacy on combination of cattle manure that is locally available with TSP should be increased to improve soil properties, crop yield, fertilizers use efficiency, income and profit to farmers.

CHAPTER ONE

1.0 INTRODUCTION

1.1 Background

Low inherent soil fertility status coupled with little or no external nutrient inputs have contributed to low maize yields that rarely exceed 1 Mg ha^{-1} in Southern Africa, threatening household food security (Kanonge *et al*., 2009; Mafongoya *et al*., 2006 and Bationo *et al.,* 2004).

Maize (*Zea mays* L.) is the staple food for a majority of the people in central Mozambique, but it is also grown as a cash crop by both small and large scale farmers. About 70% of consumers rely primarily on maize grain and it is ranked second to rice in Mozambique for food security purposes (SETSAN, 2009; Donavan and Tostão, 2010).

Declining maize production has been attributed to degradation of soil physical-chemical properties, soil acidity with high P sorption and soil nutrient depletion due to low chemical fertiliser use by most small-scale farmers who cannot afford the expensive fertilizers (Vanlauwe *et al*., 2010; Bationo *et al.*, 2004). Fertilizer consumption rate is estimated at 3.5 kg/ha which is one the lowest in the tropical world (Morris *et al*., 2007).

Improving maize productivity has been a major goal of the Mozambican Government (MINAG, 2009). However, it has been very difficult to raise maize yields and maintain household food security in country due to low yield on maize production.

Nhamatanda and Báruè districts contribute considerably to food security in the central Mozambique. In these areas, the soils are acidic, pH 5.13 and, there is very low use of mineral fertilizers where the consumption rate is estimated at 3.5 kg/ha. Only less than 7% of smallholder farmers owning cattle use cattle manure as an amendment for crop production (SIMA, 2008 and World Bank, 2006).

The challenge therefore lies in ensuring that the limited nutrient inputs available to smallholder farmers are effectively utilized to increase efficiency and sustain crop productivity. How to apply the nutrients, considering their limited availability at farm scale, farmer's management practices and the complex soil-crop interactions, which exist in diverse farmers fields' still a challenge.

1.2. Problem Statement

Currently, Mozambique lags behind all Southern and Eastern African countries in maize production leading to maize imports. For example, in 2004 maize yields obtained from smallholder farmers averaged 960 kg ha^{-1} in Mozambique compared to 1,100 kg ha^{-1} for Malawi; 2,600 kg ha^{-1} for South Africa and 3,077 kg ha^{-1} for Kenya (FAOSTAT, 2005 and SIMA, 2008). In the study area, soil nutrient depletion and lack of measures to increase or return soil organic matter content coupled to high soil acidity have been identified as a practical factor contributing to the crop yield decline and food insecurity (MINAG, 2007 and SETSAN, 2009). The central region of Mozambique is endowed with good agricultural climate and has the potential to produce sufficient food to meet the demand by the population. Despite the high agricultural potential, food production is low.

The productivity of maize is low as a result of continuous cropping, inadequate use of fertilizer inputs, very low or lack of use of cattle manure neither alone nor in combinations with mineral fertilisers although most farmers in Nhamatanda and Báruè districts own large numbers of cattle, the use of their drops as a source of nutrients to increase crop productivity is less than 7% in central Mozambique (DNSA, 2009, World Bank, 2006). Nevertheless, little has been done by the researches to show how the combination of cattle manure and mineral resources increase production in this particular region, with none at all for maize.

1.3 Objectives of the study

Overall objective

To evaluate the effect of combining cattle manure and inorganic P-fertilisers on soil properties and maize yield in Báruè and Nhamatanda districts, along Beira corridor, central Mozambique.

Specific objectives

Specific objectives of the research were:

i. To determine the effect of cattle manure and inorganic P-fertilisers (TSP) on soil pH, available Phosphorus, total Nitrogen and maize yield.

ii. To determine optimum rate of cattle manure-inorganic fertiliser combinations for increased fertilizer use efficiency.

iii. To assess the profitability of combining cattle manure and inorganic P-fertilisers compared with individual inorganic and organic sources of nutrients for smallholders farmers.

1.4. Research hypotheses

1. The integrated use of cattle manure and inorganic P-fertilisers significantly improves soil fertility (soil pH, soil available Phosphorus and total Nitrogen) and maize yield.
2. The integrated use of cattle manure and inorganic fertilisers significantly increases fertiliser use efficiency for smallholder farmers.
3. The integrated use of manure and inorganic P-fertilisers is more profitable for smallholder farmers than manure or inorganic fertilisers separately.

1.5 Justification and significance of the study

A large proportion of soils along Beira corridor in central Mozambique showed variety of constrains linked to the lack of Integrated Soil Fertility Management practices, among them: high acidity, low soil organic matter and high risks for erosion resulting in decrease of crop productivity consequently low income. Fertilization based on P nutrient combined with ORs is required for optimized returns for maize grain production.

Increased maize yield under integrated use of cattle manure with inorganic P-Fertilizers will stimulate growth in other economic sectors with which agriculture has deep linkage as well as increase nutrient use efficiency, profitability and food security improvement (FAOSTAT, 2005 and Nyiraneza *et al*., 2009 *in* Kanonge *et al*., 2009 and Folmer *et al.,* 1998). The presence of soil organic matter ensures that the inorganic fertilizers are more efficiently utilized by the crop (Gitari and Friesen, 2001).

Soil fertility replenishment techniques involving cattle manure combined with inorganic P-fertilizers have been developed and widely tested but its profitability still a gap particularly in Mozambique. Most of the researches on this approach have not been matched to the reality of central Mozambique. As the cost of inorganic fertilizers continues to rise, it is becoming more obvious that a good way to increase a farm's profitability is to practice better soil nutrient management. This study therefore focused on performance of the combination of manure and P-fertilizers under smallholder farmers conditions.

The study intends to contribute to maize yield improvement by identifying and recommending the inorganic P-fertilizers combination options that are suitable for maize production in area and will help extension service providers to design effective and efficient programs and projects. The outcome of this study will contribute positively to the adoption of ISFM measures in the region and other similar areas aiming to increase productivity of maize as the staple food, improving food security in the region and poverty alleviation at the smallholder level using the locally available organic resources.

1.6. Conceptual framework

Soil fertility degradation still remains the single most important constraint to food production in sub-Saharan Africa and an efficient cycling of nutrients among crops, animals and soil is crucial to the sustained productivity of the farming systems (Bationo *et al*, 2004).

Emerging evidence indicate that there is considerable consensus on guiding principles for integrated soil fertility management (ISFM) as the more pragmatic and feasible approach to overcome the limitations of past research approaches. As a holistic approach to research on soil fertility, ISFM embraces responses to the full range of driving factors and consequences namely biological, physical, chemical, social, economic and political aspects of soil fertility decline (Bationo *et al.*, 2006). Because of population pressure the quantities available of organic resources have dwindled. Furthermore, the quality of the ORs available to farmers is usually low and therefore the effectiveness to supply nutrients to the crop is limited (Mugwira and Murwira, 1997; Vanlauwe *et al.*, 2002) (Figure 1).

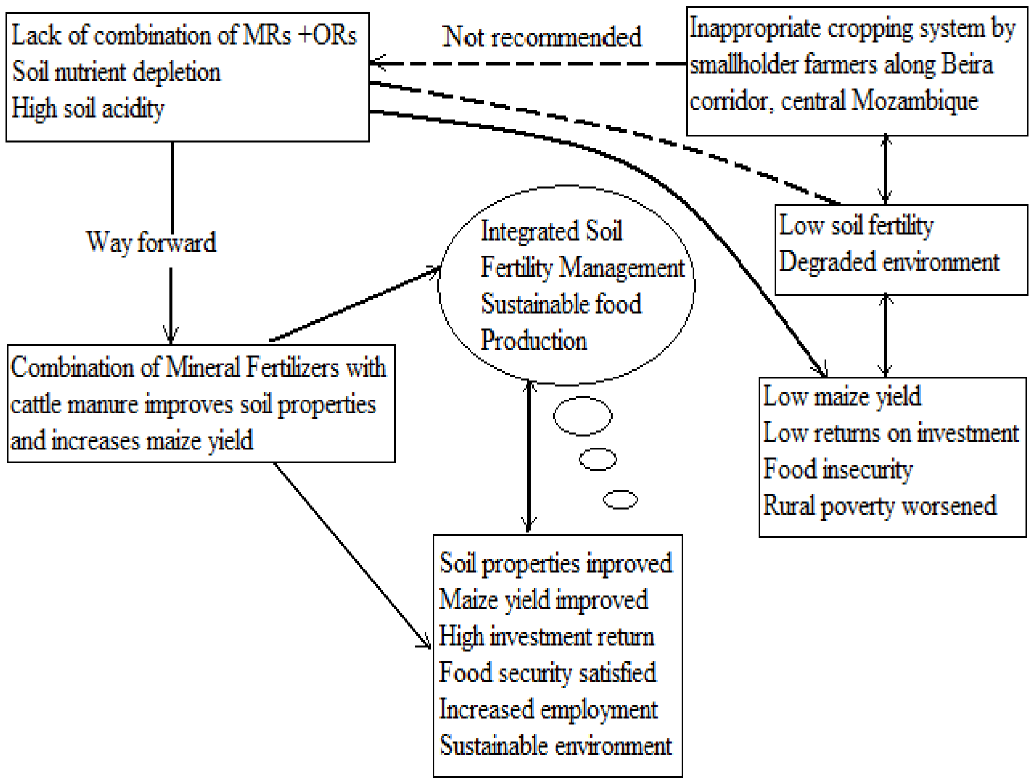

Figure 1: Conceptual framework on measures for Soil Fertility Management

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1. Overview

Soil fertility improvement is required to stimulate agricultural productivity, improve food security, and raise rural incomes. This can be achieved not only through substantial increases in fertiliser use but also by using different types of fertilisers according to the local or indigenous knowledge and practices (Sanginga *et al.*, 2009; Bationo, 2004 and Kihara *et al.*, 2011).

2.2 Characterization of Mozambican Agriculture

In Mozambique, agriculture is based on small, hand-cultivated units often farmed by women headed households and dominated by smallholders who provide about 95 percent of agricultural GDP with the balance from a small number of medium and large commercial farms. Average cultivated area per household is only about 1.4 hectares (INE, 2010). The agricultural economy is a major source of livelihood, and food represents about two thirds of total consumption, especially among the rural poor (FAOSTAT, 2005). Medium and large scale farmers are almost insignificant in terms of land area and numbers of farms. Two-thirds of agricultural production is for home consumption and only 5 percent is generated by large scale agriculture (World Bank, 2006; MINAG, 2009).

The smallholder sector in central Mozambique is characterized by holdings of multiple small plots, multiple crops and maize is the staple food (Table 1).

Agricultural production system is rainfed, traditional varieties, very low or no fertilizer and pesticide use, very little or no mechanization, and low crop productivity. Most households diversify the crops to cope with low productivity and income (MINAG, 2009 and World Bank, 2006). Increasing rural income depends on raising agricultural productivity, through intensification of the actual farming systems. Tschirley *et al.* (2009) reported that in 2007 the urban demand for maize in the south and central Mozambique was about 200,000 MT per year, of which about 70,000 MT are imported.

Table 1: Importance of staple food in Mozambique

Commodity	% of Urban Consumption Expenditure			
	South	Center	North	Overall
Maize	3.1	23.6	15.5	13.4
Cassava/Potatoes	1.7	6.1	21.1	10.9
Wheat	13.0	5	3.9	7.5
Rice	8.6	9.8	7	8.4
Others	70.6	55.5	52.5	59.8

Source: Barslund (2007)

Apart from lack of plant nutrients, the soil acidity (pH) is a major threat for plant growth and production in central Mozambique. The soil pH determines to a large extend the availability of nutrients to the plant, and thus the soil fertility. For instance in soils of high acidity, pH<5.0, fixation of P by free Aluminum can make P to be unavailable in the soil for many plant species. A low pH can be corrected through use of lime, organic fertilizers and other measures (Bationo, 2004; Vanlauwe *et al*., 2002, Sanchez *et al*., 1991).

2.3 Fertilizer use by farmers along Beira corridor

Smallholders in central Mozambique have limited access to fertilizers and little or no organic resources are used (MINAG, 2008). In 2003, only about 4 percent of farmers used chemical fertilizers and only about 5 percent used pesticides. The use of chemical inputs is generally concentrated among cash crop growers (FAOSTAT, 2005, World Bank, 2006). Inadequate extension advice from fertilizer dealers, leading to suboptimal utilization of fertilizers and, hence, suboptimal yields have been reported as main limiting factor. Average crop yields are about one half of the regional average (MIANG, 2009; World Bank, 2006; Geurts *et al*., 1997).

Access to and use of mineral fertilizers remains very limited, and there is evidence that crop yields are stagnant. If appropriate action is not taken, agricultural growth will slow and rural poverty will remain widespread (Geurts, 1997; Geurts *et al.*, 1997). Maize yield levels in Mozambique indicate vast scope for improvement, with current levels much below to their estimated potential. Compared to neighboring countries with similar agro-climatic conditions, per hectare maize yields are very low 0.9 ton/ha (World Bank, 2006; FAOSTAT, 2005).

Empirical analysis undertaken for Mozambican agricultural strategy reveals that use and adoption of improved agricultural technologies including combined application of organic and mineral resources significantly affects farm income (MINAG, 2007). The commonly used fertilizers in Mozambique are basal compound D with 12 (N): 24 (P_2O_5): 12 (K_2O) and topdressing with urea 46% N (FAOSTAT, 2005).

2.4 Use of cattle manure in Mozambican agriculture

The use of organic fertilizers in Mozambique as in most of sub-Saharan Africa countries is limited by lack and scarcity of the animals, cattle are used mainly for animal traction, as a status symbol (Geurts *et al.*, 1997; 2006Geurts, 1997 and World Bank, 206). The use of ORs in combination with mineral fertilizers offers potential for improving soil fertility and crop yields, and forms an integral part of integrated soil fertility management (Vanlauwe *et al*., 2002).

In central Mozambique, cattle and goats form an integral component of agriculture, with a population of 1.4 million and over 85% of these are owned by smallholder farmers (MINAG-TIA, 2008; MINAG, 2010). There has been very little research on manure use from small ruminants in spite of existing potential to be used in smallholder crop-livestock systems. In other parts of Mozambique, goat manure is relegated to vegetable gardens. Cattle manure has not been widely used for crop productivity purposes.

Use of manure can help supply some of these nutrients, increase pH, organic matter content and cation exchange capacity, and also improve soil physical characteristics like water holding capacity (Grant, 1970a; Mathers and Stewart, 1984; Murwira & Kirchman, 1993).

Farms along Beira corridor Districts are small due to high population pressure and need to be intensively farmed to provide enough food for consumption and sale. Since soil pH is low, the use of manure and inorganic fertilizers need to be increased to improve land productivity.

Farmers in Nhamatanda and Báruè districts recognize that soil fertility is major constraint to crop production. Existence of inorganic fertilizers and manure are widely known, but there are problems with availability, awareness, accessibility, and affordability, especially for inorganic fertilizers. Another constraint is application rate. While there are blanket application guidelines for inorganic fertilizers, soil nutrient depletion is a continuous process that renders such guidelines obsolete with time. As for manure, it is often of low quality and not available in required quantities.

According to Jama *et al*. (1997), farmyard manure has insufficient nutrients to maintain soil fertility and needs to be supplemented with inorganic fertilizers. This was also supported by Palm *et al*. (1997) who also found benefits from combining organic with inorganic fertilizers, but they reported that guidelines are needed for farmers to manage such combinations.

Lack of mineral fertilisers in rural areas might not be the only primary limiting factor for food production; however their availability might likely be the most important entry point if the aim is to increase food productivity (Morris *et al*., 2007). Organic matter may increase agricultural P by improving the availability of phosphorus. This is important in P-fixing soils where a major proportion of soil P is unavailable in the short term due to fixation (Bationo *et al.*, 2007).

The high variability of soil fertility, cropping systems and market opportunity suggest that it is necessary to adapt soil management practices into reality of the communities to achieve agronomic efficiency of fertilizer and organic inputs in crop production (Ncube *et al.*, 2006). Major factors contributing to the decline in agricultural productivity are inherently infertile soils, lack of agricultural inputs and over-exploitation of soils through monocropping with little nutrient inputs (Kanonge *et al.*, 2009). The most limiting nutrients in such soils are phosphorus (P) and nitrogen (N) (Nhamo *et al*., 2004; Okalebo and Nandwa, 1997). These nutrients are not adequately applied by smallholder farmers, because the range of nutrient sources available are few and of low quality (Mapfumo, 2006).

Using cattle manure as the only means to maintain soil fertility is possible, but in that case very large quantity of manure is needed. Moreover, the use efficiency of chemical fertilizer applied alone is low in physically and chemically degraded soils (Bationo *et al*., 2007). Currently, there is a dearth of empirical knowledge on the relationship between fertilizer use, yield response, and profitability, under a range of conditions including integrated incorporation of ORs with MRs and market conditions for both inputs and outputs (Kanonge *et al.*, 2009). For these reasons, it becomes tough to understand whether the reasons for low fertilizer use are related primarily to market failures that prevent farmers from using fertilizer despite being profitable for them to do so, or whether input/output price conditions and low response rates make fertiliser use unprofitable (Morris *et al*., 2007). The third objective of the study aims to redress this knowledge gap in central Mozambique.

Combined application of both ORs and MRs inputs can increase nutrient use efficiency, reduce costs and increase profitability (Nyiraneza *et al*., 2009), but the challenge is often about raising adequate amounts of either MRs or ORs (Mafongoya *et al*., 2006). On the other hand, mineral fertilizers can readily supply nutrients in the short term, but are beyond the reach of most farmers, susceptible to losses through leaching and induced soil acidification (Jama & Pizarro, 2008).

Mtambanengwe and Mapfumo (2009) reported that maize grain yields were increased from 1.0 up to 2.4 $Mg.ha^{-1}$ after phosphorus application at rate of 26 kg ha^{-1} with cattle manure. There is still a need to determine the effects of integrating combined nutrient application with cattle manure and residual soil N and P benefits. It is challenging that most farmers in the central Mozambique are not able to afford sufficient amounts of mineral fertilizers but combining both sources may sustain the level of productivity that adequately meet food requirements.

Organic matter can be considered a pivotal component of the soil fertility because of its role in physical, chemical and biological processes. Many of these functions interact. The high cations exchange properties of organic matter are a major means by which organic matter is able to bind soil particles together in a more stable structure (Vanlauwe *et al.*, 2002).

The long-term effects of the combined application of organic and inorganic fertilisers on improving soil fertility and crop yield have been well-demonstrated (Palm *et al.,* 1997 and Ipimoroti *et al.,* 2002). However, research on aspect of P availability when using combined incorporation of cattle manure and mineral fertilisers still has been little reported (Mujeeb *et al.*, 2010 and Nyamangara *et al.*, 2003). Organic resources have been found to enhance the soil organic matter status and the functions it supports while mineral resources are targeted for supplying key limiting nutrients. Vanlauwe *et al.,* (2002) stated that organic matter is a substantial reservoir for phosphorus and sulphur as well as nitrogen. These elements are bound within the organic structure and are released to the soil solution when microbes break down organic matter. According to Palm *et al.* (1997), Negassa *et al.* (2007) and Hussein (2009), organic inputs influence nutrient availability by the total nutrients added through controlling the net mineralization-immobilization patterns. Organic resources are also precursors to soil organic matter fractions that interact with soil minerals in complexing phosphorus (P) fixing cations thereby reducing P sorption capacity. Beside the direct release of their P content, the alteration of soil reaction governing soil P sorption processes through organic matter amendments can also increase P availability (Bationo *et al.,* 2007). These include the release of organic anions during the decomposition that in turn may compete with P for adsorption sites, increase in soil pH and in soil aggregate size and decrease exchangeable Al and specific surface area (Vanlauwe *et al*., 2002).

Cordell *et al.,* (2009) reported that manure is considered a renewable alternative source of P, currently providing about 15 million Tons of P per year to farming systems globally. Therefore, according to Morris *et al.* (2007), low agronomic efficiency often results from poor soil conditions, which could be remedied by the wider use of practices that add organic sources of nitrogen and improve soil conditions. In addition, fundamental negative contributing factor has been reported as the failure of most of small-scale farmers to intensify agricultural production in a manner that maintains soil productivity. Sanginga *et al.* (2009) stated that the future of small-scale farming in developing countries remains on adaptation of technologies into new approaches leading to the integrated production systems.

Schnurer *et al*. (1985) stated that manure added to soil with N-fertiliser lead to residue decomposition rates that were two times greater than when no amendments were added. Vanlauwe *et al.* (2002) stated that the long-term P availability is expected to be larger in combined treatments than in sole inorganic fertilizers due to microbial turnover though the lack of crucial information on these factors will continue to lead to inefficient combinations and low productivity.

2.5 Effect of organic resources on Soil chemical Properties

Organic resources play a dominant role in soil fertility management in the tropics through their short-term effects on nutrient supply and longer-term contribution to soil organic matter (SOM) formation (Palm *et al.*, 2001).

The optimal rate of combining the organic and the inorganic fertilisers as well as the optimal rate of application needs to be investigated (Ipimoroti *et al.,* 2002 and Vanlauwe *et al.* 2002). Soil CEC and pH are the most commonly measured soil chemical properties and are the more informative. Soil pH has a profound influence on plant growth. Soil pH affects the quantity, activity and types of microorganisms in soils that in turn influence decomposition of manures and other organics (Bationo *et al.,* 2007).

Animal manure can improve soil moisture content and has long-term positive effects on biological and chemical properties. Agronomic management and application of agricultural inputs effectively and efficiently could benefit the optimization of fertiliser usage, increase efficiency and decrease soil and water pollution (Lotfollahi, 2005 and Stevenson *et al*., 1998).

2.6 Improved Fertilisers Practices and Nutrient Management

It is generally presumed that a localized or band application reduces fertilizer contact with the soil thereby resulting in less P sorption and precipitation reactions and, thus, enhanced availability to crops. However, for soils with a high P-fixing capacity, where P is relatively immobile, placement of the fertiliser where root contact is enhanced may be an equally or more important mechanism than restricting fixation (Barker *et al.,* 2007; Plaster, 1997 and Palm *et al.,* 1997). Nitrogen and Phosphorus are considered the most limiting nutrients. These nutrients are not adequately applied by smallholder farmers, because the range of nutrient sources available are few and of low quality (Kanonge *et al.*, 2009). The literature contains many accounts recording the positive effects of applying P fertilizer to a localized area, usually near the plant roots, as opposed to a general soil broadcast application (Sanchez *et al*., 1990).

The amount of P required for maize production could be reduced by at least 50% if P is banded instead of broadcast. (Barker *et al.*, 2007; Plaster, 1997 and Palm *et al.*,1997). Others have reported a relationship between the relative efficiency of the localized placement of phosphorus and soil-test levels. Many factors including crop root morphology, length of crop growing season, soil chemical and physical characteristics, and crop cultural practices interact to influence the relative crop response to broadcast or band fertilization (Sanchez *et al.*, 1990; Barker *et al.*, Plaster, 1997 and Palm *et al.*, 1997).

Overwhelming evidence indicates that for annual crops, P fertilizers should largely be applied pre-plant. Phosphorus moves to plant roots primarily by diffusion, and young seedlings of most annual crops are very sensitive to phosphorus deficits. Furthermore, yields of some crops often fail to recover fully from transitory phosphorus deficits. Grunes *et al.*, (1958) showed that the proportion of fertilizer P absorbed by corn decreased as the time of application was delayed.

2.7 Effect of Soil Organic Matter on Soil available P

Organic matter in soils increase P availability, first by the formation of organophosphate complexes that are more easily assimilated by plants, second by anion replacement of $H_2PO_4^-$ on adsorption sites, and thirdly the coating of Iron and Aluminum particles by humus to form a protective cover and thus reduce P adsorption (Palm *et al.,*1997). In view of the limited supply of organic inputs and the need for P replenishment, a combination of organic and P-fertilizers should be encouraged, the best option being to maximize amount of P supplied by the organic residues. Positive nutrient interactions may occur due to improved soil physico-chemical properties controlling P availability, induced by the organic resources (Nziguheba *et al.,* 2000).

To really improve soil fertility in the long term, it is necessary to improve the soil structure and to increase the organic matter content of the soil and decreasing nutrient losses (Abunyewa *et al.,* 2007; Bationo, 2004 and Bationo *et al.,* 2006). Incidental phosphorus fertilization in the form of manures, plant and animal biomass, and other natural materials, such as bones, probably has been practiced since agriculture began. Phosphorus is utilized in the fully oxidized and hydrated form as orthophosphate. Plants typically absorb either $H_2PO_4^-$ or HPO_4^{2-} depending on the pH of the growing medium. However, under certain conditions plants might absorb soluble organic phosphates, including nucleic acids (Lopez-Hernandez and Burnham, 1974). A portion of absorbed inorganic phosphorus is quickly combined into organic molecules upon entry into the roots or after it is transported into the shoot (Palm *et al.*,1997; Lopez-Hernandez and Burnham, 1974 and Wild, 1950)

Phosphorus released to the soil solution from the mineralization of organic matter might be taken up by the microbial population, taken up by growing plants, transferred to the soil inorganic pool, or less likely lost by leaching and runoff. Phosphorus, like nitrogen, undergoes mineralization and immobilization. The net P release depends on the P concentration of the residues undergoing decay and the P requirements of the active microbial population (Alexander, 1977). In addition to phosphorus mineralization and immobilization, it appears that organic matter has indirect, but sometimes inconsistent effects on soil P reactions. Lopez-Hernandez and Burnham, (1974) reported a positive correlation between humification and phosphate-sorption capacity. Wild (1950) concluded that the P-sorption capacity of organic matter is negligible. It is observed more commonly that organic matter hinders P sorption, thereby enhancing availability. Humic acids and other organic acids often reduce P fixation through the formation of complexes (chelates) with Fe, Al, Ca, and other cations that react with phosphorus. Studies have shown that organic P is much more mobile in soils than inorganic sources (Hannapel *et al.*, 1964). Interaction between the organic and inorganic P fractions is understood poorly. It is generally presumed that P availability to plants is controlled by the inorganic P fraction, although the contribution of organic P to plant nutrition should not be dismissed (Hanway and Olson, 1980). Inorganic P entering the soil solution, by mineralization or fertilizer additions, is rapidly converted into less available forms. Sorption and precipitation reactions are involved (Watanabe *et al*., 1960).

2.8 Phosphorus Use Efficiency

Phosphorus efficiency can be generally defined as the ability of a crop plant to produce high yield in soil that is limiting in phosphorus supply (Gourley *et al.*, 1994). According to Fohse (1994) phosphorus efficiency may be defined as the ability of a plant to produce a certain percentage of its maximum yield (80% of maximum yield) at low level of soil P.

Phosphorus efficiency can arise in two ways, first being the efficiency with which P is utilized to produce yield, i.e. the amount of P needed in the plant to produce one unit of dry matter, and this is called P utilization efficiency or internal P requirement and is the P concentration in the plant to produce a given percentage of its maximum yield being 90% of maximum yield, (Gourley *et al.*, 2002); 80% of its maximum yield (Fohse *et al.*, 1998). Second, P uptake efficiency of plant is the ability of the root system to acquire P from soil and accumulate it in the shoots (Gourley *et al.*, 1994)

2.9 Economic return from manure and inorganic resources

Studies on economic aspects have indicated high potential of cattle manure and inorganic fertilizers to give higher returns in comparison to conventional farmers' practices. Adiel (2004) reported value cost return (VCR) of 3.3 for manure plus mineral fertilizers, 3.2 for sole mineral fertilizers and 2.4 for farmers' practice of no inputs. Similarly, Mutiro and Murwira (2004) reported positive returns from use of cattle manure in maize production whereby net benefits for no inputs (i.e. control) was \$20.9 ha^{-1} compared with sole manure \$142.8 ha^{-1}, manure plus 20 kg N gave \$244.8 ha^{-1} while manure plus 40 kg N gave \$326.0 ha^{-1} net benefit.

CHAPTER THREE

3.0 MATERIALS AND METHODS

3.1. Description of the Study Area

A Field experiment was carried out in two districts namely Nhamatanda and Báruè along Mozambique's Beira Corridor (MBC) in Sofala and Manica provinces in central Mozambique (Fig. 2). Báruè site lies between 18^{o}13$^{'}$11.20$^{''}$S and 33^{o}13'01.20''E, at elevation 592.2 m above sea level (ASL) while Nhamatanda lies between 19^{o}16$^{'}$00"S and 34^{o}13'00"E at elevation of 55.9 m ASL. The rainy season covers October/November to March/April and maximum rain is received in December, January and February. Minimum and maximum air temperature is 9.4 and 39.4^{o}C for Báruè district, 10.5 and 25.4^{o}C for Nhamatanda district respectively (INE, 2010 and INAM, 2003).

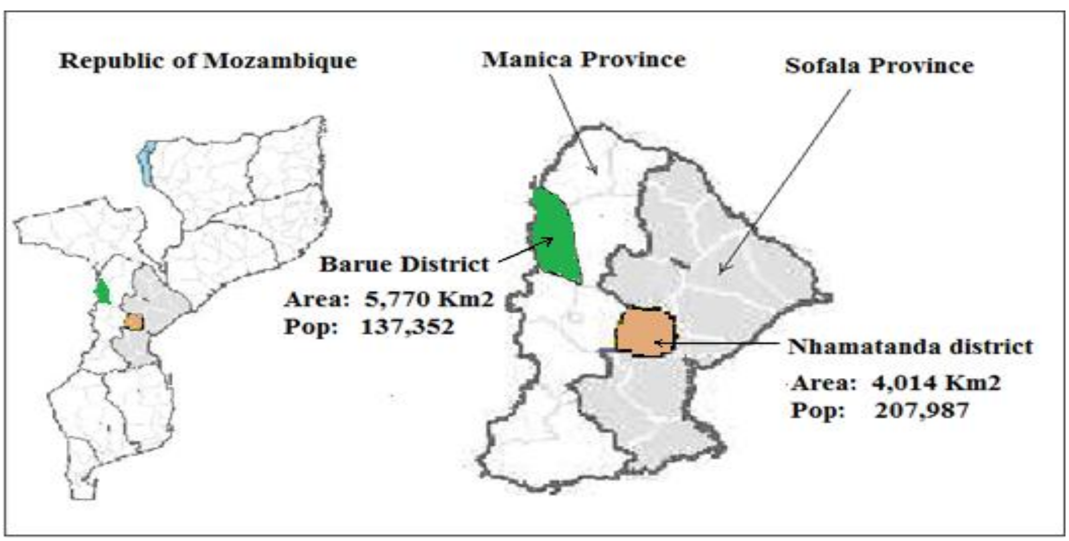

Figure 2**:** Map of the study area

The medium altitude region of central Mozambique ranges between 200 and 1,000 meters ASL located in the Provinces of Sofala and Manica. It has an annual rainfall mean of 1,000-1,200 mm concentrated between November and March. The crop growing period is 120-180 days. The temperature ranges during the crop growing period is 17.5 to 22°C. The region is characterized by good rainfall but low to medium soil fertility. The predominant soil type is Oxisols with low inherent fertility. The risk of soil erosion in some areas is very high due to terrain topography (World Bank, 2006; Isbell, 2002; Maria and Russel, 2006). Due to the tendency of rainfall patterns to be unimodal the experiment was conducted in one season (2011/2012) and replicated in two sites (Nhamatanda and Báruè) in Sofala and Manica provinces respectively.

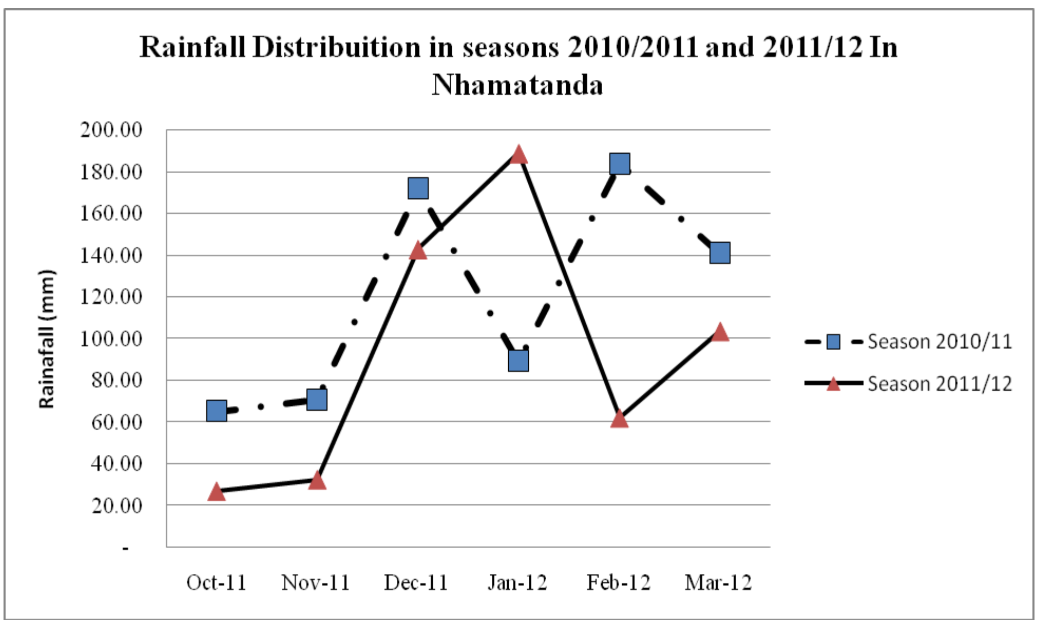

Figure 3: Rainfall distribution in seasons 2010/11 and 2011/12 in Nhamatanda

During the experiment, rainfall was unevenly distributed although total amount recorded was close to the average of the area. The 2011/2012 was a typical example of a year with poor rainfall distribution which affected the outcome of the cropping season (Fig. 3). Rainfall started late October and immediately a dry spell followed (21 days without a drop), this was critical during flowering stage.

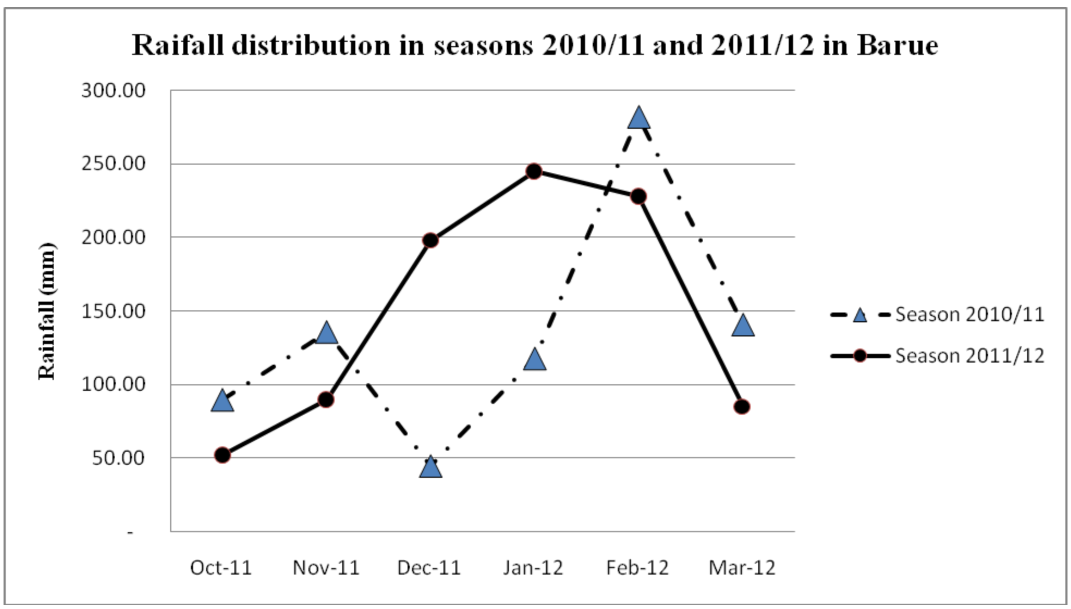

Figure 4: Rainfall distribution in seasons 2010/11 and 2011/12 in Barue site

The monthly rainfall distribution from October 2011 to April 2012 in Barue site is presented in Fig 4. Total rainfall in the growing season was 873.5 mm in Báruè and 1003.7 mm in Nhamatanda, with the greatest distribution (392.9 and 327.8 mm) in February and April 2012 for Báruè and Nhamatanda respectively. The Nhamatanda site received 130 mm more rainfall than Báruè site (Fig. 5).

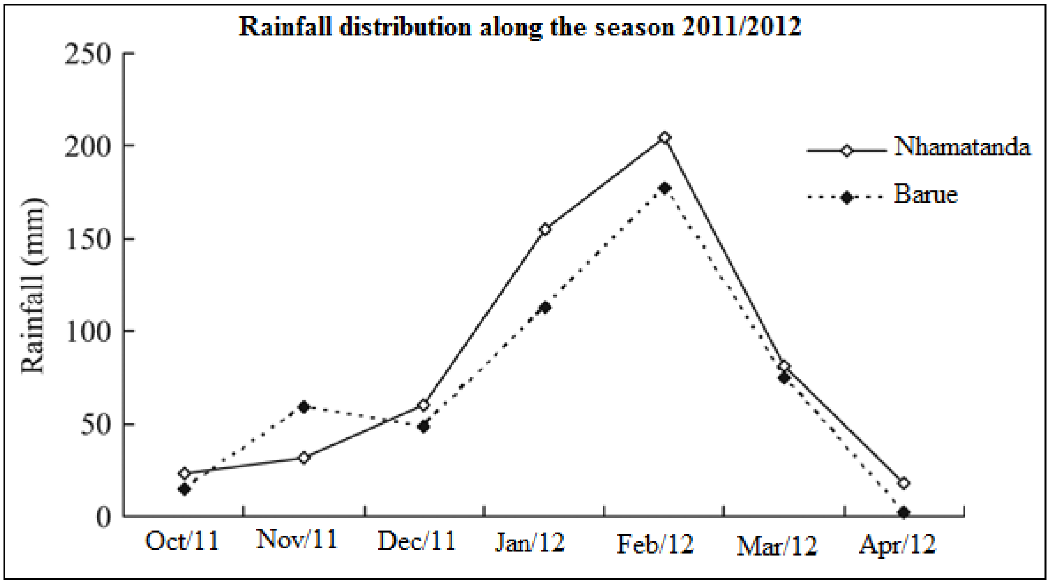

Figure 5: Rainfall distribution in season 2011/12 at Báruè and Nhamatanda sites

3.2 Treatments and Experiment design

Total of nine experimental treatments were established (Table 2). The treatments consisted of combination of three levels of inorganic fertilizers specifically TSP at rate of 0; 25 and 50 kg ha^{-1}(P_2O_5) with three levels of cattle manure at 0; 5 and 10 Mg ha^{-1} (Table 2). The criteria followed for selection of the fertilizers' levels to be combined were based on the recommendations from the Ministry of Agriculture in Mozambique. The trial was conducted using 3^2 factorial design laid out in Randomized Complete Block Design (RCBD) with four replications. The plots were measuring 6.0 m x 5.0 m having a gross size plot of 30 m^2 and plant spacing of 0.8m x 0.3m within the plot.

Table 2: Treatments and combinations of mineral fertilizers with manure

Treatment	Mineral Fertilisers	Manure applied (Mg/ha)
T_1 (M_0F_0)	Control (no fertilizers)	
T_2 (M_0F_1)	TSP (P_2O_5) 25kg.ha^{-1}	
T_3 (M_0F_2)	TSP (P_2O_5) 50kg.ha^{-1}	
T_4 (M_1F_0)		Manure 5ton.ha^{-1}
T_5 (M_1F_1)	TSP (P_2O_5) 25kg.ha^{-1}	Manure 5ton.ha^{-1}
T_6 (M_1F_2)	TSP (P_2O_5) 50kg.ha^{-1}	Manure 5ton.ha^{-1}
T_7 (M_2F_0)		Manure 10ton.ha^{-1}
T_8 (M_2F1)	TSP (P_2O_5) 25kg.ha^{-1}	Manure 10ton.ha^{-1}
T_9 (M_2F_2)	TSP (P_2O_5) 50kg.ha^{-1}	Manure 10ton.ha^{-1}

3.3 Crop establishment and management

The experiment was conducted from October 2011 to April 2012 in two sites. Land preparation commenced in late October 2011 and was done manually at 0-30 cm depth. The planting process was done manually 7 days before the onset of the rains, on 29th November and 6th December for Nhamatanda and Báruè respectively. Hybrid maize variety Pan 67 spaced 0.80 m x 0.30 m, two seeds per hill, placed 3-5 cm away from the fertilizer spots were planted at the beginning and, 10 days after emergence, the seedlings were thinned to one plant per hill, leaving the vigorous plant per hill resulting in a plant population of 41,660 plants ha^{-1} on a gross plot of 30 m^2. Weeding was done twice, first at 21days after planting and the second was done 45 days after planting.

Inorganic P-fertilizer alone, specifically TSP at rate of 25 and 50 kg.ha^{-1} (P_2O_5) was applied by spot placement and incorporated to a depth of 5 to 10cm using a hand hoe in the identified treatment plots (T_2 and T_3). Cattle manure alone at the rate of 5 and 10 Mg ha^{-1} was also spot-placed and incorporated for T_4 and T_7. Treatments assigned for combined application of both inorganic and organic resources (T_5; T_6; T_8 and T_9) mineral fertilizers were mixed with cattle manure and incorporated using a hand hoe.

3.4 Cattle manure preparation

The process involved digging manure out of the unroofed kraal and then heaped under shade that is covered to allow anaerobic decomposition. The manure was kept in the heap for three months from end August to October 2011.

3.5. Soil Sampling and laboratory analysis

Composite soil samples were collected using a soil auger, from the plough layers (0-20 cm depth) of each block just before planting and, within each plot at harvesting to examine the residual effect of treatments on selected soil chemical properties.

Regarding to soil properties, analyzed variables included (1) Soil pH which was determined in soil-water suspension of 1:2.5 (w/v) using pH meter; (2) Total organic carbon determined using digestion method as described by Walkley and Black (Anderson and Ingram, 1993), (3) The available P determined by Bray II method (4) total soil N was measured using Kjeldahl method (Bremner, 1996), (5) CEC was assessed using ammonium saturation method and (6) Potassium(K) was determined after ashing using a flame photometer.

For manure analysis, samples were taken randomly from four different heaps, just one week before field application and were air-dried, ground and passed through a 0.25 mm sieve before analysis. Organic carbon (C), total nitrogen (N), phosphorus (P) and potassium (K) were analyzed using the same procedure as for soil samples described above (Anderson and Ingram, 1993; Weaver *et al.*, 1994).

3.6 Maize yield determination

The biophysical data collected included maize grain, stover weight as well as grain moisture content. The grain and stover yield data were weighted using electronic weighing balance then converted to Mg ha^{-1}. Grain moisture content was determined by moisture meter and then corrected to 13% moisture content. At harvest, 20 plants (shoot system) from each plot were randomly collected from the four central rows to determine the biomass weight. To compare treatment effects on maize grain yield, yields were converted to relative increase compared to the control using a formula below:

$$\text{Yield increase (\%)} = \frac{\text{Yield Treatment} - \text{Yield control}}{\text{Yield control}} \text{ x } 100$$

3.7 Plant Tissue Sampling and Analysis

For measurement of plant characteristics, two edge rows were eliminated as margin effects and data collected were obtained by combining the four center rows at each experimental unit (Ghanbari *et al.*, 2012).

For plant tissue analysis, a total of 20 plants in each plot were randomly sampled 60 days after planting and at grain filling stages. The collected plant samples were washed using distilled water and subjected to air-drying for 72 hours. The dried plant tissues were ground into 0.25 mm size and analyzed for total Nitrogen, available P and total Potassium.

3.8 Fertilizer Use Efficiency

The nutrient use efficiency was computed using Dobermann (2005) equations as follows:

1) Phosphorus Use Efficiency (PUE)

PUE = [Corn grain Yield (kg.ha^{-1})]/[Fertilizer applied (P_2O_5 ha^{-1})]

2) Agronomic Efficiency (PAE):

PAE= [(Yield (Fertilizer)-Yield (control)(kg.ha^{-1})]/[Fertilizer applied (P_2O_5 ha^{-1})]

3) Recovery Efficiency (PRE):
   PRE= [(P Tot Uptake (Fertilized)–(P Tot Uptake) kg^{-1}]/ [Fertilizer applied ((P_2O_5 ha^{-1})]

4) Utilization Efficiency (UE):
UE= [(Corn grain Yield) $kg.ha^{-1}$)]/[(P Total Uptake ($kg.ha^{-1}$)]

3.9. Cost Benefit Analysis

To assess economic returns from integrated use of cattle manure and inorganic fertilizers for smallholder farmers in central Mozambique, a survey was carried out from 9th to 18th April 2012 in the study area. The complementary survey conducted just at harvesting, involved 40 farmers identified randomly from population of 500 farmers assisted by International Fertilizer Development Center (IFDC) in partnership with local Government authority through public extension services. The respondents were categorized into two groups, resource endowed (RE) and resource constrained (RC).

3.9.1 Assumptions for the analysis

A key assumption in this study is that there were changes in yields even where less fertilizer was used. In economic terms, this suggests that the marginal product of the combined applied nutrients was positive, which is not commonly observed in cropping responses for smallholders, but can occur. However, it could have been the case that the manure increased fertilizer use efficiency. Another assumption is that there are no external variables that greatly aggregate the final value. Manure management was not included considering that in central Mozambique its value is underestimated or in general it is considered as waste.

Estimates of the marginal products of *N* multiplied by the output/input price ratio define the value-cost ratio (VCR). Thus, in this study VCR was used to assess the profitability considering that as a tool commonly used in developing countries, especially when costs of labour and other inputs are not available to compute more detailed estimates such as gross margins or returns to labour. Heerink (2005) stated that technically, VCR greater than 2 would imply profitability of fertilizer as long as other inputs were not altered as a result of using fertilizer and is supported by the following formula:

$$VCR = \frac{(\text{Outuput Price kg})}{(\text{Input Price kg})} \text{ x Input response rate}$$

3.10. Statistical Analysis

Analysis of variance (ANOVA) was conducted using the general linear model procedure (GLM) of SAS (SAS institute, 1995), to compare treatment effects on the parameters studied. The least significant differences (LSD) at $P<0.05$ was used to separate the means among the treatments.

CHAPTER FOUR

4.0 RESULTS AND DISCUSSION

4.1 Effect of the treatments on soil properties

4.1.1 Effect of treatments on soil pH

Soil pH at the beginning of the season (Table 3) was at a similar level at 5.11 at Nhamatanda site and 5.13 at Báruè site, classified as medium acid but satisfactory for crops' growth for all treatments. The difference between treatments was significant at $P<0.05$ for T_9 at both sites compared to the rest of treatments (Table 4). The increase on soil pH was attained to the addition of manure at the highest rate that probably acted as soil buffer. At the harvest stage, the increase of soil pH was observed in the plots fertilized with manure at rate of 10 Mg ha^{-1} followed by manure at 5 Mg ha^{-1} (Table 4).

Table 3: Initial soil properties at the study sites and manure analyses

Treatment	pH (H_2O)	Element content				Soil texture (%)			
		%N	% Ca	P (ppm)	%K	Sand	Silt	Clay	Soil Class
Nhamatanda Site									
Soil	5.11	0.17	3.5	6.25	0.20	52	22	26	Sandy-Loam
Manure	6.2	2.19	2.25	0.87	0.72	-	-	-	-
Barue Site									
Soil	5.13	0.16	3.55	6.00	0.26	68	14	18	Sandy-Loam
Manure	6.2	2.19	2.25	0.87	0.72	-	-	-	-

Table 4: Effect of the treatments on the soil chemical properties

Treatment	pH final		Total N (%)		Available P (ppm)		K (me %)	
	Barue	Nhamatanda	Báruè	Nhamatanda	Báruè	Nhamatanda	Báruè	Nhamatanda
T_1	5.13de	5.11e	0.16b	0.17b	6.25f	6.00e	0.73a	0.64bc
T_2	5.13de	5.13d	0.16b	0.16b	6.58f	9.42de	0.69a	0.45c
T_3	5.13de	5.13d	0.18ab	0.24ab	9.64de	10.42cd	0.45a	0.55bc
T_4	5.14cd	5.16bc	0.17ab	0.23ab	11.58cde	11.83bcd	0.43a	0.81ab
T_5	5.15c	5.15bc	0.19a	0.25ab	12.42cd	12.83bcd	0.66a	0.65bc
T_6	5.15c	5.16bc	0.23ab	0.24ab	14.33c	11.03cb	0.57a	0.55bc
T_7	5.17ab	5.17ab	0.26ab	0.25ab	17.58cb	18.51bc	0.56a	0.57bc
T_8	5.18a	5.17ab	0.38ab	0.23ab	18.83b	19.51b	0.63a	0.62bc
T_9	5.18a	5.19a	0.19a	0.32a	31.00a	32.58a	0.60a	0.97a
LSD	**0.151**	**0.208**	**0.2**	**0.1**	**14.41**	**18.33**	**0.36**	**0.31**

Note: Means in a column followed by the same letter or letters are not significantly different at $P<0.05$

Generally, results show that soil pH improvement was not significantly at $P<0.05$ under experiment treatments compared to the control. In both sites, the pH improvement was ranked, from the highest to the lowest as: Manure + TSP >Manure alone >sole TSP >Control. A combination of cattle manure with P-fertilizer gave the highest soil pH increase of 3.34% followed by manure alone at 2.9% and P-fertilizers alone at 1.2% compared to the control. Studies have shown that use of cattle manure either separately or combined with mineral fertilizers improve soil pH (Kanonge *et al.,* 2009). This was confirmed in this study though the levels of variations being statistically insignificant. In fact it could be said that it helped acidity reduction in the study sites. These ranges of pH variation were expected considering that changes on soil pH due to application of cattle manure might be observed in long term experiment.

4.2.2 Effect of treatments on soil available P

Result show that T_9 recorded levels of available P significantly higher compared with the rest of treatments at $P<0.05$ (Table 5). The LSD in Nhamatanda was 18.33 while in Báruè was 14.41 as well as when compared to the initial levels of Phosphorus in the soil at the harvesting stage. The overall sequence order followed same trend as soil pH: Manure + TSP >sole Manure >sole TSP >Control. Combined application of P-fertilizers with cattle manure recorded an increase of available P, having 233% over the control, followed by sole Manure with 167% over the control and sole P-fertilizer 47%. The effect of mineral fertilizers application on total P was minimum compared to the rest of the treatment but still higher over the control. It is likely that the difference in manure quantity resulted in better levels of available P for T_9 considering that the amount applied was double compared with T_6. The difference in P values could also be attributed to other factors such as better rainfall distribution specifically in Nhamatanda site what could improve soil water holding capacity, release patterns by the organic residues in the soil synchronized with the nutrients being readily available from the fertilizers. Cordell *et al.* (2009) stated that manure is considered a renewable alternative source of P, currently providing about 15 million Tons of P per year to farming systems globally. Manure enhances P availability by fixing sesquioxides reducing fixation of P. Sanginga and Woomer (2009) stated that manure increases soil organic matter and delivers P over a long time though the amount of P in it is low. The processes responsible for better response from the integration of organic and inorganic P sources are not yet clearly established, mainly because of the complex nature of P dynamics in the soil. However, there are suggestions that the interactions resulting from this integration reduces P-sorption capacity of the soil (Palm *et al.*, 1997), thereby increasing P availability to plants.

4.2.3 Effect of treatments on soil total N

Total N in the 0–25 cm depth at the start of study averaged 0.16% and 0.17% for Báruè and Nhamatanda respectively. The results from soil analysis, after treatments application were 0.40% for treatment having P-fertilizers combined with manure, 0.34% for sole manure and 0.37 sole P-fertilizers. The total N at harvest changed from 0.16 to 0.19% in Báruè and from 0.17 to 0.21 % in Nhamatanda though the difference was not significant at $P<0.05$. This was expected considering the level of N contained in manure. The higher rate of manure probably improved the availability of other nutrients due to base cations and micronutrients and the soil physical properties.

4.3 Maize yield performance

4.3.1 Effect of treatments on maize grain yield

Overall grain yield at Nhamatanda and Báruè was 2.08 Mg ha^{-1} accounting for 3 times over the control (0.73 Mg.ha^{-1}) and 73% above the average yield of 1.2 Mg ha^{-1} recorded in 2010 in the country (MINAG, 2012). The difference between the sites was not significant although Nhamatanda registered 4% higher grain yield than Báruè at 2.12 Mg ha^{-1} compared to 2.04 Mg ha^{-1} (Table 5). At both sites, T_9 showed significant difference between the means with the rest of treatments at $P<0.05$. The highest grain yield was registered in T_9 at 3.75 Mg ha^{-1}.

In general, maize grain yield were higher in treatments that cattle manure was combined with P-fertilizers compared to the control and the trend can be extended when compared to the grain average yield of 1.2 Mg ha^{-1} recorded in the country in season 2010/2011.

Table 5: Maize grain yield performance at Nhamatanda and Báruè sites

Nutrient sources	Maize grain yield ($Mg.ha^{-1}$)	
	Nhamatanda	Báruè
T_1 – Control	0.80**h**	0.65**h**
T_2 - TSP (P_2O_5) 25 $kg.ha^{-1}$	1.83**ef**	1.66**ef**
T_3 - TSP (P_2O_5) 50kg.ha^{-1}	2.02**cd**	2.04**cd**
T_4 - Manure 5ton.ha^{-1}	0.92**fg**	0.85**fg**
T_5 - TSP (P_2O_5) 25 $kg.ha^{-1}$ + Manure 5ton.ha^{-1}	2.35**c**	2.55**c**
T_6 - TSP (P_2O_5) 50kg.ha^{-1} + Manure 5ton.ha^{-1}	3.13**b**	2.97**b**
T_7 - Manure 10ton.ha^{-1}	1.26**f**	1.11**f**
T_8 - TSP (P_2O_5) 25 $kg.ha^{-1}$ + 10ton Manure.ha^{-1}	2.93**b**	2.89**b**
T_9 - TSP (P_2O_5) 50kg.ha^{-1} + 10ton Manure.ha^{-1}	3.88**a**	3.62**a**
LSD	**0.32**	**0.58**

Note: Means in a column followed by the same letter or letters are not significantly different at $P<0.05$

The obtained results are in close agreement with those found by Kanonge *et al*. 2009, who found that application of phosphorus in combination with manure significantly increased grain and stover yield of maize due to immobilization of other nutrients that would otherwise be lost through leaching and positive physical effects associated with improved soil structure. Addition of organic residues also enhances microbial pool sizes activity. These chemical and biological processes influence both availability and utilization of nutrients. The bars in the graph bellow shows that there were not differences between the sites.

Results from this study indicate that cattle manure combined with inorganic fertilizers affected maize grain and stover yield in the same way (Table 5). Higher maize grain yield were recorded on plots where cattle manure and P-fertilizers were combined compared with plots where manure and P fertilizers were applied solely. Maize without inputs (i.e. control) produced the lowest grain yield of 0.65 Mg ha^{-1} and 0.80 Mg ha^{-1} in Báruè and Nhamatanda sites respectively. This concur with Adiel (2004) who reported higher maize grain yields under combined incorporation of organic resources with mineral resources in central highlands of Kenya. Vanlauwe *et al.* (2004) reported that combination of organic and mineral nutrient sources ensures the synchronization between nutrients release and plant uptake, therefore nutrient use efficiency that in most cases implies yield increase.

Cattle manure combined with TSP consistently increased the grain yields significantly ($P<0.05$) compared with the control (Table 7 and Table 8). In both sites, overall sequence was in order of $T_9>T_6>T_8>T_5>T_3>T_2>T_7>T_4>T_1$. Application of cattle manure alone at rate of 5 Mg ha^{-1} (T_4) produced maize grain yields of 0.85 and 0.92 Mg ha^{-1} in Báruè and Nhamatanda respectively which represent an increase of 31% and 15% respectively above the control. The same trend was followed with application of cattle manure alone at rate of 10 Mg ha^{-1} (T_7) where grain maize yield of 1.26 and 1.11 Mg ha^{-1} were obtained, representing an increase of 71% and 56% for Báruè and Nhamatanda respectively. The difference was not significant compared to the control at $P<0.05$.

Addition of P fertilizer (TSP) alone at rate of 25 kg ha^{-1}(P_2O_5) T_2 significantly increased grain yields to 1.66 and 1.83 Mg ha^{-1} ($P<0.05$) in Báruè and Nhamatanda sites respectively. This represents a maize grain yield increase of 142% over the control while, TSP alone at rate of 50 kg ha^{-1}(P_2O_5) T_3 recorded grain yield of 2.03 Mg ha^{-1} representing an increase of 183% over the control. Grain yield was significantly different at $P<0.05$ between T_2 and T_3. This was expected, considering that the two treatments had different levels of P-fertilizers.

Application of manure alone at 5 $Mg.ha^{-1}$, did not produce significantly higher grain yield (0.89 Mg ha^{-1}) at ($P<0.05$) compared to the control plots. The trend was different with manure at 10 Mg ha^{-1} that produced significantly higher grain yield (1.19 Mg ha^{-1}) at ($P<0.05$) compared to the control plots.

The consistently larger maize yield for Nhamatanda site is most probably related to the more favorable conditions including the rainfall distribution pattern as well as management factors of early planting date as it was stated earlier.

Murwira *et al*. (2001) reported 2.5 Mg ha^{-1} maize yield when applying 3 and 6 Mg ha^{-1} of amended pit and heap treated manure. It is striking they did not explain the responses in terms of nutrient supply. In high rainfall areas high responses to manure have also been reported (Waddington and Karigwindi, 2004). Results from this study concur with those reported by Murwira *et al* (2001 and Murwira *et al*., 2003).

The results from this study have shown that the yield responses were significantly related to P effects, as the soils seem to be P limited considering the soil pH from the soil analysis that was acidic. There were no studies carried out in the central Mozambique that could be used to compare or relate the results from this study. The increase in maize grain yield with the use of organic materials has also been observed by Silva *et al*. (2004 and Chivenge *et al.* 2009). This study concurs with previous findings on the role of manure and chemical fertilizer in increasing grain yield of maize. The results showed that manure and chemical fertilizer separately can increase grain yield of maize but a combination of them has more effect on increase in grain yield. Silva *et al*. (2004) found that direct effects of cattle manure combined with mineral fertilizers on corn increased green grain yield in two corn cultivars. Cattle manure also increased water retention and availability, and phosphorus, potassium, and sodium contents in the soil layer (0 to 20 cm) (Patidar and Mali, 2002).

For instance, experiments conducted in western Kenya have demonstrated that higher yields can be obtained when organic residues had been incorporated in combination with mineral fertilizers (Gachengo *et al.*, 1999 and Palm, 1996). Gachengo (1996) showed that cattle manure can increase maize yields by one and half times higher than without manure input. Furthermore, manure was found to reduce P sorption capacity of the soil and increase crop yields particularly in P limited soils by making P available to crops (Nziguheba *et al.*, 2000; and Palm *et al.* 2000). The result from soil analysis showed that both sites were deficient in P, the increased yield in manure treatment was probably related to the combined effect of rapid P mineralization and their increased availability to crops. Phosphorus availability might have also increased through reduction of P sorption by manure (Nziguheba *et al.*, 1998). Given the substantial increase in the amount of P added with manure alone compared to the control plots, the results suggest that the soils can supply the relatively small demand of P required to give these relatively small maize yields as longer as organic matter in added.

These results contradict with Gitari and Friesen (2001), who stated that the use of combined organic/inorganic soil amendments produce similar maize grain yield to those obtained where inorganic sources are used alone. A synchrony has undesirable effects on the crops because nutrients are released when their demand by crops is low. The benefits of such residues to the crop may be through the long-term build-up of N rather than the direct use of N from the decomposing residues (Palm, 1997). The benefits of manure providing other nutrients are probably also important in the central Mozambique with Oxisols showing deficiency on phosphorus. Our results also indicate that the current blanket recommendations of application of compound fertilizers 12-24-12 at 50 kg N ha $^{-1}$ are inappropriate for the acidic soils of central Mozambique and that future recommendations for fertilizers and manure should take into account the wide variability in potential yields with more attention to P fertilizers. The response of crop to added P was generally affected by soil factors among them the pH being the most determinant. Thus, poor efficiency of applied P recorded in T_1 may partially be attributed to acidic nature of soils of the study area that favours P fixation by revering the applied P to less available for plant growth. Efthimiadou *et al.* (2010) also found that combined application of organic and inorganic resources enhances soil quality and sustainability of maize.

4.3.2 Effect of treatments on maize stover yield Performance

Nhamatanda site had the highest stover yield average over the two sites registering 10.38 Mg ha^{-1} against 10.30 Mg ha^{-1} for Báruè (Table 6). The average stover yield was 57% above the control. P fertilized plots (T_5) at rate of 25 kg (P_2O_5) ha^{-1} in combination with cattle manure at rate of 5 Mg ha^{-1} produced 9.24 Mg ha^{-1} and 8.87 Mg ha^{-1} in Báruè and Nhamatanda respectively, which represented 91% increase over the control for both sites. The trend was similar for T_6 where P fertilizers at rate of 50 kgha^{-1} (P_2O_5) applied in combination with manure at rate of 5 Mg ha^{-1} produced 10.02 Mg ha^{-1} and 9.43 Mg ha^{-1}, representing an increase of 107 and 103% for Báruè and Nhamatanda respectively. The yields were not significantly different at P<0.005).

Table 6: Maize stover yield performance at Nhamatanda and Báruè sites

Nutrient sources	Stover yield (Mg.ha^{-1})	
	Nhamatanda	Báruè
T_1 – Control	4.83**h**	4.64**hi**
T_2 - TSP (P_2O_5) 25 kg.ha^{-1}	5.48**ef**	5.35**fg**
T_3 - TSP (P_2O_5) 50kg.ha^{-1}	5.94**f**	5.70**f**
T_4 - Manure 5ton.ha^{-1}	5.15**fg**	4.83**h**
T_5 - TSP (P_2O_5) 25 kg.ha^{-1} + Manure 5ton.ha^{-1}	9.24**d**	8.87**d**
T_6 - TSP (P_2O_5) 50kg.ha^{-1} + Manure 5ton.ha^{-1}	10.02**c**	9.43**bc**
T_7 - Manure 10ton.ha^{-1}	7.53**e**	7.09**e**
T_8 - TSP (P_2O_5) 25 kg.ha^{-1} + 10ton Manure.ha^{-1}	10.11**ab**	9.84**b**
T_9 - TSP (P_2O_5) 50kg.ha^{-1} + 10ton Manure.ha^{-1}	10.38**a**	10.30**a**
Mean	**7.76**	**7.29**
LSD	**0.32**	**0.58**

Note: Means in the column with the same letter or letters are not significantly different at P<0.05

Integrated application of P fertilizers at rate of 25kg (P_2O_5) ha^{-1} with cattle manure produced 10.18 Mg ha^{-1} and 9.84 Mg ha^{-1} in Nhamatanda and Báruè respectively, which represented 111 and 112% increase over the control for Báruè and Nhamatanda respectively. The same trend was followed by treatments having combination of P fertilizers at rate of 50 kg ha^{-1} (P_2O_5) with cattle manure at rate of 10 Mg ha^{-1} that produced 10.38 and 10.30 Mg ha^{-1} for Nhamatanda and Báruè respectively, which corresponds an increase of 111% and 121% for Nhamatanda and Báruè respectively over the control.

Hence, in terms of stover performance, the combination of manure with TSP (T_9) was significantly higher than all the other treatments at $P<0.005$ in both sites. The higher yields could be explained by the combined response to phosphorus applied and available water from rainfall during the growing season whereby Nhamatanda received much rainfall than Báruè site.

This probably could be attributed to the rainfall distribution that affected particularly Nhamatanda where crop did not receive rainfall for a period of 21 consecutive days that affected the vegetative growth which indeed partially explain the poor yield obtained (Fig. 4). Thus, maize stover without inputs (i.e. control) produced 4.83 Mg ha^{-1} and 4.64 Mg ha^{-1} in Báruè and Nhamatanda respectively.

4.4 Fertilizer Use Efficiency

In general, obtained result showed that combined application of mineral fertilizers with manure significantly increased phosphorus use efficiency (PUE), phosphorus agronomic efficiency (PAE), phosphorus recovery efficiency (PRE) and utilization efficiency (UE) compared to treatments without organic resources.

4.4.1 Phosphorus Use Efficiency (PUE)

The highest PUE in Nhamatanda site was recorded in T_9 at 99% and the lowest was recorded in $T_{2.}$ The same trend was recorded in Báruè site where T_9 recorded 100% while T_2 recorded 12%. Among the two sites, the highest values of PUE were recorded in Nhamatanda site. The combination of mineral P fertilizers with organic fertilizer (10 $Mg.ha^{-1}$ of Manure) in both sites achieved the highest PUE in comparison to all the treatments with or without manure (Table 8). Application of P fertilizer alone decreased PUE of crop by 56.4% in comparison to the highest PUE. The highest PUE was achieved with application of cattle manure combined with P fertilizer, because nutrient supply for crop demand is balanced.

4.4.2 Phosphorus Agronomic Efficiency (PAE)

For treatment having cattle manure combined with P-fertilizers, PAE values were 86 and 72.6 $g.g^{-1}$ T_9 and T_8respectively while TSP without manure gave 43.6 g g^{-1} in Nhamatanda site. In Báruè the treatment followed the same trend but the values were relatively low compared to Nhamatanda. The highest PAE was recorded in T_9

at 86.8 g g^{-1} in Báruè and the lowest was recorded in T_2 at 24.2 in Nhamatanda. Effects of separate or individual and combined applications of organic and inorganic materials to soils have been studied rather extensively and the results are complex. But, it appears for certain, that the application and method attributes are the driving forces towards basic processes in soils such as nutrient mineralization and release and the agronomic efficiency of added materials on crop yields. As in many studies we have considered mainly the immediate or one seasonal effect of organic and mineral resources on maize yield.

4.4.3 Phosphorus Recovery Efficiency (PRE)

The total P recovered at the end of the experiment was 0.36% of the P applied in the sole P fertilizer treatments.

The combination of cattle manure with P fertilizers resulted in larger values of P recovered compared to the pure fertilizer treatments, although the differences were not statistically significant. The highest PRE was recorded in T_9 at 0.48 while T_2 still recorded the lowest value among the all treatments in both sites (0.32). Comparing the two sites, the highest value was recorded in Nhamatanda site.

One of the major constraints to a proper management of fertilizers in small scale farming systems is the lack of information on limiting nutrients. Phosphorus supplied by combination mineral and organic resources increased the PR index compared to the control treatments. Thus, combination proved to be a more efficient P source than fertilizers by providing larger P recovery compared to sole fertilizers.

4.4.4 Use Efficiency (UE)

In terms of nutrient use efficiency, as the previous parameters, the trend was similar where T_9 recorded the highest value of 99.2 in Nhamatanda while T_2 recorded the lowest value and Nhamatanda still being the site with the highest values between the two sites (Table 8). Differences in phosphorus use efficiency from P added in the different treatments were not statistically significant. However, P use efficiency after the application of treatments from manure applied in combination with mineral P was the higher compared with treatments having sole mineral fertilizers.

Table 7: Effects of treatments on grain elemental content and P efficiency

		Nhamatanda								Barue							
Treatment	Cod	Grain Yld (kg/ha)	P content (%)	Total P uptake (kg/ha)	Applied (P_2O_5 kg/ha)	PUE	PAE	PRE	UE	Grain Yld (kg/ha)	P content (%)	Total P uptake (kg/ha)	Applied (P_2O_5 kg/ha)	PUE	PAE	PRE	UE
Control	T_1	800	0.27	9.17	0	-	-	-	-	650	0.289	8.96	0	-	-	-	-
TSP (P_2O_5) 25kg ha^{-1}	T_2	1,830	0.36	25.4	50	33.4	24.2	0.32	28.60	1,660	0.288	25.7	50	32	26.4	0.33	30.10
TSP (P_2O_5) 50Mg ha^{-1}	T_3	2,020	1.42	28.84	50	43.6	30.4	0.39	43.60	2,040	1.15	23.85	50	42.6	33.6	0.3	42.60
Manure 5 Mg ha^{-1}	T_4	920	0.25	11.25	0	-	-	-	-	850	0.095	12.3	0	-	-	-	-
TSP (P_2O_5) 25kg ha^{-1} +Manure 5 Mg ha^{-1}	T_5	2,350	0.45	23.14	50	50.6	37.4	0.28	50.60	2,550	0.109	20.31	50	53.4	44.4	0.23	53.40
TSP (P_2O_5) 50kg ha^{-1} +Manure 5 Mg ha^{-1}	T_6	3,130	0.85	26.74	50	85.8	72.6	0.35	85.80	2,970	0.684	25.1	50	83	74	0.32	83.00
Manure 10 Mg ha^{-1}	T_7	1,260	0.37	15.42	0	-	-	-	-	1,110	0.096	15.12	0	-	-	-	-
TSP (P_2O_5) 25kg ha^{-1} +Manure 10 Mg ha^{-1}	T_8	2,930	0.73	24.87	50	81.8	68.6	0.31	81.80	2,890	0.468	22.19	50	77.8	68.8	0.26	77.80
TSP (P_2O_5) 50kg ha^{-1} +Manure 10 Mg ha^{-1}	T_9	3,380	1.20	33.16	50	99.2	86	0.48	99.20	3,620	1.245	30.98	50	95.8	86.8	0.44	95.80

4.5 Cost Benefit Analysis

This study analyzes the cost-benefit return through Value Cost Ratio (VCR) to determine whether or not the combined application of manure with inorganic fertilizer will be a cost beneficial way to manage nutrients for small scale farmers in central Mozambique.

This cost-benefit analysis was based on a small-sized farm with fertilizer costs comprising a large portion of their variable costs. Therefore, results of this study may not apply to a large produce farm that has relatively high fertilizer costs. Added costs included all the expenses for buying, collecting, transporting and applying the inputs, while the added benefits referred to the gain obtained by selling the harvested maize grain at the local market.

The economic returns from the application of each treatment were calculated based on the partial budgeting, which included price of input (mineral fertilizers only), labour cost and price of output (Fig. 6). Farmers, as with most business owners, are often looking for ways to lower their costs in order to become more profitable. As the cost of inorganic fertilizers continues to rise, it is becoming more obvious that a good way to increase a farm's profitability is to practice better soil nutrient management. The labor was valued at the local wage rate of $ 60.00 per month. Monetary values were converted to USD ($) at the exchange rate of 29 MZM=$ 1 (April, 2012).

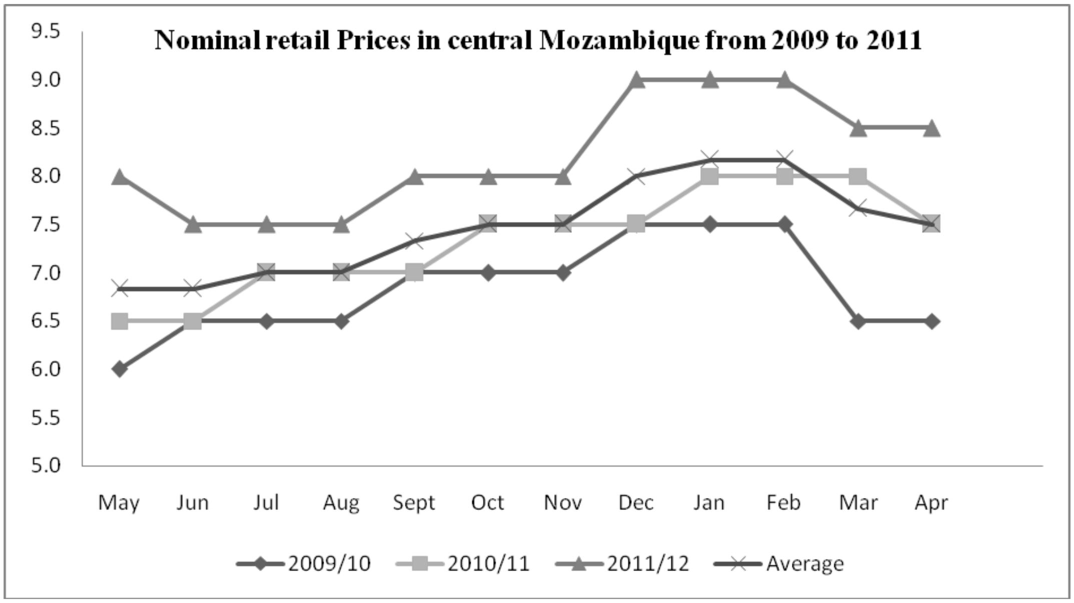

Figure 6: Nominal retail price of maize from 2009/10 to 2011/2012.

Source: MINAG/DNSA/RA 2011/2012

Table 8: Overall Value Cost Ratio (VCR)

Treatment	Cod	Fert Qty (kg)	Yield (Mg/ha)	Fertilizer Price (MZN)	Fert Cost (MZN)/ha	Price of P (MZN)	Nutrient (P) used/ ha	Fertlizer response rate	VCR
Control	T_1	-	-	-	-	-		-	-
TSP (P_2O_5) 25kg ha^{-1}	T_2	55	1,745	2,200	2,398	95.65	25.07	69.61	5.80
TSP (P_2O_5) 50kg ha^{-1}	T_3	110	2,030	2,200	4,796	95.65	50.14	40.49	3.40
Manure 5 Mg ha^{-1}	T_4	-	-	-	-	-		-	-
TSP (P_2O_5) 25kg ha^{-1} +Manure 5 Mg ha^{-1}	T_5	55	2,450	2,200	2,398	95.65	25.07	97.73	8.20
TSP (P_2O_5) 50kg ha^{-1} +Manure 5 Mg ha^{-1}	T_6	110	3,050	2,200	4,796	95.65	50.14	60.83	5.10
Manure 10 Mg ha^{-1}	T_7	-	-	-	-	-		-	-
TSP (P_2O_5) 25kg ha^{-1} +Manure 10 Mg ha^{-1}	T_8	55	2,910	2,200	2,398	95.65	25.07	116.07	9.70
TSP (P_2O_5) 50kg ha^{-1} +Manure 10 Mg ha^{-1}	T_9	110	3,750	2,200	4,796	95.65	50.14	74.79	6.30

NB: Rate $1 (USD) = 29 MZN

Based on both either treatment with or without organic resources it can be deduced that farmers preference for TSP (P_2O_5) 50 kg ha^{-1} as reference fertilizer can be deceiving. Value Cost Ration analysis was based on the conservative maize price of 8.00 MZN ($ 0.28 USD) which was offered to maize farmers in the region in season 2010/2011 as well as at the end of study (April 2012) (Fig 6). However considering that fertilizer prices were constant, the overall sequence order from the highest to the lowest for fertilizer response in both sites was $T_8 > T_5 > T_9 > T_2 > T_6 > T_3$. The highest VCR was recorded in T_8 TSP (P_2O_5) 50 kg ha^{-1} + manure 5 Mg ha^{-1} at 9.7 and the lowest VCR was obtained in the same treatment without cattle manure at 3.4 and the overall sequence order from the highest to the lowest was $T_8 > T_5 > T_8 > T_2 > T_6 > T_3$ (Table 8). This also confirms our earlier hypothesis that integrated use of manure and inorganic fertilisers is more profitable for smallholder farmers than manure or inorganic fertilisers separately.

Considering the previous studies, VCR more than 2 is considered providing viable economic consideration, the results shows that combination of cattle manure with P fertilizers in central Mozambique were economically viable than applied separately. The integration of fertilizers with organic inputs has been regarded as a more profitable alternative in low input systems, countering the large costs of fertilizers (Janssen, 1994). This study confirmed that the integration of P-fertilizers with cattle manure can be an alternative to the limited use of fertilizers.

It is also important to consider that addition of manure does not constitute an added input of P in the system but rather enhances the reutilization of P already in the system. For soil P replenishment, an addition of P-fertilizers remains unavoidable. Substantial maize yields and economic returns were obtained from combination of cattle manure at rate of 5 ton ha^{-1} with TSP at rate of 50 kg ha^{-1}. This study showed that organic resources can play an important role in supplying P to a growing crop. However, considering the constraints related to the availability of cattle manure and the need for soil P replenishment, a combination of manure and P-fertilizers will be a more sustainable strategy, the goal being to maximize the proportion of P in the combination.

CHAPTER FIVE

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1. Conclusions

The results indicated that to achieve maximum yields, farmers must apply both organic and inorganic P fertilizers. Nevertheless, optimal organic to inorganic P combination was close to the 50kg (P_2O_5) ha^{-1} with manure at rate of 5 ton ha^{-1}. However, combination of 50kg (P_2O_5) ha^{-1} as TSP and cattle manure at 10 Mg ha^{-1} showed low performance economically compared to the same treatment when cattle manure is at rate of 5 Mg ha^{-1}. Thus, combination of TSP with cattle manure at rate of 5 Mg ha^{-1} is therefore recommended for optimum maize production. Treatments containing organic resources at 10 Mg ha^{-1} combined with mineral resources at 50kg (P_2O_5) ha^{-1} (T_9) performed better on improvement of soil pH, available P as well as total Nitrogen than sole mineral sources.

From the result of the study, cattle manure at 5 Mg ha^{-1} combined with mineral P fertilizer at 50kg (P_2O_5) ha^{-1} (T_6) improved fertilizer use efficiency compared to treatments without organic resources. Thus incorporation of mineral resources combined with manure is cost beneficial for smallholder farmers in central Mozambique. This was clearly explained by significantly higher values of Value Cost Ratio (VCR) obtained in all treatment integrating manure and mineral fertilizers compared to the control (no inputs) and sole use of inorganic fertilizers.

5.2 Recommendations

To improve the productivity and profitability of maize farming in smallholder systems in the acidic soils of Beira corridor of Mozambique, this study recommends use of local available organic resources such as cattle manure in combination with mineral resources. The study recommends use of 50 kg ha^{-1} (P_2O_5) when applied in combination with 5 Mg ha^{-1} of cattle manure (T_6) or in combination with 10 Mg ha^{-1} of cattle manure (T_9).

The fact that increased grain yields were observed in treatments where manure was applied in combination with mineral resources raises more research questions. For example, how to take advantage of already existing manure on improvement of maize productivity? There is need to take advantage of already plenty of manure in many farms for the improvement of maize productivity in central Mozambique.

For increased fertilizer use efficiency, the public extension service should promote combination of TSP with manure particularly in central Mozambique where soil are becoming acidic as alternative option to increase maize productivity resulting in increased income for small-scale farmers turning the agricultural activity more sustainable.

Financial constrained farmers, particularly those who cannot afford fertilizers may be encouraged to use cattle manure already available to improve maize yield while improving the soil nutrient status turning the agricultural activity more cost beneficial. Farmers could gain a significant amount of extra income as they can reduce costs on fertilizer through cattle manure that already available contributing to a growth in exports.

There are food security benefits to farmers when manure and fertilizer are combined and used in small rates. However, there is still need to model the results over a long period to see if the technologies are sustainable in the long run.

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APPENDICES

Appendix I: Experiment details

#	Item	Details
1	Row length per plot	8.0 m
2	Number of rows per plot	6
3	Row to row spacing	0.80 m
4	Plant to plant spacing within the row	0.40 m
5	Gross plot size	30 m^2 (6.0m x 5.0 m)
6	Net plot size	18 m^2 (5.4 m x 3.2 m)
7	Gross area required per site	2,600 m^2 (64.0 m x 40.0 m)
8	Net area required per site	900 m^2
9	Number of plots per site	36
10	Gross number of plants	4,320
11	Net number of plants	2,592

Appendix II: Input details

#	Itime	Recommended dosage/ha	Size of the Site (sqr m)	Total amount	Unit	Timing	Amount need per site	T1	T2	T3	T4	T5	T6	T7	T8
1	Manure (540 kg/site)	10000	1,080	2,000	kg	1	540	0.0	0.0	0.0	0.0	135	135	135	135
2	Fertilizer (Urea 46%N)	25	1,080	25	kg	2	4.9	0.0	0.41	0.82	1.23	0.0	0.41	0.82	1.23
3	Fertilizer Diammonium phosphate (DAP 18%N + 46%P)	50	1,080	100	kg	1	12	0.0	1.0	2.00	3.0	0.0	1.0	2.00	3.00
4	Insecticides Basudin 60 EC/Cypermethrine	200 ml/ha	1,080	1,000	ml	4	691.2	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6
5	Insecticides Thiodan 60 EC/Lambdacyhalotrin	200 ml/ha	1,080	1,000	ml	4	691.2	21.6	21.6	21.6	21.6	21.6	21.6	21.6	21.6

Appendix III: Field Management plan

#	Field operation	Days Before and After Planting		Means
		Plantinting	Germination	
Land Preparation				
1	Plough/ Tillaage	-30		Manual
2	Furrowing	-2		Manual
3	Fertilizer application/broadcasting	-1		Manual
Planting				
4	Planting (spacing 80×30 cm)	0		Manual
Crop Management				
5	Germination (42.600 plants/ha)	7		Manual
6	Weeding (1) and thinning		15	Manual
7	Pesticide application (1)		15	Manual
8	Pesticide application (2)		30	
9	Weeding (2)		35	Manual
10	Fertilizer application/top dressing		36	Manual
11	Pesticide application (3)		40	Manual
Harvesting				
12	Harvest (3,584 plants)		120-130	Manual
13	Transport and weighing		120-130	Manual

Appendix IV: Experiment layout