EFFECTS OF PHOSPHORUS AND ORGANIC NUTRIENT SOURCES ON IMPROVEMENT OF SOIL FERTILITY AND MAIZE (*Zea mays* L.) PRODUCTION ON SELECTED SOILS IN KENYA.

By

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DECLARATION AND RECOMMENDATION

Declaration:

I declare that this is my original work and has not been previously presented in this or any other University for any Degree.

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DEDICATION

This Thesis is dedicated to my late father, Benjamin, children Ebby, Edith, Ken, Joy, Stephen and Collins.

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ABSTRACT

Maize yield in Kenya is low primarily due to decline in soil fertility. Inorganic fertilizers are however, too expensive and cause environmental pollution. Organic manures are low cost therefore, have great potential in increasing yield. The quality, quantity and placement methods of these diverse materials is however, not known. The supply of organic materials on farms is also insufficient, thus the need to develop other organic resources. Pymarc is a by-product of pyrethrum processing that could be used as a fertilizer. The use of organic manure as P source is limited by the low P content. Supplementation with inorganic P fertilizer is therefore required. A series of pot and field experiments were conducted in 2003 and 2004 to determine NPK release pattern from Pymarc and the optimal mode and rate of application and effect of combining Pymarc or Tithonia with TSP on maize yield and the net benefits. Pot experiment was conducted in 2003 in a greenhouse at Egerton using *Phaeozems*, *Cambisols* and *Ferralsols*. A factorial experiment in a CRD replicated thrice with rates of Pymarc equivalent to 0, 2, 4, 6 and 8 tonnes ha^{-1} was tested. Samples were taken at 0, 2, 4, 6, 8, 12 and 16 weeks for NPK analysis. Field experiments were conducted in 2003 and 2004 with Pymarc at Egerton (*Phaeozems*), Molo (*Cambisols*), Kosirai (*Ferralsols*) and Tithonia at Kosirai (*Ferralsols*). Pymarc at 0, 4 and 8 tonnes ha^{-1} and Tithonia at 0, 2.5 and 5 tonnes ha^{-1} were each tested for suitable mode of application as spot versus broadcast in a 2 x 3 factorial arrangement in a split plot design replicated thrice.

Nitrogen released after 112 days of incubation in pot experiment ranged from 142 mg N kg^{-1} in *Ferralsols* to 163 mg N kg^{-1} in *Cambisols* and 170 mg N kg^{-1} in *Phaeozems.* Phosphorus mineralized from *Phaeozems*, 6.1 mg P kg^{-1} and *Cambisols*, 7.2 mg P kg^{-1} was twice the amount of P mineralized from *Ferralsols*, 3.1 mg P kg^{-1}. Potassium mineralized at 112 days of incubation was 101 mg K kg^{-1} in *Phaeozems*, 100 mg K kg^{-1} in *Cambisols* and *Ferralsols* was 45 mg K kg^{-1}. Increasing rate of Pymarc application led to increase in the amount of Nitrogen, Phosphorus and Potassium released. *Cambisols* had the highest potential mineralized N_O of 182 m kg^{-1}, 7.6 P_O mg kg^{-1} and 101 K_O mg kg^{-1} than *Phaeozems* of N_O 163 mg kg^{-1}, 6.4 P_O mg kg^{-1} and 99 K_O mg kg^{-1} and *Ferralsols*, N_O of 148 mg kg^{-1}, 3.6 P_O mg kg^{-1} and 49 K_O mg kg^{-1}. *Ferralsols* had the highest NPK mineralization rate constant 0.12 K_N (d^{-1}) and 0.16 K_P (d^{-1}) while *Phaeozems* had highest Potassium rate constant of 0.12 K_N (d^{-1}). Nitrogen and Potassium released was consistently related to C: N, lignin, N, Pol: N and Pol+Lig: N ratio. Pymarc significantly increased root biomass, NPK concentration leaf, stover, grain yield, macrofauna fresh biomass, diversity and abundance. Pymarc and Tithonia using the Kosirai experiment had a significantly higher macrofauna fresh biomass, diversity and abundance than Pymarc. Positive and significant correlations were observed between Nitrogen and Lignin, Plant Residue Quality Index (PRQI) and earthworms; Phosphorus and PRQI, Potassium and Lignin, PRQI, earthworms and centipedes, Lignin and PRQI and earthworms, polyphenols and termites, ants and centipedes. Negative correlations were also observed between Nitrogen and Ants; Lignin and Polyphenols and PRQI and Earthworms. Phosphorus applied as Pymarc at 4 tonnes ha^{-1} or Tithonia at 2.5 tonnes ha^{-1} in combination with TSP at 13 kg P ha^{-1} had the highest relative grain yield. Tithonia integrated with TSP had the highest relative grain yield increase. The addition of either Pymarc in combination with TSP at Egerton, Molo and Kosirai resulted in added maize yield of 110%, 103% and 117%, respectively. At Kosirai, Tithonia in combination with TSP resulted in added maize yield of 123% compared to TSP, Pymarc or Tithonia alone. Maximum net benefits were obtained at 11 kg ha^{-1} when Pymarc was applied at Egerton, Molo and Kosirai for both spot and broadcast placement methods, respectively. The NPK release pattern is influenced by soil characteristics, amount, and quality of litter. Thus the release of nutrients by Pymarc and Tithonia and their effect on maize production makes them suitable for improvement of soil fertility and maize production when applied at 4 t/ha and 2.5 t/ha or integrated with TSP at 13 kg/ha, respectively.

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LIST OF ACRONYMS

ADF	Acid Detergent Fibre
AEZ	Agro Ecological Zone
FYM	Farm Yard Manure
WAFC (ICRAF)	World Agro forestry Centre (International Centre for Research in Agro forestry
KARI	Kenya Agricultural Research Institute
Ko	Potential mineralizable Potassium
LH	Lower Highland
MRR	Marginal Rate of Returns
No	Potential mineralizable Nitrogen
NUE	Nitrogen Use Efficiency
PBK	Pyrethrum Board of Kenya
PRQI	Plant Residue Quality Index
Po	Potential mineralizable Phosphorous
RAE	Relative Agronomic Effectiveness
RGY	Relative Grain Yield
SOM	Soil Organic Matter
UH	Upper Highland
UM	Upper Medium
UNESCO	United Nations Educational, Scientific and Cultural Organization
VCR	Value Cost Ratio

CHAPTER ONE

1.0 INTRODUCTION

1.1 General Introduction

Kenya's land area of 582,648 km^2 (Sombroek *et al.*, 1982) has only 20% of medium to high potential agricultural use. The remaining 80% is low potential land that is fragile and requires specialized management before it can be optimally used. Previously, self-sufficiency in food production was achieved by opening more land for cultivation. The fast growing population has led to subdivision of land, continuous cultivation with no nutrient input and reduced fallow periods, with subsequent decline in soil fertility and crop yield. This implies that efforts must be geared towards sustainable land use systems.

Maize (*Zea mays* L.), the main staple food in Kenya, accounts for 80% of the national production of cereals (KARI, 1991). The country produces about 2.6 million metric tonnes per year, out of which 70% to 90% are produced by resource poor farmers who manage small farms ranging from 0.2 to 0.8 hectares while the remaining 10% to 30% is from large scale farmers (Mwenda, 1985). The yield realized by resource poor farmers is usually very low, less than 1.5 tonnes ha^{-1} compared to the potential of 8 tonnes ha^{-1} (Hassan *et al.*, 1998). Decline in soil fertility, associated with continuous cultivation and sub-optimal fertilizer use contributes immensely to the low and variable crop yield (Mose *et al.*, 1996 and Ohlsson *et al.*, 1999). In a long term study, Kapkiyai *et al.* (1999) also showed that continuous cultivation led to a decline in soil organic matter and crop yield.

The use of commercial fertilizers in the production of maize has generally been restricted to only a few farms endowed with resources, such as cattle and land (Shepherd and Soule, 1998), or with high off-farm income. The majority of the smallholder farmers, on the other hand, lack the financial resources to purchase sufficient fertilizers to replace soil nutrients exported with harvested crop products. Farmers use farmyard manure as nutrient source, but the quality and quantities available on farms is often insufficient to maintain soil fertility. Crop residues are frequently used for livestock feed and sometimes burnt, rather than returned to soil as nutrient sources. Compost, green manure and biomass from herbaceous legumes are other potential sources of nutrients for cropped land, but the use of the organic materials for soil fertility improvement is limited. The supply of organic materials on farms, even with use of farmyard manure and leaf biomass from herbaceous legumes is likely to be insufficient to overcome soil nutrient deficiency in the highlands.

The utilization of non-traditional organic resources such as agro-industrial waste products whose value has not been fully identified may offer alternative sources of organic manure. Although these by-products have relatively high nutrient concentrations, little is known about their potential as nutrient sources for improving soil fertility and crop yield. One such organic resource is pyrethrum (*Chrysanthemum cinerariaefolium*) marc (Pymarc) which is produced in large quantities (at least 50 tonnes per week) as a by-product of pyrethrin extraction from pyrethrum flowers at the Pyrethrum Board of Kenya (PBK) factory in Nakuru (Muiruri *et al*., 2001). One tonne of dry flowers yields about 970 kg of Pymarc and less than 10% of it is used as animal feed, leaving the surplus for non-identified use. Pymarc has good digestibility or degradability in the animal rumen which can be compared to microbial decomposition in soil and thus provide a quick measure of assessing the quality of organic sources of fertilizer (Muiruri *et al*., 2001). Recognized advantages of Pymarc are the large surface area due to its fine powdery nature, nutrients contents of N (2.2%), P (0.28%) and K (3.80%), low purchase cost and environmentally friendly. The large surface area could quicken incorporation in soil and accessibility to microbial degradation hence nutrient release. It is certain that litter particle size and their contact with the soil also affects decomposition and interacts with litter quality to influence decomposition rates (Mungai and Mortavalli, 2005).

Another source of organic manure is Tithonia (*Tithonia diversifolia*), it is high in nutrients, averaging 3.5% N, 0.37% P and 4.1% K dry matter (Bashir Jama *et al*., 2000). Boundary hedges of sole Tithonia can produce about 1 kg biomass (tender stems + leaves) m^{-2} per year on dry weight basis. In some cases, maize yields have been reported to be higher with incorporation of Tithonia biomass than with commercial fertilizer at equivalent rates of N, P and K (Bashir Jama *et al*., 2000). In addition to providing nutrients, Tithonia incorporated at 5 tonnes dry matter per hectare can reduce P sorption and increase soil microbial biomass. Thus, Pymarc and Tithonia are undoubtedly potential sources of N, P and K for crops. The quantities of Pymarc and green biomass from Tithonia alone however, will typically not be sufficient to supply all the nutrients required to eliminate deficiencies. The integration of Pymarc and Tithonia with inorganic fertilizers would have added advantages as compared to sole use of inorganic fertilizers since they enhance the use efficiency of inorganic fertilizers or provide non-nutritional benefits to crops. Gachengo (1996) demonstrated that organic inputs with P fertilizers were important as an ideal combination that addresses both the problem of insufficient fertilizer supply and the large amount of organic material required for P supply. Research is therefore necessary to identify and evaluate additional organic manures as nutrients sources, nutrient release patterns, mode and rate of application and asses the costs and benefits on maize crop yield.

1.2 Statement of the Problem

Maize yield in Kenya is low primarily due to decline in soil fertility. Inorganic fertilizers are however, too expensive and cause environmental pollution. Some of the areas have low soil pH which makes use of inorganic fertilizer inefficient. Organic manures are low cost therefore, have great potential in increasing yield. The quality, quantity and placement method of these diverse materials is however, not known. The supply of organic materials such as crop residues and animal manure cannot by themselves reverse soil fertility decline because they are usually not available in sufficient quantities on farms, the need to develop other organic resources. Pymarc is a by product of pyrethrum processing that could be used as a fertilizer. The use of Pymarc as a fertilizer would be economic use of what would otherwise be organic waste and could be important for value addition. The use of organic manure as P sources is limited by the low P content. Supplementation with P inorganic fertilizers is therefore required.

1.3 Goal

The main goal is to improve food security and income among the smallholder farming communities of Nandi and Nakuru Districts.

1.4 Broad Objective

The broad objective is to improve soil fertility through use of a combination of low cost organic manure and inorganic fertilizers for sustainable maize production.

1.4.1 Specific Objectives;

The specific objectives are:-

1. To determine N, P and K release from Pymarc when added to selected soils;
2. To determine the effect of placement method and rate of application of Pymarc and on root biomass, N, P and K contents in leaf, Macrofauna biomass and population, maize yield and residual effects on soil pH, N, P and K;
3. To determine the effect of Pymarc and Tithonia on maize grain yield
4. To determine the effect of combining organic manure and inorganic P sources on maize stover and grain yield, and

5. To compare the economic returns of Pymarc and Tithonia as P source and inorganic source of P applied either alone or in combination to maize production.

1.5 Hypotheses

1. N, P and K release pattern is affected by application of Pymarc to selected soils;
2. N, P and K content in the leaf, macrofauna biomass and population, maize yield and residual soil pH, N, P and K are affected by mode and rate of application of Pymarc;
3. There are differences on the effect of Pymarc and Tithonia on maize grain yield;
4. The combination of organic and inorganic nutrients sources is more beneficial than the sole application of fertilizers on maize stover and grain yield; and
5. There are differences in economic returns of maize yield produced using either organic source of P alone or in combination with inorganic source of P.

1.6 Justification

The continuous cropping and mining of soils, with little or no external inputs has accelerated the depletion of soil organic matter, N and P, resulting in poor maize yield (Sanchez *et al.*, 1997 and Rao *et al.*, 1998). The use of inorganic fertilizers to improve soil fertility in smallholder farming systems is constrained by their high cost, (Hoekstra and Corbeit, 1995). Thus, farmers have used organic inputs without knowledge of quality, quantity and mode of application. The supply of organic materials on farms with use of farmyard manure, herbaceous legumes is insufficient. Pymarc is one of the important by products of pyrethrum processing. Though also used as livestock feed, the use has been low leading to build up of stocks hence need for assessing it for alternative uses. While much work is done with respect to Tithonia, little is known about fertility potential of Pymarc

Research is therefore needed to understand the effect of the use of Pymarc alone or incombination with P mineral fertilizers for enhanced nutrient availability and maize yield. Pymarc may have high labour and transportation cost requirements for transfer and application to the farm, this necessitates the optimal management of relatively small quantities of Pymarc. Information is needed on the minimum rate of Pymarc required to increase nutrient availability. Optimal management of Pymarc requires an understanding of the economics associated with distribution of biomass at a low rate over an entire field versus concentration of the biomass in only a section of the field. Spot application in the planting hole might be an option to reduce the required quantities of biomass.

CHAPTER TWO

2.0 LITERATURE REVIEW

2.1 Plant Residue Decomposition and Nutrient Release Patterns

Nutrient mineralization patterns during decomposition of organic materials are related to the chemical composition, or quality/quantity of the organic inputs; climatic conditions, soil physico-chemical, environment and the nature of soil organisms (Heal et *al*., 1997).

2.2 Factors affecting Decomposition

2.2.1 Residue Quality

Residue quality characteristics of the organic materials include concentrations of N, lignin, cellulose, hemicellulose and water soluble C as well as C: N and lignin/N ratio. (Kachaka *et al,* 1993). Knowledge of the nutrient contents and mineralization patterns of organic inputs and their effect on crop productivity is important to planning their use in fertility management. Nitrogen concentration in tissue ranging from 18 to 22 g kg^{-1} is the critical value for the transition from net immobilization to net mineralization (Palm, 1995). Not all organic materials with high N values, however, exhibit net mineralization because Lignin concentration greater than 150 g kg^{-1} slow N release considerably and the polyphenol contents greater than 30 to 40 g kg^{-1} can result in net immobilization of N (Palm *et al*., 2001). Lignin and polyphenols are particularly important modifiers of N release for the fresh leaves of high quality materials (Constantinides and Fownes, 1994). The immobilization resulting from polyphenolics, particularly condensed tannins may be much longer than the temporary immobilization resulting from high C: N ratios in cereal crop residues (Giller *et al*., 1997). Net P mineralization patterns are determined primarily by P concentration in the tissue, materials with P content more than 2.1 g kg^{-1} immobilize P (Giller *et al*., 1997). Phosphorus release patterns are not necessarily correlated to N release and some materials showing net N mineralization can result in net P immobilization and vice versa (Giller *et al*., 1997) stressing the importance of looking at more than just N content in organic materials. Lignin and polyphenols contents above 15% and 4%, respectively, may retard litter decomposition and N mineralization (Scroth, 2003). Lignin is considered an important component determining the rate of decomposition because it physically protects cellulose and other carbohydrates and also inhibits the synthesis and activity of celulolytic enzymes (Palm and Rowland, 1997).

2.2.2 *Soil Properties*

The relative importance of litter quality indices is influenced by soil properties and may change as decomposition progresses (Berg and McClaugherty, 2003). Soil properties favoring rapid decomposition of plant litter include a near neutral soil pH. At soil pH 6-7, most nutrients are available allowing diverse microbial populations to be active. Many alterations are known to occur to soil microbial populations and activities as soil pH changes. The population shifts from bacteria to actinomycetes to fungi as soil pH declines although acid tolerance of individual species varies widely (Berg and McClaugherty, 2003). When organic materials are added to a soil, the micro organisms decomposing them obtain the nutrients necessary for their nutrition (e.g. N, P, K Ca, and Mg) from the organic materials themselves or from the pool of available nutrients in the surrounding soil or decomposing litter. Since the nutrient required by micro organisms in the greatest amounts is N, it is not surprising that N is one of the nutrient limiting microbial activity in litter decomposition. Soil, water and temperature are important abiotic factors that influence soil microbial activities. As soil water becomes limited, microbial populations, nutrient and gas movement are also decreased which may retard soil microbial processes. Moisture stress inhibits microbial growth directly because as moisture content increases, aeration decreases and microbial growth is inhibited while cycles of wetting and drying tend to increase the amount of available substrate.

2.2.3 *Soil Microbes*

Decomposer organisms consist of a complex community of soil biota including macrofauna, and flora. Fungi and bacteria are ultimately responsible for the biochemical process in the decomposition of organic residues. Soil fauna enhance the biodegradation and humification of organic residues by comminuting organic residues and increasing the surface area for microbial activity, producing enzymes which break down complex bio-molecules into simple compounds and polymerize compounds to form humus, improve the environment for microbial growth and interactions (Tian *et al.,* 1997). Earthworms increase the decomposition of organic residues and the release of nutrients by comminuting plant residues, by incorporating the organic matter into the soil (Tian *et al.,* 1995) and by producing casts enriched with microflora and enzymes. Termites are known to be efficient in digesting cellulose and in some cases also lignified substances. Millipedes are known to break down plant litter and mix it with mineral soil, which they ingest (Tian *et al.,* 1995). By feeding on microflora, protozoa and nematodes can increase N mineralization while predatory mites have a stabilizing effect on such interactions (Bouwman *et al.*, 1994)). Soil microbes can serve as sources or sinks of nutrients while their activities and turnover resulting from the decomposition of organic materials are considered to be of primary controlling factors in nutrient cycling and availability (Smith *et al.*, 1993). Additions of organic residues can increase microbial pool sizes and activity, C and N mineralization rates and enzyme activities (Smith *et al.*, 1993), all factors that affect nutrient recycling. Since C is often the element most limiting to microbial growth and activity in soils, the amount and metabolic activity or C quality of organic additions will influence rates of nutrient cycling.

2.2.4 Potential Mineralizable Nitrogen, Phosphorus and Potassium of the Soil

The efficacy with which NPK in manure are used depends on the synchrony between rate of mineralization and the crop demand. Determining NPK release pattern of the Pymarc manure can give an estimate of the potential amount of NPK that given manure can contribute to crops. Currently there are several recommendations on the amount of manure to use on maize crops, the recommended quantities were derived from simple manure response trials in different regions of Kenya. Relationships between the mineralization of NPK from manure and indices to describe manure quality have not been examined in detail. Studies done on manures show that it is possible to use the release patterns and laboratory chemical indices to describe quality of materials and predict rates of decomposition and NPK release (Handayanto *et al.*, 1997 and Mafongoya and Nair, 1997). The rate of net NPK mineralization of manures and other organics must be known to optimize use and predict supplementation rates of mineral fertilizers (Nhamo *et* al., 2004). Therefore, it was hypothesized in this study that the NPK release pattern is influenced by Pym arc's chemical composition, rate of application and soil characteristics.

Reliable techniques for predicting N, P and K mineralization dynamics in soil are required for sustainable management of land resources. The accurate estimate of the soils' ability to supply N is essential for determining the optimum rate and time of fertilizer application and for the development of sustainable land management strategies. Stanford and Smith (1972) as cited by Wang *et al.* (2004) proposed using along term (30 weeks) incubation under optimal temperature (35 ^{0}C) and moisture (80 K tension) to determine the N, P and K mineralization potential (N_o, P_o *and* K_o). The assumption is that the net N production rate follows first order kinetics:

Equation 1, Np = N_o, P_o *and* K_o $(1\text{-}e^{-kt})$ (Smithson *et al.*, 1980)

Where:

Np: amount of inorganic N produced by time t (weeks)

k: Mineralization constant ($week^{-1}$)

N_o, P_o and K_o is interpreted as an estimate of the amount of N that will mineralize in infinite time under optimal temperature and moisture. Potentially mineralizable N, *N_o, P_o and K_o* of different soils consists of similar forms of organic N, P and K representing a more or less discrete fraction of total organic N, P and K and that the magnitude of *N_o, P_o and K_o* rather than k values indicate soil N, P and K release. The description of mass and N, P and K remaining would follow the first order kinetic model,

Equation 2, $Y=M_oe^{-kt}$ (Smithson *et al.*, 1980)

where:

Y is the NPK remaining at time t.

M_o *is* initial NPK and k is the rate constant

Many kinetic models such as sigmoid, hyperbolic and single exponential plus linear models have been used to describe inorganic N production from the soil amended organic materials (Wang *et al.*, 2004). The first order kinetic models including the single and the double exponential models remain widely used. However, in this study double exponential model was not used because there was no separation of mineralizable organic NPK into active and slow pools of which the model entails.

2.3 Plant Residue as Nutrient Source for Soil Fertility Improvement

2.3.1 Effects of Organic Materials on Nutrient Availability

Organic inputs can influence nutrient availability by the total nutrients added, controlling the net mineralization – immobilization patterns, as source of C and energy to drive microbial activities, precursors to SOM fractions and through interactions with the mineral soil in complexing toxic cations and reducing the sorption capacity of the soil. In addition to these direct effects on nutrient availability, organic materials can affect root growth, pests and soil physical properties that in turn influence nutrient acquisition and plant growth. The net effect of these different mechanisms on nutrient availability and plant growth differ with climatic regime, soil type quality and quantity of organic inputs. Organic inputs such as Farm Yard Manure, cover crops and green manures have generally been assessed in terms of their N concentrations, while little attention has been paid to other macronutrients and micronutrients present. The nutrients content of organic materials, ranging from crop residues to agro-industrial wastes, vary widely. Although all the nutrients in the organic materials will not be available to a crop, the information can be used for an initial assessment of the type and amount of organic materials that are appropriate for a given cropping system and yield goal. These estimates can then be adjusted, knowing that crop recovery of N supplied by high quality leguminous green manures is rarely more than 20% (Giller and Cadisch, 1995) while that recovered from lower quality cereal stovers is generally much lower. As a general rule, many organic materials when applied in amounts >5 tonnes dry matter ha^{-1}, contain sufficient N but they cannot meet P requirements and must be supplemented with inorganic P in areas where P is deficient (Palm, 1995). Increasingly, the traditional nutrient sources for soil fertility management are produced in insufficient quantities and quality to meet crop demands, therefore, alternative higher quality sources must be found, but there must also be niches on farms or within the vicinity where they can be produced.

Leguminous plant materials provide higher quality organic inputs to meet N demands, if not P, but incorporating non-food legumes in the farming system requires a sacrifice of space or time that is normally devoted to crop production. The additional labour requirement for planting, transplanting and incorporating these materials is also high, therefore farmers have not widely adopted planting legumes to improve soil fertility. The economic and social trade-offs of improved soil fertility using legumes and other high quality organic materials must be properly assessed in comparison with using crop residues and Farm Yard Manures. Organic materials have been shown to reduce P sorption capacity of the soil and increase P availability, the magnitude and duration of the effect varies with the soil type, the quality of the organic material and the amounts added. However, in general, only materials with > 2.5 g P kg^{-1} have been shown to reduce the P sorption capacity (Iyamuremye *et a*l., 1996 and Nziguheba *et al.*, 1998). The mechanisms involved in this process are quite complex, as outlined in a review by Iyamuremye *et al*, (1996). The most commonly cited mechanisms refer to the action of organic acids produced from decomposition or root exudation. The organic anions complex with ions of Fe and Al in the soil solution, preventing the precipitation of phosphate and also reduce Al and Fe toxicity that compete with P for sorption sites and/or solubilize P from the insoluble Ca, Fe and Al phosphates. However, complexation and competition are more important than replacing P or solubilizing native P.

The use of plant materials as ameliorants of soil acidity for the highly weathered soils of the tropics offers a viable alternative to commercial lime (Wong *et al.,* 2000). The amelioration is possible because of the alkalinity that the residues contain (Wong *et al.*, 1998). Most work reported in the literature regarding pH changes of soils amended with plant residues are measured after long periods of incubation and are measured in the context of potential alkalinity (Pocknee and Summer, 1997 and Wong *et al.*, 2000). The inherent liming potential of plant residues is attributable to the organic ligands which serve to balance charge and regulate pH within plants in response to unbalanced cation and anion uptake and nitrate reduction in the leaves (Imas *et al.*, 1997). Increase in pH following the addition of plant residues to an acid soil has been demonstrated in incubation studies (Pocknee and Sumner., 1997). The mechanisms responsible for the pH increases include ligand exchange, nitrogen mineralization and decomposition of base cations containing organic compounds (Pocknee and Sumner, 1997).

An incubation study of organic materials with three tropical soils by Wong *et al.* (1995) was used to show that the final pH obtained could be approximately predicted from knowledge of the model consisting of initial pH values of the soil, organic material and their buffer characteristics. Using tree prunings, Wong *et al.* (2000) found that the pH of an Ultisols increased over a period of up to 98 days, showing that there was a release of initially non-available alkalinity. In Oxisols, however, pH increased during the initial 14 days but then decreased probably as a result of mineralization and nitrification of the nitrogen compounds in the prunings. Thus, not all of the alkalinity in a residue is active from the onset of its addition to the soil. Ash, or potential alkalinity may be defined for plant material as the sum of cations minus the sum of inorganic anions. The excess positive charge is balanced by organic anions, which estimate the liming potential of residue (Wong *et al.*, 2000). Root growth can increase as a result of reduced exchangeable Al in the soil, caused by complexion with organic anions that are produced by the decomposition of organic materials (Iyamuremye *et a*l., 1996). It can also increase through an increase in pH caused by the addition of basic cations from organic materials (Sakala *et al.*, 2004). Organic material can also stimulate root growth either directly or through their effect on soil bacteria that can suppress root pathogens and produce plant growth hormones (Marschner, 1995).

2.3.2 Tithonia and Pymarc as Sources of Nutrients for Maize

The average nutrient concentrations of green leaves of Tithonia collected in East Africa are 3.5% N, 0.37% P and 4.1% K on dry weight basis (Gachengo *et al.*, 2004). Tithonia biomass is also high in nutrients other than N, P and K. Gachengo, (1996), for example, found 1.8% Ca and 0.4% Mg in green Tithonia biomass. Research in the mid

1990's, in Western Kenya generated awareness of Tithonia as a source of nutrients for crops (Gachengo, 1996 and Niang *et al.*, 1996). Gachengo (1996) demonstrated increased maize yield following incorporation of fresh Tithonia biomass at an equivalent of 5 tonnes dry matter ha^{-1} on a site deficient in N, P and K. Niang *et al.* (1996) also working in the same place found greater maize yield following incorporation of Tithonia than biomass of other common shrubs and trees. On-farm research has demonstrated that soil fertility benefits are greater for green than dried biomass of Tithonia (Otuma *et al.*, 1998). Mafongoya and Nair, (1997) reported increased polyphenol content and reduced nutrient release following drying of plant biomass.

Green leaf biomass of Tithonia decomposes rapidly after incorporation into soil. Gachengo (1996) reported a half-life of about one week for the disappearance of dry matter during the rainy season in Western Kenya. The corresponding half-life for nutrient release was about one week for N and two weeks for P (Gachengo *et al.*, 2004). Lignin (6.5%) and total extractable polyphenols concentration (1.6%) in Tithonia green biomass are below levels that significantly reduce decomposition (Palm and Rowland, 1997). The high N concentration and rapid decomposition of green Tithonia biomass (Gachengo *et al.*, 2004) make it an effective source of N for crops. Phosphorus and Potassium release from green biomass of Tithonia incorporated in soil is rapid and can supply plant available P thereby overcoming P and K deficiency and increase crop yield. The comparable maize yields with Urea and 60 kg K ha^{-1} as Potassium Chloride (KCl) and with Tithonia (5.0 t ha^{-1}), which supplied about 60 kg K/ha suggests that Tithonia biomass was comparable to KCl as K source (ICRAF, 1998).

The average nutrient concentrations of fine powder of Pymarc were 2.2% N, 0.28% P and 3.8% K on dry weight basis, other nutrients found included 0.37% Ca and 0.25% Mg in its fine powder (Muiruri *et al.*, 2001). Less than 10% of Pymarc has been used as animal feed with good digestibility. Degradation or digestibility of plant material in animal rumen is often compared to decomposition in soils where measure of digestibility that are used to asses forage quality could serve as a quick means of assessing the quality of organic resources (Chesson, 1997). However, there is little information on its value as an organic source of fertilizer. Based on their nutrients concentrations, both green biomass of Tithonia and fine powder of Pymarc are undoubtedly potential sources of N, P and K for crops. The quantities of green Tithonia biomass and Pymarc however will typically not be sufficient to supply all the nutrients required to eliminate nutrient deficiencies over large areas of the fields but they will improve soil organic matter (SOM) content.

A study by Ayuke *et al.* (2004) indicated that addition of Tithonia biomass at 5 t ha^{-1} increased maize yields significantly over the control. Maize yield following application of Tithonia biomass yielded 1.1 t ha^{-1} grain and 3.0 t ha^{-1} stover, which represented 38% and 58% yield increase, respectively, over the control. Tithonia decomposed and mineralized nutrients faster, probably because of its higher N and P concentration and lower C: N ratio. The overall level of secondary compounds (Lignin and Polyphenols) in Tithonia is low compared with foliage of many trees and shrubs (Chesson, 1997; Palm and Rowland, 1997). Higher maize yields with use of organic residue have been reported. For instance, experiments conducted in Western Kenya demonstrated that higher yield can be obtained when organic residues are incorporated in the soil (Gachengo *et al.,* 2004). Gachengo showed that Tithonia increased maize yield by one and half times higher than without Tithonia inputs. Furthermore, Tithonia was found to reduce P sorption capacity of the soil and increase crop yield particularly in P limited soil by making P available to crops (Nziguheba *et al.,* 1998). However, the extent to which an organic material will perform compared to mineral fertilizer is dependent on several factors especially the quality of organic material, climatic factors and site characteristics. For example a study by Kimetu *et al.* (2002), showed that Tithonia had higher biomass and grain yield as compared to sole application of Urea. Maize crop supplied with sole Urea was found to recover nitrogen at higher rate than the maize crops supplied with Tithonia biomass. It is evident that the effect of external input on crop N use efficiency (NUE) is dependant on the organic material used, and climatic conditions (especially rainfall amount) prevailing throughout the growing period of the annual crop. *Tithonia diversifolia* can be used as a source of N in place of mineral fertilizer and smallholder farmer should be encouraged to use Tithonia green biomass where available for annual crops.

2.3.3 Soil Macrofauna Biomass, Diversity and Abundance as affected by Organic Material

Macroclimate, food resources and land use practices are major factors affecting the diversity, abundance and biomass of soil fauna communities (Dangerfield, 1993). Management practices, such as continuous cultivation can cause alterations in the macrofaunal abundance and diversity of key groups and species (Beare *et al.*, 1997). Studies have shown that cultivated sites are usually poorer than natural sites in terms of faunal diversity and biomass (Brown *et al.*, 1996). Tabu *et al.* (2004) showed that niche management affected the abundance and diversity of macrofauna (earthworms, termites and ants). Earthworms, termites and ants were more abundant in productive compared to non-productive niches. He further indicated that disturbance through cultivation and grazing reduced the abundance and diversity of macrofauna. The low diversity, abundance and biomass of the soil invertebrate fauna observed, particularly in the non productive niches, implies that a change to continuous cropping decreases plant richness, thereby reducing the diversity of food resources and residue quality.

Other studies have also shown that such changes in the land use systems lead to reduced abundance, biomass and diversity of soil fauna communities (Dangerfield, 1993). Application of Senna and Tithonia residues increased the biomass of the soil fauna groups, for example earthworms. Studies have also shown that addition of organic residues, manures and tree prunings provide food to soil organisms thus, greater fauna biomass in the residue applied treatments may be as a result of a greater accumulation of organic matter (Palm and Rowland, 1997). Accumulation of organic matter from these residues (Tithonia and Senna), may provide resource base for the invertebrates. Coleman *et al.* (2000) stated that soil organisms were strongly limited by available energy sources and are in a state of starvation much of the time. The increased supply of organic matter may possibly eliminate this state, in turn allowing their consumers (earthworms and termites), to subsequently increase in numbers, hence increase in biomass. Surface applied residues preserve soil moisture, reduce soil temperature and provide conducive niches for certain faunal groups. Plant residues applied as broadcast are known to attenuate the increases of soil temperature and to retain higher soil moisture contents, in addition to providing food for soil animals.

2.3.4 Nutrient Uptake and Accumulation in Maize

Nutrient uptake begins even before the plant emerges from the soil. The amount of nutrients taken up early in the growing season is small; but the nutrient concentrations in the soil surrounding the roots of the small plant at that stage are usually high. Uptake of Potassium is completed soon after silking but uptake of other essential nutrients such as Nitrogen and Phosphorus continues until near maturity (Marschner, 1995). Much Nitrogen and Phosphorus and some other nutrients are translocated from the vegetative plant part to developing grain later in the season. A large portion of the Nitrogen and Phosphorus taken up by the plant is removed in the grain that is harvested. But most of the potassium taken up is returned to the soil in the leaves, stalks and other plant residues, unless these plant parts are removed.

Pattern of nutrient accumulation in the plant especially N, will vary with nutrient levels and their balance in the soil, tillage practices, temperature, soil type and moisture availability (Tisdale *et al.*, 1990 and Hardter and Horsdt, 1994). Relatively high nutrient concentrations in the plant are necessary for maximum growth during the vegetative phase. Leaves hold a large share of N that is translocated to the grains (Ta and Weiland, 1992).

Experiments have shown that the N budget in the maize has significant effects on leaf development and growth, biomass accumulation and seed growth (Muchow, 1994). Maximum N content in tissue may be constrained by soil N availability and plant N uptake. It has been found that inadequate N levels results in substantially depressed leaf area (LA) development (Marschner, 1995). Although maize produces grain of relatively low N concentration, the N required to support seed growth is still substantial (Cliquet *et al.*, 1990; Ta and Weiland, 1992, Muchow, 1994).

Other studies (Magdoff *et al.*, 1984 and Blacksmer *et al.*, 1989) showed positive correlation between maize yields and concentrations of NO_3^- in the upper 30 cm of the soil when the maize plant is at V6 stage of growth. Application of N greater than a crop capacity for removal results in accumulation of NO_3^- in the soil profile (Roth and Fox, 1990 and Angel *et al.*, 1993). The inhibition of grain growth in maize when there is inadequate N transfer to the grain is quite different from wheat. In wheat, grain growth is maintained by accelerating N transfer from the vegetative tissue to meristematic regions (Sinclair and Amir, 1992). Nitrogen above ground parts of a crop that are undergoing senescence is made available to the growing parts while root nitrogen appears in soils as the roots decompose (Swinnen, 1994). Without fertilization, N uptake will depend on the mineral N reserve in the soil and the rate of N mineralization.

Phosphorus is present in plant tissue and soils in smaller amounts than are N and K. Phosphorus is taken up from soil in $H_2PO_4^-$ and HPO_4^{2-} forms by plants and unless the soil contains adequate phosphorus or it is supplied to soil from external sources, plant growth will be restricted. Little of this element is lost by leaching and crop removals (Tisdale *et al.*, 1990). Plant accessible soil phosphorus levels can undergo a gradual decline where crop removals exceed the amount being returned to the soil in fertilizers, animal manures and crop residues (Tisdale *et al.*, 1990). Phosphorus is continuously taken up, by maize from the seedling stage to maturity. Its uptake is maximum during the third and sixth weeks of maize growth Bekunda (1990). Bekunda (1990) also observed that phosphorus accumulation in maize increased rapidly from vegetative to silking stage and dropped thereafter, to harvest. The largest P requirement occurs after flowering and during the ripening period, the leaves contain about 20% of the total P taken up by the plant. During grain formation, translocation to the grain is smaller compared to that of N. Phosphorus is removed first from the husks and cobs and then from stalks, tassel and leaf sheaths and lastly from the leaves. Phosphorus uptake by crops is influenced by levels of available P in the soil, pH value of the soil, form and method of fertilizer P application (Bekunda, 1990).

Large amounts of potassium are taken up by crops, which attain high yields. For example, a cereal crop yielding 5 to 10 tonne ha^{-1} there is about 200 to 300 kg K ha^{-1} removed from soil. This is either equivalent or greater than N and 3 to 4 times the P removed. Onyuka (2003), observed a nutrient uptake pattern that generally followed that of dry matter accumulation. Return of crop residues and manures are important in maintaining soil K. For example, 10 tonnes of animal manure supply about 163 kg K ha^{-1}. The annual losses of available K by leaching and erosion greatly exceed those of N and P. The K^+ requirement for optimal plant growth is 2-5% of the dry weight of the vegetative parts. By increasing the K^+ supply to plant roots, it is relatively easy to increase the Potassium content of various organs except for grains and seeds, which maintain a relatively constant Potassium content of 0.3% of the dry weight.

2.3.5 *Residual Effect of Plant Residue Application on Soil Properties*

Application of manure or composted manure can result in increased soil concentration of nutrients and organic matter (Eghball, 2002). Residual effects of manure or compost application can maintain crop yield level for several years after manure or compost application. Residual effects of organic materials on soil properties can contribute to improvement in soil quality for several years after application ceases (Grinting *et al*., 2003). Increased levels of soil N, P, K, soil pH and carbon levels in the soil can increase crop yields beyond the application years. Eghball, (2002) found that the increased plant available P levels in the soil following N based manure or composed application can contribute to crop uptake for up to 10 years without any P addition.

The use of plant residues as ameliorants of soil acidity for the highly weathered soils of the subhumid tropics offers a viable alternative to commercial lime (Tang *et al*., 1999 and Wong *et al*., 2000). The amelioration is possible because of the alkalinity that the residues contain, which is larger in legumes than non-leguminous plants (Larsen, 1998). The inherent liming potential of plant residues is attributed to the organic ligands which serve to balance cation and anion uptake and to nitrate reduction in the leaves (Imas *et al*., 1997). Increase in soil pH following the addition of plant residues to an acid soil has been demonstrated in incubation experiments (Pocknee and Summer, 1997). The mechanisms responsible for the pH increases include ligand exchange, nitrogen mineralization and decomposition of base cations containing organic compounds (Pocknee and Summer, 1997, Wong *et al.*, 1998).

2.4 Combined Use of Organic and Inorganic Phosphorus Sources on Soil Fertility and Maize Yield

Phosphorus inputs in smallholder fields consist primarily of inorganic fertilizers and organic sources such as green and Farm Yard Manure, compost and crop residues. However, low quality organic materials such as maize stover may not supply sufficient amounts of P to plants (Palm *et al.*, 1997). While inorganic fertilizers can restore the fertility of the soil and improve crop yields, their use in the East African highlands is limited (Hoekstra and Corbett, 1995) and alternative strategies for supplying P to the deficient smallholder systems are necessary. Studies in Western Kenya indicate that the incorporation of higher quality manures, like *Tithonia diversifolia*, along with TSP, increases the effectiveness of fertilizer phosphorus (Nziguheba *et a*l., 1998 ands Gachengo, 1999). Such integration of organic and inorganic resources would have agronomic advantage if the organic material enhances the availability of added P (Palm *et al.*, 1997). The process 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 the plants.

Other benefits of organic manures include immobilization of excess 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 (Smith *et al.*, 1993). These chemical and biological processes influence both availability and utilization of nutrients. Studies by Ojiem *et al.* (2004) indicated that applying P at modest rate of 30 kg P ha^{-1} either in the organic or inorganic form, can substantially increase maize grain yield, provided the organic manure rate supplies equivalent amount of P, then the organic source used would be as effective as Triple Superphosphates (TSP). However, since the quality of the organic manure determine the quantity to be applied to attain the required P rate, low quality material could mean more labour for application, making the practice economically unattractive. Phosphorus release from soil incorporated green biomass of Tithonia is rapid and Tithonia can supply plant available P. Nziguheba *et al.* (1998) reported that labile inorganic soil P was higher at two weeks after incorporation of 15 kg P ha^{-1} as Tithonia (8.1mg P kg^{-1}) than TSP (3.6 mg P kg^{-1}) on an acid soil. The corresponding soil P level in the unfertilized controls was 2.5 mg P kg^{-1}. Therefore, Tithonia can supply plant available P at least as effectively as an equivalent amount of P from soluble fertilizers.

In another study by Nziguheba *et al.* (1998), green biomass of Tithonia (1.8 tones dry matter ha^{-1}) was compared on a P limited soil with mineral fertilizers (Urea, Triple Super phosphate and Potassium Chloride) at equivalent rates of N (60 kg ha^{-1}), P (6 kg ha^{-1}) and K (60 kg ha^{-1}) for three seasons at two sites. At these application rates, maize was severely limited by P, but not limited by K or N in some cases. Under these conditions, maize yield following Tithonia application was consistently comparable to and sometimes slightly higher than yield following application of mineral fertilizers. The higher maize yield with Tithonia than mineral fertilizer when only P was limiting, suggests that P availability might be greater following application of Tithonia than soluble P fertilizer (TSP) as was shown by Nziguheba *et al.* (1998). The integration of Tithonia and Pymarc with mineral fertilizers would have an added advantage, as compared to sole use of mineral fertilizer. Tithonia and Pymarc enhanced the efficient use of mineral fertilizer and provided non-nutritional benefits to crops. Assuming mean concentration of 3.5% N, 0.37% P and 4.1% K, green biomass of Tithonia equivalent to 2 to 4 t ha^{-1} dry matter will likely supply sufficient N (70 to 140 kg N ha^{-1}) and K (80 to 165 kg K ha^{-1}) to crops. At rates below 2 tonnes ha^{-1} however the integration of Tithonia biomass with commercial N fertilizers in the crop production areas are likely to be required to eliminate N deficiency (Bashir Jama *et al.*, 2000). For Pymarc, assuming mean concentration of 2.15% N, 0.25% P and 2.8% K of fine powder equivalent to 1.2 to 2.4 tonnes ha^{-1} will likely supply low levels of N (42 to 84 kg N ha^{-1}) and (48 to 96 kg K ha^{-1}) to crops. At rates below 1.5 t ha^{-1} dry matter the integration of Pymarc with mineral fertilizer may be required to eliminate N deficiency.

Application of Tithonia at 5 t ha^{-1} of dry matter, which supplies about 18 kg P ha^{-1}, can overcome moderate P deficiency. However, it does not provide sufficient P to overcome severe P deficiency, such as on soils where crops response to well above 18 kg fertilizer P ha^{-1}. Consequently, P fertilizer must be integrated with Tithonia to overcome P deficiencies in such soils. Low maize yields (1.1 to 1.3 t ha^{-1}) with application of 6 kg P ha^{-1} as either Tithonia or mineral fertilizers were achieved, but application of an additional 50 kg P ha^{-1} as soluble P fertilizer (TSP) significantly increased yields with both Tithonia and mineral fertilizers (Gachengo *et al.*, 2004). Maize yield tended to be higher with Tithonia + P fertilizer (4.2 t ha^{-1}) than with sole mineral fertilizer (3.6 t ha^{-1}), suggesting that integration of

Tithonia and P fertilizer might provide additional benefits than sole use of mineral fertilizer to maize production.

These results are consistent with the work of Nziguheba *et al.* (2000) who observed an added benefit going up to 112% from the addition of Tithonia compared to TSP on resin extractable P during one maize growing season. Phan Thi Cong (2000) reported a reduction of extractable Aluminum and increase of soil pH after addition of Tithonia. Aluminum forms more stable complexes with organic anions than Ca does and so it is likely that some of the non-available alkalinity in the residues is made available by $AlOH^{2+}$ ion complexing with $(RCOO)_2^-$ anion. Removal of $AlOH^{2+}$ ion from solution would cause reduction in Al from the system and increase of Ca concentration thus an increase in soil pH (Sakala *et al.*, 2004). In addition, an increase in microbial biomass was observed in Tithonia treatment and not in TSP treatments (Nziguheba *et al.*, 1998) thus microbial biomass constitutes a potential source of nutrients to the crop through turnover. Soil acidity was also reduced and there was an overall improvement in soil fertility as result of applying Tithonia indicating that Tithonia, has the acid ameliorating effect. This is pertinent where acid soils are widespread and will go a long way in solving acidity problem and the associated crop production constraints. The objective of this study was to determine the effects of combining organic manure and inorganic P sources on stover weight and maize grain yield.

2.5 Economic Analysis of Combined Use of Organic and Inorganic Phosphorus Sources on Maize Yield

With the onset of market liberalization, prices of conventional fertilizers have been rising faster than farm produce prices. There are many available soil fertility technology options but their adoption is subject to farmers' perception of benefits, purchasing power and limitations to their use. Economically, however, output (maize yield) alone does not reflect much about efficiency of production. Research scientists in the past laid more emphasis on the ability of technologies to achieve high crop yield responses than on the performance of the technologies based on economic considerations. This explains why some technologies that appear superior in improving crop yield under research conditions are not always most adopted in farmers' fields.

Cost of labour forms a major part of the total cost in the use of organic materials. This is because use of this material is labour intensive (Kipsat *et al.*, 2004). Kipsat (2001), showed that the cost of labour forms over 60% of the total variable cost. However, labour contributed less to total variable cost (60.74%) when inorganic fertilizers were used than it did in the use of organic fertilizers, where it contributed between 65.7% and 74.8% of the total cost in maize production. This is explained by the difference in labour requirement for using organic and inorganic material in crop production.

Nziguheba *et al.* (2004), on the other hand found that the net benefit from Tithonia and the combined treatment were positive, but depended on the strategy adopted for Tithonia production . Where Tithonia involved the cost of cutting, carrying and applying, higher net benefits were obtained in treatment receiving Tithonia than in the sole application of fertilizers, where the benefits increased with increasing proportion of P from Tithonia. Phosphorus either supplied by TSP, Tithonia or their combination, increased the yield compared to the control treatment. However, Tithonia proved to be a more efficient P source than inorganic fertilizer by providing the largest increase in maize grain yields, the largest P recovery and added value at least 32% higher compared to sole inorganic fertilizers. A similar study was carried out to establish the economic analysis of combined use of organic Pymarc and inorganic P sources on the production of maize.

The integration of fertilizers with organic inputs has been regarded as a more profitable alternative in low input systems countering the large cost of fertilizer (Janssen, 1994). The hypothesis in this study was that there are differences in economic returns of maize yield produced using either organic source of P alone or in combination with inorganic source of P. This implies that farmers need to consider profitability of use of technologies in adoption. The technologies have comparable yield responses but the costs of adoption vary from technology to technology, resulting in profitability differences.

CHAPTER THREE

3.0 NUTRIENT RELEASE PATTERNS FROM PYMARC ON SELECTED SOILS

3.1 Introduction

Litter quality, environmental factors and soil decomposer organisms influence decomposition and nutrients mineralization patterns (Heal *et al.*, 1997). Litter quality may be the most important factor controlling decomposition within a site (Heal *et al.*, 1997). Several litter quality parameters have been proposed in the effort to develop a quantitative prediction of the time course of nutrients release and decomposition. For agricultural crops, incorporation into soil of plant materials with a C:N ratio of less than 20 may result in net nitrogen mineralization and materials with a C: N ratio > 20 tend to cause net immobilization (Palm *et al.*, 2001). Currently, there are several recommendations on the amount of manure to use on maize crops. The recommended quantities were derived from simple manure response trials in different regions of the country. The minimum amount of manure, which is required to give economic crop yields, has not been determined.

Relationship between the mineralization of nitrogen, phosphorus and potassium from manure and indices to describe manure quality has not been examined in detail. Studies done on green manures show that it is possible to use the release patterns and chemical indices to describe the quality of materials and predict rates of decomposition hence nitrogen, phosphorus and potassium release (Mafongoya and Nair, 1997). The rate of nitrogen, phosphorus and potassium mineralization of Pymarc and other organics must be known to optimize use and predict supplementation rates of mineral fertilizers (Constantinides and Fownes, 1994). However, nutrient release patterns of different manures and their contribution to soil fertility have shown varied trends depending on the chemical characteristics of the manure, the degree of fineness during use, mode of placement, type of plant species used and the nature of the soil micro organisms. The objective of this study was to determine nitrogen, phosphorus and potassium release pattern when pymarc was added to *Cambisol, Phaeozems* and *Ferralsols*.

3.2 Materials and Methods

3.2.1 Soil, Pymarc and Tithonia sampling, preparation and characterization

Soil sampling and analysis

Prior to commencement of the experiments, a total of nine soil samples were collected at depths of 0-15 cm and 15-30 cm randomly in zig zag grid layout across the three research sites: Egerton University (Njoro Campus), Molo and Kosirai using a 5cm diameter auger. The individual samples were bulked and mixed thoroughly in buckets. Sub samples were obtained from the bulk and packed in clear labeled plastic bags. The samples were placed in cooler boxes with ice for transportation to the laboratory. The composite samples were analyzed for various chemical and physical properties to characterize the soil and establish the initial (benchmark) soil fertility status (Table 1)

The samples were air-dried, ground to pass through a 2-mm mesh sieve for physical and chemical analyses. Soil texture was determined by the hydrometer method and soil pH by the soil: water or KCl solution ratio of 1:2.5 (Okalebo *et al*., 2002). Total carbon (C) was determined by oxidizing 0.3 g of soil with a solution of 5 ml of 0.0667 M potassium dichromate and 7.5 ml of concentrated Sulphuric acid in the digestion block. The concentration of potassium dichromate remaining after digestion was titrated with 0.033 M Ferrous ammonium sulphate as described by Okalebo *et al.* (2002). Soil total nitrogen (N) was determined by semi micro-kjedahl digestion where 4.4 ml of the digestion mixture (selenium, lithium sulphate and hydrogen peroxide and concentrated Sulphuric acid) was added to 0.3g soil and digested for two hours at 360 ^{0}C. Later, 25 ml of distilled water was added, the solution cooled and aliquot of 5 ml taken for distillation for total N. Another aliquot of 5 ml was taken and P determined by spectrophotometer method at wavelength 880 nm as described by Okalebo *et al.* (2002).

Cations exchange capacity (CEC), Ca, Mg and K were determined by the summation method. Five grams of the air dried soil was ground to pass through a 2-mm sieve and put in a plastic bottle with a stopper, 100 ml of ammonium acetate (pH 7.0) added and the solution shaken for 30 minutes before filtration through a No. 42 Whatman filter paper (Anderson and Ingram, 1993; Okalebo *et al*., 2002). The extract from the soil was then used for Ca and Mg determination by atomic absorption spectrophotometer, while K was determined by flame photometer. (Anderson and Ingram, 1993; Okalebo *et al*., 2002).

Pymarc and Tithonia sampling and analysis

Green biomass of Tithonia collected from the hedges and Pymarc materials were dried at 65 ^{0}C and ground to pass through a 1-mm mesh sieve. Total nitrogen (N) was determined by semi micro-kjedahl digestion where 4.4 ml of the digestion mixture was added to 0.3 g Tithonia and Pymarc litter separately and digested for two hours at 360 ^{0}C. Later, 25 ml of distilled water was added, the solution cooled and an aliquot of 5ml taken for distillation for total N. Another aliquot of 5 ml was taken from the digest from which P was determined by spectrophotometer method at wavelength 880nm, Ca and Mg determined by atomic absorption spectrophotometer, while K was determined by flame photometer, all described by Okalebo *et al.* (2002). Soluble polyphenols in Tithonia and Pymarc were determined using the Folin-Denis method (Constantinides and Fownes, 1994) and Lignin content by the acid detergent fiber (ADF) method (Okalebo *et al.*, 2002). Thus, Tithonia was included in this study as a base for comparison with Pymarc whose performance had not been verified.

Tithonia diversifolia was included in this study at Kosirai because of it is wide distribution along farm boundaries where boundary hedges of sole Tithonia can produce about 1 kg biomass m^{-1} yr^{-1} on dry weight basis. Green biomass of Tithonia has been recognized as an effective source of nutrients for crops (Gachengo *et al.*, 2004). In addition to providing nutrients, Tithonia incorporated at 5 t/ha can reduce P sorption and increase soil microbial biomass (Bashir Jama *et al.*, 2000). Thus, Tithonia was included in this study as above for comparison with Pymarc whose performance had not been verified. The chemical composition of Pymarc and Tithonia are shown in Table 2. The total nitrogen content is 2.2% in Pymarc and 6.02% in Tithonia. Tithonia contains higher concentration of phosphorus of 0.32% while Pymarc had a lower concentration of 0.28%, both of which are higher than the critical level of 0.25% for net mineralization (Palm *et al.*, 2001). Pymarc and Tithonia have other nutrient compositions that vary considerably, i.e, 1.4% Ca, 0.62% Mg, and 5.0% K in Pymarc and 0.37% Ca, 0.25% Mg and 3.8% K in Tithonia. Total extractable polyphenols concentration in Pymarc and Tithonia is 4.8% and 2.1% respectively. The characteristics of Pymarc and Tithonia are shown in Table 2.

3.2.2 Pymarc Biodegradation Study

A pot experiment was conducted in the green house at Egerton University to study the effect of five levels of Pymarc on N, P and K release. Rates of Pymarc equivalent to 0, 2, 4, 6 and 8 tonnes ha^{-1} were applied in every 2 kg of each of the soil type. The soils for the greenhouse experiment were obtained from Kosirai, Molo and Egerton University (Njoro

Campus). The five levels of Pymarc rates were mixed thoroughly with 2 kg of soil in an open 2.5 litres round plastic pots that had drainage holes at the bottom. Initial moistening of soil was done to 100% field capacity, and then maintained at 60% field capacity. Five levels of Pymarc were tested in a factorial experiment in a Completely Randomized Design (CRD) with three replications. Samples were removed periodically after 2, 4, 6, 8, 12 and 16 weeks for analysis of mineral N, available P and K according to methods of Anderson and Ingram (1993).

3.2.3 Statistical Analysis

Analysis of variance (ANOVA) using General Liner Models (GLM) was performed to determine Pymarc rates and soil treatment effects on soil nitrogen, phosphorus and potassium mineralization (SAS, 2001). Pearson linear correlation coefficient (r) between mineralization parameters and initial soil and litter characteristics were also determined. Non linear regression analysis of incubation results was also performed using the SAS non linear procedure. The regression model that best described Nitrogen, phosphorus and potassium mineralization from litter amended soils was of the form:

Equation 1,

$y = N_o P_o K_o (1-e^{-kt})$ (Smithson *et al.*, 1980)

Where:

y = cumulative inorganic Nitrogen, Phosphorus and Potassium produced by time t (days)

k = Mineralization rate constant (day^{-1})

The coefficients $N_o P_o K_o$ denote N, P and K mineralization potential

The description of mass and N, P and K remaining followed the first order kinetic model,

Equation 2,

$Y = M_o e^{-kt}$ (Smithson *et al.*, 1980)

Where:

Y is the N, P and K remaining at time t.

M_o *is* initial N, P and K and k is the rate constant

Many kinetic models such as sigmoid, hyperbolic and single exponential plus linear models have been used to describe inorganic N production from the soil amended organic materials (Wang *et al.*, 2004). The first order kinetic models including the single and the double exponential models remain widely used. However, in this study double exponential model was not used because there was no separation of mineralizable organic NPK into active and slow pools of which the model entails.

3.3 Results and Discussion

3.3.1 Results

The soils were selected to represent a range of soils types with different physical and chemical characteristics as shown in Table 1. At Egerton site the soils are slightly acidic, well-drained, dark reddish in colour and are classified as *molic Phaeozems* (FAO-UNESCO, 1988). They have high amounts of C, N, P CEC, Ca, Mg and the texture is clay loam. Molo, soils are slightly acidic, well-drained, deep, dark reddish brown and are classified as *humic Cambisols* (Jaetzold and Schmidt, 1983). The soils in Kosirai are *rhodic Ferralsols* (Jaetzold and Schmidt, 1983) and acidic, they consist of lithological gneisses rich in biotites and/or hornblendes and have less organic matter content, CEC, C, P, Ca, Mg and low CEC in the topsoil compared to the humic *Phaeozems* and *Cambisols*. They are very dark red in colour and consist of very friable clay to sandy clay. The soil samples chemical and physical properties are as shown in Table 1.

Table 1: Characteristics of soils from research sites used in the biodegradation study

	Sampling sites					
Soil Property	**Egerton**		**Molo**		**Kosirai**	
	0-15cm	15- 30cm	0-15cm	15- 30cm	0-15 cm	15- 30cm
Soil pH H_2O	6.00	6.30	6.20	6.30	4.60	4.80
Kcl	5.30	5.50	5.70	6.10	4.10	4.40
% Total Nitrogen	0.25	0. 23	0.28	0. 22	0.12	0.09
% Carbon	2.46	2.13	2.16	2.03	1.32	1.11
C:N ratio	9.84	9.26	7.71	9.23	11.0	12.3
Exchangeable bases						
Available Phosphorus (Cmol (+) Kg^{-1}soil)	1.20	0.90	1.70	1.20	1.00	0.70
Potassium (Cmol (+) Kg^{-1}soil)	0.38	0.28	0.42	0.47	1.23	0.52
Calcium (Cmol (+) Kg^{-1}soil)	11.21	12.00	6.11	5.72	3.42	3.18
Magnesium (Cmol (+) Kg^{-1}soil)	8.01	7.99	3.01	2.89	2.01	1.91
CEC (Cmol (+) Kg^{-1}soil)	38.2	36.0	35.7	32.5	23.6	21.6
Texture						
% Sand	35	31	38	32	56	53
% Silt	43	37	42	35	22	21
% Clay	22	24	20	22	22	25
Texture class	Clay loam		Clay loam		Sandy clay loam	

Table 2: Pymarc and Tithonia characteristics

Plant Residue	% N	% C	C: N	% P	% Ca	% Mg	% K	% Lignin	% Poly-phenols	Lig:N	Pol:N	(Lig+Pol): N
Pymarc	2.2	26	11.7	0.26-0.33	0.4	0.3	3.8	10.5	4.8	4.8	2.1	6.9
Tithonia	3.9	24	4.0	0.28-0.38	1.4	0.6	5.0	7.2	2.1	2.2	0.6	2.8

Note: PRQI = Lig + Pol: N

Nitrogen, Phosphorus and Potassium Release from Soil amended with Pymarc

The patterns of nitrogen, phosphorus and potassium mineralization from *Phaeozems, Cambisols* and *Ferralsols* are shown in Figures 1, 2 and 3. Cumulative nitrogen released after 112 days of incubation ranged from 142 mg N kg^{-1} in *Feralsols* to 168 mg N kg^{-1} in *Cambisols* and 170 mg N kg^{-1} in *Phaeozems* (Figure 1). This implied that *Phaeozems* and *Cambisols* soil's mineralized significantly higher amount of Nitrogen than *Ferralsols*. The scenario is opposite for the initial 50 days of incubation, where *Ferralsols* mineralized higher amount of Nitrogen than *Phaeozems* and *Cambisols.* In subsequent days beyond 112 days in *Ferralsols,* soils Nitrogen mineralized remained constant (Figure 1) while those of the other two soil types increased steadily. Therefore, comparing the soil types, *Phaeozems* and *Cambisols* mineralized higher amounts of Nitrogen than *Ferralsols* for the entire period of incubation.

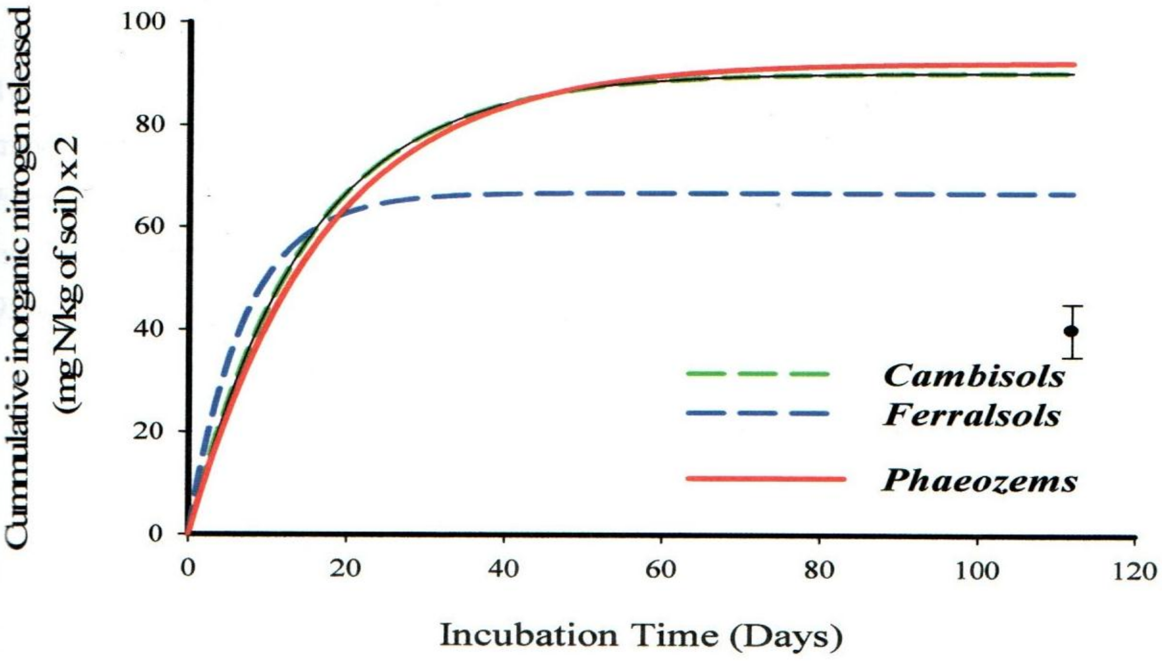

Figure 1.0: Nitrogen mineralized from soils amended with Pymarc at 4 tonnes ha^{-1}

Phosphorus mineralization was optimal at 20 days of incubation beyond which it was higher for *Phaeozems* and *Cambisols* than for *Ferralsols* throughout the incubation period (Figure 2). At 112 days of incubation Phosphorus mineralized from *Phaeozems*, 6.1 mg P kg^{-1} *and Cambisols*, 7.2 mg P kg^{-1} which was twice the amount of P mineralized from *Ferralsols,* 3.1 mg P kg^{-1} (Figure 2).

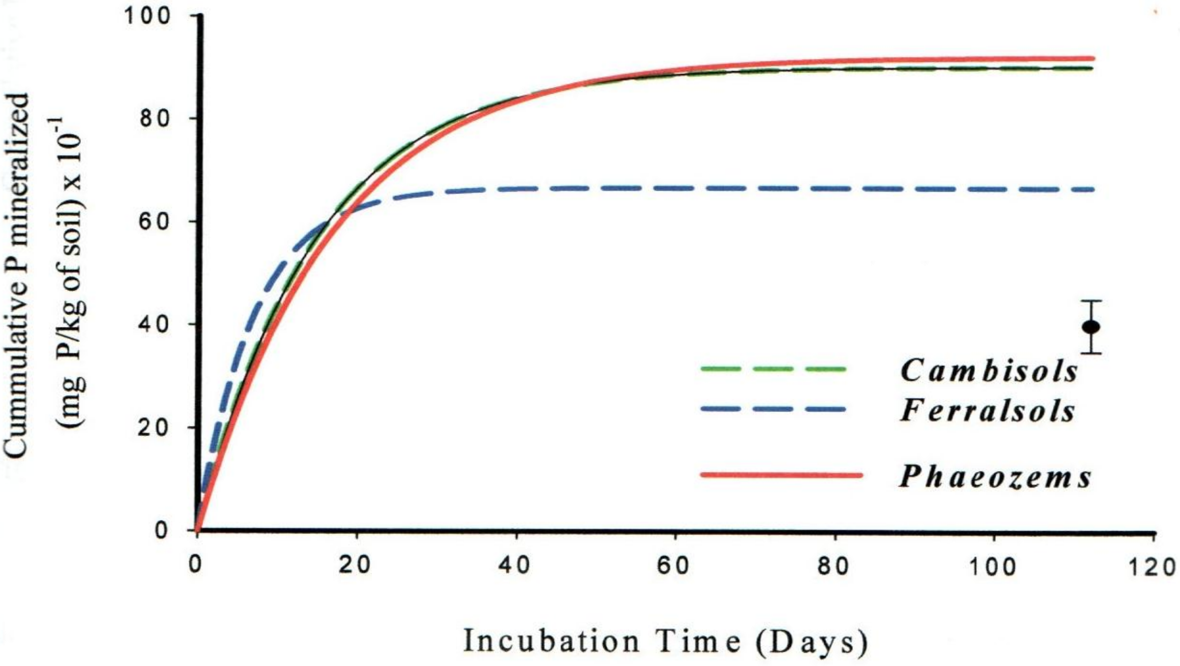

Figure 2.0: Phosphorus mineralized from soils amended with Pymarc at 4 tonnes ha^{-1}

Potassium mineralization at 112 days from *Phaoezems,* 101 mg K kg^{-1} and *Cambisols,* 100 mg K kg^{-1} were significantly higher than for *Ferralsols,* 45 mg K kg^{-1}. Potassium mineralized from *Phaeozems* and *Cambisols* was generally greater than twice than for *Ferralsols* for the entire period of incubation (Figure 3). A single exponential model with two parameters gave the best fit for the N, P and K mineralized and this model accounted for 95% for the nitrogen, phosphorus and potassium mineralization kinetics.

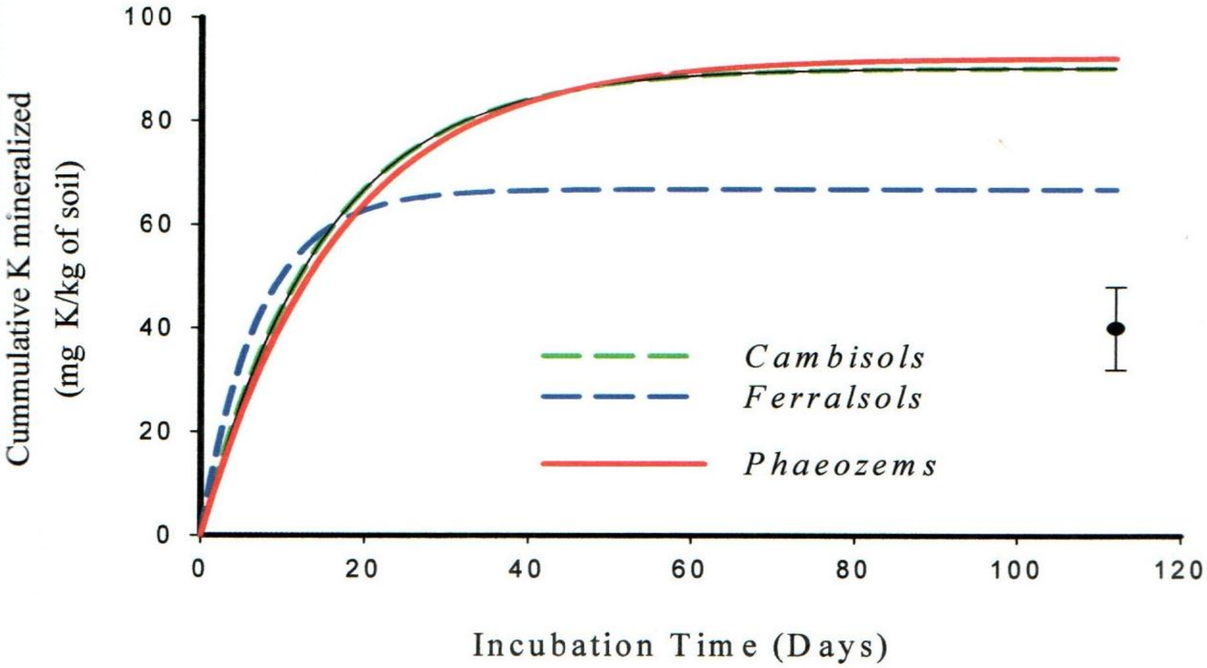

Figure 3.0: Potassium mineralized from soils amended with Pymarc at 4 tonnes ha^{-1}

Increasing rate of Pymarc application led to increase in the overall amount of nitrogen, phosphorus and potassium released from manure (Table 3). There was a significant ($P \leq 0.05$) difference in all the three soils between the nitrogen, phosphorus and potassium released at 8 t ha^{-1}, 6 t ha^{-1} and 4 t ha^{-1} from that released at 0 t ha^{-1} or 2 t ha^{-1}. The release at 8 t ha^{-1}, 6 t ha^{-1} and 4 t ha^{-1} were not significantly ($P \leq 0.05$) different from each other however there was significant difference in release from that at 0 t ha^{-1} and 2 t ha^{-1} (Table 3). This is in line with the findings of Nhamo *et al.*, (2004), who found a similar relationship from a long-term study on rates of manure application and nutrients release. In another study, Schimitt *et al.*, (1992) also found a linear relationship between release of inorganic N and manure application rate.

Table 3: **Nitrogen, Phosphorus and Potassium release (mg/kg of soil) after 112 days of incubation in different soils and rate of Pymarc application**

	Nitrogen, Phosphorus and Potassium release (mg/kg of soil)								
	Soil types								
	Phaeozems			*Cambisols*			*Ferralsols*		
Rate of Pymarc application (t ha^{-1})	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium	Nitrogen	Phosphorus	Potassium
0.00	91.00^{c}	2.30^{c}	89.00^{c}	87.00^{b}	5.20^{dc}	90.00^{c}	99.00^{c}	2.00^{c}	26.00^{b}
2.00	112.00^{abc}	2.20^{c}	94.00^{bc}	94.00^{b}	4.40^{d}	89.00^{c}	95.00^{c}	3.00^{b}	26.00^{b}
4.00	127.00^{ab}	6.00^{b}	99.00^{ab}	134.00^{a}	6.60^{bc}	101.00^{b}	142.00^{b}	3.50^{ab}	49.00^{a}
6.00	129.00^{ab}	7.10^{ab}	100.00^{a}	129.00^{a}	7.90^{ab}	105.00^{ab}	165.00^{a}	3.90^{ab}	49.00^{a}
8.00	139.00^{a}	8.10^{a}	96.00^{ab}	137.00^{a}	8.40^{a}	107.00^{a}	170.00^{a}	4.20^{a}	51.00^{a}
Lsd	**25.00**	**1.24**	**59.00**	**27.90**	**1.50**	**5.50**	**21.00**	**0.95**	**4.40**
C.V%	**29.30**	**33.20**	**8.40**	**33.00**	**31.60**	**7.80**	**21.60**	**39.10**	**14.80**

Means followed by the same letters are not significantly different ($P \leq 0.05$)

Nitrogen, Phosphorus and Potassium Release Kinetics and Half Life

Cambisols had highest potential mineralized N_o of 182 mg kg^{-1}, 7.6 of P_o mg kg^{-1} and 101 of K_o mg kg^{-1} than *Phaeozems* N_o of 163 mg kg^{-1}, 6.4 of P_o mg kg^{-1} and 99 of K_o mg kg^{-1} and *Ferralsols* N_o of 148 mg kg^{-1}, 3.6 of P_o mg kg^{-1} and 49 of K_o mg kg^{-1}(Table 4). However, *Ferralsols* had the highest NPK mineralization rate constants 0.12 K_N (d^{-1}) and 0.16 K_P (d^{-1}) while the *Phaeozems* had highest Potassium mineralization rate constant (0.33 K_K (d^{-1}) (Table 4).

The Pymarc biomass decomposed rapidly after incorporation into the soils. The corresponding half lives for nutrients release were on average about two to three weeks for N in *Phaeozems* and *Cambisols* respectively and one week in *Ferralsols* (Table 5). P release was one to two weeks in *Phaeozems* and *Cambisols,* respectively, and a week in *Ferralsols.* (Table 5). However, half life for K release was one week for all the three soils (Table 5). Gaheng *et al,* (2004) reported a half life of about one week for the disappearance of dry matter in the rainy season and half life for nutrients release of one week for N and two weeks for P from the organic residue. The N concentration in Pymarc is higher than the critical level of 2.5% below which net immobilization of N would be expected (Table 2). Similarly, P concentration is higher than the critical value of 0.25% for net P mineralization.

Table 4: Model parameters for NPK release kinetics for *Phaoezems, Cambisols* and *Ferralsols*

Soils type	N_o (mg kg^{-1})^a	P_o (mg kg^{-1})^a	K_o (mg kg^{-1})^a	K_N (d^{-1})^b	K_P (d^{-1})^b	K_K (d^{-1})^b
Phaeozems	163 (3.6)^c	6.4 (0.39)	99 (1.2)	0.051 (0.002)	0.104 (0.0015)	0.330 (0.16)
Cambisols	182 (2.0)	7.6 (0.27)	101 (2.08)	0.031 (0.002)	0.060 (0.0016)	0.224 (0.002)
Ferralsols	148 (2.52)	3.6 (0.12)	49 (1.53)	0.124 (0.004)	0.159 (0.003)	0.229 (0.005)

Note: [a] N_o, P_o and K_o is the potentially mineralizable N, P and K
[b] K_N, K_P and K_K represent N, P and K rate constants.
[c] Values in parenthesis represent standard deviation.

Table 5: Half life (Days) of nutrients released from Pymarc in *Phaeozems, Cambisols* and *Ferralsols*

	Half life (t_{50} days)		
Soils type	**N**	**P**	**K**
Phaeozems	14	7	7
Cambisols	21	14	7
Ferralsols	7	7	7

Note: N, P and K are the time when 50% of the nutrients have been released.

Based on Pearson correlation, cumulative nitrogen, phosphorus and potassium released were positively correlated to the litter quality parameters except N for soluble polyphenol content (Table 6). Soil nitrogen and potassium released was consistently related to C: N, lignin, Lig: N, Pol: N and Pol + Lig: N ratios in all the three soils during the entire incubation period. Nitrogen was related with polyphenols especially in *Ferralsols* after 56 days of incubation (Table 6).

Table 6: Pearson correlation coefficient (r) between litter characteristics and mean values of N, P and K released in three soils at different days of incubation n = 6

Incubation time (days)	R																	
	C: N			Lignin			Polyphenols			Lig:N			Pol : N			Lig+Pol:N		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Phaeozems																		
14	0.71*	Ns	0.74*	0.76*	Ns	0.74*	Ns	Ns	0.56*	0.71*	Ns	0.54*	0.77*	Ns	0.64*	0.76*	Ns	0.94*
28	0.92*	Ns	0.61*	0.82*	Ns	0.74*	Ns	Ns	0.60*	0.72*	Ns	0.60*	0.87**	Ns	0.81*	0.91*	Ns	0.61*
56	0.86*	0.89*	0.83*	0.84*	0.89*	0.83*	Ns	-0.89*	0.81*	0.75*	0.89*	0.74*	0.86*	0.89*	0.73*	0.94*	0.89*	0.53*
84	0.74*	0.97*	0.89*	0.89*	0.97*	0.89*	Ns	-0.97*	0.79*	0.76*	0.97*	0.69*	0.94*	0.97*	0.99*	0.96*	0.97*	0.89*
112	0.90*	0.82*	0.96*	0.76*	0.82*	0.81*	Ns	-0.82*	0.66*	0.80*	0.82*	0.76*	0.90*	0.82*	0.86*	0.90*	0.82*	0.96*
Cambisols																		
14	0.89*	Ns	0.73*	0.79*	Ns	0.83*	Ns	Ns	0.63*	0.73*	Ns	0.83*	0.87*	Ns	0.83*	0.82*	Ns	0.73*
28	0.78*	Ns	0.69*	0.81*	Ns	0.82*	Ns	Ns	0.78*	0.78*	Ns	0.79*	0.75*	Ns	0.69*	0.88*	Ns	0.79*
56	0.88*	0.68*	0.71*	0.79*	0.68*	0.81*	Ns	-0.68*	0.70*	0.81*	0.68*	0.81*	0.80*	0.68*	0.81*	0.91*	0.68*	0.91*
84	0.81*	0.89*	0.94*	0.81*	0.89*	0.74*	Ns	-0.89*	0.84*	0.81*	0.89*	0.74*	0.81*	0.89*	0.64*	0.94*	0.89*	0.84*
112	0.79*	0.89*	0.94*	0.78*	0.89*	0.98*	Ns	-0.89*	0.74*	0.89*	0.89*	0.84*	0.79*	0.89*	0.64*	0.75*	Ns	0.74*
Ferralsols																		
14	0.74*	Ns	0.88*	Ns	Ns	0.85*	Ns	Ns	0.78*	Ns	Ns	0.85*	Ns	Ns	0.68*	0.74*	Ns	0.78*
28	0.81*	Ns	0.74*	Ns	Ns	0.84*	Ns	Ns	0.84*	Ns	Ns	0.76*	Ns	Ns	0.84*	0.82*	Ns	0.84*
56	0.75*	0.75*	0.81*	0.84*	0.75*	0.89*	-0.75*	-0.75*	0.71*	0.73*	0.65*	0.80*	0.79*	0.75*	0.71*	0.88*	0.75*	0.80*
84	0.84*	0.86*	0.79*	0.74*	0.86*	0.79*	-0.84*	-0.86*	0.79*	0.84*	0.96*	0.89*	0.74*	0.86*	0.79*	0.92*	0.86*	0.70*
112	0.76*	0.75*	0.78*	**0.86***	0.75*	0.71*	-0.76*	-0.75*	0.88*	0.81*	0.95*	0.88*	0.91*	0.75*	0.88*	0.92*	0.75*	0.63*

Ns: refer to not significant at 5% confidence level

*: refer to significance at 5% confidence level

3.3.2 Discussion

The observed differences in N release may have been because of the variations in soil pH, organic C, N, and C: N ratio and % Clay for the soil types used. The *Phaeozems* and *Cambisols* have higher nutrients content as compared to *Ferralsols* and have been classified as productive soils by Jaetzold and Schimdit, (1983). Nutrients availability to microorganisms especially C, N, P and K have been reported to govern the rate and extent of decomposition. The N concentration in Pymarc and Tithonia is within the critical level of 2.0% to 2.5%; below which net immobilization of N would be expected likewise lignin is below the level of 15% that significantly reduces decomposition. Green biomass of Tithonia, as compared to Pymarc is relatively high in nutrients.

The three soils used in the incubation study differed in amounts of C, nitrogen, pH, clay and the potential N, P and K which may have resulted in different release rates of nitrogen, phosphorus and potassium. The soils with greater amount of carbon such as *Phaeozems* and *Cambisols* released higher amounts of nitrogen, phosphorus and potassium since soil microbial populations readily utilized such C substrate. Pymarc litter mineralized higher amounts of nitrogen, phosphorus and potassium because it was generally of higher lability (low C: N ratio, lignin, lignin: N, pol + lig: N ratios).

Many studies have examined the relationship between total N, C: N, lignin and polyphenols to litter decomposition, especially for crop residues (Trinsoutrot *et al.*, 2000). Soil micro organisms utilize N to breakdown carbon substrate, therefore, litter with high total N and narrow C: N ratio decompose more rapidly. Lignin is considered an important component determining the rate of decomposition (Palm and Rowland, 1997), because it physically protects cellulose and other carbohydrates and also inhibits the synthesis and activity of cellulolytic enzymes. Lignin was correlated to nitrogen and potassium mineralization in the *Phaoezems* and *Cambisols* and inconsistently in *Ferralsols.* The *Ferralsols* soil had lower nutrient availability than the other two soils, which may have masked the effect of lignin. The relative importance of litter quality is influenced by soil properties and may change as decomposition progresses (Berg and McClaugherty, 2003). Soil properties favouring rapid litter decomposition include near neutral pH and adequate nutrients availability. The *Ferralsol* soil had relatively lower pH and nutrients available than the *Phaoezems* and *Cambisols.* There were differences in nitrogen, phosphorus and potassium release observed among the three soils, possibly because the soils had different N_o, P_o and K_o. The release of the various nutrients by Pymarc makes it suitable for use as organic matter amendments. To be effective however, there must be a synchrony between the release of nutrients and crop demand. The half life of Pymarc for example indicated that half of the N was released within one to three weeks from the three selected soils. It is worthy to note that Pymarc released more than 75% of N by the 6th week. Within this period the amount released could coincide with the crop demand especially for maize

3.4 Conclusion

As hypothesized, nitrogen, phosphorus and potassium release pattern is influenced by soil characteristics, amount of litter and quality of the litter. The nitrogen, phosphorus and potassium mineralization was significantly correlated to nitrogen, carbon, C: N ratio, lignin contents, lig: N, Lig + Pol: N ratios. There were clear differences in nitrogen, phosphorus and potassium mineralization between the three soils, where *Phaeozems* and *Cambisols* classified as productive soils had a higher of nutrients release than *Ferralsols*. Nitrogen, phosphorus and potassium mineralization in the three soils were different, though N, P and K released was maximally within the first 30 days and this could be synchronized with crop nutrients needs.

The three soils were shown to have different N_o, P_o and K_o kinetics which may explain the differences in nitrogen, phosphorus and potassium release patterns. These results corroborate the role of litter quality and soil properties in influencing litter decomposition. (Mungai and Mortavalli, 2005). The rate at which manure is added to the soil affects the amount of nitrogen, phosphorus and potassium mineralized. The optimal rate of Pymarc manure application is 4 t/ha though 8 t ha^{-1} treatments were exceptional in all the three soils possibly because of the amount of carbon and nitrogen loading associated with application of large amounts of organic materials.

CHAPTER FOUR

4.0 EFFECTS OF PYMARC ON IMPROVEMENT OF SOIL FERTILTY, MAIZE GROWTH AND GRAIN YIELD AT EGERTON, MOLO AND KOSIRAI

4.1 Introduction

Maize yields in many parts of Kenya are low due to declining soil fertility as a result of continuous cultivation and non-application of fertilizers by farmers. Soils have low reserve Nitrogen, Phosphorus and some trace elements (ICRAF, 1998). The use of Pymarc as soil fertility amendments based on their nutrient contribution gives useful information in developing recommended rates and mode of application. An approach that includes test on the mode and rate of application of these organic inputs is needed as a solution to the prevailing conditions. High labour requirements for collection of organic inputs, transport and application necessitate the optimal management of relatively small quantities at any given time (Bashir Jama *et al*., 2000). Therefore, research should be focused on the rate that can be realistically achieved with the labour and quantities available in small holder agriculture.

Thus, the objectives of this study were to determine the effect of mode and rate of application of Pymarc on N, P and K concentrations in leaf opposite the ear, maize root biomass and grain yield, and changes in soil properties at Egerton (*Phaeozems*), Molo (*Cambisols*) and Kosirai (*Ferralsols*).

4.2 Materials and Methods

4.2.1 Description of Research Sites

The experimental sites were located at Egerton University Njoro Campus, Molo both in Nakuru district (Molo and Njoro Divisions) and Kosirai in Nandi District (Kosirai Division) (Figures 4, 5 and 6). In Njoro, the experiment was conducted at Field 7 of the Department of Crops, Horticulture and Soils, Egerton University, Njoro Campus which is about 25 km South West of Nakuru Town on the Nakuru - Njoro - Mau Narok road. It lies at latitude $00^0 22$ South and longitude $35^0 56$ East at a mean altitude of 2298 m above sea level. The area has a gently undulating slope of 2-4%. It is classified as a Wheat/Maize Agroecological Zone (AEZ), LH3, which has medium to high potential for arable agriculture with two cropping seasons (Jaetzold and Schmidt, 1983). The average annual rainfall ranges from 840 mm to 1200 mm/yr distributed as bimodal with the long rains starting from March to August and short rains from September to November (Figure 7). The site has a mean maximum and minimum temperature of 27 ^{0}C ± 2.48 ^{0}C and 11 ^{0}C ± 2.48 ^{0}C, respectively, and annual mean temperature of 15.9 ^{0}C ± 2.5 ^{0}C. The soils are well-drained, dark reddish colour and are classified as *mollic Phaeozems* (FAO-UNESCO, 1988) (See Chapter Three Section 3.2.1 Table 1 for soil characteristics and Appendix 1 for classification).

Figure 4: Location of Nakuru and Nandi Districts in Kenya

In Molo, the experiment was set at the Pyrethrum Board of Kenya, Clonal Research Centre located 5 km from Molo Town, Nakuru District on Molo - Mau Summit road (Figure 5). The Research Station lies at latitude $00^{0}14$ South and longitude $35^{0}43$ East and at an elevation of 2529 m a.s.l. The area has gently undulating slope of 2-8%. It is classified as a Wheat-Pyrethrum Agro Ecological Zone (UH2), high potential for arable agriculture with two cropping seasons (Jaetzold and Schmidt, 1983). The mean annual rainfall is 1171 mm/yr, distributed bimodaly, April to June, long rains and August to October short rains (Figure 7). The mean maximum and minimum temperatures are 20.6 ^{0}C ± 2.5 ^{0}C and 6.9 ^{0}C ± 2.5 ^{0}C, respectively, with a mean temperature of 13.8 ^{0}C. (Jaetzold and Schmidt, 1983).

The soils are acidic, well-drained, deep, dark reddish brown and are classified as *humic Cambisols (*Jaetzold and Schmidt, 1983). (See Chapter Three Section 3.2.1 Table 1 for soil characteristics and Appendix 2 for classification).

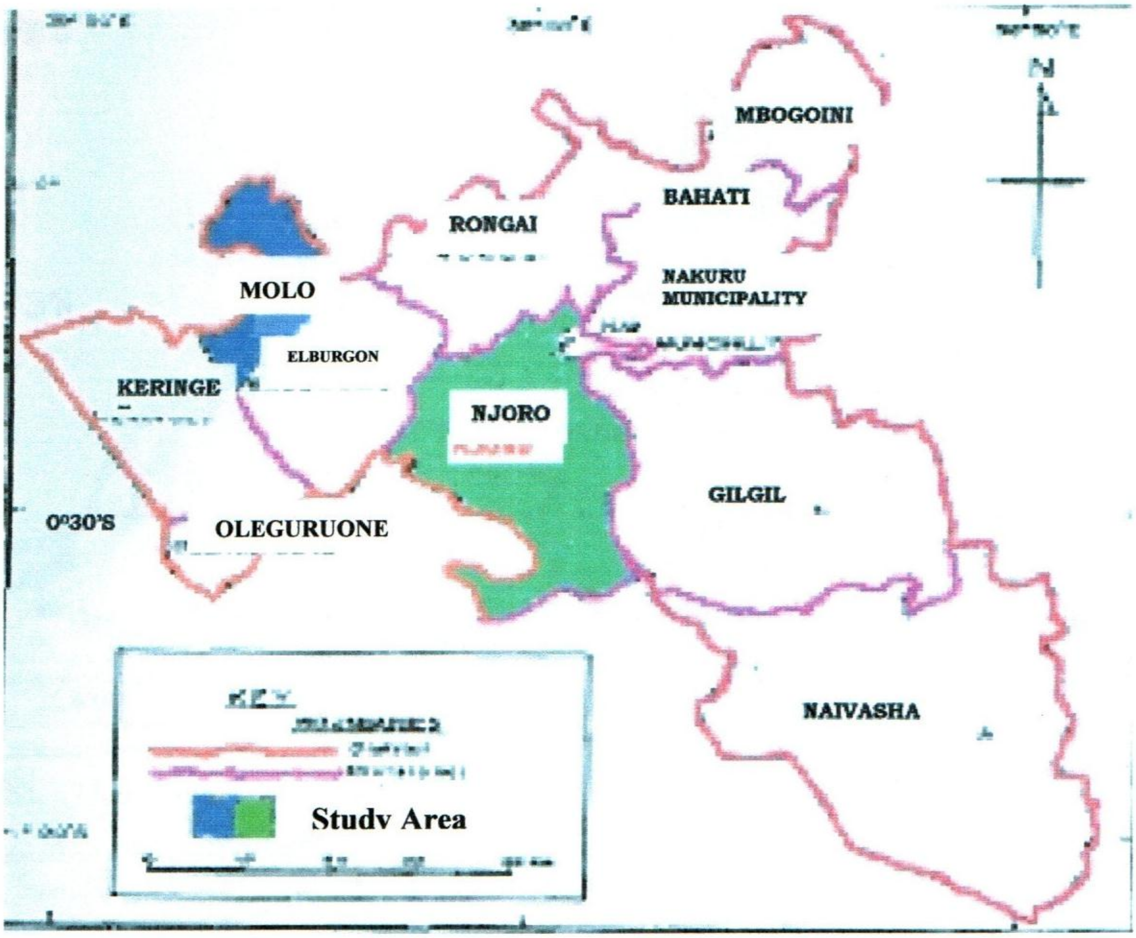

Figure 5: Location of Njoro and Molo Divisions in Nakuru District

Kosirai is located in Kosirai Division, Nandi District and located 10 km from Eldoret Town on Eldoret – Kapsabet – Kisumu road (Figure 6). It is situated at an altitude of 2109 m a.s.l. and at longitude, $00^{0}20$ North and latitude, $35^{0}11$ East. Kosirai falls within the Agro Ecological Zone (UM4) that is described as Sunflower-Maize Zone (Jaetzold and Schmidt 1983). The mean annual rainfall is 1400 mm/yr, distributed bimodaly, March to September long rains and September to December short rains (Figure 7). It experiences mean maximum and minimum temperatures of 25 °C ± 3.14 ^{0}C and 14 °C, ± 3.14 ^{0}C respectively, and a mean temperature of 19.5 ^{0}C ± 2.4 ^{0}C. The soils in Kosirai are *rhodic Ferralsols* (Jaetzold and Schmidt, 1983). (See Chapter Three Section 3.2.1 Table 1 for soil characteristics and Appendix 3 for classification).

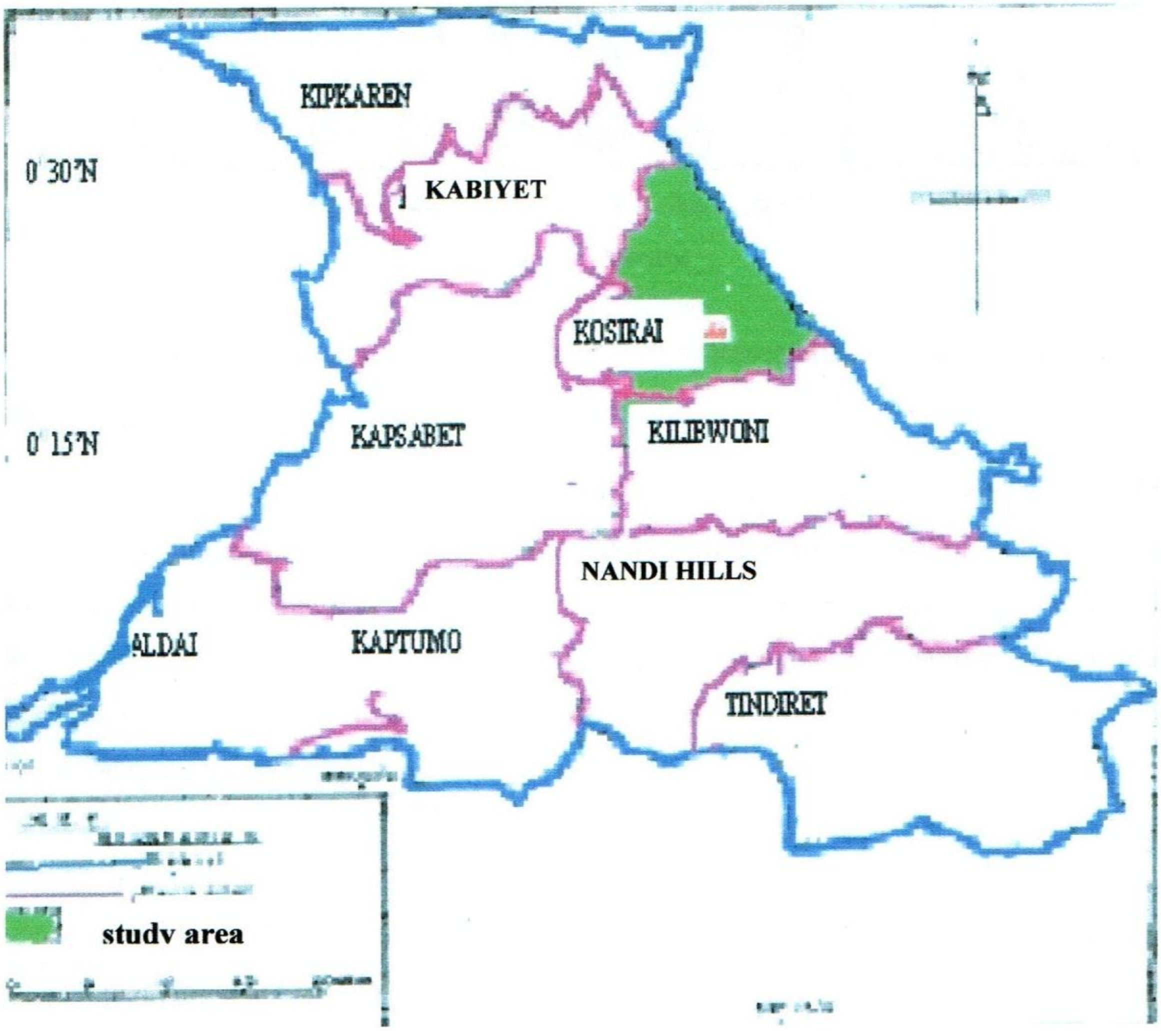

Figure 6: Location of Kosirai Division in Nandi District

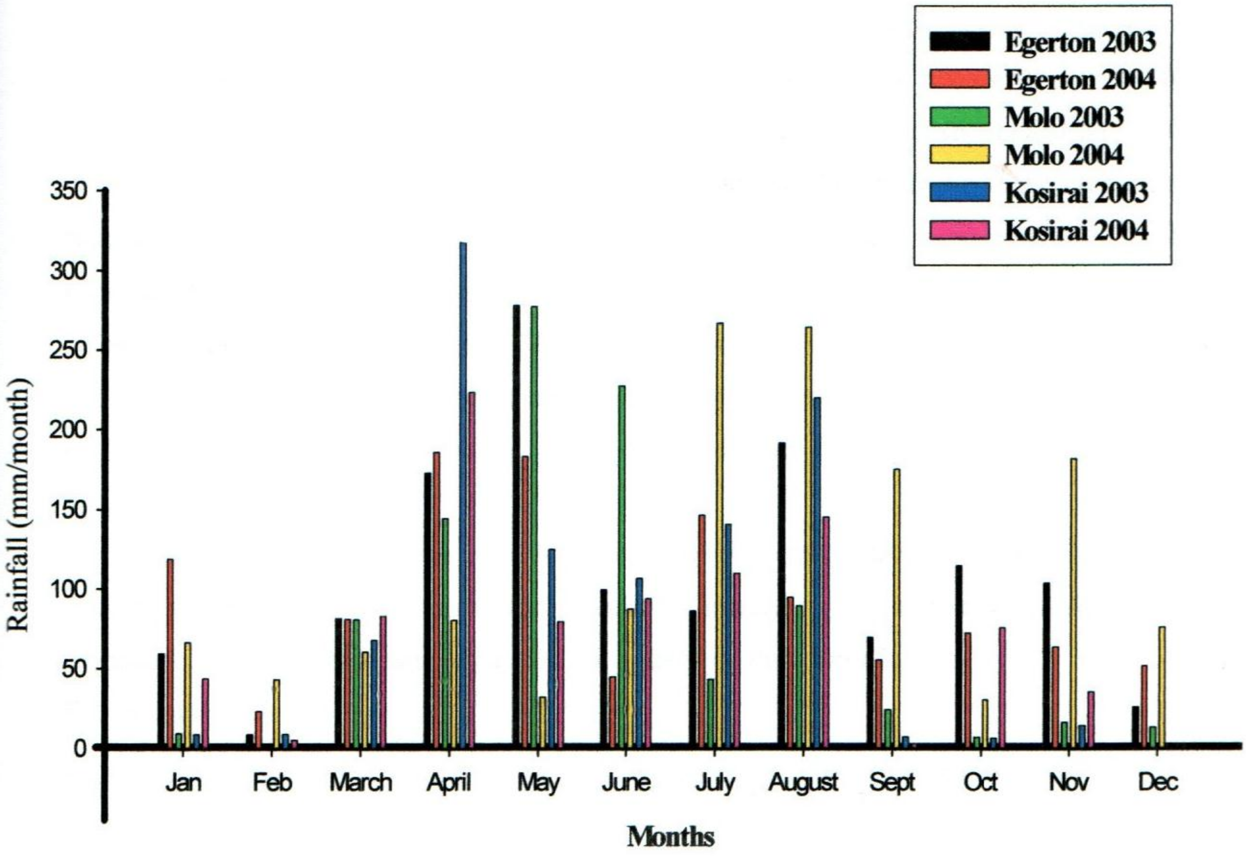

Figure 7: Rainfall pattern at Egerton, Molo and Kosirai Research sites in 2003 and 2004

4.2.2 Experimental Layout

Pymarc at 0, 4 and 8 tonnes ha^{-1} was tested for suitable method of application at two levels, spot vs. broadcast in a 2 x 3 factorial treatment combination in split plot design with mode of application as main plot factor and Pymarc rates as subplot factor replicated three times. Phosphorus and Potassium were applied as Rock Phosphate and Muriate of Potash at 26 kg P/ha and 50 kg K/ha at planting time, respectively. Nitrogen as CAN at 60 kg N/ha was applied as top dress at V6 stage of maize growth.

4.2.3 Crop Establishment and Management

Hybrid maize (H614) was planted at a spacing of 0.75 cm x 0.25 cm, which gave 4 rows per plot and 12 hills per row at the onset of long rains of 2003 and 2004. Each experimental plot measured 3 m x 3 m which occupied 162 m^2. Two seeds were planted per hill then thinned to one at V3 stage leaving a population of 53,000 plants per hectare. The plots were weeded twice at V6 and V9 maize growth stages.

4.2.4 Crop Data Collection

Germination count was taken at V3 whereas stand count was taken at V6. At V6 two plants, second moving from west to East from each of the two central rows were sampled for root biomass and NPK content. The sampled plant materials were kept in labelled polythene bags. The root systems from Trial 1, were cut and later washed with distilled water over a wire mesh. The plant sub samples were chopped into smaller pieces, oven dried at 65 ^{0}C for root and stover dry matter yields and later ground for N, P and K analysis as described by Okalebo *et al*, (2002). At maturity (R6), all seven plants from each of the two middle rows per plot were harvested. The ears were removed, maize shelled and dried to constant moisture content of 13%. The values obtained were used to calculate the total grain and stover yields on a tonnes ha^{-1} basis.

In order to compare the rate of Pymarc and P source effect for different cropping seasons, maize yields were converted to relative increase compared to the control (T1) treatments. Yield increase was calculated using the following formula:

For example:

$$\text{Yield increase (\%) for Treatment 2} = \frac{\text{Yield (T2)} - \text{Yield (T1)} \times 100}{\text{Yield (T1)}}$$

For T3, T4 the same formula is used where:

T1 = Control (0 tonnes ha^{-1})

T2 = Either Tithonia at 5 tonnes ha^{-1} or Pymarc at 8 tonnes ha^{-1} (Equivalent to P at 26 kg ha^{-1})

T3 = TSP at 26 kg P ha^{-1}

T4 = Either Tithonia at 2.5 tonnes ha^{-1} or Pymarc at 4 tonnes ha^{-1} (Equivalent to P at 13 kg ha^{-1}) + TSP at 13 kg P ha^{-1}

4.2.5 Residual Effects of Pymarc and Tithonia Application

The soil samples were collected from 0 to 15 cm depth with an auger during the harvest of the second season, 2004. Three samples, one from each of the three middle rows in a diagonal manner were obtained, put in a bucket, thoroughly mixed, a sub sample taken and placed in plastic bag. For soil sample preparation and N, P and K analyses see Chapter Three, Section 3.2.1.

4.2.5 *Statistical Analysis*

General Linear Model (GLM) as described in SAS, Version 8.1 (SAS, 2001) statistical package was used to perform the Analysis of Variance (ANOVA) and DMRT for mean separation for maize root biomass, N, P and K concentrations in the leaf opposite the ear, stover and grain yield, soil pH, total N, P and K.

4.3 Results and Discussion

4.3.1 *Results*

Root Biomass

Root biomass yield at Egerton, Molo and Kosirai sampled at V6 stage of maize growth indicated that the control treatment was significantly different from treatments with addition of Pymarc in 2003. In 2004, similar results were obtained except at Egerton (Table 7). At Molo, the addition of Pymarc at 4 tonnes ha^{-1} and 8 tonnes ha^{-1} gave relative increase in root biomass yield of 26% and 44% in 2003 and 4% and 43% in 2004, respectively. Pymarc applied at Kosirai at 4 tonnes ha^{-1} and 8 tonnes ha^{-1} gave relative increase in root biomass yield of 34% and 152% in 2003 and 72% and 29% in 2004, respectively. There were low root biomass yield in 2004 as compared to 2003. This could have been attributed to low rainfall amounts in 2004. The results also show that broadcast mode of application of Pymarc had increased root biomass more than spot at the three sites except in Molo, 2003 and 2004 (Table 8).

Table 7: Effect of rate of Pymarc and soil type on root biomass (kg ha^{-1}) in 2003 and 2004

	Root Biomass (Kg ha^{-1})					
	Egerton (*Phaeozems*)		Molo (*Cambisols*)		Kosirai (*Ferralsols*)	
Rate of Pymarc (Tonnes ha^{-1})	2003	2004	2003	2004	2003	2004
0.0	194^{a}	101^{a}	348^{c}	144^{b}	295^{c}	157^{b}
4.0	142^{b}	99^{a}	439^{b}	150^{b}	394^{b}	270^{b}
8.0	158^{ab}	110^{a}	501^{a}	206^{a}	742^{a}	315^{a}

Means followed by the same letter(s) within a column are not significantly different at $P \leq 0.05$

Table 8: Effect of mode of Pymarc application and soil type on root biomass (kg ha^{-1}) in 2003 and 2004

	Root Biomass (kg ha^{-1})					
	Egerton (*Phaeozems*)		Molo (*Cambisols*)		Kosirai (*Ferralsols*)	
Pymarc application method	**2003**	**2004**	**2003**	**2004**	**2003**	**2004**
Broadcast	208^a	140^a	347^b	176^a	394^b	254^b
Spot	121^b	67^b	512^a	157^a	560^a	907^a

Means followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$

N, P and K Leaf Tissue Concentrations at V6 Stage of Maize Growth

Differences in N, P and K concentration in the leaf opposite the ear at V6 stage of maize growth from Pymarc added at 4 tonnes ha^{-1} and 8 tonnes ha^{-1}, were significantly different from no input control in all the three sites, except for K that was significant only at Molo (Table 9). Application of Pymarc resulted in a significant ($P \leq 0.05$) relative increase of N concentration by 20% and 60% in 2003 and 50% in 2004 at Egerton (in *Phaeozems*) when Pymarc was applied at 4 tonnes ha^{-1} and 8 tonnes ha^{-1}, respectively (Table 9). At Molo (in *Cambisols*), the relative increase in N concentration was 17% in 2003 and 12% in 2004 when Pymarc was applied at 4 tonnes ha^{-1} and 8 tonnes ha^{-1}, respectively.

Pymarc at 4 tonnes ha^{-1} and 8 tonnes ha^{-1} had significant ($P \leq 0.05$) relative increase in P content of 43% and 50% in 2003 and 40% and 50% in 2004 respectively, at Egerton, while at Molo it was 50% and 43% in 2003 and 16% and 9.3%, respectively. At Kosirai, Pymarc applied at 4 tonnes ha^{-1} and 8 tonnes ha^{-1} gave a significant ($P \leq 0.05$) relative P content increase of 36% and 45% in 2003 and 27% in 2004, respectively. There was no significant effect of Pymarc addition on K content in all the three sites except in Molo in 2003 (Table 9). Broadcast mode of application treatment of Pymarc had significantly ($P \leq 0.05$) higher P and K at Egerton in 2003 and P and K at Molo in 2004 as compared to spot application. (Table 10).

Table 9: Effect of Pymarc application and soil type on N, P and K leaf tissue concentrations at V6 stage of maize growth in 2003 and 2004

N, P and K concentrations in leaf opposite the ear (mg kg^{-1})																		
	Egerton (*Phaeozems*)						Molo (*Cambisols*)						Kosirai (*Ferralsols*)					
Pymarc (t/ha)	2003			2004			2003			2004			2003			2004		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
0.0	2.5^{b}	14^{b}	245^{a}	1.8^{b}	10^{b}	166^{a}	2.4^{b}	14^{b}	227^{b}	1.7^{b}	12.9^{a}	158^{b}	3^{a}	11^{b}	241^{a}	1.2^{a}	8^{b}	86^{a}
4.0	3^{a}	20^{a}	245^{a}	2.7^{a}	14^{a}	172^{a}	2.8^{a}	21^{a}	229^{b}	1.9^{a}	14.9^{a}	160^{b}	3^{a}	15^{a}	248^{a}	1.0^{a}	11^{a}	101^{a}
8.0	4^{a}	21^{a}	223^{a}	2.7^{a}	15^{a}	156^{a}	2.8^{a}	20^{a}	263^{a}	1.9^{a}	14.1^{a}	188^{a}	4^{a}	16^{a}	266^{a}	1.0^{a}	11^{a}	97^{a}

Means followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$

Table 10: Effect of mode of Pymarc application and soil type on N, P and K leaf tissue 2003 and 2004

N, P and K concentrations in leaf opposite the ear (mg kg^{-1})																		
	Egerton (*Phaeozems*)						Molo (*Cambisols*)						Kosirai (*Ferralsols*)					
Pymarc application	2003			2004			2003			2004			2003			2004		
	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K	N	P	K
Broadcast	3.6^{a}	21^{a}	302^{a}	2.8^{a}	14^{a}	212^{a}	2.7^{a}	21^{a}	252^{a}	1.9^{a}	17^{a}	177^{a}	3.7^{a}	25^{a}	32^{a}	2.6^{a}	10^{a}	184^{a}
Spot	2.8^{a}	16^{b}	173^{b}	2.0^{b}	11^{b}	118^{b}	2.5^{a}	16^{b}	231^{b}	1.8^{a}	11^{b}	161^{b}	3.2^{a}	4^{a}	271^{a}	2.2^{a}	9.7^{a}	160^{a}

Means followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$

Stover and Grain Yields

Highly significant treatment effects were observed in stover and grain yield at all the three sites. Pymarc at 4 tonnes ha^{-1} and 8 tonnes ha^{-1} significantly increased stover and grain yield in 2003 and 2004, respectively (Table 11). The addition of Pymarc at 4 tonnes ha^{-1} and 8 tonnes ha^{-1} at Egerton had significant relative increase in stover yield of 24% and 38% in 2003 respectively and grain yield of 86% and 79% in 2003 and 6% and 12% in 2004, respectively (Table 11). Similarly at Molo, Pymarc applied at 4 tonnes ha^{-1} and 8 tonnes ha^{-1} had significant relative increase in stover yield of 33% and 53% in 2003 and 20% and 28% in 2004, respectively (Table 11).

Significant relative increase in grain yield was 86% and 79% at Egerton in 2003 when Pymarc was applied at 4 tonnes ha^{-1} and 8 tonnes ha^{-1}, respectively. The grain yield had a similar trend at Molo, where there was relative significant relative increase in grain yield of 52% and 62% in 2003 and 46% and 62% in 2004, when Pymarc was applied at 4 tonnes ha^{-1}

and 8 tonnes ha^{-1} , respectively (Table 11). At Kosirai, Pymarc applied at 4 tonnes ha^{-1} and 8 tonnes ha^{-1} had significant relative increase in stover yield of 35% and 45% in 2003 and 34% and 55% in 2004, respectively. The significant relative increase in grain yield was 31% and 44% in 2003 and 55% and 107% in 2004 when Pymarc was applied at 4 tonnes ha^{-1} and 8 tonnes ha^{-1}, respectively at Kosirai. Broadcast mode of application had significant higher effect on stover and grain yield at most of the three sites than spot application (Table 12).

Table 11: Effect of rate of Pymarc application and soil type on stover and grain weight in 2003 and 2004

	Stover and Grain weight (Tonnes ha^{-1})											
	Egerton (*Phaeozems*)				Molo (*Cambisols*)				Kosirai (*Ferralsols*)			
	2003		2004		2003		2004		2003		2004	
Pymarc (t/ha)	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain
0.0	9.7^b	2.9^b	5.0^a	3.3^a	7.3^b	2.9^b	8.1^b	1.3^b	4.37^b	3.2^b	2.25^b	0.45^b
4.0	12^a	5.4^a	5.3^a	3.5^a	9.7^a	4.4^a	9.7^a	1.9^a	5.88^a	4.2^a	3.02^a	0.70^a
8.0	13^a	5.2^a	5.3^a	3.7a	11^a	4.7^a	10.4^a	2.1^a	6.35^a	4.6^a	3.48^a	0.93^a

Means followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$

Table 12: Effect of mode of Pymarc application and soil type on stover and grain weight in 2003 and 2004

	Stover and Grain Weight (Tonnes ha^{-1})											
	Egerton (*Phaeozems*)				Molo (*Cambisols*)				Kosirai (*Ferralsols*)			
	2003		2004		2003		2004		2003		2004	
Mode of Pymarc application	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain	Stover	Grain
Broadcast	11.4^b	4.2^a	5.99^a	3.8^b	9.8^a	4.1^a	9.6^a	1.9^a	4.94^b	3.7^b	2.94^a	0.58^b
Spot	9.3^a	4.8^a	4.4^b	3.2^a	8.9^a	3.8^a	9.2^a	1.6^a	6.12^a	4.3^a	2.89^a	0.81^a

Means followed by the same letter (s) within a column are not significantly different at ($P \leq 0.05$)

Residual effects of Pymarc and Tithonia Application on Soil pH, Total N, P and K

Across the treatments, there was significant relative increase in soil surface (0-15 cm) pH after two years of Pymarc application of 0.8 units at Egerton, 1.0 unit and 0.8 units at Molo and 0. 6 units and 0.4 units at Kosirai with Pymarc at 4 tonnes ha^{-1} and 8 tonnes ha^{-1}, respectively (Table 13). There was significant residual effect on soil nitrogen and phosphorus when Pymarc was applied at 4 tonnes ha^{-1} at Kosirai of 0.63% and 44%, respectively (Table 13). However, at Molo, Pymarc applied at 4 tonnes ha^{-1} and 8 tonnes ha^{-1} had relative significant increase in soil K of 19% and 27%, respectively. The broadcast mode of application had higher significant influence on soil pH (Table 14). At Egerton, Pymarc broadcasted gave soil pH of 0.3 units and P of 40% significantly higher than the spot application.

Table 13: Effect of rate of Pymarc application and soil type on soil pH, total N, P and K at maize harvest in 2004

	Soil pH, total N, P and K at maize harvesting (mg kg^{-1}) in 2004											
	Egerton (*Phaeozems*)				Molo (*Cambisols*)				Kosirai (*Ferralsols*)			
	Egerton		Molo		Kosirai							
Rate of Pymarc (t/ha)	**pH**	**N**	**P**	**K**	**pH**	**N**	**P**	**K**	**pH**	**N**	**P**	**K**
0.0	5.7^{b}	2.2^{a}	7.4^{a}	67^{a}	5.4^{b}	0.81^{a}	14^{a}	64^{b}	4.5^{b}	0.8^{b}	5.0^{b}	73^{a}
4.0	6.5^{a}	2.1^{a}	9.2^{a}	73^{a}	6.4^{a}	0.73^{a}	12^{a}	76^{ab}	5.1^{a}	1.3^{a}	7.2^{a}	71^{a}
8.0	6.5^{a}	0.9^{a}	9.7^{a}	78^{a}	6.2^{a}	0.88^{a}	14^{a}	81^{a}	4.9^{a}	0.5^{b}	4.6^{b}	81^{a}

Means followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$

Table 14: Effect of mode of Pymarc application and soil type on soil pH, N, P and K at maize harvest in 2004

	Stover and Grain Weight (Tonnes ha^{-1})											
	Egerton (*Phaeozems*)				Molo (*Cambisols*)				Kosirai (*Ferralsols*)			
	2003		2004		2003		2004		2003		2004	
Mode of Pymarc application	**pH**	**N**	**P**	**K**	**pH**	**N**	**P**	**K**	**pH**	**N**	**P**	**K**
Broadcast	6.2^{a}	1.3^{a}	7.2^{b}	78^{a}	5.7^{a}	0.9^{a}	12^{a}	74^{a}	4.7^{a}	0.8^{a}	5.2^{a}	71^{a}
Spot	5.9^{b}	2.1^{a}	10^{a}	68^{b}	5.9^{a}	1.2^{a}	15^{a}	73^{a}	4.6^{a}	1.0^{a}	5.9^{a}	79^{a}

Means followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$

4.3.2 Discussion

The root biomass yield, Nitrogen, Phosphorus and Potassium concentration in the leaf opposite the ear, stover and grain yield differences among treatments could be related to nutrients availability to crops and release patterns by the organic materials. Nutrients availability as a result of organic residues application depended on nutrients concentration and release in synchrony with crop needs and other soil environmental activities. Higher yields with use of organic residues have been obtained when organic residues have been incorporated (Palm, 1996 and Gachengo *et al.*, 2004). The increase of root biomass, N, P and K content, stover and grain yield in the Pymarc applied systems was as a result of plant available nutrients from decomposing Pymarc. On the other hand, the low yield in no input control could be due to soil fertility depletion and deterioration of soil properties. Experiments by Chirwam *et al.* (2004) confirmed the low yield of continuously cropped maize without fertilizer as being due to soil fertility depletion and deterioration of soil physical properties. The benefit of plant residues as sources of nutrients is well documented. Besides, addition of nutrients, manure also increases water holding capacity, pH, infiltration of water and decreases bulk density of soil (Azevedo and Stout, 1997).

The higher N, P and K in leaf could be attributed to higher root length and density, this greater root biomass could be as a result of a reduction in exchangeable Al in the soil, or stimulation of root growth from the organic materials, or both. Root growth can increase as a result of reduced Al in the soil, caused by complexion with organic anions that are produced by the decomposition of organic materials. It also can increase through an increase in pH caused by the addition of basic cations from organic materials (Kretzchnmar *et al.*, 1991). Organic materials also can stimulate root growth either directly or through their effect on soil bacteria that can suppress root pathogens and produce plant growth hormones (Marschner, 1995). The increase in root length and density implies that roots can access a large amount of soil reservoir root thus nutrients uptake. Kretzchmar *et al.* (1991) found an increase in base saturation, pH and decrease in labile Al with addition of organic residue in the soil, because of the addition of basic cations with crop residue. The reduction of Al also might be partly due to chelation of Al by organic anions produced by decomposing Pymarc. The decrease in exchangeable Al would result in an increase in extractable P. The incorporation of organic residue in the soil improves water holding capacity and soil structure, which would have a positive influence to root growth hence nutrients uptake. In a study by Gachengo (1996) an application of a high quality organic material applied either alone or in combination with P in a pot trial resulted in greater maize biomass and P concentration in leaf opposite the ear than from equal amounts of nutrients added from inorganic fertilizers. A subsequent field study showed that Tithonia application reduced P sorption in the soil up to 16 weeks (Nziguheba *et al.*, 1998) and might account for the improved plant growth and increased concentration of nutrients from combined nutrient sources in leaf opposite the ear.

The results indicate an increase in soil pH with application of plant residues Pymarc. The results are consistent with those of Eghball, (2002) and Sakala *et al.* (2004) who found

4.4 Conclusion

Application of Pymarc significantly increased root biomass, NPK concentration in leaf opposite the ear, stover weight and grain yield. Therefore, these results show the importance of organic residues in maintaining soil fertility and maize yield. Pymarc has a potential to supply soil nutrients on decomposition. The evidence of Pymarc's contribution to crop yield was shown by increased maize yields after these plant residues were incorporated as compared to no input treatment. Broadcast mode of application is suitable when applying the two organic residues: probably it acts as mulch thus conserves soil moisture and moderating of soil surface temperature which, inturn influences microbial activity enhancing decomposition and mineralization. Resource poor farmers who cannot afford fertilizers may be encouraged to use it to improve soil nutrient status. However, for long term plan resource poor farmers should be encouraged to use organic residues such as Pymarc to help build up steady soil fertility with slow release of nutrients.

Residual effect of Pymarc on soil pH is sensitive within the two years study period. Soil pH, N, P and K levels were greater for the manure applied treatments than the no input control. However, the period of study could have been short for the sensitive effect of manure on soil N, P and K.

CHAPTER FIVE

5.0 EFFECTS OF PYMARC ON SOIL MACROFAUNA BIOMASS, ABUNDANCE AND DIVERSITY IN *Phaeozems, Cambisols* AND *Ferralsols*

5.1 Introduction

Soil is inhabited by a diverse community of organisms that perform important functions like nutrients acquisition (microflora), decomposition and modification of soil structure (macrofauna). Based on biomass, abundance and percent composition, macrofauna are the dominant faunal group, readily accessible and potentially manageable as 'ecosystem engineers' because of their integrative role in decomposition and soil quality (Brown *et al.*, 1996). Soil fauna may affect soil function in a variety of ways, and could be used as indicators of nutrient status of soil in a given site (Doube, 1997 and Rao *et al.*, 1998). Indeed, soil biota, including soil microbial biomass and soil fauna play an important role in enhancing and sustaining soil productivity through their effects on soil organic matter decomposition and availability of plant nutrients (Tian *et al.*, 1997 and Vanlauwe *et al.*, 1996). Hence, soil biota have been identified as potential resource for soil fertility management because of their role in facilitating nutrient acquisition, decomposition and mineralization and it has even been suggested as early warning bio-indicators of changes in soil quality (Blair *et al.,* 1996).

Plant residues and their chemical composition vary in their palatability for soil fauna. They are therefore expected to have different effects on soil fauna populations (Tian *et al.,* 1993). Mafongoya *et al.* (1996) reported that changes in microbial community could be manipulated by applying prunnings of different quality such that processes of litter decomposition and nutrients dynamics are enhanced. Similarly, Ayuke *et al.,* (2004) showed that addition of organic residues increased faunal biomass over the control, indicating that soil fauna functions can be manipulated by external inputs of organic residues. Studies have also shown that rates and patterns of litter decomposition can be described as a function of season, climate and the conditions within the soil environment (Mafongoya *et al.*, 2000 and Kwabiah *et al.*, 1999). This study, which was superimposed on the experiment conducted on Field Trial 1, Chapter Four, Section 4.2.2, was carried out to determine the impact of input of Pymarc and Tithonia on diversity, populations and biomass of soil invertebrate fauna in *Phaeozems, Cambisols* and *Ferralsols.*

5.2 Materials and Methods (Macrofauna Sampling for Biomass, Abundance and Diversity)

Soil macrofauna characterization and identification was based on body size as described by Blair *et al.* (1996) and Anderson and Ingram (1993). Using a monolith unit of size 25 cm diameter and 30 cm height, samples were taken at V6 stage of maize growth during the growing season. At this stage, two samples were taken at selected spots, within the rhizosphere of the second plant diagonally. While using a metallic mallet, the core ring was driven into the soil until it was level with the ground. The soil monolith was then removed by hand depth wise (0-30cm) and placed on plastic sheets. The soil was placed on plastic sheets (1 m by 1 m) and gently sorted out to locate the organisms, which were first placed in distilled water to clean them then put in 70% alcohol for preservation. The organisms were separated into major taxonomic groups, recorded and then collected in plastic bottles. In the laboratory, counting and weighing (for biomass), was done. Fresh weight (in grams) determination was done within 12 hours from the time of sampling. Biomass of different categories of organisms was expressed per metre square (Anderson and Ingram, 1993).

Species diversity based on Shannon and Werner Diversity Index was used to assess changes in soil fauna within the treatments. The index was calculated using the following equation:

$H' = -\sum(P_i \text{ In } P_i)$,

Where:

H' is the Shannon Index,

P_i is the proportion of individuals of the i^{th} species and estimated as n_i/N; where n_i is the number of individuals of the i^{th} species and N the total number of individuals within the sample.

In is natural logarithm.

The diversity index assumes that individuals are randomly sampled from a large population and that all species are represented in the sample. The index combines species richness (total number of species present) and evenness (relative abundance). Pearson correlation was used to determine the relationship between macrofauna, soil and Pymarc and

Tithonia chemical characteristics. Principal component and factor analysis were used to determine spatial relationships between variables.

5.3 Results and Discussion

5.3.1 Results

Macrofauna Fresh Biomass in *Phaeozems, Cambisols* **and** *Ferralsols*

Addition of Pymarc significantly ($P \leq 0.05$) increased fresh faunal biomass substantially over the no input control in three selected soils in the two seasons (Figures 8 and 9). Pymarc applied in *Phaeozems*, either at 8 tonnes ha^{-1} or 4 tonnes ha^{-1}, increased faunal biomass by 184% and 232%, respectively, in 2003 (Figure 8), while 135% and 296% in 2004, respectively (Figure 9). In *Cambisols*, Pymarc applied at 8 tonnes ha^{-1} or 4 tonnes ha^{-1} increased total faunal biomass by 275% and 190%, respectively in 2003 season. In 2004, the increase was 108% and 67% at 8 tonnes ha^{-1} or 4 tonnes ha^{-1}, respectively. Likewise, Pymarc incorporation into *Ferralsols* at 8 tonnes ha^{-1} or 4 tonnes ha^{-1} increased fresh biomass over the control by 134% and 146%, respectively, in 2003 and 121% and 284%, respectively, in 2004. While comparing the effect of Pymarc on macrofauna biomass in the three soils, it was shown that the highest influence was in *Phaeozems* and less effect in the *Ferralsols* (Figures 8 and 9).

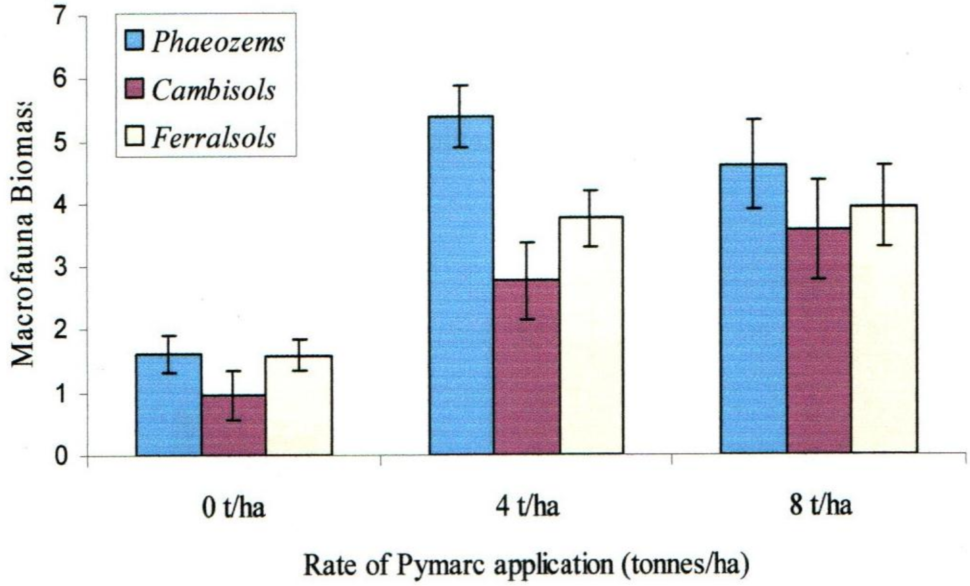

Figure 8: Macrofauna fresh biomass (gm^{-2}) in maize fields manured with Pymarc in Phaeozems, Cambisols and Ferralsols in 2003

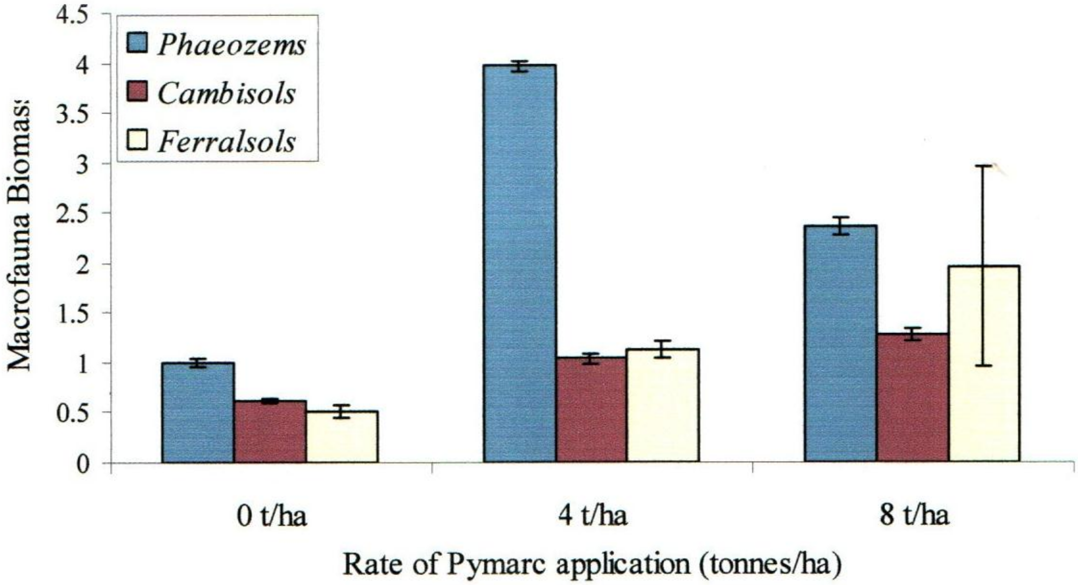

Figure 9: Macrofauna fresh biomass (gm^{-2}) in maize fields manured with Pymarc in Phaeozems, Cambisols and Ferralsols in 2004

Macrofauna Diversity in *Phaeozems, Cambisols* and *Ferralsols*

In 2003, Pymarc applied in *Phaeozems* at 8 tonnes ha^{-1} had highest macrofauna diversity (1.02) followed by 4.0 tonnes ha^{-1} (0.86) and lastly the control (0.56) (Figure 10). However, in 2004 there were no differences among treatments (Figure 11). Similar results were obtained in *Cambisols* where in 2003, Pymarc applied at 8 tonnes ha^{-1} had highest diversity (0.88) followed by 4.0 tonnes ha^{-1} (0.79) and lastly the control (0.48) (Figure 10). In 2004 there were no differences among the treatments (Figure 11). Broadcast mode of Pymarc application in both *Phaeozems* and *Cambisols* had effect on the macrofauna diversity in both 2003 and 2004 than spot application (Appendix 6).

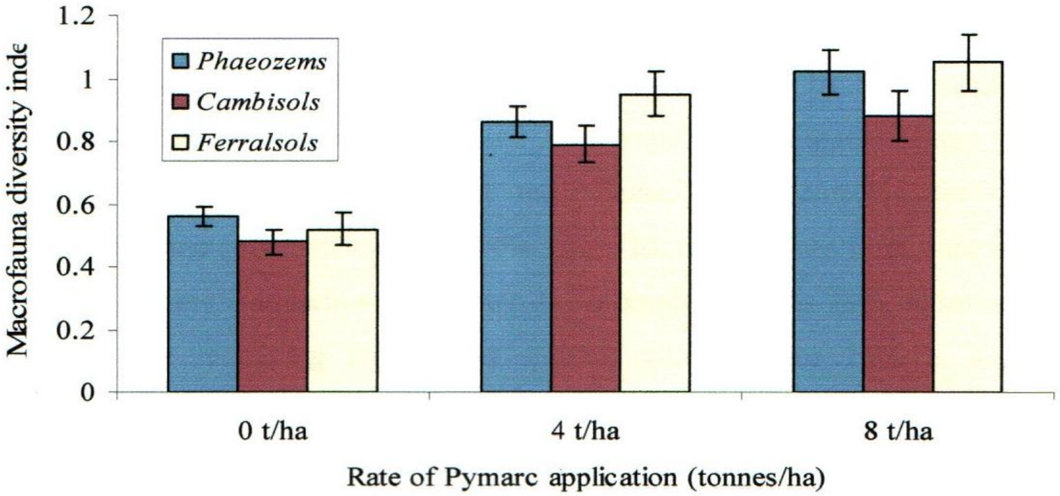

Figure 10: Macrofauna diversity in maize fields as affected by different rates of Pymarc in Phaeozems, Cambisols and Ferralsols in 2003

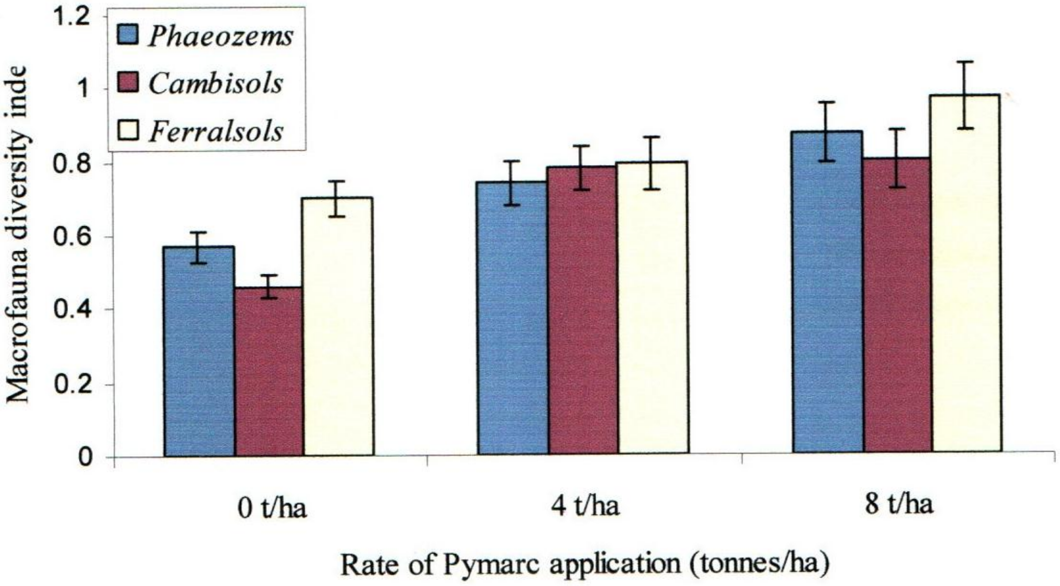

Figure 11: Macrofauna diversity in maize fields as affected by different rates of Pymarc in Phaeozems, Cambisols and Ferralsols in 2004

Macrofauna Abundance in Phaeozems, Cambisols and Ferralsols

Macrofauna species sampled from different treatments during the long rain seasons of 2003 and 2004 in *Phaeozems, Cambisols* and *Ferralsols* were *Oligochaeta* (Earthworms), *Isoptera* (Termites), *Hymenoptera* (Ants), *Chilopoda* (Centipede) and *Coleoptera* (Beetles)

Earthworms were the most abundant (67% in both seasons) macrofauna followed by termites (22% and 17%) in *Phaeozems* when Pymarc was applied at 4 tonnes ha^{-1} in 2003 and 2004, respectively. The beetles, centipedes and ants accounted for 42% and 35%, respectively (Figures 12 and 13). Similarly, in *Cambisols*, earthworms were the most dominant (55% and 57%, respectively) macrofauna, followed by termites (21%), beetles, centipedes and ants accounted for 45% and 37%, respectively (Figures 12 and 13). Termites and Earthworms, the most abundant macrofauna, are responsible for communition, decomposition and structural changes in the soil. This corroborates work done by Tabu *et al.* (2004) that showed that earthworms' macrofauna dominance was 38%, followed by termites (35%) and the remaining macrofauna species accounted for 29% in a soil fertility management study on macrofauna.

However, in *Ferralsols* in 2003 and 2004, termites were the most abundant (43% and 44%, respectively) followed by earthworms (38%) with the remaining species accounting for 45% and 43%, respectively (Figure 12 and 13).

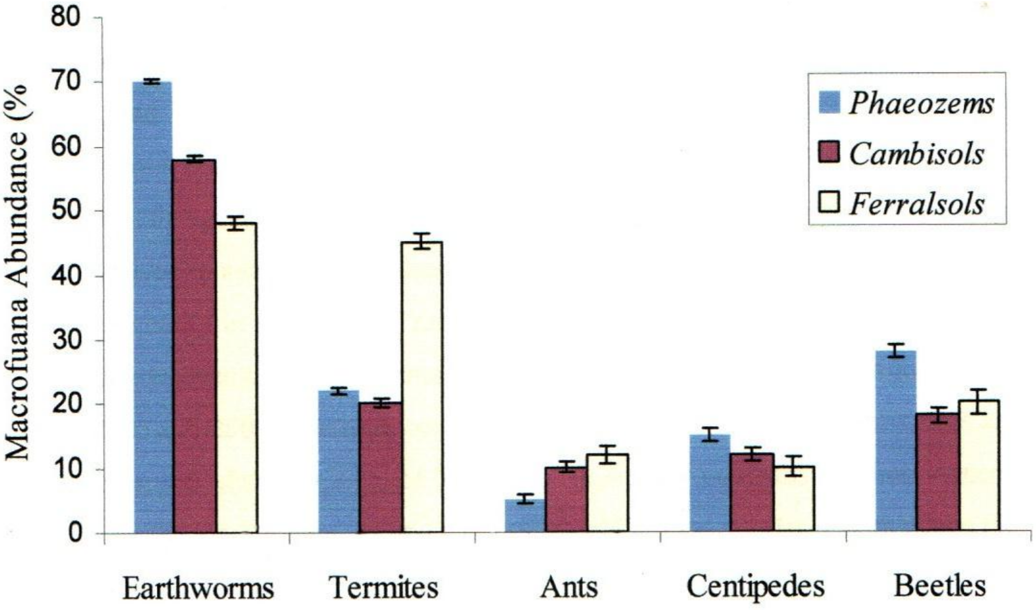

Figure 12: *Macrofaunal abundance in maize fields as affected by Pymarc at 4 tonnes ha^{-1} rate of application in Phaeozems, Cambisols and Ferralsols in 2003*

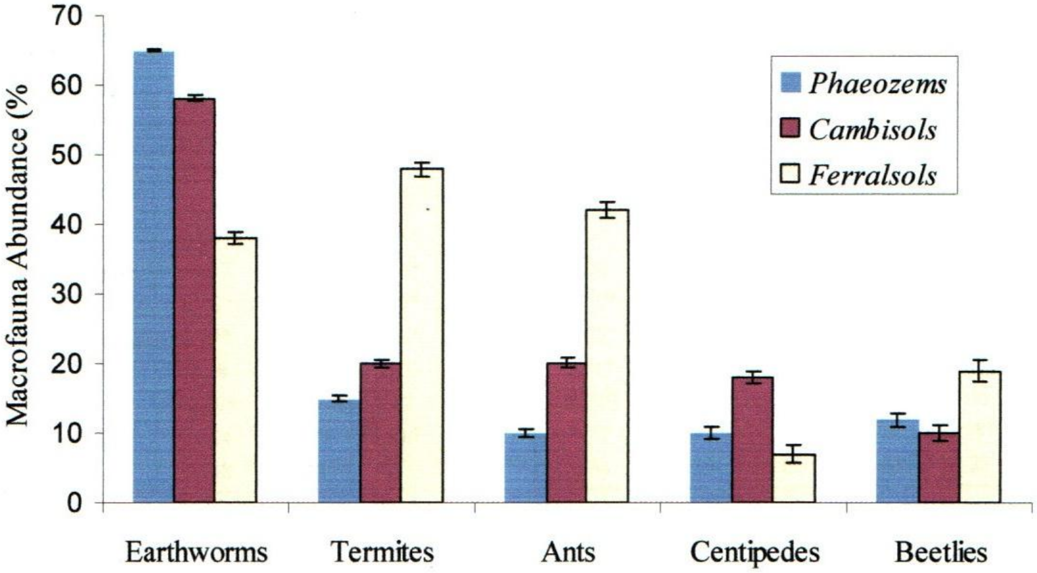

Figure 13: Macrofaunal abundance in maize fields as affected by Pymarc at 4 tonnes ha^{-1} . rate of application in Phaeozems, Cambisols and Ferralsols in 2004

Relationship between Chemical Composition of Pymarc and Soil Fauna in *Phaeozems, Cambisols* and *Ferralsols*

Positive and significant correlations were observed between the following variable combinations: Nitrogen and Lignin, Plant residue quality index (PRQI) and earthworms; Phosphorus and PRQI; Potassium and Lignin, PRQI, earthworms and centipedes, Lignin and PRQI and earthworms, Polyphenols and Termites and Ants; PRQI and Earthworms; Earthworms and termites, Ants and centipedes (Table 15 and 16). The positive correlation between Nitrogen, Phosphorus and Potassium with PRQI indicates the effect of quality of the plant residue in availability of these nutrients. It further shows the need to use organic inputs of high quality in soil fertility management systems in order to increase soil nutrient level. Earthworms, centipedes and ants were correlated with Pymarc chemical characteristics in both 2003 and 2004. The high correlation observed between earthworms, ants and centipedes with chemical characteristics of Pymarc in this study confirms the importance of nitrogen, PRQI for the macrofauna. Tian *et al.* (1997), also found similar results where there was high correlation observed between macrofauna population and lignin:N ratio of plant residues. However, there were negative correlations between Nitrogen and Ants, Lignin and Polyphenols, polyphenols and PRQI and Earthworms (Tables 15 and 16). The significant correlation was mainly related to the plant residue quality index and indicates potential for their use in improving soil fertility.

Table 15: **Correlation coefficient (r) of chemical composition of Pymarc and Soil fauna in 2003 (Means of three samples)**

	N	P	K	Lig.	Polyp.	PRQI	Earth	Term.	Ants	Centi.	Beetle
N	1.00										
P	0.54	1.00									
K	-0.47	0.78	1.00								
Lignin	0.84*	0.27	0.55*	1.00							
Polyphenols	-0.67	-0.43	-0.47	-0.78*	1.00						
PRQI	0.78*	0.96*	0.89*	0.91*	-0.72*	1.00					
Earthworms	0.87*	0.67	0.94*	0.65*	-0.79*	0.98*	1.00				
Termites	0.78	0.56	-0.3	-0.94	0.91*	0.78	0.94*	1.00			
Ants	-0.89*	0.67	0.72	-0.80	0.99*	-0.66	-0.71	0.47	1.00		
Centipedes	-0.54	-0.77	0.91*	0.83	0.78	-0.37	-0.91*	0.54	0.98*	1.00	
Beetle	-0.88	0.46	0.71	0.65	0.64	-0.30	0.66	-0.83	0.22	0.44	1.00

* Significant at P ≤ 0.05 (Mean values for soil fauna from the three sites used in the statistical analysis)

Table 16: **Correlation coefficient (r) of chemical composition of Pymarc and Soil fauna in 2004 (Means of three samples)**

	N	P	K	Lig.	Polyp.	PRQI	Earth.	Term.	Ants	Cent.	Beetle
N	1.00										
P	0.66	1.00									
K	-0.53	0.58	1.00								
Lignin	0.78*	0.16	0.56*	1.00							
Polyphenols	-0.46	-0.43	-0.91*	-0.79*	1.00						
PRQI	0.80*	0.96*	0.89*	0.88*	-0.72*	1.00					
Earthworms	0.87*	0.67	0.93*	0.54	-0.79*	0.66	1.00				
Termites	0.78	0.56	-0.41	-0.94	0.89*	0.78	0.94*	1.00			
Ants	-0.67	0.67	-0.68	-0.80	0.99*	-0.66	-0.3	0. 47	1.00		
Centipedes	-0.54	0.74	0.89*	0.83	0.78	-0.37	0.91*	0.53	0.77	1. 00	
Beetle	-0.71	0.46	0.71	0.65	0.62	-0.30	0.62	-0.67	0.22	0.44	1.00

* Significant at $P \leq 0.05$ (Mean values for soil fauna from the three sites used in the statistical analysis)

Principal Component Analysis

Principal component analysis (SAS, 2001) is a mathematical multivariate technique for examining relationship among several quantitative variables and is used for summarizing data and detecting linear relationships. Principal component analysis showed that the data could be grouped into three principal components accounting for 57% and 58% of the spatial variation in 2003 and 2004, respectively (Table 17). In 2003, factor loading 1 characterized Nitrogen, Phosphorus, lignin, PRQI, earthworms and ants i.e a litter chemical characteristics factor. Factor loading 2, Nitrogen, Potassium, Polyphenols, termites and ant's i.e macrofauna factor. Factor loading 3, represented, Phosphorus, Potassium termites and beetles and could also be referred to as the macrofauna factor. In 2004, factor loading 1, represented Nitrogen, polyphenols, earthworms and ants i.e litter chemical characteristics, Factor 2, Nitrogen and termites i.e macrofauna factors and factor 3 is Potassium and polyphenols it could also be referred to as litter chemical characteristics (Table 17). The high inclusion of litter quality characteristics imply that the cause effect relationship with macrofauna may be high i.e other interacting factors may be playing a low role.

Table 17: Rotated factor pattern of factors affecting soil macrofauna (Means of three samples)

Variable	**FACTOR LOADING**					
	2003			**2004**		
	Factor 1	**Factor 2**	**Factor 3**	**Factor 1**	**Factor 2**	**Factor 3**
N	**0.91***	**-0.84***	0.07	**-0.61***	**-0.78***	-0.14
P	**-0.56***	0.41	**0.78***	0.08	-0.02	0.21
K	0.42	**0.50***	**0.50***	0.01	-0.14	**0.89***
Lignin	**0.73***	0.01	0.23	0.40	0.001	0.42
Polyphenols	0.08	**- 0.52***	0.22	**0.79***	-0.003	**-0.56***
PRQI	**0.67***	0.24	-0.21	-0.24	0.02	-0.44
Earthworms	**0.75***	0.11	0.03	**0.67***	0.13	0.08
Termites	0.14	**0.78***	**0.57***	0.31	**0.71***	-0.25
Ants	**0.54***	**0.86***	-0.12	**- 0.54***	-0.12	0.31
Beetle	0.17	-0.10	**0.72***	- 0.11	-0.13	-0.14
Variance explained	**2.71**	**2.42**	**2.01**	**2.44**	**2.31**	**1.71**
Eigen Value	**4.1**	**1.98**	**1.67**	**3.91**	**2.87**	**1.41**
Proportion Variance	**0.26**	**0.18**	**0.13**	**0.31**	**0.16**	**0.11**
Cumulative Variance	**0.23**	**0.44**	**0.57**	**0.32**	**0.47**	**0.58**

PRQI = (Lignin + Polyphenols) / N, * Significant at $P \leq 0.05$

5.3.2 Discussion

These results show that application of plant residue of Pymarc affect soil fauna biomass, diversity and population. Effects varied with the rates of application, macrofauna biomass inevitably depends on other factors including litter quality. Litter quality is usually defined in terms of several indices such as C:N ratio, lignin and polyphenols content. The relative effects of Pymarc on macrofauna biomass seem to be influenced by soil properties that changed from *Phaeozems, Cambisols* to *Ferralsols*. Soil properties in *Phaeozems* and *Cambisols* favour higher rapid macrofauna biomass increase due to a near neutral pH and adequate nutrients availability. The *Ferralsols* on the other hand had relatively lower pH and less nutrient availability than the other two soils (Chapter Three, Section 3.2.1 and Table 1). Ayuke *et al.* (2004), in their study, also reported an increased total faunal biomass with addition of organic residue over the no input control in which Senna leaves increased total faunal biomass by 100%.

Food resource is a major factor affecting the biomass, diversity and abundance of soil fauna communities as confirmed by Warren *et al.* (1987). Similarly, Tabu *et al.*, (2004) observed that soil fertility management significantly affected the abundance and composition of macrofauna (earthworms, ants and beetles). They further showed that termites and ants dominated the Oboma (home garden) niches probably because of the large amounts of food resources present. Application of Pymarc residue increased the biomass, diversity and abundance of soil fauna groups mainly earthworms and termites. Other studies have also shown that addition of organic residues such as Senna and Tithonia increase the fauna population by 100% over the control (Ayuke, 2000). Organic inputs such as crop residues and manures provide food to soil organisms. Greater faunal biomass in residue applied treatment may be the result of greater accumulation of organic matter. Accumulation of organic matter from this residue Pymarc may provide resource base for the invertebrates. Coleman *et al.* (2000) also reported that soil organisms are strongly limited by available energy sources and are in a state of starvation much of the time. The increased supply of organic matter may possibly eliminate this state, in turn allowing their consumers i.e. earthworms and termites, to subsequently increase in numbers hence in biomass. The presence of high numbers of termites in the *Ferralsols* could imply that they were better able to withstand low pH, nutrients availability, as well as diminishing food resources. It could also have been that the termites being ecosystem engineers influenced the access of litter to other faunal groups, hence their abundance over the rest. Termites may as such be able to survive a wide range of conditions. This corroborates with the work done by Christopher (1994) which showed that the influence of termites is not confined to other decomposers to such an extent that exceeds their influence by direct consumption. In all sites, broadcast enhanced more soil fauna biomass and population, this could be because surface applied residues preserve soil water from evaporation, reduce soil temperature and provide conducive niches for certain faunal groups. Application of organic residues significantly affected the macrofaunal diversity. The no input control had lowest diversity than where the organic residues had been applied. The number of soil fauna families was generally low in no input control treatment. Tabu *et al.* (2004), similarly observed comparable diversity, where the niche of home gardens (Oboma) had the highest diversity (0.59) which would be comparable to the management of organic residues treatment at either 8 tonnes ha^{-1} or 4.0 tonnes ha^{-1} , because home gardens (Oboma) had higher nutrients received from litter and FYM. They further observed a lower diversity index in the cultivated continuous maize niche (0.44) which could be comparable to properties of no input control treatment. The no input control treatment has low amount and diversity of food resources and ultimately macrofauna diversity. High litter input in control treatment led to better food supply to macrofauna; this partially contributed to higher macrofauna numbers and biomass. Tian *et al.* (1995) reported that application of plant residues with various chemical composition all increased macrofauna populations.

Other studies by Tian *et al.* (1995) showed that application of plant residues as broadcast, acted as mulch and it is known to attenuate the increase of soil temperature and to retain high moisture contents, in addition to providing food for soil animals. Probably the good soil microclimate created by broadcast could partially account for high macrofauna populations. According to Edwards and Bohlen (1996), soil moisture can influence macrofauna numbers and biomass.

However, the significant differences observed in faunal biomass and population between Pymarc and Tithonia could be due to plant residue quality index (PRQI), whereby Tithonia was of high quality than Pymarc. The nutritional quality of plant residue thus appears to play an important role in influencing soil fauna biomass and populations. Tian *et al.* (1993) also reported high correlation between earthworm population and Lignin: N ratio of plant residues. The low diversity, abundance and biomass of the soil fauna observed, particularly in no input control, typically represent the status of soil fauna in the fields of resource poor farmers. Most small scale farmers clear then burn the land and rarely add external inorganic inputs to the soil for nutrient replenishment. The implication is that a change to continuous cropping decreases soil richness, thereby reducing the diversity of food resources and residue quality. Studies have shown that such changes in the land use systems lead to reduced abundance, biomass and diversity of soil fauna communities which is in agreement with Warren *et al.* (1987) and Dangerfield (1993).

The effect of the chemical composition of plant material on macrofauna population has been reported by Tian *et al.* (1997), where N, soluble carbohydrate, polyphenols contents and PRQI are the main factors affecting the attraction of macrofauna to plant residues. Their study reports that highly nutritious plant residues (with low lignin: N ratio) decompose and release nutrients (particularly N) fast and gradually show an increase in earthworms. However, termites prefer plant residues with low nutritional quality, which decompose slowly and have large effect on microclimate. Termites are susceptible to desiccation, have a soft cuticle with poor water retaining properties essential for termite survival and growth hence the need for effective microclimate. The results of this study indicate that plant residues significantly increase earthworms or termite populations, with less distinct effects on centipedes, ants and beetles.

5.4 Conclusion

It is evident from this study that, addition of organic residues in these soils (*Phaeozems, Cambisols* and *Ferralsols)* increased faunal biomass and population within the cropping systems. However, in arable land use systems characterized by low quantity, range and diversity of food resource the type and quality of organic residues do not play a significant role in influencing foraging behavior, hence biomass and population of soil invertebrates. Faunal biomass and population was high in Pymarc treatment than the no input control, it therefore showed that addition of organic residues of different quality may change foraging behavior resulting in increased biomass and consequently their functions in agro ecosystems. The effects on soil fauna abundance may be determined also by the chemical composition of plant residue, which implies that among factors controlling the effects of plant residue on soil fauna is nutritional. The litter quality affected the abundance and diversity of macrofauna (Earthworms, termites and ants). The majority of the organisms are litter dwelling. The spatial pattern of macrofauna was reflected in the litter quality properties of the Pymarc.

CHAPTER SIX

6.0 EFFECT OF PYMARC AND TITHONIA ON MAIZE YIELD AT KOSIRAI (*Ferralsols*)

6.1 Introduction

The use of Pymarc and Tithonia as soil fertility amendments based on their nutrient contribution gives useful information in developing recommended rates and mode of application for improved maize yield. An approach that includes test on the mode and rate of application of these organic inputs is needed as a solution to the prevailing conditions.

Thus, the objective of this study was to determine the effect of mode and rate of application of Pymarc and Tithonia maize yield at Kosirai (*Ferralsols*).

6.2 Materials and Methods

6.2.1 Description of Research Sites

The experimental site was located at Kosirai in Nandi District (Kosirai Division) (Figures 6) as in chapter four (Section 4.2.1).

6.2.2 Experimental Layout

Pymarc at 0, 4 and 8 tonnes ha^{-1} and Tithonia at 0, 2.5 and 5 tonnes ha^{-1} were each tested separately for suitable method of application at two levels, in a 2 x 3 factorial treatment combination in split plot design with mode of application as main plot factor and Pymarc and Tithonia rates as subplot factor replicated three times. Phosphorus and Potassium were applied as Rock Phosphate and Muriate of Potash at 26 kg P/ha and 50 kg K/ha at planting time, respectively. Nitrogen as CAN at 60 kg N/ha was applied as top dress at V6 stage of maize growth.

6.2.3 Crop Establishment and Management

As in chapter four section 4.2.3.

6.2.4 Crop Data Collection

As in chapter four section 4.2.4

6.2.5 Statistical analysis

As in chapter four section 4.2.5.

6.3 Results and Discussion

6.3.1 Results

Root biomass, stover and grain yield

The results also show relative increase in root biomass of 110% and 156% in 2003 and 135% and 188% in 2004 when Tithonia was applied at 2.5 tonnes ha^{-1} and 5 tonnes ha^{-1}, respectively (Table 18). However, Tithonia applied at 2.5 tonnes ha^{-1} and 5 tonnes ha^{-1} had a significant relative increase in stover yield of 56% and 89% in 2003 and 28% and 44% in 2004, respectively (Table 18). There was significant relative increase in grain yield of 32% and 58% in 2003 and 108% and 180% in 2004, when, Tithonia was applied at 2.5 tonnes ha^{-1} and 5 tonnes ha^{-1}, respectively (Table 18). The results also indicated a significant different effect on stover and grain yield by mode of application of Pymarc and Tithonia (Table 19). Green biomass of Tithonia had higher significant influence on macrofauna fresh biomass over the Pymarc in both seasons. Similar results were obtained by Ayuke *et al.* (2004), where Senna treatment increased total biomass by 45% and Tithonia by 49%, indicating different influence of the two organic residues on macrofauna biomass. The green manure of Tithonia had significantly higher mean macrofauna diversity (0.94) than the Pymarc (0.74) (Appendix 5).

Table 18: Effect of rate of application of Pymarc and Tithonia on Root biomass (Kg ha^{-1}), stover weight and grain yield (t ha^{-1}) in 2003 and 2004

Root Biomass (kg ha^{-1}); Stover and Grain yield													
	Root biomass		Stover		Grain			Root biomass		Stover		Grain	
Pymarc (t ha^{-1})	2003	2004	2003	2004	2003	2004	Tithonia (t ha^{-1})	2003	2004	2003	2004	2003	2004
0	295^c	157^b	4.37^b	2.25^b	3.2^b	0.45^b	0	199^c	107^c	5.12^c	4.32^b	3.1^b	0.4^c
4	394^b	270^b	5.88^a	3.02^a	4.2^a	0.70^a	2.5	418^b	251^b	7.98^b	5.55^a	4.1^a	0.83^b
8	742^a	315^a	6.35^a	3.48^a	4.6^a	0.93^a	5	510^a	308^a	9.70^a	6.23^a	4.9^a	1.12^a

Means followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$

Table 19: Effect of mode of application Pymarc and Tithonia on root biomass; stover grain yield in 2003 and 2004

Root Biomass (kg ha^{-1}); Stover and Grain yield													
	Root biomass		Stover		Grain			Root biomass		Stover		Grain	
Mode of Pymarc application	2003	2004	2003	2004	2003	2004	Mode of Tithonia application	2003	2004	2003	2004	2003	2004
Broadcast	394^b	254^b	4.94^b	2.94^a	3.7^b	0.58^b	Broadcast	401^a	212^a	8.5^a	4.48^b	4.0^a	0.73^a
Spot	560^a	907^a	6.12^a	2.89^a	4.3^a	0.81^a	Spot	350^b	232^a	6.7^b	6.26^a	4.1^a	0.83^a

Means followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$

Stover and grain yield responses to Phosphorus sources at Kosirai

Maize stover and grain yield were significantly increased by the addition of Phosphorous sources (Table 20). Pymarc applied at 4 tonnes ha^{-1} in combination with organic P at 13kg P ha^{-1} had the highest relative stover weight with a relative increase of 74% (Table 20). However, Tithonia applied at 2.5 tonnes ha^{-1} in combination with inorganic P at 13 kg P ha^{-1} had the highest relative stover weight increase of 75% (Table 20). P applied as either Tithonia or Pymarc in combination with P at 13 kg P ha^{-1} had significantly higher stover yield as compared to either Tithonia or Pymarc applied alone or P applied as TSP (Table 20).

Phosphorus applied as Pymarc at 4 tonnes ha^{-1} or Tithonia at 2.5 tonnes ha^{-1} in combination with TSP at 13 kg P ha^{-1} had the highest significant relative grain yield increase (Table 20). The relative grain increase was 84% when Pymarc was integrated with TSP and 205% for Tithonia integrated with TSP (Table 18). P applied as Pymarc, TSP or integrated were not significantly different in their influence on maize grain yield. However, when P was applied as either TSP or Tithonia in combination with P at 13 kg P ha^{-1} there was a significant increase in maize grain yield as compared to applying P as Tithonia alone. Tithonia had a higher influence on maize grain yield as compared to Pymarc or sole fertilizer (Table 20).

Relative Agronomic Effectiveness of the different P sources

The addition of either Pymarc or Tithonia in combination with TSP at Kosirai resulted in added maize yield of 117% (Table 20). Tithonia in combination with TSP resulted in added maize yield of 123% compared to TSP, Pymarc or Tithonia alone (Table 20). These results are consistent with those of Nziguheba *et al.* (2004), who reported that combination of fertilizer and Tithonia resulted in increased maize yield as compared those obtained by applying fertilizer only. This study shows that a high quality organic resource such as Tithonia and Pymarc can play an important role in supplying P to a growing crop. However, considering the constraints related to the availability of organic residues and inorganic fertilizers, a more sustainable strategy is to maximize the proportion of P derived from organic residues in the combination. The results reveal that crop yield can be much higher with combined use of Tithonia and Pymarc with inorganic P than with solely P mineral fertilizer, as organic manures overcome additional nutrients constraints.

Table 20: Effect of Pymarc, Tithonia and TSP on stover; grain yield; Relative grain yield (RGY %) and Relative agronomic effectiveness (RAE %) in 2004

Pymarc; Tithonia and Inorganic P									
Treatment Pymarc + P	**Stover**	**Grain**	**RGY %**	**RAE %**	**Treatment Tithonia + P**	**Stover**	**Grain**	**RGY (%)**	**RAE (%)**
0	1.80c	0.80b	0b	0b	0	2.00b	0.60c	0c	0c
8t/ha	2.40b	1.13ab	41ab	55ab	5t/ha	3.33a	1.07b	78b	47b
26kg /ha	2.53b	1.40a	75a	100a	26kg P/ha	3.33a	1.60a	167a	100a
4t/ha+13kg P/ha	3.13a	1.47a	84a	117a	2.5/ha+13kg P/ha	3.50a	1.83a	205a	123a

Means followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$

6.3.2 Discussion

Tithonia had higher nutrients content and may have undergone rapid mineralization, while Pymarc which had low nutrients content may have exhibited slow mineralization during early stages of maize growth. Root biomass yield, stover and grain yield with Tithonia application were therefore higher than with Pymarc. The green biomass of Tithonia was previously recognized to be high in nutrients and effective as a nutrient source for maize. Studied in highlands of western Kenya identified green biomass of Tithonia as an effective source of nutrients for maize (Gachengo, 1996 and Niang *et al.*, 1996). Similar observations were found by Malama (2001) where incorporation of Tithonia improved both stover and grain yield. Tithonia prunings were found to improve soil fertility and maize yield, alone or in combination with inorganic P source. The results of stover and grain yield are consistent with those of Gachengo (1996) who demonstrated increased maize yield following incorporation of fresh Tithonia biomass at the equivalent of 5 t/ha dry matter on a site deficient in N, P and K. Elsewhere, Niang *et al.* (1996) also found greater maize yield following incorporation of Tithonia biomass than biomass of other common shrubs and trees. On farm research has demonstrated that soil fertility benefits are greater for green biomass of Tithonia than for dried biomass of Tithonia (Otuma *et al.,* 1998). Based on the results of this study, Tithonia is a better organic residue for soil nutrients management than Pymarc. Tithonia had higher influence on biomass because it was of higher lability (low C: N ratio, lignin and polyphenols) content than Pymarc (Chapter Three, Section 3.2.1, Table 2).

These results are consistent with those of Ayuke *et al.* (2004), who reported higher yield with Tithonia than Senna, which was partly because of high concentration of nutrients. Tithonia proved to be a better P source by providing the largest increase in maize grain yields as compared to Pymarc and sole fertilizers. Nziguheba *et al.* (2004) reported similar observation, where addition of P sources more than tripled the yields obtained from the control treatments. In another study by ICRAF (1998), maize yield tended to be higher with Tithonia + P fertilizers (4.2 tonnes ha^{-1}) than with sole mineral fertilizers (3.6 tonnes ha^{-1}), suggesting that integration of Tithonia and P fertilizers might provide additional benefits than sole use of mineral fertilizer to maize production, though no significant ($P \leq 0.05$) differences were observed in these yields. Ayuke *et al.* (2004), also found that fertilizer use increased maize grain yield by 63% over the control, whereas Senna increased maize yield by 6% over the no input control.

The observed yield differences among treatments could be related to nutrient availability to crops and release patterns by the organic residues. This study showed that Tithonia had higher nutrient concentration than Pymarc, thus Tithonia may have undergone rapid mineralization, while Pymarc which has low concentration of nutrients may have exhibited slow mineralization. Maize yield with Tithonia were significantly higher than with Pymarc. Higher yields with use of organic residues have been reported in Western Kenya. For instance, experiments conducted in Western Kenya in *Ferralsols,* demonstrated that higher yields can be obtained when organic residues are incorporated (Palm, 1996, Gachengo, 1996). Gachengo *et al.*, (2004), observed that application of Tithonia increased maize yield by one and half times higher than where Tithonia was not used.

The results of integration of Pymarc or Tithonia with TSP suggest that either the addition of Tithonia or Pymarc converted part of non- available P forms into available forms.

However, the added P from TSP is easily transformed into non-available forms, therefore reducing the efficiency of TSP as P sources (Nziguheba *et al.* 1998). Nziguheba *et al.* (1998) found a decrease in P sorption from application of organic residue but not from TSP at equal P rates. In this study, an increase in microbial biomass constitutes a potential source of nutrients to the crop through turnover. Tithonia and Pymarc could have enhanced the efficient use of mineral fertilizers or provided non nutritional benefits to the maize crop. Studies by Bashir Jama *et al.* (2000) realized low maize yield with application of only 6 kg P/ha as either Tithonia or mineral fertilizers (TSP). Application of an additional 50 kg P/ha as soluble P fertilizers increased yields with both Tithonia + P fertilizer. Maize yield tended to be higher with Tithonia + P fertilizer than with sole mineral fertilizers, suggesting that integration of Tithonia and P fertilizers might provide additional benefits than sole use of mineral fertilizer to maize production.

6.4 Conclusion

Root biomass, stover and grain yield indicated that the addition of Pymarc and Tithonia had significant influence than the control. The results also show that broadcast mode of application of Pymarc and Tithonia had had higher effect on root biomass, stover and grain yield. Pymarc and Tithonia should be applied at either 4 t ha^{-1} or 2.5 t ha^{-1} respectively because of no significant difference when applied above this rate or inorganic P applied. The integration of fertilizers with organic inputs has been regarded as a more profitable alternative in low input crop production systems, countering the large cost of fertilizers. This study confirmed that the integration of fertilizers with either Tithonia or Pymarc can be an alternative to the limited use of inorganic fertilizers. Considering the constraints related to availability of Tithonia and Pymarc biomass and the need for soil P replenishment, a combination of Tithonia and Pymarc with inorganic P fertilizer will be a more sustainable strategy. Tithonia had a higher relative agronomic effectiveness than Pymarc

CHAPTER SEVEN

7.0 EFFECT OF COMBINING PHOSPHORUS FERTILIZER AND ORGANIC NUTRIENT SOURCE ON MAIZE GROWTH AND GRAIN YIELD AT EGERTON, MOLO AND KOSIRAI

7.1 Introduction

The contribution of organic manures as P sources for crop production is limited by their low P content, thus requiring large amounts to meet moderate yield increases (Palm, 1995). However, large amounts of organic residues so required cannot be produced on small scale farms. The limited land therefore has to be allocated to other uses than the production of organic materials for soil fertility replenishment. Where the materials can be found, the labour required for collection, transport and incorporation becomes another handicap to the use of large amounts of organic inputs (Bashir Jama *et al.,* 2000). The supplementation of organic inputs with P fertilizers may be envisaged as it addresses both the problem of insufficient fertilizer supplies and the large amounts of organic material required for P supply. Substitution type of experiments in which total nutrient supplied by organic and inorganic inputs are added separately or combined in different proportions, provide the appropriate design for investigating the effects combining organic and inorganic nutrient sources (Mittal *et al.,* 1992). Therefore, field experiments were conducted to determine effect of combining organic manure and inorganic P sources on N, P and K contents in maize leaf opposite the ear, root biomass and maize grain yield and secondly to compare the economic returns of Pymarc and Tithonia as P source either alone or in combination with inorganic source of P for maize production.

7.2 Materials and Methods

7.2.1 Description of Research Sites

The experiment was conducted at the three sites as described in Chapter Four, Section 4.2.1.

7.2.2 Experimental Layout

This experiment was conducted to determine the effect of combined use of either Pymarc or Tithonia with phosphorus fertilizer on maize stover and grain yield in 2004. The broadcast methods of application from Field Trial 1 (Chapter Four, Section 4.2.2), which had

Significant effect on most of the parameters measured on mode of application was used when applying Pymarc in this Trial. The treatment was: Pymarc (T1 =0, T2=8 t/ha, T3=26 kg P/ha, and T4=4 t/ha + 13 kg P/ha). These were laid in a 2x3 factorial experiment in RCBD arrangement with three replications. Potassium as Muriate of Potash at 50 kg K/ha was applied to all treatments at planting. Nitrogen as CAN at 60 kg N/ha was applied as top dress at V6 stage of maize growth.

7.2.3 Crop Establishment and Management

See Chapter Four Sections 4.2.3

7.2.4 Crop Data Collection

See Chapter Four Sections 4.2.4. However in order to compare the rate of Pymarc and P source effect for different cropping seasons, maize yields were converted to relative increase compared to the control (T1) treatments. Yield increase was calculated using the following formula:

For example:

$$\text{Yield increase (\%) for Treatment 2} = \frac{\text{Yield (T2)} - \text{Yield (T1)}}{\text{Yield (T1)}} \times 100$$

For T3, T4 the same formula is used where:

T1 = Control (0 tonnes ha^{-1})

T2 = Pymarc at 8 tonnes ha^{-1} (Equivalent to P at 26 kg ha^{-1})

T3 = TSP at 26 kg P ha^{-1}

T4 = Pymarc at 4 tonnes ha^{-1} (equivalent to P at 13 kg ha^{-1})$^{+}$ TSP at 13 kg P ha^{-1}

The relative agronomic effectiveness (RAE) values of the P sources relative to the yields obtained in the sole fertilizer treatments (T3) were calculated using the formula:-

For example,

$$\text{RAE\% for Treatment T2} = \frac{\text{Yield (T2)} - \text{Yield (T1)}}{\text{Yield (T3)} - \text{Yield (T1)}} \times 100$$

For T4 the same formula is used where:

T1 = Control (0 tonnes ha^{-1})

T2 = Pymarc at 8 tonnes ha^{-1} (Equivalent to P at 26 kg ha^{-1})

T3 = TSP at 26 kg P ha^{-1}

T4 = Pymarc at 4 tonnes ha^{-1} (Equivalent to P at 13 kg ha^{-1}) $^{+}$ TSP at 13 kg P ha^{-1}

Partial budgets, Value cost ratio and marginal rate or returns were used to determine the economic benefits of combining organic and inorganic sources of P for maize production.

$$\text{Value cost ratio (VCR)} = \frac{\text{(Yield X – Yield of control) x (Maize market price)}}{\text{Fertilizer cost}}$$

Where:

X is the treatment other than the control.

Marginal rate of return (MRR) was computed by calculating the difference in net benefits between different P rates and any other, divided by the difference in costs between them.

7.2.5 Statistical Analysis

General Linear Model (GLM) as described in SAS, Version 8.1 statistical Package was used to compute the analysis of Variance (ANOVA) and DMRT for mean separation for maize root biomass, stover and grain yield.

7.3 Results and Discussion

7.3.1 Results

Stover and grain yield responses to Phosphorus sources at Egerton, Molo and Kosirai

Maize stover and grain yield were significantly increased by the addition of Phosphorous sources (Table 21). Pymarc applied alone had the highest significant relative increase in stover weight at Egerton and Molo at the rate of 63% and 55%, respectively. At Kosirai, Pymarc applied at 4 tonnes ha^{-1} in combination with organic P at 13kg P ha^{-1} had the highest relative stover weight with a relative increase of 74% (Table 18). Phosphorus applied as Pymarc, TSP or Pymarc in combination with P at 13 kg P ha^{-1} at Egerton and Molo had no significant effect on stover yield. While at Kosirai, P applied as Pymarc in combination with

P at 13 kg P ha^{-1} had significantly higher stover yield as compared to Pymarc applied alone or P applied as TSP (Table 21).

Phosphorus applied as Pymarc at 4 tonnes ha^{-1} at 2.5 tonnes ha^{-1} in combination with TSP at 13 kg P ha^{-1} had the highest significant relative grain yield increase at Egerton, Molo and Kosirai (Table 21). The relative grain increase was 17% at Egerton, 41% at Molo and 84% at Kosirai when Pymarc was integrated with TSP (Table 21). At the three sites, P applied as Pymarc, TSP or integrated were not significantly different in their influence on maize grain yield.

Relative Agronomic Effectiveness of the Different P Sources at Egerton, Molo and Kosirai

The addition of Pymarc in combination with TSP at Egerton, Molo and Kosirai resulted in added maize yield of 110%, 103% and 117%, respectively (Table 21). These results are consistent with those of Nziguheba *et al.* (2004), who reported that combination of TSP fertilizer and organic manure resulted in increased maize yield as compared those obtained by applying fertilizer only. This study shows that a high quality organic resource such as Pymarc can play an important role in supplying P to a growing crop. However, considering the constraints related to the availability of organic residues and inorganic fertilizers, a more sustainable strategy is to maximize the proportion of P derived from organic residues in the combination. The results reveal that crop yield can be much higher with combined use of Pymarc with inorganic P than with solely P mineral fertilizer, as organic manures overcome additional nutrients constraints.

Table 21: Effect of Pymarc and TSP on stover, grain yields (tonnes ha^{-1}), Relative grain yield (RGY) and Relative agronomic effectiveness (RAE) in 2004

Pymarc + P												
	Egerton				Molo				Kosirai			
Treatment Pymarc + P	Stover	Grain	RGY (%)	RAE (%)	Stover	Grain	RGY (%)	RAE (%)	Stover	Grain	RGY (%)	RAE (%)
0	4.10^{b}	3.77^{b}	0^{b}	0^{b}	4.53^{c}	1.77^{b}	0^{b}	0^{b}	1.80^{c}	0.80^{b}	0^{b}	0^{b}
8t/ha	6.67^{a}	4.33^{ab}	15^{ab}	87^{ab}	7.00^{a}	2.47^{a}	40^{a}	94^{a}	2.40^{b}	1.13^{ab}	41^{ab}	55^{ab}
26Kg P/ha	5.90^{a}	4.07^{ab}	8^{ab}	100^{a}	5.80^{b}	2.13^{a}	20^{a}	100^{a}	2.53^{b}	1.40^{a}	75^{a}	100^{a}
4t/ha+13kg P/ha	6.37^{a}	4.40^{a}	17^{a}	110^{a}	5.73^{b}	2.50^{a}	41^{a}	103^{a}	3.13^{a}	1.47^{a}	84^{a}	117^{a}

Means followed by the same letter(s) within a column are not significantly ($P \leq 0.05$) different.
RGY (%); Relative Grain Yield (%)
RAE (%); Relative Agronomic Effectiveness of P sources (%)

7.3.2 Discussion

The observed yield differences among treatments could be related to nutrient availability to crops and release patterns by the organic residues. Higher yields with use of organic residues have been reported in Western Kenya. For instance, experiments conducted in Western Kenya in *Ferralsols,* demonstrated that higher yields can be obtained when organic residues are incorporated (Palm, 1996, Gachengo, 1996).

The results of integration of Pymarc with TSP suggest that either the addition of Pymarc converted part of non- available P forms into available forms. However, the added P from TSP is easily transformed into non-available forms, therefore reducing the efficiency of TSP as P sources (Nziguheba *et al.* 1998). Nziguheba *et al.* (1998) found a decrease in P sorption from application of organic residue but not from TSP at equal P rates. In this study, an increase in microbial biomass constitutes a potential source of nutrients to the crop through turnover. Pymarc could have enhanced the efficient use of mineral fertilizers or provided non nutritional benefits to the maize crop. Studies by Bashir Jama *et al.* (2000) realized low maize yield with application of only 6 kg P/ha as either organic manure or mineral fertilizers (TSP). Maize yield tended to be higher with Pymarc + P fertilizer than with sole mineral fertilizers, suggesting that integration of Pymarc and P fertilizers might provide additional benefits than sole use of mineral fertilizer to maize production.

7.4 Conclusion

The integration of fertilizers with organic inputs has been regarded as a more profitable alternative in low input crop production systems, countering the large cost of fertilizers. This study confirmed that the integration of fertilizers with Pymarc at 4 t/ha and inorganic P at 13kg P/ha can be an alternative to the limited use of inorganic fertilizers. Considering the constraints related to availability of Pymarc biomass and the need for soil P replenishment, a combination of Pymarc with inorganic P fertilizer will be a more sustainable strategy.

CHAPTER EIGHT

8.0 NET BENEFIT ANALYSIS OF COMBINING PHOSPHORUS AND ORGANIC NUTRIENT SOURCES ON MAIZE GRAIN YIELD

8.1 Introduction

The benefits from Pymarc and Tithonia are maximum when the difference between the added maize value and the added cost from fertilizers is maximum. Net benefits are calculated by subtracting the total cost that varies from the gross field benefits for each treatment. The values of parameters used in calculations of economic returns of fertilizers, Tithonia and Pymarc applied either alone or in combination in a maize based system of Egerton, Molo and Kosirai are shown in Table 19.

Table 22: Value of Parameters used in calculations of economic returns of inorganic fertilizers, Tithonia at Kosirai and Pymarc applied either alone or in combination in a maize based system at Egerton, Molo and Kosirai in 2004

Parameters	Actual Value in Kenya shillings		
	Egerton	**Molo**	**Kosirai**
Price of TSP (Kg^{-1})	33.76	33.76	32.76
Price of CAN (Kg^{-1})	25.40	25.40	25.40
Price of Rock Phosphate (Kg^{-1})	8.80	8.80	7.80
Price of Muriate of potash (Kg^{-1})			
Price of Agricultural Lime	23.40	23.40	24.40
Labor cost (Per person day)	17.94	17.94	11.96
Labor cost of planting (Per person day)	6.24	6.24	7.24
Price of Pymarc (Kg^{-1})			
Price of Tithonia (Kg^{-1})	-	-	2.34
Price of Maize (Kg^{-1})	17.50	17.50	14.50

8.2 Results and Discussion

8.2.1 Results

Maximum net benefits were obtained at 11 kg P/ha when Pymarc was applied at Egerton, Molo and Kosirai, respectively, for both spot and broadcast placement methods, respectively (Tables 23, 24, 25 and 26). Net benefits were positive for Pymarc applied at 11 kg P/ha irrespective of placement method season and site (Tables 23, 24, 25 and 26). Similarly, in this study, optimal level of nutrient concentration in leaf opposite the ear, stover and grain yield were obtained at the same level of P application. However, negative net benefits were also obtained when Pymarc was applied at 22kg P/ha irrespective of placement method and site in 2003.

In 2003, maximum net benefits were obtained at 9.3 kg P/ha with both spot and broadcast placement method using Tithonia at Kosirai (Tables 23, 24, 25 and 26). However, in 2004, a maximum net benefit was obtained at 9.3 kg P/ha with broadcast method while it was at 19 kg/ha with spot method at the same site. However, negative net benefits were obtained when Tithonia was applied at 19 kg/ha irrespective of placement method in 2003 and 2004, and which application gave positive net benefits. (Tables 23, 24, 25 and 26). Added costs were lowest for Pymarc irrespective of the season, method of placement and the sites (Tables 23, 24, 25 and 26).

The use of either Tithonia or P as TSP alone at 5 tonnes ha^{-1} and 26 kg P/ha at Kosirai had higher net benefits of 54.7 and 2.2, respectively, as compared to Pymarc integrated with P and control. Integration of Tithonia + P had the highest value cost ratio (Table 27). Pymarc applied at 22 kg P/ha as TSP in Kosirai, Egerton and Molo had the highest net benefits of 3.37, 3.45 and 5.34, respectively.

Table 23: Effect of spot application of Tithonia at Kosirai and Pymarc at Egerton, Molo and Kosirai on net benefits for Maize grain yield in 2003

	TREATMENT											
	KOSIRAI						EGERTON			MOLO		
SPOT	**Tithonia, P (P/ha) Source**			**Pymarc, P (P/ha) Source**			**Pymarc, P (P/ha) Source**			**Pymarc, P (P/ha) Source**		
	0	9.3	19	0	11	22	0	11	22	0	11	22
Gross Yield (Kg ha^{-1})	3400	4000	4500	3470	4800	5000	4730	10000	7900	2570	4200	4700
Adjusted Yield (Kg ha^{-1})	3060	3600	4050	3123	4320	4500	4257	9000	7110	2313	3780	4230
Gross benefits (Kg ha^{-1})	44370	52200	58725	45284	62640	65250	74498	157500	124425	40478	66150	74025
Added benefits (Ksh ha^{-1})	0	8790	7215	0	17356	2610	0	83002	-33075	0	25672	7875
Added Costs (Ksh ha^{-1})	0	1190	2670	0	1540	3300	0	2700	4860	0	2450	4410
VCR	**0**	**7.40**	**2.70**	**0**	**11.30**	**0.80**	**0**	**30.7**	**-6.81**	**0**	**10.5**	**1.79**
MRR	**0**	**7.40**	**-1.06**	**0**	**11.30**	**-8.40**	**0**	**30.7**	**-53.74**	**0**	**10.5**	**-9.08**

Table 24: Effect of broadcast applied Tithonia at Kosirai and Pymarc at Egerton, Molo and Kosirai on net benefits for Maize grain yield at in 2003

BROADCAST	TREATMENTS											
	KOSIRAI						EGERTON			MOLO		
	Tithonia, P (P/ha) Source			Pymarc, P (P/ha) Source			Pymarc, P (P/ha) Source			Pymarc, P (P/ha) Source		
	0	9.3	19	0	11	22	0	11	22	0	11	22
Gross Yield (Kg ha^{-1})	2700	4200	3400	2900	3900	4200	3600	9400	8600	3000	4600	4800
Adjusted Yield (Kg ha^{-1})	2430	3780	3960	2610	3510	3780	3240	8460	7740	2700	4140	4320
Gross benefits (Kg ha^{-1})	35235	54810	57420	37845	50895	60900	56700	148050	135450	47250	72450	75600
Added benefits (Ksh ha^{-1})	0	22965	-13260	0	15090	4065	0	91350	-12600	0	25200	3150
Added Costs (Ksh ha^{-1})	0	1190	2670	0	1540	3300	0	2700	4860	0	2450	4410
VCR	**0**	**19.3**	**-4.97**	**0**	**9.8**	**1.23**	**0**	**33.8**	**-2.59**	**0**	**10.3**	**0.71**
MRR	**0**	**19.3**	**-16.4**	**0**	**9.8**	**-6.26**	**0**	**33.8**	**-5.07**	**0**	**10.3**	**-11.25**

Table 25: Effect of spot applied Tithonia at Kosirai and Pymarc at Egerton, Molo and Kosirai on net benefits for Maize grain yield in 2004

SPOT	TREATMENTS											
	KOSIRAI						**EGERTON**			**MOLO**		
	Tithonia, P (P/ha) Source			**Pymarc, P (P/ha) Source**			**Pymarc, P (P/ha) Source**			**Pymarc, P (P/ha) Source**		
	0	9.3	19	0	11	22	0	11	22	0	11	22
Gross Yield (Kg ha^{-1})	400	600	1200	530	800	1100	2600	3300	3300	1230	1700	2000
Adjusted Yield (Kg ha^{-1})	360	540	1080	477	720	990	2340	2970	2970	1107	1530	1800
Gross benefits (Kg ha^{-1})	6300	9450	18900	8348	12600	17325	40950	51975	51925	19373	26775	31500
Added benefits (Ksh ha^{-1})	0	3150	9450	0	4252	4725	0	11025	0	0	6902	4725
Added Costs (Ksh ha^{-1})	0	1850	3330	0	2200	3960	0	2700	4860	0	2450	4410
VCR	**0**	**2.1**	**3.29**	**0**	**2.33**	**1.23**	**0**	**4.1**	**0**	**0**	**2.8**	**1.07**
MRR	**0**	**2.1**	**4.26**	**0**	**2.33**	**0.27**	**0**	**4.1**	**-5.1**	**0**	**2.8**	**1.11**

Table 26: Effect of broadcast applied Tithonia at Kosirai and Pymarc at Egerton, Molo and Kosirai on net benefits for Maize grain yield in 2004

BROADCAST	TREATMNTS											
	KOSIRAI						EGERTON			MOLO		
	Tithonia, P (P/ha) Source			Pymarc, P (P/ha) Source			Pymarc, P (P/ha) Source			Pymarc, P (P/ha) Source		
	0	9.3	19	0	11	22	0	11	22	0	11	22
Gross Yield (Kg ha^{-1})	400	700	800	400	600	700	3700	3700	4000	1500	2200	2300
Adjusted Yield (Kg ha^{-1})	360	630	720	360	540	630	3330	3330	3600	1350	1980	2070
Gross benefits (Kg ha^{-1})	6300	11025	12600	6300	9450	11025	5825	61515	63000	23625	34650	36225
Added benefits (Ksh ha^{-1})	0	4725	1575	0	3150	1575	0	3240	4725	0	11025	1575
Added Costs (Ksh ha^{-1})	0	1850	3330	0	2200	3960	0	2700	4860	0	2450	4410
VCR	**0**	**3.42**	**0.34**	**0**	**1.62**	**0.28**	**0**	**1.2**	**0.97**	**0**	**4.5**	**0.35**
MRR	**0**	**3.42**	**-2.13**	**0**	**1.62**	**-0.89**	**0**	**1.2**	**0.69**	**0**	**4.5**	**-4.82**

8.2.2 Discussion

The benefits of Pymarc, Tithonia and Phosphorus fertilizer is limited by the response of maize grain yield to manure and P. The sole P applied as Tithonia and Pymarc at 9.3 kg P/ha and 11 kg P/ha, respectively, and P as TSP would be required for maximum economic benefits. Tithonia and Pymarc applied at 9.3 kg P/ha and 11 kg P/ha, respectively, had the best added net benefits as compared to the control and P applied at 19 Kg P/ha and 22 kg P/ha, for Tithonia and Pymarc, respectively, with either of the placement method. The study also showed that broadcast placement method had a better added net benefit than the spot placement of P as manure in the planting hole. This observation are inconsistent with those of Warren *et al*, (1992) who found occasionally but inconsistent superiority of spot placement of P on soils with very low available P and high P fixation. The relatively high net benefits for Tithonia and Pymarc application, whether placed with the seed or broadcast highlighted the importance of manure as a source of nutrient on P deficient soil.

This study has shown that limited supplies of manure can be effectively integrated with commercial P such as TSP. value cost ratio for integrated use of manure with TSP remained positive and comparable to those of applied as TSP. Integration of manure with inorganic fertilizers may result in the benefits of greater residual effect of organic than inorganic sources and, advantage of manure, in addition to supply of P, for example, improved soil physical properties and supply of bases Murwira *et al.* (1995). The higher maize yield for Tithonia as P source at 22 kg P/ha than Pymarc at equal P rates (22 kg P/ha) suggests possible higher resource quality index for Tithonia than Pymarc.

8.3 Conclusion

In P deficient soils, applying P in the form of soluble fertilizers, Tithonia or Pymarc or their combination is very crucial for maize production. However, this study showed that a high maize yield could be obtained with a combination of Tithonia or Pymarc with inorganic fertilizers. This could be more sustainable strategy given that it enhances effectiveness of P sources. The application of only either 9.3 kg P/ha or 11 kg P/ha as Tithonia and Pymarc, respectively, and integration of Tithonia + P (22 kg P/ha) and Pymarc (24 kg P/ha) increased maize yields. The relative high net benefits from manure (Tithonia at 9.3 Kg P/ha and Pymarc at 11 kg P/ha), and integrated manure with P illustrates the need to:

i) Increase the availability and use of high quality manure, and

ii) Effectively integrate inorganic P sources (TSP) into tropical agricultural systems.

CHAPTER NINE

9.0 CONCLUSIONS AND RECCOMMENDATIONS

9.1 Conclusions

1. Pymarc and Tithonia residues contained nutrients concentrations of N, P, K, Mg and Ca. The lignin content in the two residues is below the critical level (15%) that significantly reduces decomposition
2. The potential and the rate of N, P and K release patterns are influenced by soil type, quality and quantity of litter. This study indicated significant correlation of N, P and K release patterns to Pymarc quality parameters and its rate of application. The potential and rate of N, P and K release varied with the soil type.
3. The addition of organic residues in *Phaeozems, Cambisols and Ferralsols* increases faunal biomass and population within the cropping system.
4. The application of organic residues to the soil as broadcast enhances macrofauna biomass, diversity and abundance, N, P and K concentrations in the maize leaf opposite the ear, maize growth and grain yield.
5. Phosphorus applied in the form of soluble fertilizers, Tithonia, Pymarc or their combination is very important for maize production. Substantial maize yields and economic returns were obtained from Pymarc and Tithonia integrated with TSP. Provided Pymarc and Tithonia rates applied supply equivalent amount of P, they appear to be as effective as TSP.
6. These organic manures especially Pymarc which is readily available should be incorporated into soils of the resource poor small-scale farmers to ameliorate long term soil fertility.

9.2 Recommendations

1. Pymarc present management opportunities that could be exploited to increase nutrients N, P and K availability, soil macrofauna diversity, population and maize crop growth and yield.
2. The potential and rate of N, P and K release patterns in the soils indicate that Pymarc is a good source of N, P and K hence incorporating it 4 weeks before crop peak demand which is at V6, may facilitate synchrony between N, P and K release and maize demand for these nutrients. However, the results are based on controlled conditions and a similar study under field conditions is necessary for useful conclusions.
3. Phosphorus applied as TSP, Tithonia, Pymarc at 26 kg P ha^{-1} or their combination at 4 tonnes ha^{-1} of Pymarc or 2.5 tonnes ha^{-1} of Tithonia with 13 kg P tonnes ha^{-1} of TSP substantially increased the yields compared to the control treatment. However, Pymarc proved to be a more efficient P source as compared to inorganic mineral fertilizers (TSP) by providing the largest increase in maize grain yields and higher added benefits than the control and equivalent to sole fertilizers. Integration of fertilizers with inorganic inputs has been regarded in this study as a more profitable alternative in low input crop production. Therefore, in P deficient soils, application of P in the form of soluble fertilizers, Pymarc or Tithonia or their combination is very crucial for maize production.
4. Pymarc should be broadcasted in order to increase soil fauna biomass, diversity and abundance, maize growth and yield in *Phaeozems, Cambisols and Ferralsols*
5. Since the quality of organic residue determines the quantities to be applied to attain the required P rate, Pymarc could be fortified through composting to improve on its quality index.
6. Pymarc and Tithonia ideally should be applied at either 4 tonnes ha^{-1} or 2.5 tonnes ha^{-1}, respectively, because there are no major differences when applied above these rates, e.g., 8 tonnes ha^{-1} or 5 tonnes ha^{-1}, respectively. This will also save the resource poor small scale farmers on labour and quantity of organic manure utilized.
7. Further research should done with Pymarc and Tithonia rates less than 4 tonnes ha^{-1} or 2.5 tonnes ha^{-1} respectively, in combination with inorganic P source

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APPENDICES

APPENDIX 1

PROFILE 1.0 EGERTON

1.0 Profile Number 1.0

Date of description: 28/10/04
Authors: Nyongesa H.W, S.K. Mwangi, R.K. Obura, B.K. Kitur and J.P. Ouma.
Location Egerton University, Agronomy Field 7.
UTM grid coordinates; S 00^{O} 21 latitude, E 035 55 Longitude.
Elevation; +/- 2298m

Physiography:
-Physiographic position of the site; Upland, slope 2-4% linear and simple straight.
-Topography of surrounding country: flat to gentle undulating.
-Microtopography; Nil

Vegetation and land use:
-Vegetation; Grassland
-Land use; Maize and Wheat.

2.0 General information on the soil.

Parent material: Ash/Tuff
Drainage: Well drained.
Effective soil depth: Deep.
Inherent fertility; fairly fertile.
Top soil properties: Udic
Presence of salt or Alkali: None
Excess surface stones: None
Evidence of erosion: Nil

Classification:
FAO-UNESCO: *mollic Phaeozems*

3.0 Profile description (Depth in cm).

AP_1 (0-10 cm), Very dark brown (10YR 2.5/2, Moist); Clay loam; strong, fine coarse, subgrannual, slightly sticky, slightly hard, plastic, common, very fine to fine roots, very few to few pores, clear boundary.

AP_2 (10-33 cm), Dark reddish brown (5YR 2.5/2, Moist); Clay loam; weak to moderate, very fine to coarse, subangular blocky; slightly sticky, friable, moist, slightly hard, dry plastic few to common, very fine to fine, roots, very few, very fine to fine, pores, gradually smooth boundary.

BA (33-46 cm), Dark brown (7.5YR 3/2, Moist); Dark reddish brown (5YR 3/3, dry). Clay loam; moderate, fine to moderate, subangular blocky; slightly sticky; slightly hard, plastic, very few to common, fine roots, common, very fine to fine, medium, pores, clear wavy boundary.

BW$_1$ (46-66 cm), Dark reddish brown (5YR 3/4, Moist, 7.5 YR 4/4, Dry), Sandy Clay loam, moderate, medium to coarse sub angular blocky; sticky, slightly hard, dry, friable, moist, plastic, few to common, fine roots, many, very few to few, pores, iron and manganese deposits, gradual wavy boundary.

BW$_2$ (66-82 cm), Dark reddish brown (5YR 3/3, Moist, Dark to dark brown 7.5 YR 4/4, Dry), Sandy Clay loam, moderate, medium to coarse sub blocky; slightly sticky, slightly hard, dry, friable, moist, plastic, few to common, very fine to fine roots, many to few, very fine to fine, pores, clear wavy boundary.

BWg$_3$ (82-117 cm), Dark brown (7.5YR 3/4, Moist, light brown 7.5 YR 6/4, Dry), Clay, weak to moderate, medium to coarse, massive, sub blocky; slightly hard, dry, friable, moist, few to common, very fine to fine roots, common to many, very fine to fine, pores, gradual and smooth boundary.

BWg$_4$ (117-142 cm), Dark brown (7.5YR 3/4, Moist, light brown 7.5 YR 6/4, Dry), Clay, weak to moderate, medium to coarse, massive, sub blocky; slightly sticky slightly hard, dry, friable, moist, rare, very few roots, common to very few, pores, clear and smooth boundary.

BWg$_5$ (142-150+ cm), Dark brown (7.5YR 3/4, Moist, light brown 7.5 YR 6/4, Dry), Clay, weak to moderate, medium to coarse, porous and massive, sub angular blocky; slightly sticky, friable, plastic, rare to none roots, common, very few to few, pores, clear and smooth boundary.

Profile: Physico-Chemical data

Horizon	Depth (cm)	Particle size distribution				O.C %	N %	C/N	pH (1:2.5)	
		Clay %	Silt %	Sand %	Class				H_2O	KCL
Ap$_1$	0-10	34	28	38	Clay loam	2.38	0.24	9.91	6.00	5.30
Ap$_2$	10-33	31	34	35	Clay loam	1.19	0.25	4.76	6.02	5.49
BA	33-46	37	30	33	Clay loam	1.86	0.20	9.30	6.87	5.07
Bw$_1$	46-66	28	25	47	Sandy Clay loam	1.76	0.17	10.35	5.67	4.96
Bw$_2$	66-82	29	24	47	Sandy Clay loam	1.34	0.16	8.34	5.89	4.80
Bwg$_3$	82-117	52	18	30	Clay	1.12	0.14	8.00	5.60	5.34
Bwg$_4$	117-142	54	21	25	Clay	1.12	0.15	7.47	6.01	5.31
Bwg$_5$	142-150+	63	18	19	Clay	0.19	0.13	1.47	6.98	5.01

Horizon	Exchangeable basic cations			Exchangeable acidity			CEC		ACEC [cmol (+) Kg^{-1} Clay]		V (%)	AL saturation (%)
	Na	K	Mg	Ca	Total	Al	NH4OAc	ECEC				
	[Cmol (+) Kg^{-1} Soil]											
Ap$_1$	0.35	4.43	7.98	10.41	0.44	0.18	39.0	19.50	62.00		59.0	0.78
Ap$_2$	0.32	4.77	7.73	11.10	0.48	0.46	36.6	13.90	38.00		64.0	1.89
BA	0.54	3.47	6.40	11.68	0.59	0.30	32.4	8.99	39.00		67.0	1.34
Bw$_1$	0.55	3.41	6.45	9.60	0.41	0.62	35.75	5.45	30.00		54.0	3.00
Bw$_2$	0.62	3.11	7.15	10.75	1.01	0.18	35.84	5.24	28.00		59.0	0.83
Bwg$_3$	0.69	3.61	4.98	9.37	0.24	0.16	21.10	6.40	40.00		85.0	0.85
Bwg$_4$	0.71	3.40	5.10	9.99	0.21	0.10	31.01	7.10	9.92		60.0	0.52
Bwg$_5$	0.80	3.44	4.51	9.14	0.37	0.05	32.04	5.93	6.72		53.0	0.28

APPENDIX 2

PROFILE 2.0 MOLO

2.0 Profile Number 2.0

Classification: *humic Cambisols*
Date of description: 29/10/04
Authors: Nyongesa H.W, S.K. Mwangi, R. K. Obura, B.K. Kitur and J.P. Ouma.
Location: Molo, Pyrethrum Clonal Research Centre, 5km from Molo town, Molo – Mau Summit road
UTM grid coordinates; S 00^{O} 13 latitude, E 035 42 Longitude.
Topographic map sheet; Molo sheet
Elevation: +/- 2529m
Physiography:
-Physiographic position of the site; Upland, slope 2-8% irregular convex and linear and undulating.
-Topography of the surrounding country; flat to gentle
-Microtopography; Contours
Vegetation and land use:
-Vegetation; Grassland
-Land use; Maize, Pyrethrum and grassland.

2.0 General information on the soil.

Parent material: Ash/ Pyroclastic tuff
Drainage: Well drained.
Effective soil depth: Very deep.
Inherent fertility: fairly fertile.
Top soil properties: Udic
Presence of salt or Alkali: None
Excess surface stones: rock outcrops
Evidence of erosion: Nil

3.0 Profile description (Depth in cm).

AP$_1$ (0-10 cm), Dark reddish brown (5YR 3/2, Moist); Clay loam; strong, fine coarse, slightly sticky, friable slightly hard, plastic, many very fine imbed roots; many very fine, pores, clear and smooth boundary.

AP$_2$ (10-22 cm), Dark reddish brown (5YR 2.5/2, Moist); Clay loam; moderate, medium coarse, subangular blocky; sticky, friable plastic, coarse very fine to fine roots, many very fine to fine pores, clear and smooth boundary.

AP$_2$ (22-42 cm), Dark reddish brown (5YR 2.5/2, Moist); Clay, moderate to medium coarse, subangular blocky sticky, plastic, coarse, very fine to fine roots, many very fine to fine pores, clear and smooth boundary.

AP$_3$ (42-54 cm), Dark reddish brown (5YR 3/2, Moist,), Clay, weak to moderate, fine to medium to coarse angular blocky; slightly sticky, friable, plastic, few, very fine to fine, imbed roots, many, coarse to medium, very fine to fine, pores, reddish manganese and iron deposits, clear and smooth boundary.

BW (54-70 cm), Dark reddish brown (5YR 3/2, Moist,), Clay, weak to moderate, fine to medium angular blocky; slightly sticky, friable, plastic, few, very fine to fine, roots, many, coarse to medium, very fine to fine pores, reddish manganese and iron deposits, clear and smooth boundary.

BW_1 (70-95 cm), Black (5YR 2.5/1, Moist,), Clay loam, moderate, fine to very fine roots, medium, very fine to fine tubular pores big rounded termite nests, clear and smooth boundary.

BW_2 (95-117 cm), Dark reddish brown (5YR 3/3, Moist,), Clay, moderate, medium angular blocky, slightly sticky, friable, plastic, very few, very fine, few, very few pores, abrupt smooth boundary.

AB (117-128 cm), Dark reddish brown (5YR 3/3, Moist), Sandy Clay loam, moderate to small, fine subgrannualy, sticky, friable, plastic, coarse, very fine to fine, roots, common, very fine to fine, few, very pores, abrupt smooth boundary.

BW_3 (128-150+ cm), Dark reddish brown (5YR 3/4, Moist), Clay, moderate medium angular blocky to sub blocky, slightly sticky, friable, plastic, few, very fine to fine roots, many, common, medium, very fine to fine, abrupt smooth boundary.

Profile: Physico-Chemical data

Horizon	Depth (cm)	Particle size distribution					O.C %	N %	C/N	pH (1:2.5)	
		Gravel %	Clay %	Silt %	Sand %	Class				H2O	KCL
Ap$_1$	0-10	,,	30	42	28	Clay loam	2.18	0.32	6.81	5.90	4.70
Ap$_2$	10-22	,,	32	36	32	Clay loam	2.09	0.30	6.96	6.00	4.90
Ap$_2$	22-42	,,	39	31	30	Clay	1.76	0.29	2.62	6.81	5.07
Ap$_3$	42-54	,,	42	30	28	Clay	1.55	0.27	2.03	6.89	5.96
BW	54-70	,,	47	29	24	Clay	1.23	0.15	8.2	4.30	4.80
BW$_1$	70-95	,,	42	35	23	Clay loam	0.91	0.92	0.99	5.10	4.90
BW$_2$	95-117	,,	43	37	20	Clay	0.57	0.78	0.65	5.00	4.90
AB	117-128	,,	34	41	25	Clay loam	0.46	0.51	0.90	6.72	5.01
BW$_3$	128-150+	,,	45	30	25	Clay	0.50	0.30	1.70	6.18	4.98

Horizon	Exchangeable basic cations				Exchangeable acidity		CEC		ACEC [cmol (+) Kg^{-1} Clay]	V (%)	AL saturation (%)
	Na	K	Mg	Ca	Total	Al	NH4OAc	ECEC			
	[Cmol (+) Kg^{-1} Soil]										
Ap$_1$	0.14	0.47	2.99	5.42	1.22	0.75	29.0	8.20	67.0	31.0	7.68
Ap$_2$	0.18	0.37	2.70	4.18	1.18	0.56	26.8	9.91	60.0	27.0	7.01
Ap$_2$	0.10	0.33	2.40	7.68	0.50	0.50	22.0	8.43	50.2	47.0	4.50
Ap$_3$	0.17	0.27	2.41	5.74	0.71	0.62	25.7	7.34	49.0	33.0	6.73
BW	0.25	0.31	2.13	1.53	1.08	1.01	35.8	5.28	32.0	11.0	19.3
BW$_1$	0.22	0.28	3.20	2.61	2.11	1.61	33.0	4.80	35.0	18.0	20.3
BW$_2$	0.15	0.35	2.03	2.01	2.01	1.50	29.0	3.92	36.0	15.0	24.83
AB	0.19	0.37	1.70	1.98	1.98	1.60	23.0	4.10	29.0	18.0	27.4
BW$_3$	0.21	1.70	2.85	1.33	1.70	1.40	22.0	3.90	24.5	27.0	18.69

APPENDIX 3

PROFILE 3.0 KOSIRAI.

3.0 Profile Number 3.0

Classification:	*rhodic Ferralsols*
Date of description:	30/10/04
Authors:	Nyongesa H.W, S.K. Mwangi, R.K. Obura, B.K. Kitur and J.P. Ouma.
Location	Kosirai, 2 km East of Mosoriot T.T.C, North Nandi District. UTM grid coordinates; N 00^{O} 19 720 latitude, E 035 11 044 Longitude. Topographic map sheet; -
Elevation:	+/- 2109

Physiography:

-Physiographic position of the site; Plain/plateau, slope 0-3% linear.
-Topography of the surrounding country; Flat to gently undulating
-Microtopography; Nil

Vegetation and land use:

-Vegetation; Grassland
-Land use; Maize, beans, cow peas, weeds and grasses.

2.0 General information on the soil.

Parent material:	Basalt
Drainage:	Well drained.
Effective soil depth:	Very deep.
Inherent fertility:	Poor.
Top soil properties:	Udic
Presence of salt or Alkali:	None
Excess surface stones:	None
Evidence of erosion:	Slight sheet erosion.

3.0 Profile description (Depth in cm)

Ap (0-24 cm), Yellow red (5YR 4/6, Moist); Sandy clay; moderate, fine medium subangular blocky; slightly sticky, slightly plastic, friable, many, fine, pores; clear and wavy boundary.

BW_1 (24-52 cm), Dark reddish brown (2.5YR 3/4, Moist); Sandy clay; moderate, fine to coarse, subangular blocky; slightly sticky, slightly plastic, friable, fine to coarse, very fine to fine, medium, very fine to fine, pores, gradual and smooth boundary.

BW_2 (52-69 cm), Red to dark red (2.5YR 3/6, Moist); Clay; moderate, fine to coarse, subangular blocky; slightly sticky; slightly plastic, friable, rare, very fine to fine; medium, very fine pores, gradual and smooth boundary.

BW_3 (69-100 cm), Dark reddish brown (2.5YR 3/6, Moist), Clay, loam to clay loam, moderate, fine coarse, subangular blocky; slightly sticky, slightly plastic, friable, rare, very fine to fine, medium, very fine pores, gradual and smooth boundary.

BW_4 (100-170+ cm), Dark red (2.5YR 3/6, Moist), Clay, moderate, fine coarse subangular blocky; sticky, plastic, friable, rare, very fine to fine, medium, very fine pores, soft, few to common Manganese concretions, gradual and smooth boundary.

Profile: Physico-Chemical data

Horizon	Depth (cm)	Particle size distribution					O.C %	N %	C/N	pH (1:2.5)	
		Gravel %	Clay %	Silt %	Sand %	Class				H_2O	KCL
Ap	0-24	,,	38	9	53	Sandy clay	1.18	0.12	9.83	4.98	4.30
Bw1	24-52	,,	40	8	52	Sandy clay	1.09	0.10	10.9	5.02	4.09
Bw2	52-69	,,	53	6	41	Clay	0.76	0.09	8.44	5.87	4.07
Bw3	69-100	,,	56	6	38	Clay	0.55	0.07	7.86	5.89	3.96
Bw4	100-170+	,,	59	6	35	Clay	0.23	0.05	4.60	4.30	3.80

Horizon	Exchangeable basic cations				Exchangeable acidity		CEC		ACEC [cmol (+) Kg^{-1} Clay]	V (%)	AL saturation (%)
	Na	K	Mg	Ca	Total	Al	NH4OAc	ECEC			
	[Cmol (+) Kg^{-1} Soil]										
Ap	0.21	1.23	1.99	3.42	0.42	0.18	19.1	5.20	37.0	20.0	5.01
Bw1	0.28	0.47	1.71	3.18	0.48	0.16	16.8	3.93	30.0	14.0	19.80
Bw2	0.20	0.33	1.41	2.68	0.39	0.30	12.6	2.99	20.2	19.6	13.11
Bw3	0.15	0.17	2.45	2.74	0.31	0.22	5.73	2.45	19.80	27.0	23.42
Bw4	0.12	0.11	2.13	2.47	0.30	0.28	5.81	1.28	19.8	8.2	61.76

APPENDIX 4: Macrofauna fresh biomass in maize as affected by Pymarc and Tithonia application in *Phaoezems*, *Cambisols* and Ferralsols in 2003 and 2004

	Macrofauna fresh biomass (g m^{-2})								
	Phaeozems		*Cambisols*		*Ferralsols*			*Ferralsols*	
Treatment (Pymarc) tonnes ha^{-1}	**2003**	**2004**	**2003**	**2004**	**2003**	**2004**	**Treatment (Tithonia)tonnes ha^{-1}**	**2003**	**2004**
0	1.62^{b}	1.00^{b}	0.95^{b}	0.61^{b}	1.60^{b}	0.51^{b}	0	1.60^{b}	0.51^{b}
4.0	5.38^{a}	3.96^{a}	2.76^{a}	1.03^{a}	3.75^{a}	1.13^{a}	2.5	4.65^{a}	1.46^{ab}
8.0	4.60^{a}	2.36^{ab}	3.57^{a}	1.27^{a}	3.94^{a}	1.96^{a}	5.0	5.03^{a}	3.12^{a}
Lsd	**2.67**	**2.93**	**2.18**	**2.18**	**2.96**	**2.46**	**Lsd**	**3.02**	**2.55**
C.V	**2.18**	**2.18**	**1.49**	**0.67**	**2.05**	**2.05**	**C.V**	**2.04**	**2.04**

Means followed by the same letters (s) within a column are not significantly $P \leq 0.05$ different

APPENDIX 5: Macrofauna diversity index in maize as affected by Pymarc and Tithonia application in *Phaoezems, Cambisols* and *Ferralsols* in 2003 and 2004

	Macrofauna diversity index								
	Phaeozems		*Cambisols*		*Ferralsols*			*Ferralsols*	
Treatment (Pymarc) tonnes ha^{-1}	**2003**	**2004**	**2003**	**2004**	**2003**	**2004**	**Treatment (Tithonia)tonnes ha^{-1}**	**2003**	**2004**
0	0.56^{b}	0.57^{a}	0.48^{b}	0.46^{a}	0.52^{b}	0.70^{a}	0	0.50^{b}	0.74^{a}
4.0	0.86^{a}	0.74^{a}	0.79^{ab}	0.78^{a}	0.95^{a}	0.79^{a}	2.5	0.93^{a}	0.83^{a}
8.0	1.02^{a}	0.87^{a}	0.88^{a}	0.80^{a}	1.05^{a}	0.97^{a}	5.0	1.26^{a}	0.84^{a}
Lsd	**0.21**	**0.38**	**0.33**	**0.36**	**0.29**	**0.33**	**Lsd**	**0.23**	**0.28**
C.V	**2.18**	**2.18**	**2.18**	**2.18**	**2.04**	**2.04**	**C.V**	**2.05**	**2.05**

Means followed by the same letter (s) within a column are not significantly different at ($P \leq 0.05$)

APPENDIX 6: Macrofauna diversity index in maize as affected by two modes of Pymarc and Tithonia application in *Phaoezems, Cambisols* and *Ferralsols* in 2003 and 2004

	Macrofauna diversity index								
	Phaeozems		*Cambisols*		*Ferralsols*			*Ferralsols*	
Mode of Pymarc application	**2003**	**2004**	**2003**	**2004**	**2003**	**2004**	**Mode of Tithonia application**	**2003**	**2004**
Spot	0.69^{a}	0.53^{a}	0.71^{a}	0.64^{a}	0.78^{a}	0.89^{a}	Spot	0.81^{a}	0.79^{a}
Broadcast	0.94^{b}	0.92^{b}	0.73^{a}	0.72^{a}	0.90^{a}	0.75^{a}	Broadcast	0.94^{a}	0.99^{a}
Lsd	**017**	**0.31**	**0.27**	**0.30**	**0.23**	**0.28**	**Lsd**	**0.24**	**0.29**
C.V	**2.18**	**2.18**	**2.18**	**2.18**	**2.05**	**2.05**	**C.V**	**2.18**	**2.05**

Numbers followed by the same letter (s) within a column are not significantly different at $P \leq 0.05$