RESPONSE OF TOMATO (*Lycoperscon esculentum M.*) TO COFFEE PULP COMPOST, MINJINGU PHOSPHATE ROCK AND COFFEE PULP - MINJINGU PHOSPHATE ROCK COMPOST APPLIED TO A CHROMIC ACRISOL

BY

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# ABSTRACT

A study was conducted in a glasshouse at Sokoine University of Agriculture Morogoro, Tanzania to investigate the effect of coffee pulp compost (CP), Minjingu phosphate rock (MPR) and coffee pulp composted with Minjingu phosphate rock (CPMPR) on phosphorus availability and response of Tomato (*Lycopersicon esculentum M.*) var. Carl J in 3x8 completely randomized block design experiment. The P sources were applied on a P deficient Chromic Acrisol at eight equivalent rates of 0, 40, 80, 100, 120, 140, 160 and 200 kg P ha$^{-1}$. Five tomato seeds were directly sown in each pot then thinned to three seedlings at 30 days after planting (DAP). Two out of the three plants were harvested from each pot 60 DAP for assessment of dry matter yield response to the three P sources and nutrient concentrations in the plants. One plant was maintained per pot to harvesting maturity for assessment of growth and yield responses. Crop responses were further assessed in terms of plant heights and number of true leaves per plant, number of flowers, fruits and trusses per plant as well as numbers and weights of marketable fruits harvested per plant. Experimental soil was analyzed at the end of the experiment to assess the effect of the three P sources on residual P and other chemical properties of the soil. The application of CP, MPR and CPMPR at 40 to 200 kg P ha$^{-1}$ increased the overall P uptake 11, 13 and 18 folds while the overall plant P contents increased by 23%, 36% and 110%, respectively above the control. The average number of flowers increased from 0 to17, 0 to 23 and 0 to 29 per plant, while the average number of fruits increased from 0 to 6, 0 to 19 and 0 to 24 fruits per plant, respectively. The average number of marketable fruits increased by 4, 5 and 7 fruits per plant while the average fruit weight increased by 152.2 g, 168.2 g and 242.0 g per plant, respectively. CPMPR thus, significantly (p=0.05) increased P uptake and concentrations in plant tissues, the numbers of flowers, fruits, marketable fruits and weight of tomato fruits; while its effect on residual soil P at the end of the

experiment was comparable to MPR. Composting coffee pulp with MPR was thus concluded as a potential technique for improving MPR dissolution, P and other nutrient supply as well as the physical, chemical and biological properties of the soil.

# DECLARATION

I, **MAWAZO JAMSON SHITINDI**, do here by declare to the Senate of Sokoine University of Agriculture that this dissertation is my own original work and that it has neither been submitted nor concurrently being submitted for a degree award in any other University.

_____ _____

Mawazo Jamson Shitindi                                                               Date

  (MSc. Candidate)

The above declaration is confirmed

_____ _____

Prof. J. P. Mrema                                                                         Date

  (Supervisor)

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May God bless them abundantly!

# DEDICATION

Glory to God!

His grace and love makes everything possible through prayers and actions.

To my parents for their constant love, care and decision to take me to school which opened my eyes and mind to see and understand what the world is. It was a serious love for them to provide me what themselves missed in their life. I have nothing worth their investment to pay, except constant prayers for them. May the almighty God rest my late father's soul in peace and extend my mother's life for her guidance on my life.

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## SYMBOLS AND ABREVIATIONS

| | |
|---|---|
| ADP | Adenosine diphosphate (high energy molecule) |
| ANOVA | Analysis of variance |
| ATP | Adenosine triphosphate (high energy molecule) |
| C: N: P: S | Ratio of carbon to nitrogen to phosphorus to sulphur |
| CEC | Cation Exchange Capacity |
| cmol | Centimole |
| Conc. | Concentration |
| CP | Coffee pulp compost |
| CPMPR | Coffee pulp composted with Minjingu phosphate rock |
| CV | Coefficient of variation |
| DMY | Dry matter yield |
| DNA | Deoxyribonucleic acid |
| DNMRT | Duncan's new multiple range test |
| DTPA | Diethylene tri amine pentaacetic acid |
| *et al.* | and others |
| FAO | Food and Agricultural Organization |
| GDP | Gross Domestic Product |
| kg | Kilogram |
| kg ha$^{-1}$ | kilogram per hectare |
| kg$^{-1}$ | per kilogram |
| LSD | Least significant difference |
| Ltd | Limited |
| M.Sc | Master of science degree |

| | |
|---|---|
| MDGs | Millennium Development Goals |
| meq | millequivalent |
| mg pot$^{-1}$ | milligram per pot |
| MPR | Minjingu phosphate rock |
| N d | Not determined |
| N: P: K | Compound fertilizer of nitrogen, phosphorus and potassium |
| $^{o}$C | degree celsius |
| p=0.05 | 0.05 probability level or five percent probability level |
| PAPRs | Partially acidulated phosphate rocks |
| pH | Measure of acidity or alkalinity ( -log of $H^+$ concentration in the soil solution) |
| PhD | Doctor of philosophy degree |
| PR | Phosphate rock |
| PRs | Phosphate rocks |
| RNA | Ribonucleic acid |
| SSSA | Soil Science Society of America |
| SSP | Single super phosphate (Ca $(H_2PO_4)_2$) |
| SUA | Sokoine University of Agriculture |
| TaCRI | Tanzania Coffee Research Institute |
| TNBC | Tanzania National Business Council |
| TSP | Triple super phosphate (Ca $(H_2PO_4)_2$) |

# CHAPTER ONE

## 1.0 INTRODUCTION

Most of the tropical agricultural soils, Tanzanian soils inclusive, are highly weathered, leached and consequently acidic. These soils are highly deficient in phosphorus (P) thus require substantial P inputs for optimum crop production (Buehler *et al*., 2002). Research findings by Weil (2000), Mowo (2000), Szilas (2002), Ikerra *et al*. (1994) and Msolla (2005) showed that phosphorus and nitrogen deficiencies are the biophysical causes of the declining crop production in Sub Saharan Africa (SSA) small holder farming systems.

Phosphorus deficiencies are mainly corrected via application of water soluble P fertilizers and manures. However, water soluble P fertilizers are too expensive and unaffordable to most small scale farmers (Msolla, 2005). Similarly, farmyard manures and high quality plant biomass are of limited availability, subsequently then, their use under smallholder farming systems remains low (Buresh *et al*., 1997). Current average fertilizer use in Tanzania is only about 9 kg of fertilizer per hectare of arable land (TNBC, 2009). This amount of fertilizer is three times less than the average of 27 kg used per hectare of arable land in Malawi and about six times less than amounts used in South Africa (TNBC, 2009).

Continuous cropping associated with such low levels of fertilizer use has resulted into land degradation and subsequently season after season decline of small holder crop production per unit area of cultivated land. This poses problems to attain the annual food production increase of 5% recommended by the World Bank (2002) for self food sufficiency. Declining crop production also threatens the possibility of attaining the 10% annual growth rate of the agricultural sector recommended under the millennium development

goals so as to reduce by half the number of Tanzanians below the poverty line by 2015 (TNBC, 2009).

Promoting the use of locally available natural P sources such as phosphate rocks (PRs) in Tanzania has been considered to be one of the most promising alternatives to the expensive mineral P fertilizers. Minjingu phosphate rock (MPR) in Manyara region Tanzania has been reported as the most potential and cheap phosphorus source in Tanzania (Semoka *et al*., 1992; Butegwa *et al*., 1996; Weil, 1994; Szilas, 2002; Agbenin, 2004; Msolla, 2005). The MPR deposits are of medium to high reactivity with moderate to relatively high agronomic effectiveness compared to other PRs in the country (Van Straaten, 2002).

Despite its promising potential as an alternative P source, MPR is still underutilized by most smallholder farmers in Tanzania. Lack of significant first season crop response to MPR application and inadequate knowledge on the nature of the transformation and effectiveness of phosphate rocks among smallholder farmers contribute to the underutilization of PRs (Weil, 2000). The insignificant crop response to MPR in the first cropping season is attributed to its insolubility in water and its gradual dissolution and transformation in soils (Ikerra *et al*., 2006).

Combined application of MPR with farm manure and plant biomass has been recommended as a promising technique to improve MPR dissolution hence crop response in the first cropping season (Kitua, 1997; Mhagama, 2003; Ikerra, 2004). It is unfortunate that farm manure and high quality plant biomass are of limited availability at farm level (Palm *et al*., 1997). Further limited research has been conducted in Tanzania to assess the

effects of composting MPR with locally available crop residues before field application on MPR dissolution rates and crop response to MPR- crop residues composts.

Coffee pulp is a readily available crop residue in all coffee producing areas of Tanzania. Its poor management poses soil and water pollution hazards around coffee processing centers and on the coffee farms. Direct application of fresh coffee pulp as a soil amendment in coffee fields is restricted by the presence of toxic compounds like phenols, local heat generation and coffee berry disease spread risks (Preethu *et al.,* 2007). Although known to be rich in phenol, lignin, cellulose, nitrogen and potassium; its potential to improve PR dissolution is still unknown.

Of all the vegetables grown in Tanzania, tomato (*Lycopersicon esculentum M.*) ranks first in acreage and second after cabbage in production and economic value (Nono-Womdim *et al.*, 2002). It is the most consumed vegetable and forms an integral part of the household's diet all over the country. URT (2006) indicated that 129 588 tones of tomato were produced in various parts of Tanzania in the 2002/03 cropping season. Tomato production (ton/ha) in Tanzania is on the decline and this decline has been attributed to inadequate supply of some of the essential plant nutrients, P inclusive, from the soils under continuous tomato cultivation and to some extent inadequate soil moisture.

This study was conducted with an overall objective to investigate the effects of composting coffee pulp with MPR on MPR dissolution and response of tomato to coffee pulp compost, MPR and coffee pulp-MPR compost applied to a phosphorus deficient Chromic Acrisol.

Specific objectives of the study were:

    (i)      To determine the effect of composting coffee pulp with MPR on compost quality.

    (ii)     To investigate the effect of coffee pulp-MPR composting on MPR dissolution, P and other nutrients availability and uptake.

    (iii)    To compare the responses of tomato plants at various rates of P from coffee pulp compost, MPR and coffee pulp composted with MPR

    (iv)    To study the effect of coffee pulp compost, MPR and coffee pulp - MPR compost application on some selected properties of the Chromic Acrisol.

**CHAPTER TWO**

**2.0 LITERATURE REVIEW**

**2.1 Importance of Phosphorus in Tropical Agriculture**

Phosphorus is an indispensable element for all forms of life and one of the essential nutrient elements required for plant growth, development and reproduction (Tisdale *et al*., 1993). The key physiological and metabolic roles of phosphorus in plants include energy transfer and storage in the form of ADP and ATP. It is also a constituent of coenzymes, nucleotides, nucleic acids (DNA and RNA), phospholipids, phosphoproteins and sugar phosphates (Tisdale *et al*., 1993). Stimulated root development, increased stem length and strength, increased number of tillers, improved flower formation, seed production and grain filling, early and uniform crop maturity are some of the specific growth effects that have been associated with improved phosphorus fertilization and utilization (Tisdale *et al*., 1993). Bioavailability of P has thus been reported as a key factor regulating productivity, efficiency and profitability of most tropical agricultural systems (Sanchez *et al.*, 1997; Kosia, 2003).

P is reported to be the main limiting plant growth factor on highly weathered tropical acid soils with high P fixation (sorption) capacities (Szilas *et al*., 2006). Semoka and Kalumuna (2000) reported phosphorus deficiency to be a major constraint to crop production in Tanzania where over 50% of the cultivated soils are considered to be deficient in phosphorus. Crops usually recover less P from soils than any other nutrients in the short term thus substantial P inputs are required for optimum plant growth and adequate food and fibre production (FAO, 2004).

## 2.2 Sources of Phosphorus and their Contribution to Crop Production

Plant available P in the soil originates from various sources within and outside the soil system. The internal and external sources or inputs of P can be classified into two main groups namely the organic and inorganic sources (Tisdale *et al.*, 1993).

### 2.2.1 Organic P sources

Organic sources of plant P include various inputs of animal and/or plant origin such as farmyard manures, green manures, composts, crop residues, domestic (municipal) wastes, industrial wastes and microbial biomass (Palm *et al.*,1997). The P in organic sources is not directly available for plant uptake because it is in complex forms and such materials must be biochemically degraded by micro organisms to release inorganic P. The process of conversion of organic P to inorganic P is catalyzed by phosphatase enzyme and can be represented by the biochemical reaction equation (Tisdale *et al.*, 1993):

$$R\text{-}PO_4^{2-} + H_2O \xrightarrow[\text{Enzyme}]{\text{Phosphatase}} HPO_4^{2-} + R-OH \quad \text{......................} \quad (i)$$

(Organic P)      Enzyme      (Inorganic P)      (Organic constituents)
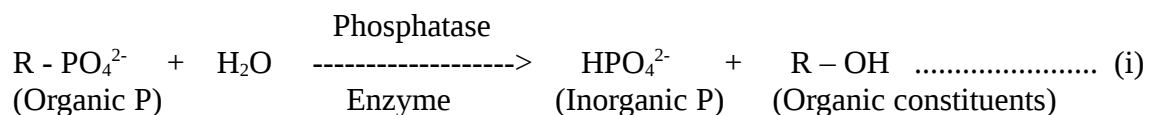
The rate of mineralization of organically bound P is determined by C: N: P: S ratio of the organic material, soil temperature, moisture supply, soil aeration, pH, cultivation intensity and P fertilization (Tisdale *et al.*, 1993). Generally, P mineralization increases with increase in organic P content of the organic material, soil pH, temperature and the soils' redox potential. High N contents in the organic material, adequate moisture supply and inorganic P fertilization also increase the mineralization rate. However, the rate of mineralization decreases with increase in cultivation intensity as a result of organic P depletion. Since P mineralization and immobilization reactions occur simultaneously in soils, organic turnover in soils can be depicted by the following biochemical reaction

equation (Tisdale *et al.*, 1993):

Mineralization

Organic P        <================>   Inorganic P ($H_2PO_4^-$ or $HPO_4^{2-}$)……... (ii)
Immobilization
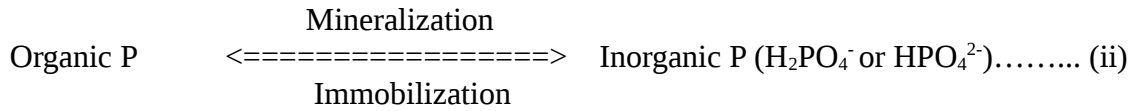
Additions of relatively large quantities of high quality organic P sources can increase availability of P to plants. However, sufficient quantities of such resources are not available at the farm level to meet crop P requirements in most African smallholder farming situations (Palm *et.al*., 1997). The available low quality organic materials are poor sources of plant nutrients including P when used alone. Integrated use of organic and inorganic P sources can arrest and correct the depletion of P in many soils thus ensuring optimum P supply and hence increased crop production (FAO, 1987; 2004).

## 2.2.2 Inorganic P sources

Inorganic P sources are mainly phosphate rocks and water soluble mineral P fertilizers classified into various groups on the basis of their chemical composition. The common inorganic P fertilizers used in Tanzania includes mono-ammonium phosphate ($NH_4H_2PO_4$), diammonium phosphate ($(NH_4)_2HPO_4$), single super phosphate Ca ($H_2 PO_4)_2$, triple super phosphate Ca ($H_2 PO_4)_2$ and various grades of compound N: P: K fertilizers. The extent of the use of inorganic P fertilizers is very low in Tanzania and Africa as a whole (excluding South Africa) mainly because of their limited availability and unaffordable high prices for the resource poor farmers (Buresh *et al.,* 1997; Sanchez *et al*., 1997). Consequently, the amounts of P added to the soils for crop production are always lower than the amounts exported from the system through plant harvestable parts and other losses. According to Izac (1997), inadequate use of both organic and inorganic sources of P calls for an integrated soil fertility management strategy that can make efficient use of both organic and inorganic nutrient sources; with effective soil management practices for increased

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crop production and income to farmers as well as environmental benefits to the society as a whole.

## 2.3 Availability of Phosphorus in Agricultural Soils

Kifuko *et al*. (2006) reported P to be the second most limiting nutrient element after nitrogen in most tropical agricultural soils. The limited P availability in tropical soils has been associated with its high susceptibility to fixation (sorption) particularly in very acidic and calcareous soils. Most tropical and subtropical soils are predominantly acidic with high phosphate fixation capacities thus P deficient. P fixation or retention occurs through sorption or precipitation reactions with Fe and/or Al in acid soils or Ca in calcareous soils (Chien and Hammond, 1989). The P fixation reactions can be represented by the following chemical equations (Chien and Hammond, 1989):

### a) *In acid soils*

$X(OH)_2^+$      +      $H_2PO_4^-$      ↔      $X(OH)_2H_2PO_4$ (precipitate) ...………... (iii)
(Soil solution)          (Available P)          (Unavailable P), where X stands for Fe or Al

### b) *In calcareous soils*

$2Ca^{2+}$   +   $Ca(H_2PO_4)_2$   ↔   $Ca_3(PO4)_2$ + $4H^+$ ....................................................... (iv)
(Soil solution)   (Soluble P)       (Insoluble P)
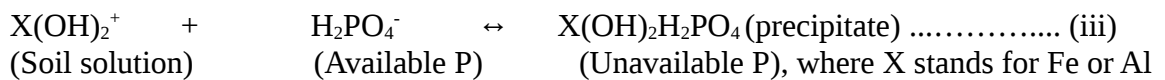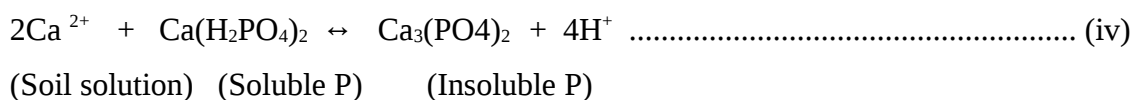
Various techniques have been employed to reduce P fixation capacities of soils such as liming of acid soils, direct application of reactive PR and manure and the application of large quantities of P fertilizers to satisfy the soils' P fixation sites thus increased P availability (Waigwa *et al*., 2003). However the use of water soluble P fertilizers in many developing countries including Tanzania is restricted by severe economic constraints which include high prices of the fertilizers and low prices of farm produce. Thus

integration of local PRs with farm based organic residues has been recommended as a promising strategy towards improved P availability and use efficiency in various crop production systems. This is due to their local availability and thus not that expensive.

## 2.4 Potential of Tanzanian Phosphate Rocks as an Alternative P Source

In Tanzania PR deposits of different types are found in various parts, like Minjingu phosphate rock (MPR) in Babati district, Panda phosphate rock at Panda Hills in Mbozi district, Sangu Ilola deposits in Mpanda district and Ngualla deposits in Chunya district (Ikerra, 2004). On the basis of their mode of formation the deposits are of two major types namely sedimentary and igneous PRs (Ikerra, 2004). Generally, sedimentary PRs are more soluble in neutral ammonium citrate and less costly to excavate for direct use in agriculture or for processing than the igneous PRs which are of limited solubility and reactivity hence their limited potential for use as plant P source (Buresh *et al*., 1997; FAO, 2004). The differences in solubility between igneous and sedimentary PRs are attributable to their differences in physical, mineralogical and chemical compositions.

The chemical composition of Tanzanian PR ores vary greatly but both the soft and hard PR apatites have the general formula $Ca_{10}(PO4)_6(X)_2$ where X is either $F^-$, $OH^-$ or $Cl^-$ (Schluter *et al*., 2000). The basic components of soft MPR ore include: 20 - 29.23% $(P_2O_5)$, 37.15 - 42.03% (CaO), 9.5 - 13.89% $(SiO_2)$, 1.8 - 3.5% ($F^-$), 1.56 - 2.89% $(Al_2O_2)$, 0.51 - 1.3% $(Fe_2O_3)$, 2.22 - 4.05% (MgO), 1.14 - 1.55% $(K_2O)$, and 0.85 - 1.4% $(Na_2O)$ (Szilas *et al.*, 2006).

Minjingu PR deposits are of sedimentary biogenic type and reported to be the most promising PR in East Africa (Ikerra, 2004; Jama and Van Straaten, 2005; Szilas *et al*., 2006) that can serve as P source. The suitability of Minjingu PR as P source for crops in P

deficient soils has been highlighted by a number of studies conducted in different parts of Africa. For example, in the assessment of the effectiveness of ground PR and elemental sulphur on the yield and P uptake by maize in Western Kenya, Bromifield and Debenham (1981) reported an agronomic effectiveness of 75% for MPR relative to TSP. Further, from 559 comparative studies of PRs and P-fertilizers at equal levels of added P, Woomer *et al.* (1997) observed higher maize yield increases with MPR than with some other PRs found in Africa. Jama and Van straiten (2005) reported relative agronomic effectiveness of 70 to 75% for MPR and recommended it for application to P deficient acidic soils. The suitability of MPR on acid P deficient soils has also been reported by Semoka (1988) and Szilas *et al.* (2006). The superiority and suitability of MPR in acid soils is due to its dissolution as influenced by the readily available protons ($H^+$) in the soil solution. However, most of the evaluation studies of MPR as P source for plants have been conducted with cereals while very limited studies have been done with vegetable crops especially in Tanzania. This is probably due to the fact that cereals comprise most of staple food crops in Tanzania hence giving less preference to vegetables which are mostly cultivated on small farms, or backyard gardens.

## 2.5 Status of PR use in Tanzania

Despite the adequate local availability of PRs in Tanzania, they are not extensively used in agricultural production. MPR which has promising reactivity can be directly used in agricultural production but its use at farm level is still low. Inadequate first season crop response due to slow P release, health hazards (heavy metal contents) and inadequate knowledge on the nature and performance of PR among smallholder farmers are among the major reasons for the under utilization of the PR in crop production (Weil, 2000). However, Semu and Singh (1995) reported that MPR is not associated with many heavy

metal risks hence not a health hazard as considered by smallholder farmers. Kimbi (1991) reported the varied agronomic effectiveness of MPR in different soils and climatic conditions, inconvenience of handling and application of the powdery MPR and high transportation costs per unit P as the major reasons for its underutilization. Such contradictions call for extensive research to identify factors affecting the agronomic effectiveness of PRs and simple technologies that can be used at farm level to improve the availability of P from PRs, hence the response to MPR by various crops on different soils.

## 2.6 Factors Affecting Agronomic Effectiveness of PR

Agronomic effectiveness of phosphate rock is a function of various factors but the main ones include reactivity of the PR, soil properties, climatic conditions, crop species and management practices (FAO, 2004).

## 2.6.1 Reactivity of PR

According to Rajan *et al*. (1996) reactivity of PRs is a measure of the rate of dissolution of PRs under standard laboratory conditions or under given field conditions. This is mainly determined by the chemical composition and particle size of the PR. Chemical properties known to influence the reactivity of PRs include the phosphate crystal (apatite) structure and the presence of secondary minerals especially calcium carbonate (FAO, 2004).

The substitution of carbonate to phosphate in the crystal structure decreases the cell *a* dimensions and weakens the apatite crystal structure hence increasing the reactivity of PRs. Accessory calcium carbonate in PRs is more soluble than most of the chemically reactive phosphate minerals, hence the dissolution of the PR increases the Ca concentration and pH at the phosphate mineral surface resulting into reduced rate of PR

dissolution (Robinson *et al*., 1992) cited by FAO (2004). Particle size of PRs has an important bearing on their rate of dissolution because PRs are relatively insoluble materials hence the finer the particle, the greater the degree of contact of PR with soil and thus the higher the rate of PR dissolution (FAO, 2004).

**2.6.2 Soil properties**

In addition to the dissolution rate of PR, availability to plants of the P from PR is another determining factor for the agronomic effectiveness of PR. Dissolution of PR is favored by soil properties such as low pH (less than 5.5), low concentration of Ca ions in soil solution, low available P levels and high soil organic matter content (FAO, 2004). Continuous dissolution of PR requires adequate supply of hydrogen ions (Bolan and Hedley, 1990 cited by FAO, 2004). It also requires removal of Ca from the dissolution site to maintain its concentration in the soil solution at lower levels than in the film surrounding the dissolving PR particle. This is achieved if there are adequate soil cation exchange sites available to adsorb the Ca ions released from the PR or if Ca is removed from the site of PR dissolution through processes like leaching, fixation, precipitation of discrete Ca- compounds and complexation (Msolla, 2005).

The lower the soil solution P concentration the higher is the rate of PR dissolution. It therefore follows that the greater the P sorption capacity of the soils, the greater the dissolution of PR (Chien *et al*., 1990). The number of sites available to adsorb released P from PR is important to maintain low P concentrations in the soil solution near the PR particles (FAO, 2004). Despite the fact that P sorption capacities of soils may favour PR dissolution, availability of P depends on soil P status and amounts of PR added to the soil. Adding low amounts of PR to severely P-deficient soils results into almost all of the

dissolved P being tightly retained by the soil components thus very little increase in soil solution P (Tisdale *et al.,* 1993; FAO, 2004).

Soil organic matter is another soil component known to affect PR dissolution and P availability to plants. According to Chien *et al*. (1990) the influence of soil organic matter is due to its high cation exchange capacity which increases Ca retention capacities of soils, its ability to form complexes with Ca ions, production of organic acids that dissolve PR and blocking of soil P sorption sites.

### 2.6.3 Climatic conditions

The most important climatic factor that influences PR dissolution and agronomic effectiveness is rainfall (FAO, 2004). This can be expressed by the general PR dissolution reaction equation:

$$Ca_{10}(PO_4)6F_2 \quad + \quad 12H_2O \quad \leftrightarrow \quad 10Ca^{2+} + 6H_2PO_4^- + 2F^- + 12OH^- \quad \ldots\ldots\ldots\ldots \text{(v)}$$
(Phosphate rock)   (Water/protons)    (Dissolution products)
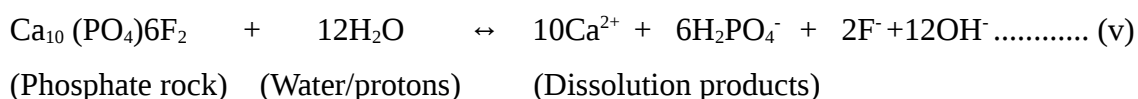
For continuous PR dissolution, $Ca^{2+}$ and $OH^-$ produced from the dissolution reaction should not accumulate in the soil solution close to the PR particles. Accumulation of $Ca^{2+}$ could saturate the $Ca^{2+}$ sinks thus providing no room for similar ions produced as PR dissolution products. Hydroxyl ions generated in the reaction must be neutralized to shift the equilibrium further right (Weil *et al.,* 1994). Rainfall or irrigation water thus plays an important role in neutralizing the hydroxyl ions and removing Ca and other reaction products from the area around PR particles undergoing dissolution. Research findings by Chien *et al*. (1980) indicated that temperature has negligible or no direct influence on the solubility and agronomic effectiveness of PRs within a range of 3-35ºC. However, the interactive effect of soil moisture and temperature may influence the dissolution of PR.

## 2.6.4 Crop species

Different plant species differ in their P uptake demands and patterns, abilities to absorb soil solution P and access to sparingly available forms of P that are unavailable to some plants (Baligar *et al*., 2001; Hocking, 2001). Perennial plants require a steady supply of P over extended time span thus gradual dissolution of PR attracts its use as P source for perennial crops (Chew, 1992). High root density of perennial plants also facilitates extensive exploitation of large soil volume for P hence the high agronomic effectiveness of PR realized with perennial plants.

Legumes are reported to be more effective than cereals in dissolving PR and absorbing PR dissolution products namely calcium and hydrogen phosphate ions (Ankomah *et al*., 1995; Kamh *et al*., 1999). Vanlauwe *et al*. (2000) associated the afore mentioned condition with the legumes' high demand for Ca and the acidifying effect of the nitrogen fixation process and recommended its use as an attempt to improve P utilization of a companion crop or subsequent crop in the rotation. The legume's high demand for Ca creates a $Ca^{2+}$ sink in the soil ecosystem and biological N –fixation process produces $H^+$ ions (protons) which neutralize the $OH^-$ released during the PR dissolution process hence the continuation of the PR dissolution process.

## 2.6.5 Management practices

Some management practices such as placement of PR material in relation to the plants, PR application rate, timing of PR application and lime application are reported to significantly influence the agronomic effectiveness of PRs (FAO, 2004). Incorporation of PR in the soil

increases its dissolution by increasing the contact between PR particles and the soil, while high rates of PR application are required in soils with high P fixation capacities to meet the fixation capacities of soils and crop P demands. FAO (2004) recommended the minimum rate of PR application for soils with medium P status not to be less than the amount of P removed from the site as farm produce plus the amount of phosphate retained by the soil in forms that are not available to plants under near maximum production levels. In soils of low P status incorporation of large amounts of PR (500-1000 kg/ha) followed by regular maintenance application of P is recommended (FAO, 2004).

For acid soils with pH < 5.5 and high P retention capacities, incorporation of P close to planting time purposely to minimize conversion of dissolved P to plant unavailable forms is recommended. PR dissolution and P transformation in acid soils may be represented by the following reaction equations (Hu *et al*., 1995 cited by Mhagama, 2003):

$$Ca_{10}(PO_4)6F_2 \quad + \quad 12H_2O \quad \rightarrow \quad 10Ca^{2+} + 6H_2PO_4^- + 2F^- + 12OH^- \text{........ (vi)}$$
(Phosphate rock)   (Water/protons)                (Available P)

Reactivity of $Fe^{3+}$ and $Al^{3+}$ in the soil solution increases with increase in soil acidity thus, with time $H_2PO_4^-$ may be precipitated as Al- and Fe- phosphate which are plant unavailable forms. According to Mrema (1988), availability of exchangeable $Al^{3+}$ and $Fe^{3+}$ in the soil solution could control P precipitation according to the following reaction equations:

$$Fe^{3+}/Al^{3+} + 2H_2O \leftrightarrow Fe/Al(OH)_2^+ + 2H^+ \text{ (Hydrolysis)} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\text{..... (vii)}$$

$$Fe/Al(OH)_2^+ + H_2PO_4^- \leftrightarrow Fe/Al(OH)_2 H2PO4 \text{ (Precipitation of P)} \dots\dots\dots \text{ (viii)}$$
(Available P)      (Unavailable P)

In accordance with the law of mass action, precipitation of P as Al-phosphate or Fe phosphate induces further hydrolysis of $Al^{3+}$ or $Fe^{3+}$ into soil solution until the ionic activity product of $(Al^{3+})(H_2PO_4)^{2-}$ or $(Fe^{3+})(H_2PO_4)^{2-}$ attains the solubility product constant of Al- or Fe-phosphate (Hsu and Rannie, 1965 cited by Ikera, 2004).

In moderately acid soils with pH about 5.5 – 6.0 and low P retention capacity the reaction between $Al^{3+}$ and $Fe^{3+}$ produces less stable precipitates according to the following reaction (Mrema, 1988):

$$6Al(H_2O)_6{}^{3+} + 6H_2P0_4{}^- \leftrightarrow Al_6(OH)_{12}(H_2PO_4)_6 + 24H_2O \quad .......................................... \text{(ix)}$$
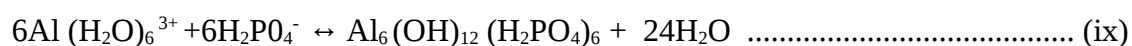
Being less stable, $Al_6(OH)_{12}(H_2PO_4)_6$ will not persist long in the soil but may transform with time into more stable forms such as variscite ($AlPO_4.2H_2O$). Under such conditions incorporation of PR four to eight weeks ahead of planting is recommended to allow time for some dissolution of PR and its subsequent availability to plants (Chien *et al*., 1990).

Liming of acid soils increases the pH of the soils thus may have an adverse effect on PR dissolution. This is due to the neutralization effect of liming material on hydrogen ions which occur in the soil solution according to the following equation:

$$2H^+ \quad + \quad CaCO_3 \rightarrow Ca^{2+} \quad + \quad CO_2 \quad + \quad H_2O \quad ............................................. \text{(x)}$$
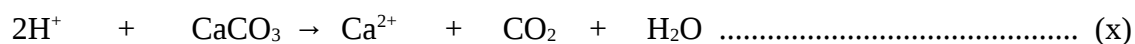
Soil              Lime
Soln.

As indicated in the equation above, lime applied to the soil neutralizes $H^+$ ions thus reducing its concentration in the soil solution. Since $H^+$ ions (protons) are required for PR dissolution, liming is of beneficial effects only in highly acid soils where it reduces the solubility and availability of $Al^{3+}$ and $Fe^{3+}$ which could precipitate $H_2PO_4{}^-$ released from

PR dissolution (FAO, 2004). Liming of acid soils to pH 6.8-7.0 can reduce PR dissolution as a result of increasing $Ca^{2+}$ concentration in the soil solution (FAO, 2004).

## 2.7 Techniques for Improving Agronomic Effectiveness of PR

Various techniques have been employed to improve the agronomic effectiveness of PRs. For example, FAO (2004) classified the techniques into three major groups as biological, chemical and physical. Biological techniques includes composting organic wastes with PRs, inoculation of seeds or seedlings with phosphorus solubilizing micro organisms and growing crop species that are efficient in soil exploration and P absorption under low P conditions (FAO, 2004).

Chemical techniques includes partial acidulation of phosphate rocks (PAPR) which involves reacting PRs with $H_2SO_4$ or $H_3PO_4$ in amounts less than those required to produce SSP or TSP, respectively (Ikerra, 2004). Partial acidulation of PR with $H_2SO_4$ can be represented by the following chemical equation (Ikerra, 2004):

$$Ca_{10}(PO_4)6F_2 + 7y\ H_2SO_4 + 3yH_2O \rightarrow 3yCa\ (H_2PO_4)2\ .\ H_2O + 7y\ CaSO_4 + 2y\ HF + (1-y)\ Ca_{10}(PO_4)6F_2 \dots\dots\dots\dots\dots\dots (xi)$$
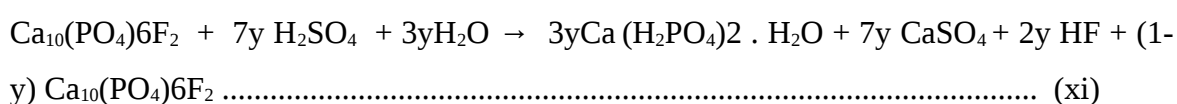
In the equation (xi) above, y represents the degree of acidulation given as 0.5 and 1 for 50% and 100% acidulation, respectively. This technique may offer an economic means of enhancing the agronomic effectiveness of PRs that may not otherwise be suitable for direct application (FAO, 2004). This is due to the fact that less acid is required per unit of P from partially acidulated phosphate rocks (PAPRs) than fully acidulated water soluble P fertilizers. Partial acidulation of PR requires 40 to 50% of $H_2SO_4$ and 10 to 20% of the $H_3PO_4$ used in the industrial manufacture of SSP and TSP, respectively (Tisdale *et al*., 1993). However, the acidulation process increase the cost of acidulated PR products hence limits the affordability by resource poor smallholder farmers.

Physical techniques include compacting PR with water soluble phosphate fertilizers like triple super phosphate (TSP) under pressure, dry mixing of PR with water soluble phosphate fertilizers and granulation of phosphate rock with elemental sulphur (Msolla, 2005). Compaction of PR with water soluble phosphate fertilizers involves pressing the solid into a compact block that is subsequently broken into granules (Msolla, 2005). The principle behind this technique is that when water soluble P fertilizer come in contact with soil water (soil solution) it undergoes dissociation producing phosphate ions and protons. Protons produced in the dissociation of water soluble P fertilizer thus enhance the dissolution of the PR.

Working with Panda PR from Tanzania, Mnkeni *et al.* (2000) reported increase in relative agronomic effectiveness of the PR from 2% to 75% in acid soils and 50% to 94% increase in alkaline soils after compacting it with TSP. Butegwa *et al.* (1996) reported increase in maize dry matter yields and P uptake from 1.9% to 94% and 2% to 73.5%, respectively when Sukulu PR from Uganda was compacted with TSP. Granulation of phosphate rock with elemental sulphur is based on the principle that sulphur oxidizing bacteria (e.g. *Thiobacillus thiooxidans* and *Thiobacillus thioparus*) oxidize sulphur into sulfate ions with the production of protons ($H^+$) that enhance PR dissolution according to the reactions:

<p align="center">*Thiobacillus spp.*</p>

$$CO_2 + S^0 + {}^1/_2 O_2 + 2H_2O \xrightarrow{\hspace{2cm}} [CH_2O] + SO_4^{2-} + 2H^+ \text{ ……..……....... (xii)}$$

$$Ca_{10}(PO_4)6F_2 \quad + 2H^+ \quad \leftrightarrow \quad 10Ca^{2+} + H_2PO_4^- + 12F^- \text{................................ (xiii)}$$
(Phosphate rock)   (Protons)       (Dissolution products)

Overall reaction:

<p align="center">*Thiobacillus spp.*</p>

$$Ca_{10}(PO_4)6F_2 + CO_2 + S^0 + {}^1/_2 O_2 + 2H_2O \xrightarrow{\hspace{2cm}} 10Ca^{2+} + H_2PO4 + 12F^- +$$
$$[CH_2O] + SO_4^{2-} \text{........ (xiv)}$$
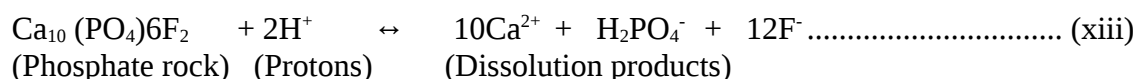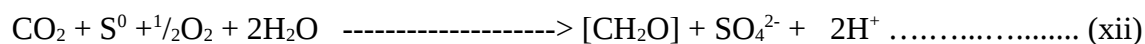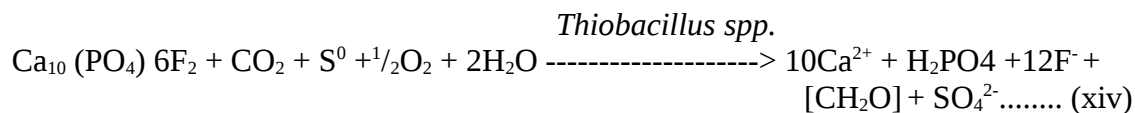
**2.7.1 Composting PRs with crop residues as means of improving their effectiveness**

Treating PRs with organic materials and composting them has been reported as promising technique for improving the solubility of PRs and subsequently availability of the released P for plant uptake (FAO, 2004). This technique is based on the principles that during decomposition of organic materials, intense microbial activity produce organic acids and humic substances as products of decomposition. For example in the process of organic matter decomposition, microbes use enzymes to hydrolyze protein molecules into their constituent amino acids. Under conditions of insufficient supply of carbonaceous compounds to accommodate amino acids in the synthesis of new protoplasm the excess amino acids are deaminated and organic acids are produced according to the following simplified biochemical equation (Graves and Hattemer, 2000).

$$CH_3CHNH_2\ COOH + ½\ O_2 \quad \underline{alanine\ deaminase} \quad \rightarrow \quad CH_3COCOOH + NH_3 .......... (xv)$$
(Alanine) (Enzyme) (Pyruvic acid)

Dissociation of the so formed organic acids results into production of protons ($H^+$) according to the reaction:

$$CH_3COCOOH \leftrightarrow CH3COCOO^- + H^+ ................................................... (xvi)$$
(Pyruvic acid) (Pyruvate) proton

Since dissolution of the PR consumes protons, dissociation of organic acids such as pyruvic acid produced during organic matter decomposition and their chelating ability on Ca, Fe and Al enhance the release of P from PR as the pyruvates act as sinks for the $Ca^{2+}$, $Al^{3+}$ and $Fe^{3+}$ (Pohlman and McColl, 1986; Kpoblekou and Tabatabai, 1994 cited by FAO, 2004).

The humic substances produced also compete for and form a protective coating over soil phosphate-sorption sites thus make more P available to plants by reducing phosphate

retention by the soil components with high affinity for P (Ikerra *et al.*, 2006). Findings by Larne (2000) indicated that P in phospho-compost may be available to plants in similar amounts as in TSP. The increased availability of P in phospho-composts could be due to solubilizing effect of organic acids on phosphate rock and P released as decomposition and mineralization products of organic materials. Based on the above principles, composting MPR with coffee pulp could improve MPR dissolution and compost quality, resulting into higher cumulative P release from both MPR and coffee pulp than could be expected from either of the two in isolation or separately.

**2.7.2 Processes and reactions involved in composting**

The composting process involves a number of processes carried out by interplay of various organisms. Sharma *et al.* (1997) defined composting as a biological oxidative decomposition of organic constituents in wastes of almost any nature under controlled conditions of temperature, moisture and air supply. Microbes and invertebrates carry out the decomposition of the organic litter by the utilization of its carbon and nitrogen contents as energy sources with oxygen and water resulting into production of carbon dioxide, heat, water and soil – enriching compost (Sharma *et al.*, 1997).

The principle process under composting is microbial oxidation of organic matter. For micro organisms to synthesize new cellular material sufficient energy is required to facilitate the process. Respiration and fermentation are the two energy yielding metabolic processes for heterotrophic microorganisms. Via the two processes soil microbes oxidize organic compounds to yield energy and release essential nutrient elements such as nitrogen, phosphorus and sulfur required for the growth of plants and other soil organisms. Respiration can either be aerobic or anaerobic depending on whether molecular oxygen is used or not. In aerobic respiration aerobic microorganisms use molecular oxygen to

liberate energy from carbon source producing carbon dioxide and water as represented by the following simple biochemical reaction (Graves and Hattemer, 2000):

$$[C,O,4H] + O_2 \rightarrow CO_2 + 2H_2O + Energy .................................................................. (xvii)$$

In anaerobic respiration, the microorganisms use electron acceptors other than oxygen such as $NO_3^-$, $SO_4^{2-}$ and $CO_3^{2-}$ to obtain energy. In all processes, oxidation of organic compounds is achieved through a series of biochemical reactions which serve not only to yield energy but also produce large number of organic intermediates. Aerobic respiration is much preferred over anaerobic respiration and fermentation in composting because it generates more energy, operates at higher temperatures and produces less quantity of odorous compounds like $NH_3$ and $H_2S$. The process also produces organic acid intermediates that are readily consumed by subsequent reactions resulting into more complete degradation and stabilization of the compost material (Graves and Hattemer, 2000). Fermentation is the simplest means of energy generation that does not require oxygen. It is said to be quite an inefficient process producing only small amounts of energy and most of the carbon decomposed is converted to end products that are not cell constituents.

The oxidation of organic material (composting) is a dynamic biochemical process in nature accomplished by succession of activities of organisms (Chen and Bejosano-Gloria, 2005). Each group of organisms is said to reach its peak population when conditions become optimum for its activities. According to Chen and Bejosano-Gloria (2005), the processes involved can be grouped under the following four phases:

   **(i)**      **Mechanical break down of the composting materials**

This phase is accomplished by mesofauna such as mites, sow bugs, worms, springtails, ants, nematodes and beetles that feed on raw organic materials. In the process of feeding they break organic materials by cutting and chewing into smaller pieces (Chen and Bejosano-Gloria, 2005). This physical/mechanical process increases the surface area of materials thus facilitating further microbial attack.

### (ii)    Initial composting /Mesophilic phase

During the mesophilic phase, initial breakdown of organic materials and energy (heat) release by bacteria, actinomycetes, fungi, and protozoa takes place (Chen and Bejosano-Gloria, 2005). The mesophilic group of organisms functions at temperatures between $10^{\circ}C$ and $45^{\circ}C$ and utilize the most readily accessible carbohydrates and decomposable proteins within the organic materials as source of carbon and energy. The mesophilic phase is generally short lived because the function of mesophilic organisms cease as temperature builds up due to oxidation of organic material (Chen and Bejosano-Gloria, 2005).

### (iii)    Active composting  / Thermophilic phase

As the temperatures of the composting piles increase due to oxidation of carbon compounds, thermophilic bacteria and fungi take over the process (Chen and Bejosano-Gloria, 2005). Initially thermophilic bacteria decompose proteins and non-cellulose carbohydrates, lipids and hemi cellulose components of the organic materils. The nitrogenous organic residues or proteins are oxidized into complex amino compounds, carbon dioxide, energy and other products as examplified by the following simplified biochemical reaction equation (Graves and Hattemer, 2000):

Proteins + $O_2$ → complex amino compounds + $CO_2$ + Energy + other products...... (xviii)

The complex amino compounds so formed can be synthesized into microorganisms' protoplasm/tissue or further decomposed into simpler products. The oxidation products of proteins can only be used in the synthesis of new cellular material if sufficient carbon is available; otherwise unstable nitrogen compounds are formed and accumulate through the process of ammonification (Graves and Hattemer, 2000) according to the reaction;

$$R - NH_3 + HOH \text{--------------------}> R - OH + NH_3 + Energy \ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(xix)}$$

The ammonium compound interconvert between two forms ($NH_3$ and $NH_4^+$) depending on the pH and temperature of the pile or compost pit as represented by the following equation (Graves and Hattemer, 2000);

$$4NH_3 + 2H_2CO_3 \text{---------}> (NH_4)_2CO_3 <\text{--------}> 6NH_4^+ + 3CO_3^{2-} \ldots\ldots\ldots\ldots\ldots..... \quad \text{(xx)}$$
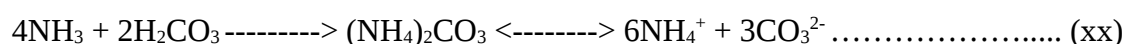
Acidic conditions promote the formation of $NH_4^+$ which is one of the plant available forms of N, while basic conditions and elevated temperature favors formation of $NH_3$ which is emitted from the pile or pit into the air. Thermophilic fungi decompose hemi cellulose and cellulose at this phase but they die beyond 60°C (Graves and Hattemer, 2000). As temperature increases further the species diversity narrows and thermophilic actinomycetes become dominant and decompose cellulose, lignin and other more resistant compounds into simple organic molecules (such as glucose) according to the reaction;

$$(C_6H_{10}O_5) n + nH_2O \text{--------------------}> nC_6H_{12}O_6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad \text{(xxi)}$$
Cellulose                                    Glucose
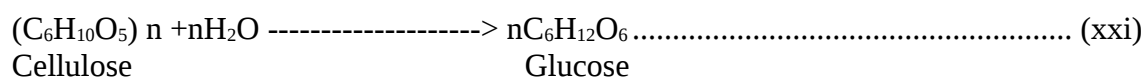
### (iv)    Curing/Maturation and stabilization phase of composting

As the active composting process subsides, temperatures gradually fall and mesophilic organisms re-colonize the compost and the curing process/phase begins (Chen and

Bejosano-Gloria, 2005). In this phase organic materials continue to decompose and are converted to biologically stable humic substances. According to Tisdale *et al*. (1993) during this phase $NH_3$ and $NH_4^+$ are oxidized to nitrates ($NO_3^-$) another plant available form of N in two steps. Initially $NH_4^+$ - N is oxidized to $NO_2$ through the action of *Nitrosomonas* and *Nitrosolubus* bacteria (Tisdale *et al*., 1993). The nitrites ($NO_2$) are then rapidly converted to nitrates ($NO_3^-$) by nitrifying bacteria such as *Nitrobacter* and *Nitrocystis* (Tisdale *et al*., 1993). Formation of nitrate –N is an indication of well regulated aerobic composting process and the two steps of the nitrification process can be represented by the following biochemical reaction equations (FAO, 2000):

$$NH_4^+ + 1\tfrac{1}{2}O_2 \xrightarrow{\text{\textit{Nitrosomonas}}} NO_2 + H_2O + 2H^+ + Energy \quad \text{............................ (xxii)}$$

$$NO_2 + \tfrac{1}{2}O_2 \xrightarrow{\text{\textit{Nitrobacter}}} NO_3^- + Energy \quad \text{....…………….......................... (xxiii)}$$

Overall reaction:   $NH_4^+ + 2O_2 \xrightarrow[\text{\textit{Nitrobacter}}]{\text{\textit{Nitrosomonas}}} NO_3^- + H_2O + 2H^+ + Energy$ .... (xxiv)
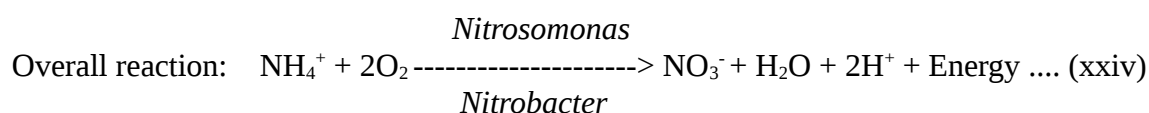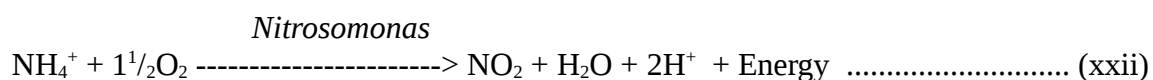
During decomposition of organic materials humus/humic substances are produced as the final products (FAO, 2004). The so formed humic substances compete for fixation sites on the soil active component surfaces thus reducing the number of sites available for P fixation/retention.  Mineralization of humic substances releases other elements contained in organic materials such as P and S which undergo oxidation into plant available P and S ($H_2PO_4^-$ or $HPO_4^{2-}$, $PO_4^{3-}$ and $SO_4^{2-}$) forms in the soil. Organic acids like pyruvic acid produced during the decomposition of proteins and complex amino compounds; also contribute into dissolution of the PRs hence release and subsequent increase of phosphorus as phosphate in the soil solution. Composting is considered to have been completed when

the energy and nutrient-containing materials have been transformed into a stable organic mass and the temperature within the pile or pit remains near the ambient temperatures for several days (Graves and Hattemer, 2000).

**2.8 Use of Crop Residues in Crop Production in Tanzania**

Crop residues are generally misused in the agricultural sector in Tanzania. Most of the cereal straws are taken off fields to feed livestock or burnt after crop harvest with very limited amounts of the materials being used as mulch or incorporated into soil. Similarly, primary processing byproducts such as maize bran, rice husks, coffee husks and pulp are used as livestock feeds and/or for burning bricks. In most cases where crop residues are fed to animals, manure is not taken back to the crop fields.

According to FAO (2000), 50, 11 and 66kg of N, P and K, respectively are removed from the soil per ha for every 3000kg of rice (paddy) produced. Production of 3000kgha$^{-1}$ of maize removes 72, 16 and 45kg of N, P and K, respectively while the same amount of wheat produced in a ha removes 72,12 and 54kg of N, P and K, respectively. Such quantities are contained in both consumable and non consumable bellow and above ground parts of the crop (FAO, 2000). Continuous export of crop residues without efficient fertilization of the soil thus results into heavy losses of nutrients and soil nutrient mining.

Although low in nutrient contents, efficient use of crop residues in agriculture improves the physical, chemical and biological conditions of the soils. Appropriate incorporation of residues in the soil improves the soil structure through the cementing of soil particles by humus (Chen and Bejosano-Gloria, 2005). Cementing of soil particles improves soil aggregation which in turn results into stabilization of soil structure, improved soil

permeability, drainage, and aeration while the dark colour of organic matter absorbs heat thus warming the soil (Chen and Bejosano-Gloria, 2005).

The Porous nature of organic matter gives it high water retention capacity and reduces soil compaction thus improving its bulk density. According to Tisdale *et al*. (1993), organic matter can retain water up to 20 times its weight, thus may significantly improve the moisture retention capacities of soils. Soil organic matter can also form stable complexes with $Cu^{2+}$, $Mn^{2+}$, $Zn^{2+}$, $Fe^{3+}$, $Al^{3+}$ and other polyvalent cations thus, reduce the precipitation of P by $Fe^{3+}$ and $Al^{3+}$ in acidic soils. The buffering effect of soil organic matter on soil pH helps to reduce drastic and erratic changes in soil reaction. Incorporation of organic matter improves soil CEC due to the high total acidities of the humus fraction which range from 300 to 1400 cmol(+)/kg (Tisdale *et al*., 1993).

Mineralization of organic matter yields $NH_4^+$, $NO_3^-$, $H_2PO_4^-$ and $SO_4^-$ thus contributing to increased availability of N, P and S for plant uptake and growth. Soil organic matter complexes in soils can affect bioactivity, persistence and biodegradability of pesticides and heavy metals, thus reducing their contribution to pollution hazards in the environment (Palm *et al*., 1997). Crop residues provide carbon and energy for soil microorganisms, thus their proper incorporation into soils enhance microbial activities and build up of soil organic matter (Chen and Bejosano-Gloria, 2005). All the aforementioned effects contribute towards improved soil fertility for enhanced crop production.

**2.9 Crop Response to MPR, Crop Residues and Crop Residues – MPR Compost.**

Delay in crop response from direct application of PR has been reported as one of the reasons for slow adoption of MPR by farmers in Tanzania (Kimbi, 1991; Weil, 2002). Good crop response is similarly not expected from direct application of coffee pulp alone

due to its low contents of most of the essential plant nutrients (FAO, 1987). Ikera (2004) reported increased release of P from MPR as influenced by the contact with decomposing organic materials. Kitua (1997) reported an increase in Bray-1 extractable P from 3.53 to 13.0 mg P kg$^-$ soil, maize P content from 0.2 to 0.33 % and maize dry matter yield from 37.43 to 50.5 g per pot when MPR was incubated with manure for one month before sowing the maize seeds on an Oxic Haplustult in a glass house pot experiment. Other findings by Mhagama (2003) revealed a significant increase in dry matter yields of maize due to combined application of MPR with organic residues of goat weeds (*Ageratum conyzoides*), mountain mint (*Pycnanthemum tenuifolium*) and elephant grass (*Hyparenia sp.*) on two acidic soils with contrasting characteristics.

Composting coffee pulp with MPR before field application could improve the dissolution rate of MPR attributable to the solvent effect of organic acids released during the decomposition of the coffee pulp. This could increase the cumulative availability of P and other nutrient elements from both MPR dissolution and mineralization of the coffee pulp. The overall effect would be increased plant uptake of P and other nutrients thus improving the first season crop response to MPR. Improved crop response would be expected due to the obvious amendment effects of the compost on the soil thus improving the physical, chemical and biological properties of the soil as a plant growth medium.

**2.10 Growth Requirements of Tomato**

**2.10.1 Soil conditions**

Tomato can grow on a wide range of mineral soils but silt or clay loam soils are generally considered the best for tomato production (Phene, 1989). According to Phene (1989), poorly drained heavy clays are not good for tomato because the crop is highly affected by

water logging conditions. The crop requires a pH range of 6.0 to 7.0 which is the range in which soil microorganisms do best (Atherton and Rudich, 1989).

### 2.10.2 Climatic requirements

Tomatoes are sensitive to both low and high ambient and soil temperatures. The optimum temperature range for tomato growth and production is $20^{o}C$ to $27^{o}C$. Low temperatures below $10^{o}C$ results into poor growth and fruit setting (Lin *et al.*, 2007). High temperature above $30^{o}C$ affects both availability and uptake of nutrients as well as physiological and biochemical processes in the plant resulting into poor fruit setting subsequently reducing the yield and quality of tomatoes (Abdelmageed *et al.*, 2003).

### 2.10.3 Nutrient requirements

Inadequate nutrient supply and imbalances are said to be the most limiting factors responsible for very low yields of tomatoes in the tropics (Atherton and Rudich, 1989). Although tomato can moderately grow over a range of levels of each nutrient, adequate and balanced supply of nutrients is essential to achieve high yield of good quality tomato (Atherton and Rudich, 1989). The crop is considered a heavy feeder due to its rapid growth and long growing season thus high levels of nutrient uptake from the soil in the entire season. Nitrogen, phosphorus and potassium are the main nutrients affecting growth and productivity of tomato (Hartz *et al.*, 1999). On average 1.4 to 3.6 kg N, 0.22 to 0.61 kg P, and 1.9 to 4.6kg K are removed by tomato plants from the soil for every ton of fresh tomatoes produced (Hegde, 1997). The three nutrients are mostly required by tomato plants ten days after flower initiation to just before fruit ripening because during this stage most assimilates are translocated to the fruits (Hedge, 1997).

Nitrogen is important for vegetative growth as well as flower and fruit setting. Its deficiency results into stunted plants and accelerated flower loss while excess supply leads to delayed maturity and reduced fruit size (Atherton and Rudich, 1989). High levels of available phosphorus are essential for root development and efficient water use as well as uptake and utilization of other nutrient elements. Potassium improves fruit setting and quality of tomato and is required in much higher amounts than the other nutrients. Potassium is also reported to be a key player for tomato fruit quality thus vital to maintain high levels of the element during tomato fruit development (Morgan, 2006).

In addition to the three nutrient elements (that is N, P and K), calcium (Ca), magnesium (Mg), sulfur (S), zinc (Zn), manganese (Mn) and boron (B) are of special importance among the essential nutrients for tomato growth (Atherton and Rudich, 1989). Ca is essential for cell elongation and division, permeability of cell membranes, enhancement of $NO_3$ –N uptake and regulation of cation uptake. Mg is a primary constituent of the chlorophyll molecule thus important for photosynthesis and serves as a structural component in ribosomes (Tisdale *et al*., 1993). S is a constituent of coenzymes; it is required for the synthesis of S-containing amino acids (cystine, cystein and methionine) as well as for the synthesis of chlorophyll molecule (Tisdale *et al*., 1993). Zn is important in production of plant growth hormones (auxins), Mn is involved in photosynthesis and activation of enzyme reactions and transformations while B plays an essential role in the development and growth of new cells in the plant meristem (Tisdale *et al*., 1993).

**2.11 Tomato Yield Levels**

The average yield of tomato in Morogoro is low (3.5t ha$^{-1}$) while the national tomato yield average is 8 t ha$^{-}$ (Nono-Womdim *et al*., 2002). Production potential for improved tomato varieties is however reported to range from 10 to 40t ha$^{1-}$ when the crop is well fertilized,

supplied with adequate moisture and other climatic factors are not limiting (FAO, 2000). Low nutrient supply by soils, inadequate moisture supply and insect pests and disease infestation have been reported to be among the key factors leading to low levels of tomato yields in Tanzania (URT, 2006).

## 2.12 Response of Tomato to Fertilizers and Manure

### 2.12.1 Response to nitrogenous fertilizers

Tomato vigour generally increases with nitrogen supply. Atherton and Rudich (1989) reported increased plant height, leaf area and number of flowers produced in response to added nitrogen. Tomato yield usually increase with moderate dressing of nitrogen under glass house conditions as well in the field but excessive application of nitrogen depress tomato yield (Atherton and Rudich, 1989). Generally the response of tomato to applied nitrogen depends not only on initial nitrogen content of the soil but also on immobilization, mineralization or denitrification processes during the plant's growth cycle.

### 2.12.2 Response to phosphorus

Growth and development of tomato plants is affected by phosphorus fertilization. Massey and Winsor (1969) as cited by Atherton and Rudich (1989) reported an increase in fresh weight of young tomato plants with phosphorus applied to soils especially at high pH. Atherton and Rudich (1989) reported a significant increase in processed tomatoes on soils with low contents of available phosphorus upon application of 800 - 2400 kg ha$^{-1}$ of super phosphate. Negative effects such as uneven ripening and increased incidences of hollow fruits have also been reported in relation to high levels of P fertilization (Winsor, 1966; Winsor and Long, 1967) as cited by Atherton and Rudich (1989). This was attributed to the possibilities of nutrient imbalances.

### 2.12.3 Response to potassium fertilization

Tomato response to K fertilization in terms of plant height, flowering, fruit yield and quality has been reported by Atherton and Rudich (1989). Atherton and Rudich (1989) reported 65% increase of plant height in response to application of potassium on sandy soils but the response on soils with high K was correspondingly low. They also reported 30% increase in yield with K fertilization of soils with low K reserves. Other findings Hartz *et al.* (1999) indicated an increase in tomato fruit yields, soluble solids content and reduced incidences of both internal and external blotchy ripening with adequate K supply. This was probably due to the regulatory effect of K on the metabolic processes in the plant including protein synthesis.

**2.12.4 Response to manure application**

Manures are bulky and contain low quantities of nutrients per unit weight when compared to the inorganic fertilizers. Their use in crop production is important for the supply of both macro and micro plant nutrients. In addition to nutrient supply, manures improve the physical, chemical and biological conditions and properties of the soil thus improved crop response (Tisdale *et al.*, 1993).

Both positive and negative effects have been reported from the use of manure alone or mixed with mineral fertilizers in tomato production. Ramadan *et al.* (2008) reported significant increase in micro nutrient uptake, vegetative growth and fruit yield of tomato attributed to the application of poultry manure as compared with crops treated with inorganic fertilizer. Observed increase in nutrient uptake, vegetative growth and fruit yield of tomato with application of poultry manure was attributed to both improved nutrient supply and amendment effect of manure on soil's chemical, biological and physical properties. High rates (above 30 t ha$^-$) of manure application were however reported to

depress tomato growth with no clear reasons (Ramadan *et al*., 2008). This observation could be due to nutrient imbalances and immobilization as influenced by the C: N: P: S ratios of the manures.

## CHAPTER THREE

**3.0 MATERIALS AND METHODS**

**3.1 Collection of Experimental Materials**

The organic material (coffee pulp) was collected from one of the primary coffee processing centers owned by LIMA Company Ltd in Mbozi district. The coffee pulp was transported to the Tanzania Coffee Research Institute (TaCRI) Mbimba station in Mbozi for compost production under field conditions. Powdered MPR was bought from Minjingu Mines and Fertilizer Ltd, while Carl J tomato seeds (the test crop) were from the Holland Seed Company in Arusha region Tanzania.

**3.2 Material Analysis and Composting**

**3.2.1 Coffee pulp characterization**

Fifteen random samples were taken from a pile of fresh coffee pulp mixed into a homogenous representative sample, weighed and dried to constant weight at 60°C. The oven dried coffee pulp sample was ground to pass through a 0.5 mm sieve for laboratory total analysis. The pulp's moisture content, pH, total organic carbon, total N, P, Ca, and K were determined following the procedures described by Okalebo *et al.* (1993).

**3.2.2 Compost preparation**

Coffee pulp was composted by the pit method (FAO, 1987) both alone and mixed with MPR. Four pits each of 3x2x1m$^3$ were prepared at the Tanzania Coffee Research Institute Mbimba station in Mbozi district. The floor of each pit was lined with polythene sheets in order to avoid underground seepage losses. One tone of fresh coffee pulp at 70% moisture content (equivalent to 300 kg air dry weight) were mixed with 100 kg of air dry surface soil to get 400 kg of air dry mixture which was filled into the first pit (FAO, 1987).

Another portion of 400 kg air dry mixture prepared in the same fashion was mixed with 100 kg of MPR (4:1) (FAO, 1987) on air dry weight basis to fill the third pit. The two pits 1 and 3 were covered with banana leaves followed by a layer of dry soil while pits 2 and 4 remained empty for the turning of the compost materials.

The composting materials in pit 1 and 3 were turned at 4 weeks intervals on rotational basis. Compost material in pit 1 was turned into 2 while material from pit 3 was turned into pit 4 and vice versa to allow optimum aeration. Water was sprinkled onto the compost materials at every turning so as to maintain the moisture around 60% for optimum microbial activity (Graves and Hattemer, 2000). The composting period lasted for 4 months and this period allowed for completion of the composting processes.

**3.3 Compost and Soil Sampling**

**3.3.1 Compost sampling**

At the end of the composting period, ten random samples were taken from each of the two composting sets, homogenized and reduced by quartering into two separate 0.5 kg representative samples. The two representative compost samples were air dried ground and sieved through 2mm sieve for laboratory analysis for some of their physical and chemical properties following the procedures described by Graves and Hattemer (2000).

**3.3.2 Soil sampling for the glass house pot experiment**

Soil sampling was done at Magadu farm located on the western part of SUA Main campus. The process was preceded by a preliminary survey to identify an area with a Chromic Acrisol that has neither been under cultivation nor received any fertilizer or manure treatment for the past ten years. Ten representative surface samples (0-20 cm), 50 kg each

were randomly collected and thoroughly mixed to constitute a representative composite soil sample from the study area. The soil was air dried and sieved to pass through 8 mm for the pot experiment. One kg representative sample was drawn from the entire soil reduced by the quartering procedure to 0.5 kg ground and sieved to pass through 2mm for laboratory analysis.

## 3.4 Soil analysis

The Chromic Acrisol was analyzed for physical and chemical properties in the Department of Soil Science laboratory, SUA, Morogoro. Particle size distribution was determined by the hydrometer method (Gee and Bauder, 1986) while pH was determined in 1:2.5 (soil: water) suspensions using pH meter (Mclean, 1982). Organic carbon was determined by the Walkley and Black method (Nelson and Sommers, 1982). Total N was determined by the micro Kjeldah method (Bremner, 1996). Available P in the soils was extracted by the Bray 1 procedure (Bray and Kurtz, 1945). CEC was determined by the ammonium acetate saturation method (Rhodes, 1982). Exchangeable bases, that is $Ca^{2+}$ and $Mg^{2+}$ in the CEC determination filtrates ($NH_4$-acetate filtrates) were determined by atomic absorption spectrophotometer, while K and Na were determined by the flame photometer method (Thomas, 1982). Plant extractable Cu, Zn, Mn and Fe were extracted by the DTPA extractant and measured by atomic absorption spectrometer (Lindasy and Norvell, 1978).

## 3.5 Compost Analysis

Compost samples (coffee pulp compost and coffee pulp-MPR compost) collected at the end of composting period were analyzed for physical and chemical properties in the laboratory. Moisture content of the composts was determined following the procedures described by Graves and Hattemer (2000). The pH, total organic carbon, total nitrogen,

total phosphorus, total potassium and total calcium were determined by the standard procedures as described by Okalebo *et al.* (1993).

**3.6 Pot Experiment**

**3.6.1 Location and design of the experiment**

A glasshouse pot experiment was carried out at Sokoine University of Agriculture (SUA), Morogoro Tanzania to study the effects of coffee pulp compost, MPR and coffee pulp-MPR compost on phosphorus availability and the response of tomato as a test crop. The experiment was arranged in a 3x8 completely randomized block design using three different P sources (CP, MPR and CPMPR) all applied at eight equivalent rates of P (0, 40, 80, 100, 120, 140, 160 and 200 kg P ha$^{-1}$) in two replicates. The respective equivalent quantities of oven dry CP, MPR and CPMPR applied to supply the eight levels of P ware determined on the basis of their total P contents as summarized in Table 1.

Ten kilogram soil sample portions were thoroughly mixed with each of the P sources starting with the lowest to the highest level to avoid contamination. Nitrogen was uniformly applied to all pots at an equivalent rate of 225 kg N ha$^{-1}$ in three splits (75 kg N ha$^{-1}$ each). The first split of nitrogen was thoroughly mixed with the soil along with P sources, and then filled into 20 liter plastic buckets with five drainage holes at the bottom. The remaining 150 kg ha$^{-1}$ was applied at the 30$^{th}$ and 60$^{th}$ day after planting at equal splits.

**Table 1:** **P application rates and respective quantities of CP, MPR and CPMPR applied on oven dry basis in the glasshouse pot experiment.**

| Application rate | mg P/pot | Quantity of each source applied (g/pot = 10 kg soil) | | |
|---|---|---|---|---|
| (kg P ha$^{-1}$) | (10 kg soil) | CP | MPR | CPMPR |
| 0 | 0 | 0 | 0 | 0 |
| 40 | 200 | 133.33 | 1.54 | 14.39 |
| 80 | 400 | 266.67 | 3.08 | 28.78 |
| 100 | 500 | 333.33 | 3.85 | 35.97 |
| 120 | 600 | 400.00 | 4.62 | 43.17 |
| 140 | 700 | 466.67 | 5.39 | 50.36 |
| 160 | 800 | 533.33 | 6.15 | 57.55 |
| 200 | 1000 | 666.67 | 7.69 | 71.94 |

*NB: Total P contents of the CP, MPR and CPMPR used were 0.15, 13 and 1.39 % respectively*

**3.6.2 Agronomic practices**

The pots were equilibrated with two liters of water/pot for two days to bring the moisture content to field capacity before sowing the seeds. Five tomato seeds were sown per pot and watered to maintain soil moisture content at around field capacity. Weeding was done by up rooting of any emerging weeds to keep weed competition at minimum level possible. Thirty days after planting, two seedlings were thinned out leaving three seedlings per pot. After thinning the plants, a second split of nitrogen (75 kg N/ha) was applied uniformly to all pots followed by the last split (75 kg N/ha) at 60$^{th}$ day after planting.

**3.6.3 Data collection**

The response of tomato to various levels of P applied as CP, MPR and CPMPR was determined by observing both the vegetative and reproductive growth phases of the tomato plants. Indicative parameters used to assess plant response included plant height and true leaves per plant at 60, 75 and 90 days after planting, number of flowers, fruits and trusses

per plant at 75 days after planting, dry matter yield and nutrient uptake per pot at 60 days after planting.

### 3.6.3.1 Dry matter yields and nutrient uptake

Dry matter yields ware determined at sixty days after planting by harvesting two seedlings from each pot. Two plants were harvested by removing the above ground parts at the soil surface, washed with distilled water and oven dried to constant weight at $80^{\circ}C$ in paper envelopes. Oven dry shoots were weighed on a chemical balance for the assessment of dry matter yields. After recording the dry matter weights, the shoots were chopped into small pieces then ground by motor and pestle into a fine powder to pass through 0.5 mm sieve. The fine powder was digested by the $HNO_3$ - $H_2O_2$ procedure and the digests were analyzed for N, P, K, Ca and Mg contents following procedures described by Okalebo *et al.* (1993).

### 3.6.3.2 Flower and fruit yield determination

One plant per pot was maintained to harvesting for further determination of tomato response to the treatments. The number of flowers, fruits and trusses produced for each treatment were counted and recorded. Tomato fruits harvested from each treatment were similarly counted, weighed and recorded for comparison purposes.

### 3.7 Data Analysis

Analysis of variance (ANOVA) was done on dry mater yields, plant tissue N, P K, Ca and Mg contents (%), plant height, number of leaves and flowers, number and weight of fruits harvested to determine the response of tomato to different sources and rates of P. Treatment means were compared by the Duncan's New Multiple Range Test (DNMRT)

at $\leq 0.05$ probability level. The statistical model used was $\mathbf{Y_{ijk} = \mu + \alpha_i + \beta_j + y_{ij} + e_{ij}}$ Where: $Y_{ijk}$ = observed response, $\mu$ = general effect, $\alpha_i$ = effect due to factor A (P source), $\beta_j$ = effect due to factor B (P application rate), $y_{ij}$ = interaction effect of factor A and B and $e_{ij}$ = random error effect.

Simple linear correlations between plant P, K and Ca contents and plant heights, number of true leaves, dry matter yields, number of flowers, total number of fruits, marketable fruits and fruit weights were undertaken following procedures described by Steel and Torrie (1984).

# CHAPTER FOUR

## 4.0 RESULTS AND DISCUSSION

## 4.1 Properties of the Chromic Acrisol, Minjingu Phosphate rock and Composts used in the Study

### 4.1.1 Properties of the Chromic Acrisol

The experimental soil was classified as a Chromic Acrisol based on its physical - chemical properties and profile description (Ikerra, 2004). Some of the physical and chemical properties of the surface (0-20 cm) Chromic Acrisol analyzed before CP, MPR and CPMPR applications are as presented in Table 2. The soil pH is low (< 5.5) with a very strong acid reaction and very low level of organic carbon (< 4%) (Landon, 1991). This could either be attributed to the nature of the parent material (acidic parent material), extensive weathering, loss of basic cations and anions through the processes of plant uptake and most probably due to leaching.

Bray I extractable phosphorus in the Chromic Acrisol is low (< 7 mg kg$^{-1}$ soil) and this could be attributed to the low inherent P in the soil's parent material and transformation of plant available P to plant unavailable forms of P. The transformation of plant available P to plant unavailable forms could have been enhanced by the high activities of $Fe^{3+}$ and $Al^{3+}$ in the soil solution as influenced by the very acidic reaction of the soil. The activities of Fe and Al increases with increasing soil acidity as the soils are dominated by hydrous oxides of Fe and Al which precipitate phosphorus into Fe and Al phosphate (equations vii and viii in section 2.6.5).

According to the categorization by Landon (1991) the DTPA extractable zinc was in the medium range, copper and manganese were in the high range while iron was in the very high range. The high to very high levels of DTPA extractable micronutrients in the soil could be due to their high contents in the parent materials and their high solubility as

influenced by the soils' acidic conditions. Such very high level of Fe in the Chromic
Acrisol suggests transformation of plant available P into Fe phosphate consequently the
low Bray I extractable P (Table 2).

**Table 2: Some of the Physical - chemical properties of the Chromic Acrisol (0-20cm)**
**from Magadu farm, SUA in Morogoro, Tanzania.**

| Parameter | Magnitude | Rating | Rating reference |
|---|---|---|---|
| pH ($H_2O$) | 4.30 | Low | Landon (1991) |
| Organic carbon (%) | 1.10 | Very low | Landon (1991) |
| Total N (%) | 0.11 | Low | Landon (1991) |
| Total P (%) | 0.10 | Low | Dierolf *et al*. (2001) |
| Bray I P ($mgkg^{-1}$) | 5.59 | Low | Landon (1991); Baize (1991) |
| Exchangeable K (cmol(+)/kg) | 0.35 | Medium | Landon (1991) |
| Exchangeable Ca (cmol(+)/kg) | 1.45 | Low | Landon (1991) |
| Exchangeable Mg (cmol(+)/kg) | 1.69 | High | Landon (1991) |
| CEC (pH 7) | 16.80 | Medium | Landon (1991) |
| DTPA extractable Cu (mg/kg) | 4.64 | High | Landon (1991) |
| DTPA extractable Zn (mg/kg) | 1.80 | Medium | Landon (1991) |
| DTPA extractable Mn (mg/kg) | 19.04 | High | Landon (1991) |
| DTPA extractable Fe (mg/kg) | 69.72 | Very high | Landon (1991) |
| Sand (%) | 40 | | |
| Silt (%) | 7 | | |
| Clay (%) | 53 | | |
| Textural class | Clay | | Gee and Bauder (1986) |

According to Dierolf *et al*. (2001), Bray 1 extractable P has been categorized as <
15mg/kg (low), 15-25 mg/kg (medium) and > 25 mg/kg (high). Exchangeable K is
categorized as < 0.2cmol (+)/kg (low), 0.2-0.4cmol(+)/kg (medium) and > 0.4cmol(+)/kg
(high). Exchangeable Ca is categorized as < 1cmol (+)/kg (moderately low), 1-2cmol
(+)/kg (moderately high) and 2-3cmol (+)/kg (high). Critical values of Mg are categorized
as $\leq$ 0.2cmol (+)/kg (low), 0.2-0.5cmol (+)/kg (medium) and > 0.5cmol (+)/kg (high).
Based on this categorization the Chromic Acrisol requires substantial N, P, K and Ca
inputs for successful tomato production. Its pH is also less than the optimum pH range of
6.0 to 7.0 recommended for successful tomato production thus requires liming. The use of

MPR and composts rich in Ca was thus expected to contribute to amending the soil pH as a secondary effect to plant nutrient supply.

### 4.1.2 Properties of Minjingu phosphate rock

Some of the chemical properties of the Minjingu phosphate rock (MPR) used in the study are as presented in Table 3.

**Table 3: Some of the properties of Minjingu phosphate rock (MPR)**

| Parameters | Magnitudes |
|---|---|
| pH ($H_2O$) | 8.5 |
| Total P (%) | 13 |
| Bray I P (%) | 0.01 |
| Solubility in NAC (%) | 3.6 |
| Ca (%) | 35.5 |
| $CaCO_3$ (%) | 6.9 |
| $K_2O$ (%) | 1.4 |
| MgO (%) | 3.4 |

Source: Msolla (2005) and Ikera *et al*. (2006)

Chemical composition of MPR used in the study (Table 3.) indicates that MPR has high contents of phosphorus and calcium. The high P and Ca contents of the MPR accounts for its potential to qualify as a fertilizer material for acid soils. In addition to its role as source of plant nutrients, MPR could contribute in amending the pH of highly acid soils due to it high Ca contents hence behave as a liming material.

### 4.1.3 Properties of composts used in the study

Selected properties of compost materials used in the study were as presented in Table 4.

**Table 4:  Some of the properties of compost materials used in the study**

| Compost | Parameters and magnitude | | |
|---|---|---|---|

| | Moisture (%) | pH (H$_2$O) | OC (%) | Total N (%) | C:N | Total P (%) | Total K (%) | Total Ca (%) |
|---|---|---|---|---|---|---|---|---|
| **CP** | 26.42 | 8.26 | 46.91 | 1.61 | 29.14 | 0.15 | 2.87 | 4.38 |
| **CPMPR** | 29.08 | 8.54 | 38.3 | 1.43 | 26.78 | 1.39 | 2.28 | 7.37 |

*CP = Coffee pulp composted alone, **CPMPR** = Coffee pulp composted with MPR*

The moisture content of the coffee pulp compost was slightly lower than that of the coffee pulp composted with MPR (26.42 and 29.08%, respectively). Differences in moisture contents of the two composts could be due to minor differences in drainage of the composting pits. Graves and Hatteemer (2000) recommended 30-40% moisture content to be the optimal moisture content for finished or mature composts ready for soil application. Based on this criterion both CP and CPMPR had moisture contents close to the recommended moisture content range. Minor difference in moisture contents could not have significant effect on tomato plant response since all soils were equilibrated before sowing the tomato seeds and irrigation water was applied to field capacity moisture status.

 High pH (H$_2$O) for CP and CPMPR might be due to high contents of basic cations (Ca, K and Mg) in the raw materials (coffee pulp and MPR) used to produce the composts. Both CP and CPMPR had high organic carbon contents (46.9 and 38.3% respectively) due to elevated carbon contents of coffee pulp used as raw materials for the compost production. However, the two composts had C: N ratio within the range $\leq 30$ recommended by Graves and Hatteemer (2000) for successful mineralization of organic materials in soils. Total P and Ca contents were higher in CPMPR than CP suggesting its higher contents in MPR than coffee pulp while total K was in the reverse order for the two composts suggesting the effect of higher K contents in coffee pulp than was in MPR.

## 4.2 Effect of P Source and Application Rates on Plant Nutrient Uptake and Their Contents in Plant Shoots

The effects of various rates of CP, MPR and CPMPR on uptake and contents of some nutrients in the plant tissue were as presented in Fig. 1, Appendix 1 and Appendix 2.

### 4.2.1 Effect on P, K and Ca uptake

Generally P, K and Ca uptake increased with increasing rates of CP, MPR and CPMPR. Despite the observed general increase in P, K and Ca uptake, the overall mean uptake values (Appendix 1) indicate that only P uptake differed significantly ($p = 0.05$) between CP, MPR and CPMPR according to Duncan's New Multiple Range Test. High coefficients of variation in K and Ca uptake (Appendix 1) associated with insignificant differences in K and Ca uptake could be due to the effect of the glasshouse conditions such as high temperatures and restricted soil volume which might have limiting effects on root growth and nutrient exploitation.

The overall mean plant P uptake values observed for the plants treated with P at 40 to 200 kg ha$^{-1}$ as CP, MPR and CPMPR were 11, 13 and 18 times those of respective control plants. The increase in P uptake observed with CP application could be due to additional P and other nutrients supplied to the soil through the biochemical decomposition of the pulp. This is further attributed to the competition of the humic substances for P fixation sites thus increasing availability of P for plant uptake.

lxii

P, Ca and K uptake (mg/pot)

250
200
150
100
50
0

Legend:
- 0 kg P/ha
- 40kg P/ha
- 80kg P/ha
- 100kg P/ha
- 120kg P/ha
- 140kg P/ha
- 160kg P/ha
- 200kg P/ha

CP  MPR  CPMPR    CP  MPR  CPMPR    CP  MPR  CPMPR

P            K            Ca

**P sources and application rates**
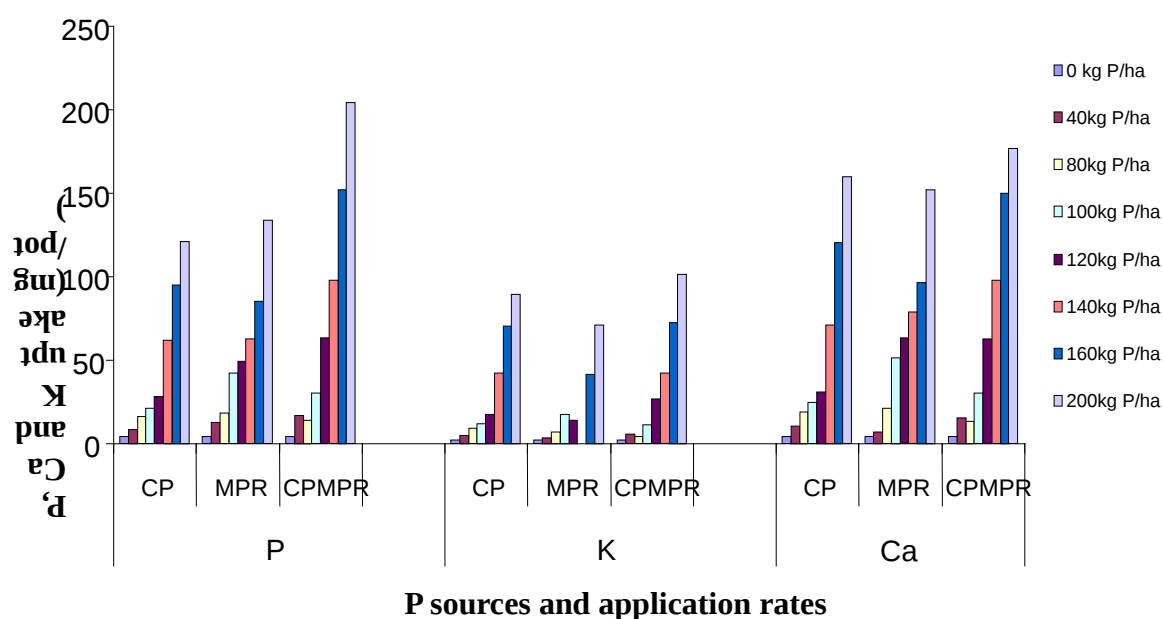
**Figure 1:  The effect of P sources and application rates on P, K and Ca uptake**

The increase in P uptake as a result of MPR application was largely associated with the dissolution of MPR as influenced by the high availability of protons in the highly acidic Chromic Acrisol. The rate of increase in P uptake from MPR was less than the observed increase with CPMPR probably due to slow and continuous dissolution of singly applied MPR in the soil as well as transformation of some P released from MPR into plant unavailable forms.   The highest increase in P uptake observed with CPMPR treated plants was attributed to extra supply of plant available P from microbial decomposition of the pulp and dissolution of the MPR as influenced by organic acids released during the decomposition of the pulp. This might be further attributed to improved soil structure and moisture retention as well as reduction of P fixation sites on the soil's active surfaces as could have been influenced by coffee pulp decomposition products. Superior P and Ca uptake from CPMPR treatments over CP and MPR treatments indicates that composting MPR with coffee pulp improves MPR dissolution and availability of P and Ca for plant uptake. Higher K uptake observed from CP and CPMPR as compared to MPR treatments

suggests that coffee pulp compost is a potential source of plant available K for tomato and other vegetables.

### 4.2.2 Effects of CP, MPR and CPMPR on the percentage N, P, K, Ca and Mg contents in   plant shoots

The N, P, K, Ca and Mg contents in CP, MPR and CPMPR treated plant shoots were as presented in Fig. 2 to Fig. 4 and Appendix 2.

### 4.2.2.1 Effect on plant tissue N contents

Nitrogen contents in the plants were in the medium range (3.0-4.5%) according to the categorization by Dierolf *et al.* (2001). The percentage N contents in the plants slightly increased with increasing rates of CP, MPR and CPMPR. The increase in plant N contents was in the order CPMPR > MPR > CP with overall means of 3.37, 3.27 and 3.11% respectively. The overall percentage N in plants for the MPR and CPMPR treatments had no significant (p = 0.05) difference but were different from CP treatments.  Slight increase in N contents with increasing P rates despite of the uniformly applied N for all treatments suggests a positive effect of P on plant development and N uptake and hence the importance of a balanced fertilization programme.

### 4.2.2.2 Effect on plant tissue P contents

Application of all P sources at equivalent rates of 40 to 200 kg P ha$^{-1}$ had a positive effect on plant P contents (Fig. 2 and Appendix 2).  The general effect of P sources on plant P contents was in the order CP < MPR < CPMPR with overall means of 0.37%, 0.41% and 0.49%, respectively. Based on the overall means of plant P contents, the increase in P contents for the CP, MPR and CPMPR treatments were 23%, 36% and 110%,

respectively above the control implicating that, composting CP with MPR increased the dissolution of MPR hence the release of P forms available for plant uptake.
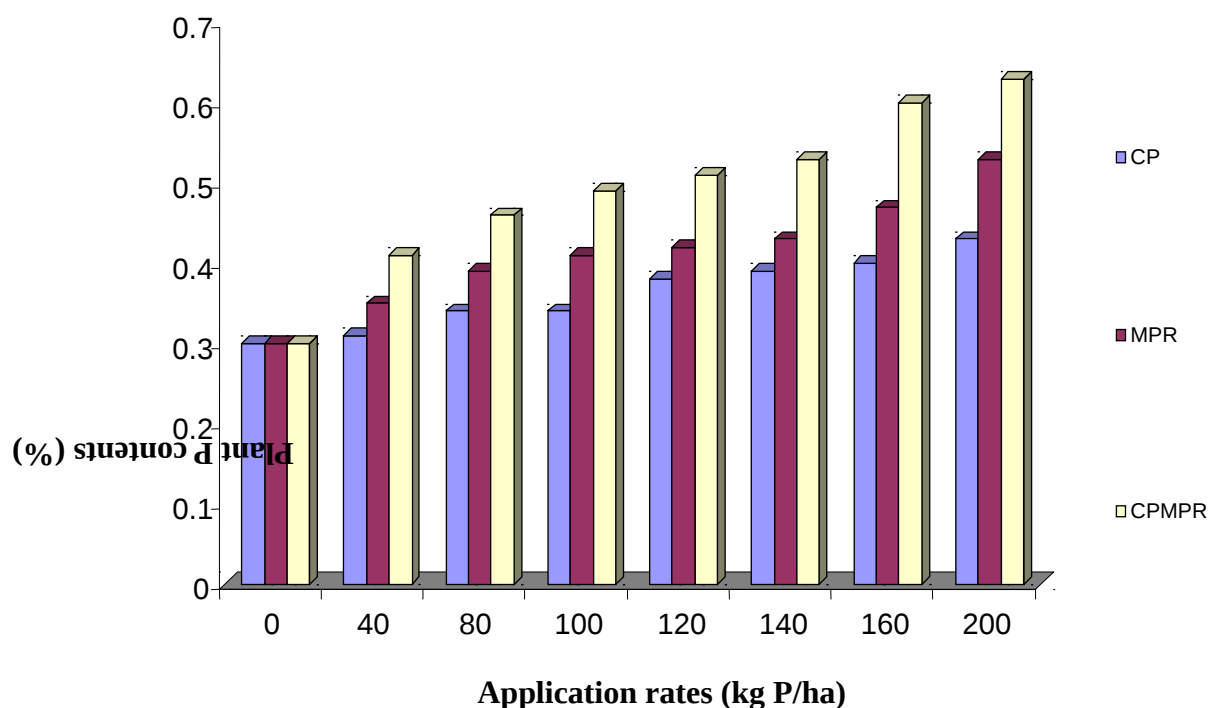


**Figure 2: Effect of P sources and application rates on tomato plant P contents**

The P contents observed in all plants were in the medium range (0.3 - 0.8) according to Dierolf *et al*. (2001), further suggesting that all P sources used in the experiment had a potential of improving plant P availability for tomato and other crops growing on highly P deficient acid soils. Although all plants had P contents within the medium range, CPMPR treated tomato plants had the highest P contents probably due to the dissolution effect of organic acids produced during the microbial decomposition of the pulp as well as the competition of the humic substances for P fixation sites on the soil colloidal surfaces thus increasing plant available P in the soil solution.

The lowest increase in plant P contents for CP treatments relative to CPMPR and MPR treatments could be due to small quantities of plant available P in the pulp as well as slow release of mineral P as a result of microbial decomposition and mineralization of the pulp. Further the low P contents in plants for the MPR treatments relative to CPMPR treatments suggests continuous dissolution of the MPR thus slow release of plant available P to the soil solution as well as fixation of some of the released P by soil components before plant uptake. This conforms to the observation by Mowo (2000) and Szilas (2002) who reported inferior performance of MPR in the first season as compared to TSP due to gradual dissolution and thus slow P release from MPR. Limited crop response to direct MPR in season one of application could be attributed to such slow P release from MPR and therefore the need for combined composting and application of crop residues with MPR.

**4.2.2.3 Effect on K contents in plant tissue**

Generally K contents increased with increase in application rates for all P source materials (Fig. 3 and Appendix 2). The increase in plant K contents was in the order MPR < CPMPR < CP with mean K concentration magnitudes 2%, 2.07% and 2.29%, respectively. Observed differences in percentage K contents in tomato plants for the CP treatments as compared to CPMPR and MPR treatments was probably due to substantial amounts of K released upon mineralization of the coffee pulp. However, K contents in tomato plants were in the low (< 2%) to medium (2.5-4.5%) range (Dierolf *et al*., 2001). The low plant K contents for the MPR treatments might be due to imbalance between K, Mg and Ca in the soil solution, hence the need for balanced fertilization.
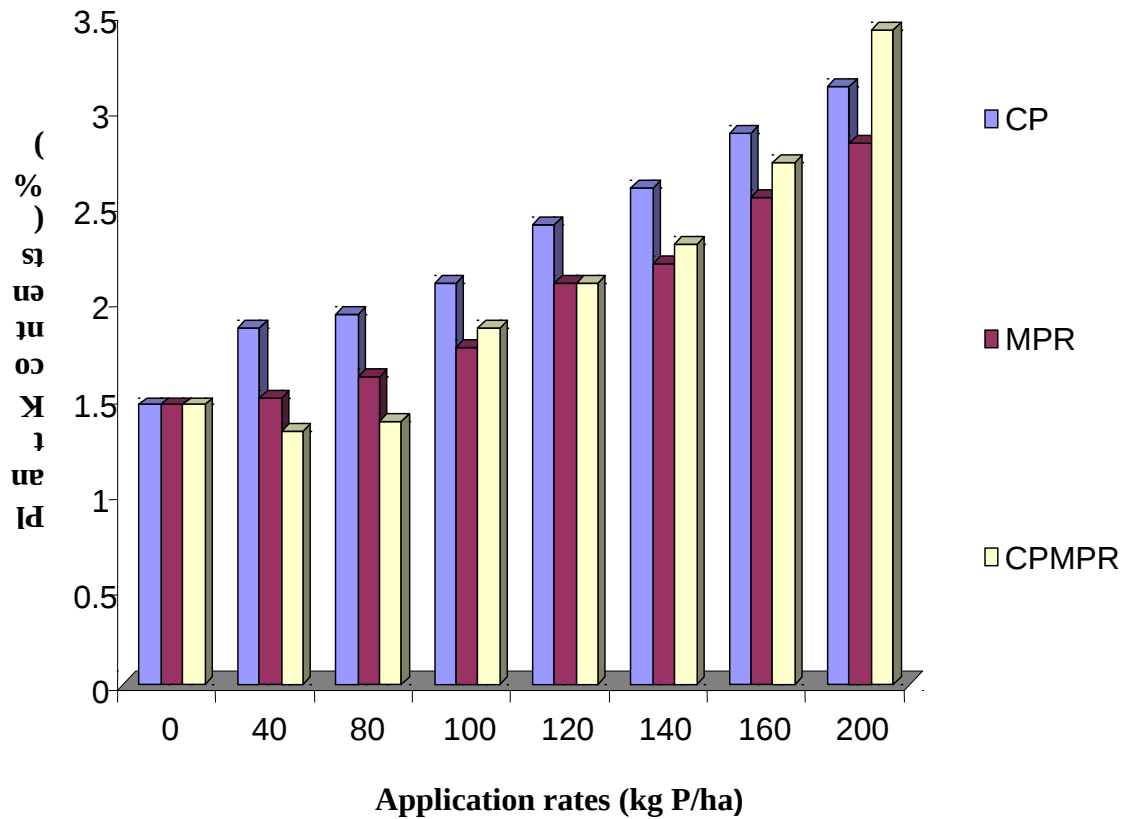
**Figure 3: The effect of P sources and application rates on plant K contents**

**4.2.2.4 Effect on Ca contents in tomato plants**

Plant Ca contents increased with increasing P application rates for all P sources indicating improved supply of the $Ca^{2+}$ (Fig. 4). The percentage Ca contents in tomato plants were in the order CP < CPMPR < MPR with overall means of 4.25%, 4.73% and 4.91% respectively (Appendix 2). Higher Ca contents in the tomato plants for the MPR treatments than those recorded with the CP and CPMPR were due to the higher Ca contents in MPR than CP and CPMPR (Table 3 and Table 4) thus its availability for plant uptake.
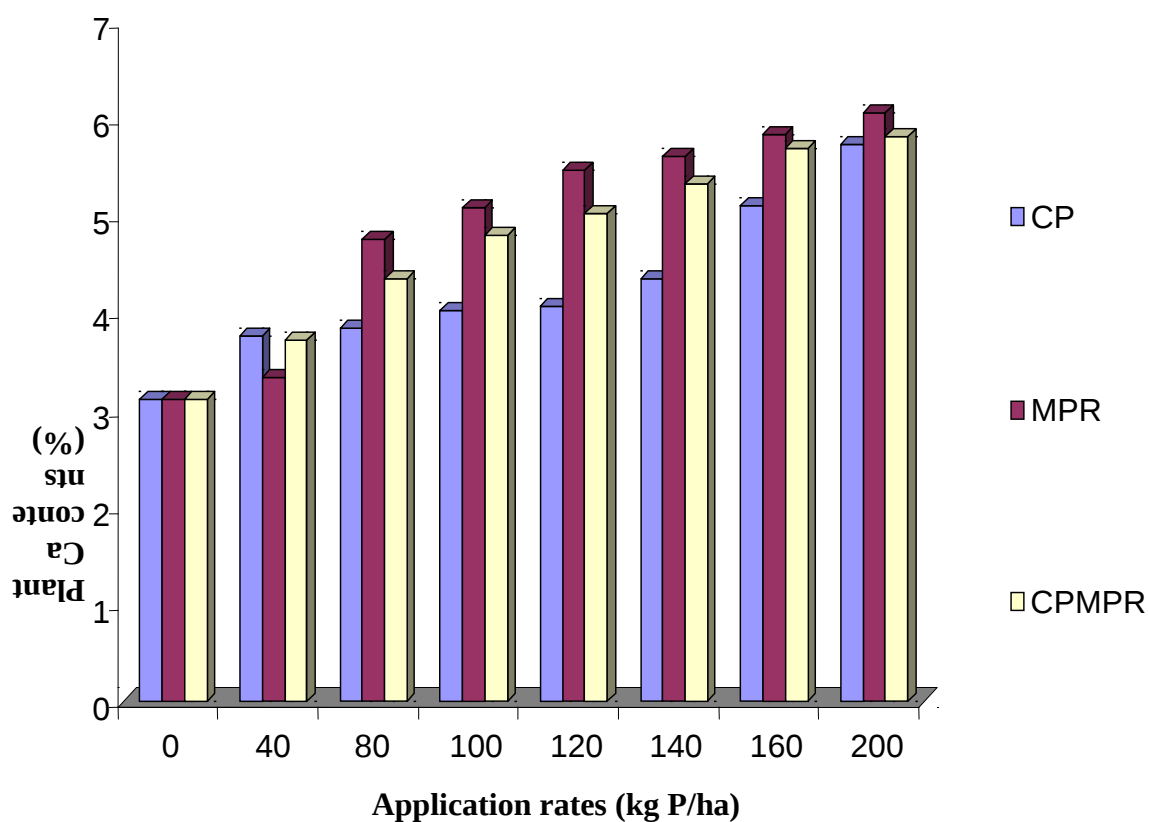
**Figure 4:  Effect of P sources and application rates on plant Ca contents**

Dierolf *et al*. (2001) categorized Ca contents in tomato plants as < 2% (low), 3.0% - 4.0% (medium) and > 4.0% (high). Based on this categorization, all plants had medium to high percentage Ca contents with high overall mean contents. Overall mean Ca contents in the tomato plants were statistically (p=0.05) the same for all P sources according to the Duncan's new multiple range test regardless of the fact that the chromic acrisol was deficient in exchangeable Ca (Table 2). This observation needs more intensive studies on Ca uptake by tomato plants.

**4.2.2.5 Effect on Mg contents in tomato plants**

With the exception of plants treated with P rates beyond 140 kg P ha$^{-1}$, Mg concentration in all plants was within the sufficiency range (0.35-1.0%) as rated by Campbell (2000). Treatments involving higher application rates beyond 140 kg Pha$^{-1}$ had high plant Mg

concentrations beyond the sufficiency range (Appendix 2). The overall Mg contents in plants were above the 0.35-1.0% range and statistically (p=0.05) not different for all P sources. According to Landon (1991) the effects of major soil cations on plant growth are often closely interlinked thus oversupply or undersupply of either of these, results into negative effects on the supply and availability of other cations to plants. High plant Mg contents could be due to high levels of exchangeable Mg in the Chromic Acrisol (Table 2) and therefore contributing to the low K levels due to negative interactions of the two nutrients in the soil solution.

**4.3 Effect of Treatments on Tomato Plant Growth Performance**

The effects of different P sources applied at various rates on tomato plant response in terms of plant height, number of true leaves, dry matter yields, numbers of flowers, fruits, trusses and marketable fruits as well as the weight of marketable fruits were as summarized in Fig. 5 to Fig. 9 and Appendix 3 to Appendix 4.

**4.3.1 Effect of CP, CPMPR and MPR on plant heights and numbers of leaves**

Plant height increased with increasing P application rates for all the P sources although the overall means for MPR and CPMPR were not statistically (p=0.05) different but different from those treated with CP (Fig. 5). Application of CP at equivalent rates of 40 to 200 kg P ha$^{-1}$ increased plant height from 15.5 to 78cm with an overall mean of 47.4 cm (Appendix 3). The same rate of P applied as MPR and CPMPR increased plant height from 15 to 89cm and 15 to 89.5cm with overall means of 58.9 and 60.1 cm, respectively. Heights recorded with application of $\leq$ 140 kg P ha$^{-1}$ ware not significantly (p = 0.05) different for all P sources used in the experiment indicating that the soil was highly P deficient thus required high application rates to meet the tomato crop P requirement. Visual observation of all plants treated with $\leq$ 120 kg P ha$^{-1}$ revealed stunted plants with purple colored leaves

and stems, weak shoots and reduced or no flowers and fruits at all indicating the effect of P deficiency and probably nutrient imbalances. This could be attributed to the high P retention capacity of the chromic acrisol and transformation of the plant available P into unavailable forms as described under section 2.6.5. Soils with high P retention capacity require high rates of P application to meet both soil's P retention and crop P requirements.
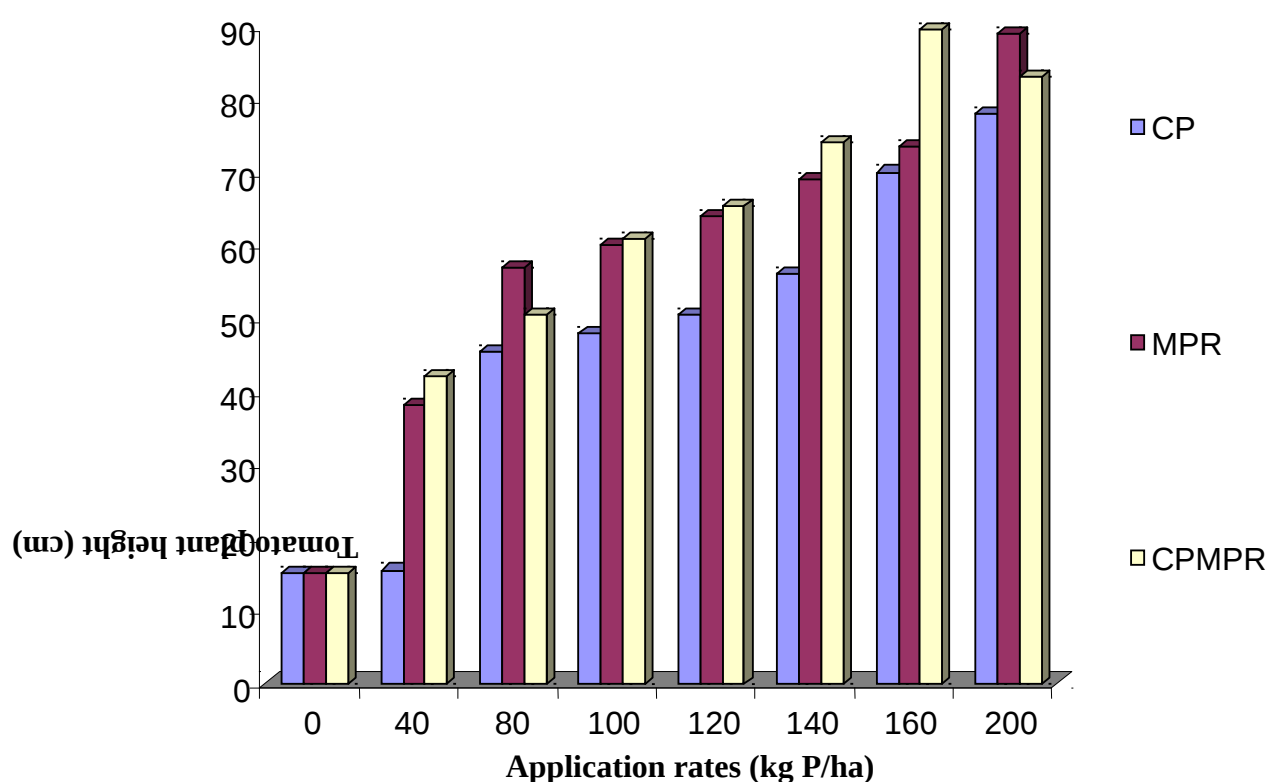


**Figure 5: Effect of P sources and application rates on tomato plant heights**

Low plant height recorded with CP as compared to MPR and CPPMR indicates low amounts of plant available nutrients per unit weight of material (CP) a common characteristic for all manures. The trend could also be due to imbalanced availability to plants of N, P, K, Ca and Mg. The number of true leaves increased with P application rates for all P sources in a non systematic order thus difficult to explain the relationship between P supply and leaf numbers. This observation could be due to glasshouse effects such as

high temperatures and restricted soil volume hence this calls for field experiments to study tomato response to CP, MPR and CPMPR under field conditions.

### 4.3.2 Effect on tomato dry matter yields

The influence of all P sources applied at various rates on tomato DMY was significant in comparison to the control (Appendix 3). Although overall dry matter yields for the different P sources were not statistically different (p = 0.05), CPMPR had a higher overall effect on dry matter yield response relative to CP and MPR. Increase in dry matter with increasing P application rates over the control confirmed the observation that the experimental soil (the Chromic Acrisol) was deficient in plant available P (Table 2). Unlike CP and CPMPR, dry matter yield response to MPR application was higher at lower application rates ($\leq$120 kg P ha$^{-1}$) but increased at a decreasing rate with P application from 120 kg P ha$^{-1}$ to 160 kg P ha$^{-1}$ (Fig. 6). Similar trends in DMY response to MPR were reported by Kanabo and Gilkes (1988), Rajan *et al*. (1991), Mowo (2000) and Ikerra (2004) using maize as a test crop. They attributed such trends to the effect of $CaCO_3$ and other proton consuming compounds in the MPR and concluded that low rates of MPR are associated with low levels of such compounds and therefore more protons available for MPR dissolution. This meant that increasing MPR application rate was associated with an increase of $CaCO_3$ and other proton consuming compounds therefore decreasing dissolution rates for every additional unit of MPR applied to the soil.
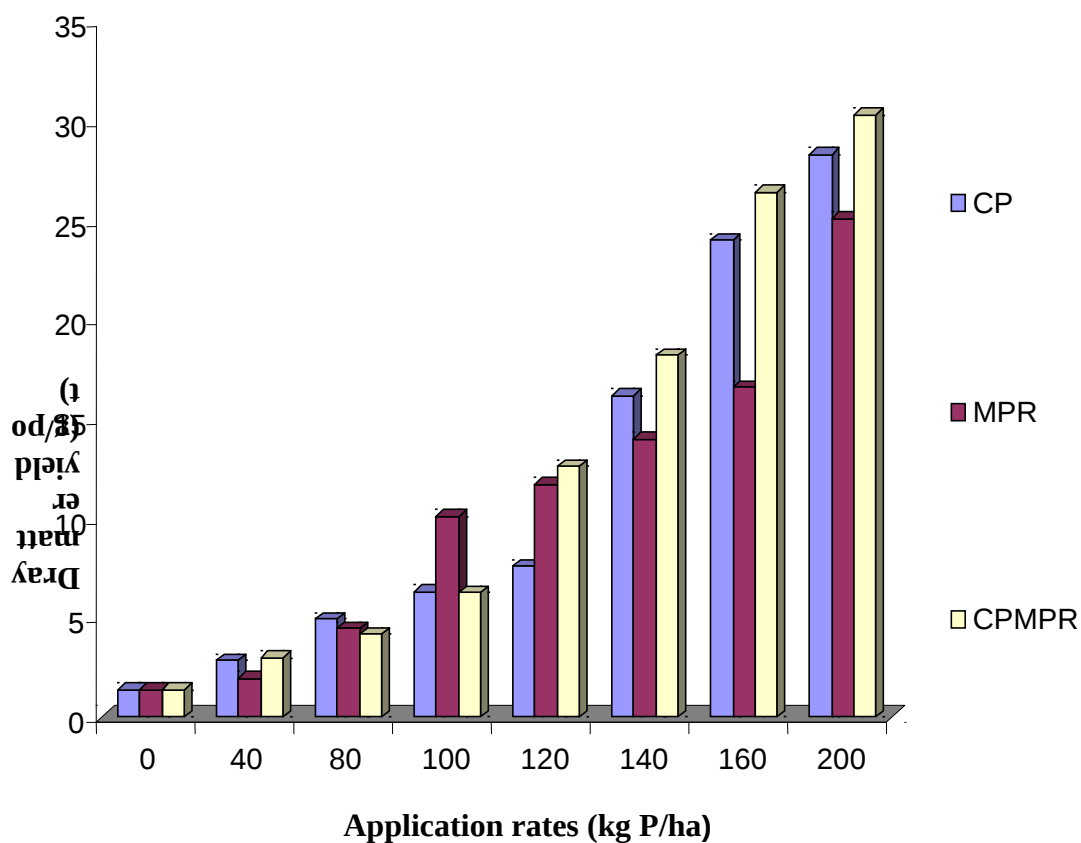
**Figure 6: Effect of P sources and application rates on dry matter yield**

Continuous increase in dry matter yield observed with CPMPR suggests reduction of the effect of such proton consuming compounds in the MPR. This could have been achieved through extra protons (organic acids) produced during biochemical oxidation of organic matter thus improving MPR dissolution (equations v and xii under sections 2.6.3 and 2.7.2, respectively).

**4.3.3 Effect on flower formation**

Flower formation as influenced by different P sources applied at various rates was as presented in Fig. 7 and Appendix 4. The average number of flowers recorded per plant increased with P application rates for all P sources but the CPMPR treatments recorded the highest overall flower response among P sources. Overall flower response to P application

was statistically (p=0.05) different in the order CP < MPR < CPMPR with overall means of 17, 23 and 29 flowers, respectively (Appendix 4). The order of increase in flower response was similar to that of P uptake and concentrations in plants indicative of the initial P deficiency in the Chromic Acrisol (Table 2).
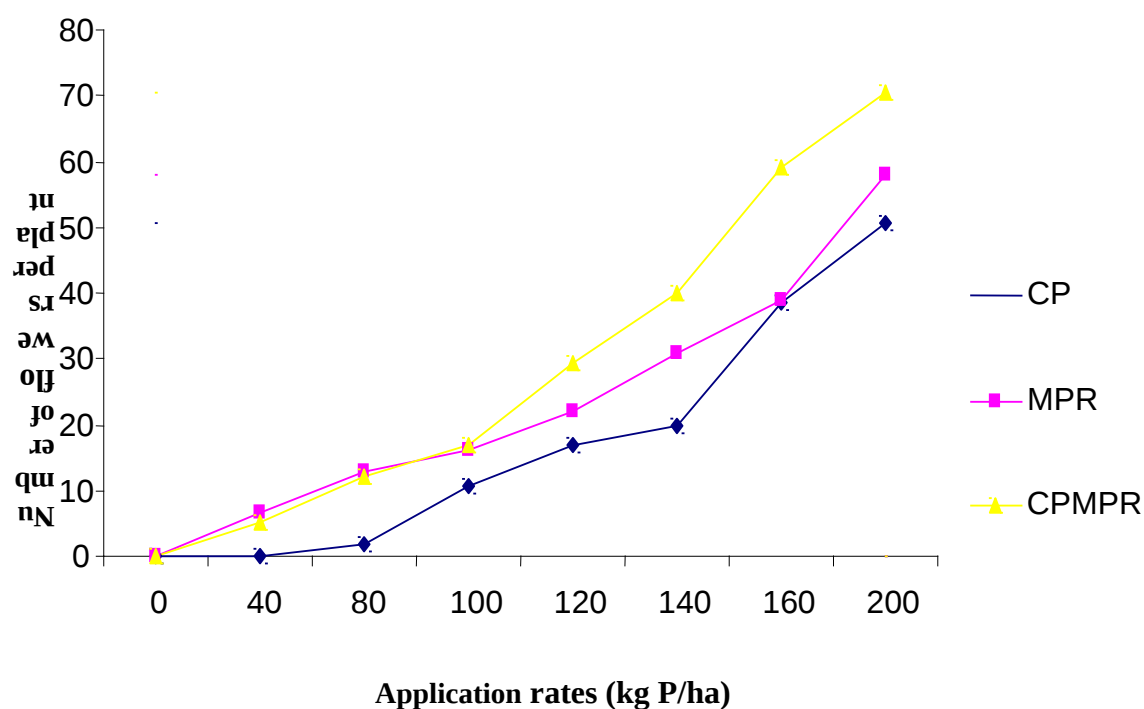


**Figure 7: Effect of P sources and application rates on the total number of flowers**

The highest number of flower trusses was similarly recorded with CPMPR at 90 days after planting although there was no significant difference (p = 0.05) in the overall number of trusses between the CPMPR and MPR treatments. Higher numbers of flowers and trusses observed for CPMPR treatments as compared to CP and MPR could be attributed to the effect of increased availability and uptake of P and other nutrients as influenced by composting coffee pulp with MPR (section 4.2.1).

Although the effect of nitrogen on vegetative growth and fruit yield of tomato is said to be more obvious than any other nutrient, high level of available phosphorus throughout the root zone is essential for rapid root development and efficient utilization of soil water and other nutrients (Kaya *et al.* 2009). Increasing flower formation with P application rates could be attributed to the role played by P in energy storage and transfer via ATP as well as being a constituent of nucleic acids, proteins, phospholipids and coenzymes thus affecting all plant physiological processes including photosynthesis. This could also be attributed to the role of P on plant root establishment and therefore improved ability of tomato plants to exploit other nutrients and water from the soil.

**4.3.4 Effect on fruit formation**

The number of fruits increased with P application rates for all P sources but low application rates had insignificant effects on fruit numbers (Fig. 8 and Appendix 4). The order of increase in the number of fruits was CPMPR > MPR > CP > control with respective overall means of 24, 19 and 6 fruits per plant. Fruit formation matched well with plant P uptake, P concentration in the tomato plants and flower formation, further reflecting the role of P in plant development and the positive effects of composting coffee pulp with MPR on MPR dissolution with consequent enhanced phosphorus availability to plants. Non significant increase in fruit numbers observed with low P application rates confirms that the Chromic Acrisol was highly P deficient and therefore the amounts of P supplied from all P sources applied at low rates (<120kg P/ha) was insufficient to account for the soils P retention capacity and meet the tomato crop P requirements.
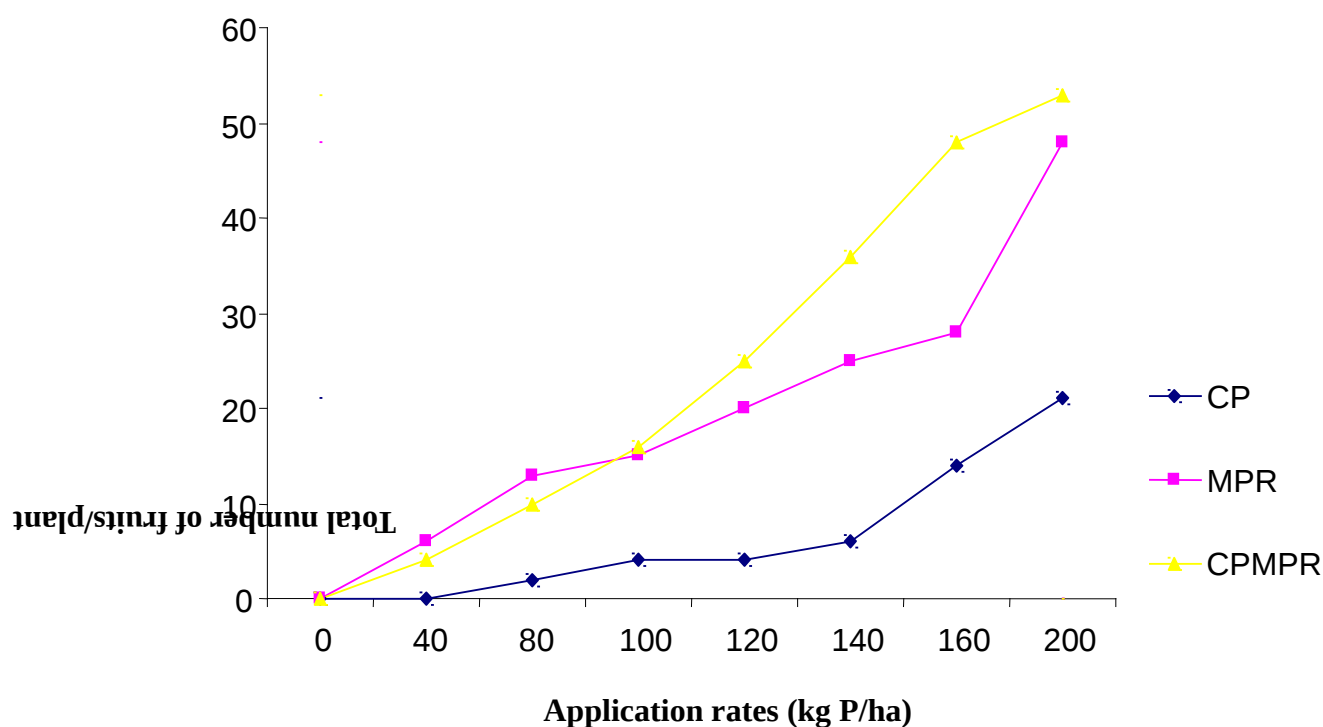
**Figure 8: Effect of P sources and application rates on tomato fruit production**

**4.3.5 Effect on number and weight of marketable fruits**

The number and weight of marketable fruits per plant (Fig. 9 and Appendix 4) was in the order similar to plant P uptake and concentrations, flower and fruit production. CPMPR application at 0 to 200 kg P ha$^{-1}$ increased the number of marketable fruits from 0 to 16 with an average of 7 fruits per plant. Respective weight of marketable fruits increased from 0 to 666 g plant$^{-1}$ with an overall mean of 242.8 g plant$^{-1}$. The same rates of P applied as CP and MPR increased marketable fruits from 0 to 14 and 0 to 9, respectively. However, MPR had higher overall effect on number and weight of fruits than CP due to relatively higher fruit response at low application rates of MPR than CP.
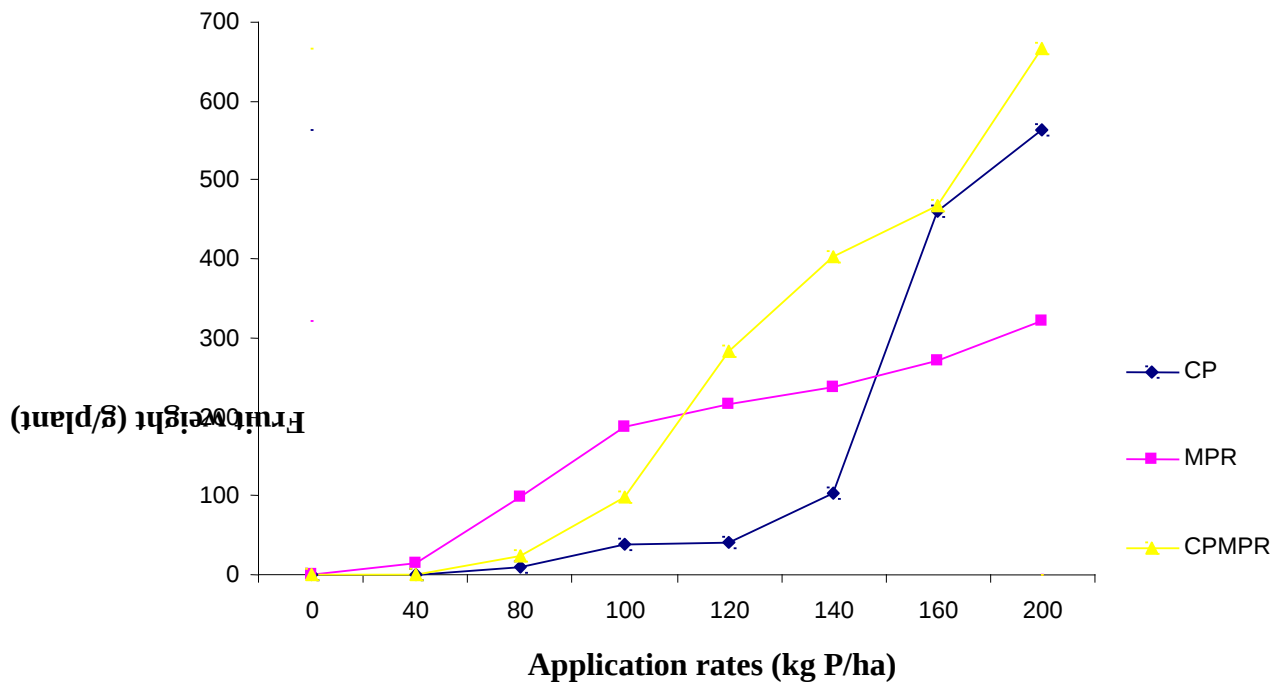
**Figure 9: Effect of P sources and application rates on fruit weight**

The rate of increase in numbers and weight of marketable fruits produced per plant with different P sources at various application rates further supported the positive effect of composting coffee pulp with MPR on P availability, its uptake by plants and tomato yield response attributed to the functions of P in plants as described under section 2.1 and 4.3.3. However, the average fruit weight per plant was low probably due to the glasshouse effects such as high temperatures and limited soil volume which could have negative effects on fruit development and therefore smaller sized fruits than could be under field.

**4.4 Effect of CP, MPR and CPMPR Treatments on Properties of the Chromic Acrisol at the End of the Experiment**

Some of the chemical properties of the Chromic Acrisol analyzed immediately after harvesting tomatoes treated with different P sources at various rates were as presented in Appendix 5 and Appendix 6.

**4.4.1 Effect on soil pH**

The pH of soils determined immediately after harvesting were in the order MPR < CP < CPMPR with mean values 4.32, 4.38 and 4.39, respectively. Comparing these values with the initial pH of the soil (4.30) before subjecting it to treatments, all P sources had slight effect on soil pH probably due to their base and soluble salt contents although not high enough to neutralize the soil acidity. The effect of P sources on pH was clearly indicated by a general increase in pH with increasing application rates from 40 to 200 kg P ha$^{-1}$ for all P sources. Overall pH values were not significantly (p=0.05) different between CP and MPR but different from the CPMPR treated soils (Appendix 5). Slightly higher pH values for CPMPR treated soils as compared to CP and MPR treated soils could be due to the total effect of basic cations and soluble salt contents of coffee pulp and MPR. This indicates that in addition to the improved availability of P, composting coffee pulp with MPR has a slight amendment effect on soil pH thus improves crop growth environments.

Ikerra (2004) reported a significantly higher pH for soils treated with a combination of MPR and organic materials than that of the control. Increase in soil pH due to application of organic materials has also been reported by Whalen *et al*. (2000). They attributed such increases in pH to the liming effect of the basic cations and OH$^{-}$ released during decomposition of organic materials, microbial decomposition of basic cations containing organic anions like Ca oxalate and reduction of Mn or Fe at anaerobic microsites.

Despite the minor changes in pH, final soil analysis indicates the soil pH to be low thus, some of the P applied to the Chromic Acrisol could have been fixed by the Fe and Al present in the soil solution thus reducing the amounts available for plant uptake as indicated by low to medium levels of plant tissue P contents (Fig. 2 and Appendix 2). The

low soil pH values observed at the end of the experiment suggest that the amounts of basic materials added to the soil were insufficient to neutralize the acidic nature of the Chromic Acrisol despite the high pH values of the CP, MPR and CPMPR (Table 3 and Table 4). This observation further suggests that the pH of the Chromic Acrisol is probably highly buffered at pH 4.30 and P sources did not contain or furnish enough basic cations and anions to significantly neutralize the pH of the Chromic Acrisol.

### 4.4.2 Effect on soil organic carbon

Organic carbon content of the Chromic Acrisol ranged from 1.06 to 1.51%, 1.06 to 1.17% and 1.06 to 1.45% for soils treated with 0-200 kg P ha$^{-1}$ in the form of CP, MPR and CPMPR, respectively. CP recorded the highest overall effect on soil organic carbon with an overall mean of 1.26%, followed by CPMPR and lastly MPR with overall means 1.15% and 1.09% respectively. Highest organic carbon contents in soils treated with CP was attributed to high contents of organic carbon in the CP as influenced by carbon contents of the raw material (coffee pulp) used for the compost production (Table 4).

### 4.4.3 Effect on soil nitrogen

Despite the fact that nitrogen was applied at a uniform rate to all pots, both plant and final soil analyses observed an increase in nitrogen contents with increasing rates of P applied as CP and CPMPR. The increase in soil nitrogen content of experimental soil previously treated with different P sources was in the order CP > CPMPR > MPR with overall mean concentrations of 0.18, 0.12 and 0.12% respectively.

Based on these results, CP had the highest and significant (p=0.05) effect on soil nitrogen contents whereas the effects of MPR and CPMPR were statistically not different according

to the Duncan's new multiple range test. High nitrogen contents for CP treated soils were attributed to the combined effect of nitrogen applied in the form of $CO(NH_2)_2$ and some additional nitrogen released during microbial decomposition of the coffee pulp.

It can therefore, be concluded that apart from improving MPR dissolution and other soil properties, coffee pulp compost improved the total N contents of the soil and its availability to plants

**4.4.4 Effect on Bray 1 extractable phosphorus**

Bray I extractable P in the experimental soils increased with P application rates for all P sources (Fig.10 and Appendix 5). Contrary to soil nitrogen, the increase in P of experimental soils treated with different P sources were in the order MPR > CPMPR > CP with overall magnitudes of 10.20, 9.29 and 3.29 mg P $kg^{-1}$, respectively. Although the overall P contents of MPR and CPMPR treated soils were statistically (p=0.05) not different, MPR treated soils had slightly higher Bray 1 P levels compared to CP and CPMPR. This was due to high residual effects of MPR as influenced by its gradual dissolution and slow release of P in acid soils (Szilas, 2002). Low Bray I extractable P observed in the soils treated with CPMPR as compared to MPR could be due to higher crop removal of P from the CPMPR treated soils as influenced by increased P availability in the CPMPR.
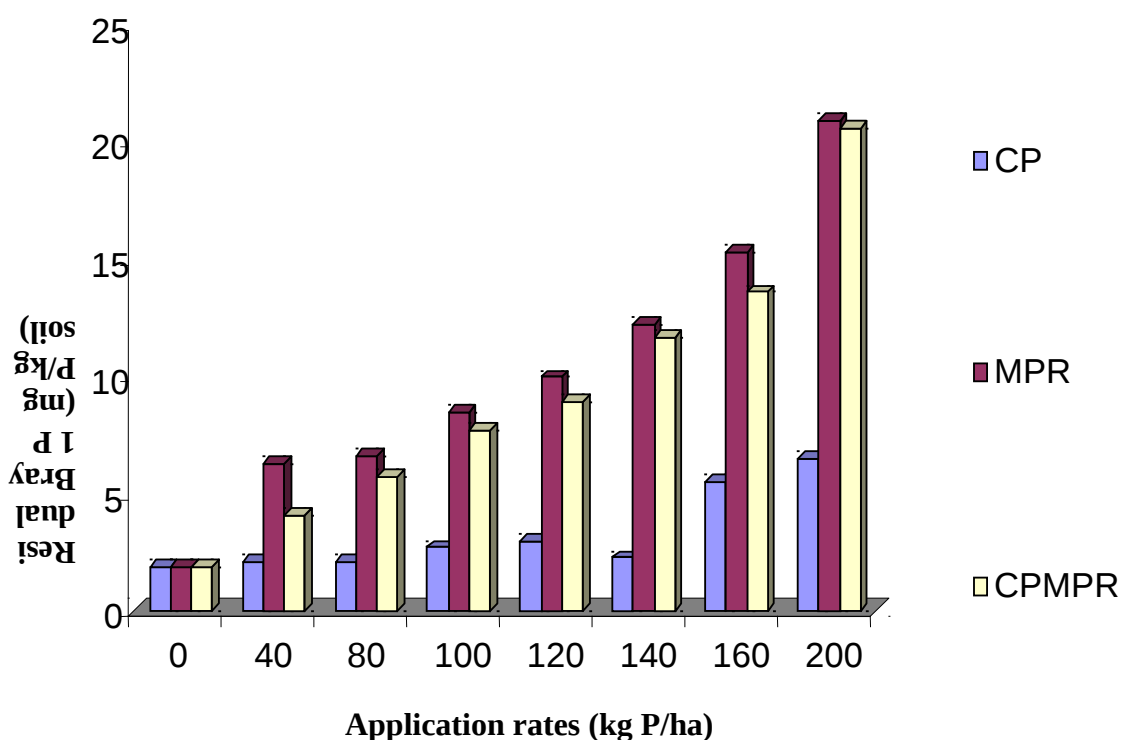
**Figure 10: Effect of P sources and application rates on residual Bray 1 extractable P**

Although all P sources had increasing effects on residual P, all soil samples except those treated with 160 - 200 kg P ha$^{-1}$ as MPR and 200kg P ha$^{-1}$ as CPMPR had low available P (< 15 mg P kg$^{-1}$) according to Dierolf *et al*. (2001). Control treatment soils as well as those treated with low level of P had lower available P than P levels found in the chromic acrisol before subjecting it to treatments probably due to higher crop P removal than the amounts applied to the highly P deficient chromic acrisol.

Observations of this study resembles those reported by Ikerra (2004) where MPR and TSP applied to the chromic acrisol at application rates < 100 mg P kg$^{-1}$ soil or 220 kg P ha$^{-1}$ resulted into lower extractable P levels than those determined before planting the maize. Used in the same study, organic materials (manure, lantana, gliricidia and tithonia) applied

at the rates of 5 t ha$^{-1}$ did not supply enough soil P to support maize growth on the chromic acrisol (Ikerra, 2004).

Based on the observations in this section, it can be concluded that CP, MPR and CPMPR had the potential of increasing extractable soil P levels but the effect of CP alone on Bray 1 P was not significant. Further more highly P deficient acid soils require high rates of P application to meet the crop's P requirements while composting organic materials with phosphate rock improves P availability and subsequently crop response to applied phospho composts. Also MPR has high residual P effect in soils therefore crop production with MPR as P source should take into account the P requirement of the subsequent crop in the rotation or next growing season for efficient P utilization.

**4.4.5 Effect on exchangeable potassium**

Final soil analysis results (Appendix 6) indicate a general increase in exchangeable K with increasing application rates of CP, MPR and CPMPR. The increase in exchangeable K was in the order of CP > MPR > CPMPR with overall mean K magnitudes 1.2cmol (+) kg$^{-1}$, 0.85mol (+) kg$^{-1}$ and 0.76cmol (+) kg$^{-1}$ respectively. Although the overall means for all soils were in the high range of exchangeable K (FAO, 2008), CP treated soils had the highest and significant (p=0.05) exchangeable K contents. The higher K values observed in CP treated soils as compared to MPR and CPMPR treated soils suggest the potential of coffee pulp as a source of plant available K in addition to its amendment effects on soil properties, enhancement of PR dissolution and release of other nutrients during decomposition.

**4.4.6 Effect on exchangeable calcium**

Residual Ca concentrations in the experimental soils as influenced by the application of three different P sources were as presented in Appendix 6. The overall mean exchangeable Ca for soils treated with different P sources were in the order MPR > CPMPR > CP. The higher overall exchangeable Ca contents observed for MPR and CPMPR treated soils as compared to CP treated soils were due to the effect of higher Ca and associated $CaCO_3$ in the MPR than in the CP (Table 1 and 2). Although statistically not different from MPR treated soils, CPMPR treated soils had exchangeable Ca values slightly below MPR treated soils but above CP treated soils. This observation could be attributed to the joint effect of Ca compounds in the coffee pulp and MPR used as raw material for the preparation of the CPMPR. The increase in exchangeable Ca of CP treated samples of the Chromic Acrisol was attributed to the plant available Ca released after decomposition of the Ca rich coffee pulp. Similar trends of increase in exchangeable Ca levels due to application of plant biomass and MPR have been reported by George *et al*. (2002), Baltazary (2002) and Ikerra (2004).

Although exchangeable Ca increased with application rates for all P sources, all soils had moderately low to moderately high Ca values according to the categorization of exchangeable Ca for upland acid soils (Dierolf *et al.*, 2001). This could be attributed to the effect of large number of Ca sinks existing in the very acidic Chromic Acrisol, as well as its removal by plant uptake. Further more, overall exchangeable Ca contents were not statistically (p=0.005) different between MPR and CPMPR treated soils suggesting that there was no significant reduction in Ca supply power of the MPR after composting coffee pulp with MPR. With reference to the discussion above, it can therefore be concluded that composting coffee pulp with MPR improves plant available Ca in addition to the supply of other nutrients and its amendment effects on soil properties.

**4.4.7 Effect on exchangeable magnesium**

All samples of the Chromic Acrisol analyzed at the end of the experiment had high levels of exchangeable magnesium according to Landon (1991). Such elevated Mg levels could be attributed to the high initial exchangeable Mg in the Chromic Acrisol as well as additional Mg supplied through CP, MPR and CPMPR. According to Landon (1991), high levels of exchangeable Mg in the soil results into reduced availability of Ca and this could be among the reasons for low Ca levels reported in section 4.4.6 above. For all P sources, application rates of 140-200 kg P ha$^{-1}$ seem to have significant effect on soil exchangeable Mg, with CP having the most significant (p=0.05) effect on Mg concentrations among the P sources. This is possibly due to extra Mg added through microbial decomposition and mineralization of the coffee pulp within the soil.

Despite the high levels of extractable Mg, soils treated with low MPR and CPMPR rates had less exchangeable magnesium levels than those recorded before treatments (Table 2 and Appendix 6). Such observations suggest the removal of Mg by plants as well as possibilities of its fixation by the 2:1 clay minerals and precipitation with $Al(OH)_3$ thus, transforming Mg into less available forms.

**4.4.8 Effect on CEC**

Application of CP, MPR and CPMPR slightly increased soil CEC in comparison to levels determined prior to the treatments applied to the Chromic Acrisol (Appendix 6). The higher CEC values than the 16.8cmol (+) kg$^{-1}$ determined prior to the treatments indicated an increase in soil's capacity to hold cations, hence soil fertility improvement. CPMPR treated soils recorded the most significant (p=0.05) CEC levels ranging from 19.3 to 25.1 with an overall mean of 21cmol (+) kg$^{-1}$, while there was no significant difference

(p=0.05) in CEC levels among soils treated with CP and MPR. Higher CEC values for CPMPR could be due to combined effect of exchangeable cations released from both coffee pulp and MPR indicative of the positive effect of composting coffee pulp with MPR on soil fertility and crop response.

# CHAPTER FIVE

## 5.0 CONCLUSIONS AND RECOMMENDATIONS

## 5.1 Conclusions

The results obtained in the current study indicates that composting coffee pulp with MPR produced a phosphate enriched compost with high pH value above the neutral point, high organic carbon contents and improved N, K and Ca contents. The use of CP, MPR and CPMPR as phosphorus sources in the glasshouse experiment improved P, K and Ca uptake and their contents in tomato plants indicative of the increased availability of the nutrients for plant uptake. The P, K and Ca uptake increased with increasing rates of CP, MPR and CPMPR but CPMPR resulted into the highest and significant P uptake. All P sources improved tomato crop response relative to the control with no P supply but CPMPR had the highest and significant effects on the tomato crop response. MPR and CPMPR had similar effects on residual soil P and Ca while CP had the highest and significant effects on organic carbon, total N, exchangeable K and Mg at the end of the experiment. Based on these findings, it was concluded that:

1. Composting coffee pulp with MPR improves availability of P and other nutrients in the compost as compared to singly composted coffee pulp and fresh MPR; and this technique results into compost products with high pH thus suitable for application to acidic soils.

2. CP, MPR and CPMPR improves nutrient uptake, their contents in tomato plant tissues and subsequent tomato response on a Chromic Acrisol but the highest and significant response can be achieved with CPMPR.

3. Composting coffee pulp with MPR does not affect the residual P and Ca effects of the MPR while coffee pulp compost improves soil organic carbon/organic matter, total nitrogen, exchangeable K and Mg of the Chromic Acrisol.

4. Composting coffee pulp with MPR could serve as a means of improving the first season crop response to MPR especially for high P, K and Ca demanding crops grown on acidic soils as well as a means of reducing environmental hazards associated with mismanagement of coffee pulp in coffee growing areas.

## 5.2 Recommendations

Current results are based on glasshouse conditions therefore further studies should be carried out to study the effect of composting coffee pulp with MPR on crop response under field conditions. Field experiments should involve other organic residues reported to improve MPR dissolution and P availability for comparison purposes. The use of more soils and higher P application rates than those tested in the current study is similarly recommended to come up with the optimal application rates for crop production. The current study recommends the application of CP, MPR and CPMPR at equivalent rates of 80 to 350 kg P $ha^{-1}$ and above for further studies to establish optimal application rates.

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# APPENDICES

## Appendix 1:  Effect of P sources and application rates on plant P, K and Ca uptake

| P Source | Rate (kgP/ha) | P uptake mg pot $^{-1}$ | K uptake (mg pot $^{-1}$) | Ca uptake (mg pot $^{-1}$) |
|---|---|---|---|---|
| **CP** | 0 | 4.07 h | 1.94 d | 4.15 h |
| | 40 | 8.80 h | 5.14 d | 10.6 gh |
| | 80 | 16.3 gh | 9.02 cd | 18.9 fgh |
| | 100 | 21.0 gh | 12.3 cd | 24.9 efgh |
| | 120 | 28.4 fgh | 17.9 cd | 30.7 efgh |
| | 140 | 62.3 defgh | 42.5 bc | 71.0 cdef |
| | 160 | 95.3 bcdef | 70.2 ab | 120.1 bc |
| | 200 | 121.1 bcd | 89.3 a | 159.7 ab |
| | **Mean** | **44.6 b** | **31.0 a** | **55.0 a** |
| **MPR** | 0 | 4.07 h | 1.94 d | 4.15 h |
| | 40 | 12.7 h | 3.47 d | 7.30 gh |
| | 80 | 18.2gh | 7.17 d | 20.9 fgh |
| | 100 | 42.3 efgh | 17.9 cd | 51.5 defgh |
| | 120 | 49.1 efgh | 14.4 cd | 63.5 defg |
| | 140 | 62.5 defgh | 30. 8 cd | 78.7 cde |
| | 160 | 85.1 cdefg | 41.7 bc | 96.6 cd |
| | 200 | 133.7 abc | 70.8 ab | 152.3 ab |
| | **Mean** | **51.0 b** | **23.5  a** | **59.4 a** |
| **CPMPR** | 0 | 4.06 h | 1.94 d | 4.15 h |
| | 40 | 17.0 gh | 5.58 d | 15.2 fgh |
| | 80 | 14.2 h | 4.07 d | 13.7 gh |
| | 100 | 30.4 efgh | 11.4 cd | 30.2 efgh |
| | 120 | 63.2 defgh | 26.5 cd | 63.0 defg |
| | 140 | 97.6 bcde | 42.1 bc | 97.6 cd |
| | 160 | 152.2 ab | 72.4 ab | 150.3 ab |
| | 200 | 204.0 a | 101.7 a | 176.6 a |
| | **Mean** | **72.8 a** | **33.2 a** | **68.8 a** |
| **LSD** | | 59.0 | 29.4 | 49.1 |
| **CV (%)** | | 50.8 | 48.5 | 38.8 |

*Means in a column followed by the same letter(s) are not significantly (p=0.05) different*

*according to the Duncan's new multiple-range test*

**Appendix 2: Concentrations of N, P, K, Ca and Mg in plant shoots as influenced by the different P sources applied at various rates**

| P Source | Rate (kg P/ha) | N conc. (%) | P conc. (%) | K Conc. (%) | Ca conc. (%) | Mg conc. (%) |
|---|---|---|---|---|---|---|
| CP | 0 | Nd | 0.30 i | 1.46 hij | 3.11 i | 0.77 cd |
| | 40 | Nd | 0.31 hi | 1.86 efghi | 3.76 ghi | 0.87 bcd |
| | 80 | 3.78 fg | 0.34 ghi | 1.93 efghij | 3.85 ghi | 0.88 bcd |
| | 100 | 3.91 fg | 0.34 ghi | 2.10 defghi | 4.02 fgh | 0.92 bcd |
| | 120 | 4.09 defg | 0.38 fghi | 2.40 cdef | 4.07 fgh | 0.99 bcd |
| | 140 | 4.19 def | 0.39 fghi | 2.59 cde | 4.36 efg | 1.10 bc |
| | 160 | 4.40 cde | 0.40 fghi | 2.88 bc | 5.11 bcde | 1.20 ab |
| | 200 | 4.56 bcd | 0.43 cdefg | 3.12 a | 5.74 ab | 1.02 bcd |
| | **Mean** | **3.11 b** | **0.37 c** | **2.29 a** | **4.25 b** | **0.97 a** |
| | | | | | | |
| MPR | 0 | Nd | 0.30 i | 1.46 hij | 3.11 i | 0.77 cd |
| | 40 | 5.59 gh | 0.35 ghi | 1.50 hij | 3.34 hi | 0.72 cd |
| | 80 | 3.61 gh | 0.39 fghi | 1.61 ghij | 4.75 def | 0.81 bcd |
| | 100 | 3.22 hi | 0.41 efgh | 1.76 fghij | 5.09 bcde | 0.84 bcd |
| | 120 | 3.03 i | 0.42 defg | 2.10 defghi | 5.46 abcd | 0.88 bcd |
| | 140 | 4.05 efg | 0.43 cdefg | 2.20 cdefgh | 5.62 abcd | 0.98 bcd |
| | 160 | 4.19 def | 0.47 cdef | 2.54 cde | 5.84 ab | 1.50 a |
| | 200 | 4.49 cde | 0.53 bcd | 2.83 bcd | 6.06 a | 1.03 bcd |
| | **Mean** | **3.27 a** | **0.41 b** | **2.00 b** | **4.91 a** | **0.94 a** |
| | | | | | | |
| CPMPR | 0 | Nd | 0.30 i | 1.46 hij | 3.11 i | 0.77 cd |
| | 40 | 3.21 hi | 0.41 efgh | 1.32 j | 3.73 ghi | 0.69 d |
| | 80 | 3.80 fg | 0.46 cdef | 1.37 efghij | 4.36 efg | 0.74 cd |
| | 100 | 3.87 fg | 0.49 cdef | 1.86 efghij | 4.80 cdef | 0.83 bcd |
| | 120 | 4.49 cde | 0.51 bcde | 2.10 defghi | 5.02 bcde | 0.93 bcd |
| | 140 | 4.87 bc | 0.53 bc | 2.30 cdefg | 5.33 abcd | 0.96 bcd |
| | 160 | 5.01 b | 0.60 ab | 2.73 bcd | 5.70 abcd | 1.05 bcd |
| | 200 | 5.64 a | 0.63 a | 3.42 b | 5.82 ab | 1.09 bcd |
| | **Mean** | **3.37 a** | **0.49 a** | **2.07 ab** | **4.73 a** | **0.88 a** |
| | | | | | | |
| LSD | | 0.43 | 0.09 | 0.66 | 0.79 | 0.34 |
| CV (%) | | 6.08 | 10.7 | 15.1 | 8.24 | 17.7 |

*Means in a column followed by the same letter(s) are not significantly (p=0.05) different*

*according to the Duncan's new multiple-range test*

*Nd = Not determined*

**Appendix 3: Effect of P sources and application rates on plant height, number of true leaves and dry matter yields**

| P source | Rate (kg P ha⁻¹) | Height (cm) | No. of Leaves | DMY (g plant⁻¹) |
|---|---|---|---|---|
| **CP** | 0 | 15.0 k | 5 d | 1.34 i |
| | 40 | 15.5 k | 6 d | 2.84 hi |
| | 80 | 45.5 hij | 21 bcd | 4.92 ghi |
| | 100 | 48.0 ghij | 14 cd | 6.30 fghi |
| | 120 | 50.5 fghij | 14 cd | 7.57 fghi |
| | 140 | 56.0 efghi | 11 cd | 16.2 cdef |
| | 160 | 70.0 bcde | 30 bcd | 24.0 abcd |
| | 200 | 78.0 abc | 27 bcd | 28.3 ab |
| | **Mean** | **47.4 b** | **16 b** | **11.4 a** |
| | | | | |
| **MPR** | 0 | 15.0 k | 5 d | 1.34 i |
| | 40 | 38.0 j | 13 cd | 1.91 hi |
| | 80 | 57.0 efghi | 27 bcd | 4.44 ghi |
| | 100 | 60.0 defgh | 18 cd | 10.1 efghi |
| | 120 | 64.0 cdef | 25 bcd | 11.7 efghi |
| | 140 | 69.0 bcde | 16 cd | 14.0 defg |
| | 160 | 73.5 bcd | 43 ab | 16.6 cdef |
| | 200 | 89.0 a | 20 bcd | 25.1 abc |
| | **Mean** | **58.2 a** | **21 ab** | **10.7 a** |
| | | | | |
| **CP MPR** | 0 | 15.0 k | 5 d | 1.34 i |
| | 40 | 42.0 ij | 17 cd | 2.95 hi |
| | 80 | 50.5 fghij | 18 cd | 4.18 ghi |
| | 100 | 61.0 defg | 12 cd | 6.26 fghi |
| | 120 | 65.5 cdef | 29 bcd | 12.6 efgh |
| | 140 | 74.0 bcd | 56 a | 18.2 bcde |
| | 160 | 89.5 a | 33 bc | 26.4 abc |
| | 200 | 83.0 ab | 28 bcd | 30.3 a |
| | **Mean** | **60.1 a** | **25 a** | **12.8 a** |
| **LSD** | | 13.3 | 21.4 | 9.18 |
| **CV (%)** | | 11.7 | 50.6 | 38.2 |

*Means in a column followed by the same letter(s) are not significantly (p=0.05) different*

**Appendix 4: Effect of P sources and application rates on the number of flowers, fruits, trusses, marketable fruits and fruit weights**

| P Source | App. Rate (Kg P/ha) | No. of Flowers | No. of fruits | No. of trusses | Marketable fruits | Fruit weight (g plant$^{-1}$) |
|---|---|---|---|---|---|---|
| **CP** | 0 | 0 j | 0 h | 0 f | 0 k | 0.0 h |
| | 40 | 0 j | 0 h | 0 f | 0 k | 0.0 h |
| | 80 | 2 ij | 2 gh | 2 ef | 1 k | 8.7 h |
| | 100 | 10 ghij | 4 gh | 3 ef | 2 jk | 37.8 gh |
| | 120 | 17 fgh | 4 gh | 4 ef | 4 ij | 41.3 gh |
| | 140 | 20 efg | 6 fgh | 5 def | 5 hij | 104.3 fgh |
| | 160 | 39 c | 14 def | 10 bcd | 10 cde | 461.3 bc |
| | 200 | 51 b | 21 cd | 12 abc | 14 ab | 564.0 ab |
| | **Mean** | **17 c** | **6 c** | **4 b** | **4 c** | **152.2 b** |
| | | | | | | |
| **MPR** | 0 | 0 j | 0 h | 0 f | 0 k | 0.0 h |
| | 40 | 7 hij | 6 fgh | 3 ef | 2 jk | 14.1 h |
| | 80 | 11 ghij | 13 def | 6 cde | 6 fghi | 98.3 fgh |
| | 100 | 16 fgh | 15 de | 5 def | 6 fghi | 187.5 efg |
| | 120 | 22 def | 20 cd | 6 cde | 7 efghi | 216.7 ef |
| | 140 | 31 cd | 25 c | 7 cde | 7 efghi | 237.5 ef |
| | 160 | 39 c | 28 c | 7 cde | 7 efghi | 270.5 de |
| | 200 | 58 b | 48 a | 15 a | 9 def | 321.2 cde |
| | **Mean** | **23 b** | **19 b** | **6 ab** | **5b** | **168.2 b** |
| | | | | | | |
| **CP MPR** | 0 | 0 j | 0 h | 0 f | 0 k | 0.0 h |
| | 40 | 5 ij | 4 gh | 3 ef | 0 k | 0.0 h |
| | 80 | 12 fghi | 10 efg | 4 ef | 2 jk | 25.1 gh |
| | 100 | 17 fgh | 16 de | 5 def | 5 hi | 98.6 fgh |
| | 120 | 30 cde | 25 c | 7 cde | 9 efg | 282.8 de |
| | 140 | 40 c | 36 b | 13 ab | 12 bc | 402.8 cd |
| | 160 | 59 b | 48 a | 15 a | 12 bc | 467.4 bc |
| | 200 | 71 a | 53 a | 17 a | 16 a | 666.0 a |
| | **Mean** | **29 a** | **24 a** | **8 a** | **7 a** | **242.8 a** |
| | | | | | | |
| **LSD** | | 9.65 | 7.47 | 4.97 | 2.73 | 143.5 |
| **CV (%)** | | 20.2 | 21.8 | 40.4 | 23.8 | 37.0 |

*Means in a column followed by the same letter(s) are not significantly (p=0.05) different*

*according to the Duncan's new multiple-range test*

**Appendix 5: Effect of CP, MPR and CPMPR treatments on soil pH, organic carbon, total nitrogen and Bray1 extractable phosphorus at the end of the experiment**

| P source | Appl. Rate (kg P /ha) | pH (H₂O) | OC (%) | Total N (%) | Bray I P (mg/kg) |
|---|---|---|---|---|---|
| **CP** | 0 | 4.12 hij | 1.06 bcd | 0.03 f | 1.95 i |
| | 40 | 4.15 hij | 1.09 bcd | 0.21 ab | 2.17 hi |
| | 80 | 4.21 ghij | 1.17 abcd | 0.17 bcde | 2.17 hi |
| | 100 | 4.31 efgh | 1.23 abc | 0.17 bcde | 2.74 hi |
| | 120 | 4.37 defg | 1.28 abc | 0.19 bcd | 2.98 hi |
| | 140 | 4.51 cde | 1.33 abc | 0.19 bcd | 2.29 hi |
| | 160 | 4.62 bcd | 1.37 abc | 0.21 ab | 5.51 fghi |
| | 200 | 4.74 bc | 1.51 a | 0.26 a | 6.48 fgh |
| | **Mean** | **4.38 ab** | **1.26 a** | **0.18 a** | **3.29 b** |
| **MPR** | 0 | 4.01 j | 1.06 bcd | 0.03 f | 1.95 i |
| | 40 | 4.06 ij | 0.83 de | 0.15 bcde | 6.27 fghi |
| | 80 | 4.10 hij | 1.08 bcd | 0.13 cde | 6.61 fgh |
| | 100 | 4.27 fghi | 1.17 abcd | 0.14 bcde | 8.45 defg |
| | 120 | 4.37 defg | 1.17 abcd | 0.10 ef | 9.97 cdef |
| | 140 | 4.51 cde | 1.14 abcd | 0.12 de | 12.2 bcd |
| | 160 | 4.55 bcd | 1.17 abcd | 0.13 de | 15.3 b |
| | 200 | 4.67 bc | 1.10 bcd | 0.12 de | 20.9 a |
| | **Mean** | **4.32 b** | **1.09 b** | **0.12 b** | **10.2 a** |
| **CPMPR** | 0 | 4.01 j | 1.06 bcd | 0.03 f | 1.95 i |
| | 40 | 4.03 j | 0.95 de | 0.13 de | 4.14 ghi |
| | 80 | 4.17 ghij | 1.05 bcd | 0.13 cde | 5.78 fghi |
| | 100 | 4.26 ghi | 1.11 bcd | 0.12 de | 7.75 efg |
| | 120 | 4.47 cdef | 1.18 abcd | 0.13 de | 8.91 def |
| | 140 | 4.51 cde | 1.18 abcd | 0.12 de | 11.7 bcde |
| | 160 | 4.73 b | 1.19 abcd | 0.12 de | 13.6 bc |
| | 200 | 4.95 a | 1.45 ab | 0.14 bcde | 20.6 a |
| | **Mean** | **4.39 a** | **1.15 b** | **0.12 b** | **9.29 a** |
| **LSD** | | 0.19 | 0.33 | 0.022 | 3.87 |
| **CV (%)** | | 2.09 | 14.0 | 17.46 | 24.4 |

*Means in a column followed by the same letter(s) are not significantly (p=0.05) different according to the Duncan's new multiple-range test*

**Appendix 6: Effect of CP, MPR and CPMPR on the exchangeable bases and CEC of the Chromic Acrisol at the end of the experiment**

| P source | App. Rate (Kg P/ha) | Exchangeable bases and CEC ( Cmol(+) /kg) | | | |
|---|---|---|---|---|---|
| | | K | Ca | Mg | CEC |
| CP | 0 | 0.80 fg | 1.46 fghijk | 1.65 hi | 17.1 i |
| | 40 | 0.82 f | 1.43 jk | 1.74 fghi | 17.4 hi |
| | 80 | 0.91 e | 1.41 k | 1.93 defg | 17.9 ghi |
| | 100 | 1.12 d | 1.57 bcde | 1.86 defg | 19.4 efgh |
| | 120 | 1.30 c | 1.48 efghijk | 1.98 bcd | 19.9 defg |
| | 140 | 1.33 c | 1.44 ijk | 2.05 ab | 20.6 cde |
| | 160 | 1.52 b | 1.64 b | 2.08 ab | 21.9 bcd |
| | 200 | 1.80 a | 1.55 cdefg | 2.20 a | 21.6 bcd |
| | **Mean** | **1.20 a** | **1.50 b** | **1.94 a** | **19.4 b** |
| | | | | | |
| MPR | 0 | 0.80 fg | 1.46 fghijk | 1.65 hi | 17.1 i |
| | 40 | 0.82 f | 1.46 ghijk | 1.44 j | 16.9 i |
| | 80 | 0.82 f | 1.54 cdefgh | 1.70 ghi | 17.8 ghi |
| | 100 | 0.93 e | 1.55 cdef | 1.77 efgh | 18.0 fghi |
| | 120 | 0.74 gh | 1.56 bcde | 1.86 defg | 18.9 efghi |
| | 140 | 0.92 e | 1.58 bcd | 1.88 cdef | 20.7 cde |
| | 160 | 0.92 e | 1.58 bcd | 1.99 bcd | 22.1 bcd |
| | 200 | 0.83 f | 1.61 bc | 2.04 abc | 22.7 bc |
| | **Mean** | **0.85 b** | **1.54 a** | **1.79 b** | **12.3 b** |
| | | | | | |
| CPMPR | 0 | 0.80 fg | 1.46 fghijk | 1.65 hi | 17.1 i |
| | 40 | 0.71 h | 1.45 hijk | 1.59 ij | 19.3 efgh |
| | 80 | 0.73 gh | 1.49 defghijk | 1.66 hi | 19.9 defg |
| | 100 | 0.73 gh | 1.51 defghij | 1.73 fghi | 20.1 def |
| | 120 | 0.74 gh | 1.52 defghij | 1.85 defg | 20.6 cde |
| | 140 | 0.77 fgh | 1.53 cdefghi | 1.88 cdef | 22.0 bcd |
| | 160 | 0.80 fg | 1.57 bcd | 1.92 bcde | 23.3 ab |
| | 200 | 0.82 f | 1.72 a | 2.06 ab | 25.1 a |
| | **Mean** | **0.76 c** | **1.53 a** | **1.79 b** | **21.0 a** |
| | | | | | |
| LSD | | **0.07** | **0.08** | **0.15** | **1.91** |
| CV (%) | | **2.99** | **7.23** | **4.67** | **5.17** |

*Means in a column followed by the same letter(s) are not significantly (p=0.05) different*

*according to the Duncan's new multiple-range test*

**Appendix 7: Analysis of variance (ANOVA) table for the plant P contents**

| K Value | Source | Degrees of Freedom | Sum of Squares | Mean Square | F Value | Probability |
|---|---|---|---|---|---|---|
| 1 | Replication | 1 | 0.004 | 0.004 | 2.0329 | 0.1674 |
| 2 | Factor A | 2 | 0.115 | 0.057 | 27.7042 | 0.0000 |
| 4 | Factor B | 7 | 0.216 | 0.031 | 14.8872 | 0.0000 |
| 6 | AB | 14 | 0.044 | 0.003 | 1.5068 | 0.1857 |
| -7 | Error | 23 | 0.048 | 0.002 | | |
| | Total | 47 | 0.427 | | | |

Coefficient of Variation: 10.7%

**Appendix 8: Correlation of Plant P, K and Ca contents with some of the tomato yield variables**

| | Height (cm) | No. of leaves | DMY (g/pot) | No. of flowers | No. of fruits | Marketable fruits | Fruits weight |
|---|---|---|---|---|---|---|---|
| **P (%)** | 0.78** | 0.48 * | 0.67** | 0.77 ** | 0.82** | 0.70 ** | 0.65** |
| **K (%)** | 0.73 ** | 0.42 * | 0.82** | 0.82 ** | 0.66** | 0.79 ** | 0.77** |
| **Ca (%)** | 0.90** | 0.55 ** | 0.75** | 0.82 ** | 0.82** | 0.82** | 0.79** |

*** = Strong and positive correlation,  * Weak but positive correlation*