MINERALISATION AND BIOAVAILABILITY OF PHOSPHORUS FROM POULTRY MANURE AND SEWAGE SLUDGE-BASED PHOSPHO-COMPOSTS FOR MAIZE PRODUCTION

By

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DEDICATION

I dedicate this mini-dissertation to my beloved daughter, Nhlohlotelo, and to my parents, Mr. E.K. and Mrs N.E. Chauke.

DECLARATION

I declare that the mini-dessertation hereby submitted to University of Limpopo, for the degree of Master of Science Agriculture (Soil Science) has not previously been submitted by me for a degree at this or any other university; that it is my work in design and in execution, and that all material contained herein has been acknowledged.

Chauke R (Ms) 31 March 2014

Surname, Initials (title) **Date**

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ABSTRACT

Phospho-composts of different mix ratios (5:5, 7:3, 8:2 and 9:1) were produced through thermophilic co-composting of poultry manure (PM) and sewage sludge (SS) with ground phosphate rock (GPR). Composted PM and SS without GPR addition were included as control. Cured phospho-composts were chemically characterised and used for both laboratory incubation and greenhouse studies, respectively for phosphorus (P) mineralisation and bioavailability, over a period of 42 days. Results revealed that Bray-P1 concentration measured in compost amended soils at 14, 21 and 42 DAI differed significantly ($P<0.05$) and ranged between 5.47 and 11.14 mg kg^{-1} and between 5.28 and 11.78 mg kg^{-1} in poultry manure and sewage sludge-based phospho-composts, respectively. The maximum amount of cumulative P mineralised of 16.06 and 9.98 mg kg $^{-1}$, respectively in PM and SS-based phospho-composts were obtained from the 8:2 mix ratio. The content of the acid detergent fibre of the different phospho-composts showed positive and significant correlation with cellulose, lignin and total organic carbon (TOC). Similarly, cellulose as well as C:P ratio showed significant correlation with both lignin and TOC. The polynomial relationship between cumulative P mineralised and the various GRP and manure mix ratios revealed significant and positive R^2-values of 0.731 and 0.613 for PM and SS-based phospho-composts, respectively.

The maximum amount of maize tissue P uptake of 0.12 and 0.11 mg pot^{-1} in PM and SS-based phospho-compost respectively were also obtained from the 8:2 mix ratio while the least amount of 0.04 mg P pot^{-1} was obtained from GPR and unamended pots. Maize tissue P uptake following the phospho-compost application was significantly affected by the differences in soil type. Tissue P uptake was 0.06 and 0.11 mg P/pot, respectively in low potential and high potential soils with a significantly higher value. The use of the different phospho-composts showed great potential for amelioration of P-deficiency problems in crops while thermophilic co-composting improved the solubility and bioavailability of P from non-reactive GPR.

Keywords: Ground phosphate rock; poultry manure; sewage sludge; phospho-composts; phosphorus mineralisation; soil fertility management.

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CHAPTER 1

INTRODUCTION

1.1 Background information

The fertility status of any given soil is determined by the amount of essential nutrients present in that soil to support crop growth. Hence, the success of crop production in any given agricultural field will depend on the fertility status of the soil since crops require essential elements to complete their life cycle. South Africa soils are reported to be generally fragile and infertile (Mills and Fey, 2003; Odhiambo, 2011); hence, careful management of such soils is essential to obtaining high and sustainable crop yields. However, the little to no fertiliser use particularly by smallholder farmers often exerts negative effects on soil and crop productivity. This has been attributed to these farmers' resource-poor condition, the high cost of inorganic fertilisers and limited availability or sub-optimal use of organic manures. The development of cheaper alternative fertiliser nutrient sources to help overcome soil fertility problems on smallholding farmlands in South Africa is very crucial.

1.2 Problem statement

Reports of earlier studies carried out in Limpopo Province suggested that low soil phosphorus (P) is one of the major factors contributing to low productivity on most farmlands (Ramaru, 2000; Machethe *et al*., 2004; Kutu, 2008). The high prices of agricultural inputs such as fertilisers have limited the amount of fertiliser-use and hence, resulted in rapid decline in soil quality particularly in resource-poor farmers' fields following continuous cultivation. Furthermore, the efficiency of use of alternative fertiliser sources such as the sole application of animal manures is reduced due to limited availability, low nutrient content, slow release characteristics and poor synchrony between release and plant demand or uptake (Rosen and Bierman, 2005). Similarly, the potential for a direct use of P-rich nutrient material such as Phalaborwa ground phosphate rock (GPR) to address P deficiency problems in agricultural fields is constrained by its low reactivity and insolubility (FAO corporate document repository, 2003a; Barnard and Du Preez, 2004). The consequences of these problems are massive P deficiency, low crop yields and poor crop quality, acute food shortages leading to food insecurity and poor nutrition. Similarly, the quality of life and human health are compromised, particularly in many under-resourced rural households where there is widespread poverty and unemployment.

1.3 Motivation of the study

The recent sharp increases in the prices of agricultural inputs, particularly inorganic P fertiliser, have continued to limit their utilization on farmlands especially on smallholder farmlands. This calls for the development of cheaper alternatives through the use of locally available raw materials so as to help overcome the low soil-P status and availability problem on smallholder farmlands in Limpopo Province. The Foskor mining company, which is located in Phalaborwa, currently has an annual production capacity of 2.6 million tonnes for the mining and processing of P-rich phosphate rock that abounds in the Province. The mining of Phalaborwa Phosphate rock accounts for nearly 95 % of the country's production (Roux *et al*., 1998) while Foskor company produces nearly 34% of the phosphate rock used in the production of phosphorus fertilizer in the Southern African Development community (SADC) (van Straaten, 2002).

The use of P-rich GPR and organic materials have been regarded as agronomically and economically sound alternative P sources to the conventional use of expensive superphosphates (Binh and Zapata, 2002; Hellal *et al*., 2013). Co-composting of GPR with manures or biological wastes has also been reported to increase the solubility of non-reactive rock phosphates (Hellal *et al*., 2013). It is also considered as a low-input technology to improve the fertilizer value of manures. Effective utilization of this technology will allow for better and more effective management of the large volume of available biodegradable wastes that sometimes constitute problems in most poultry farms, waste treatment plants and in many communities. Furthermore, it will allow for the production of a safe, clean and easy-to-use single organic fertiliser product that is rich in P and can be used on farmlands to increase soil-P and guarantee healthy soil during crop production.

1.4 Purpose of the study

1.4.1 Aim

The aim of this study was to assess the suitability of poultry manure and sewage sludge as raw materials for increasing P release from non-reactive Phalaborwa GPR in the production of phospho-composts as cheaper P-source alternatives for maize production.

1.4.2 Objectives

i. Quantify the extent of P solubility and bioavailability from the different mix ratios of co-composted GPR, poultry manure and sewage sludge.

ii. Compare the rates and patterns of P release from the phospho-composts.

iii. Evaluate maize performance and residual soil-P content following application of the different phospho-composts.

1.5 Hypotheses

Three different hypotheses were tested that included:

i. The amount of P solubility and availability from non-reactive Phalaborwa GPR can be improved through thermophilic co-composting with poultry manure and sewage sludge.

ii. The rate and pattern of P release from phospho-composts produced from various bio-degradable organic wastes are affected by variation in chemical composition of the organic wastes.

iii. Maize performance and available soil-P level can be improved following application of poultry manure and sewage sludge-based phospho-composts.

CHAPTER 2

LITERATURE REVIEW

2.1 Maize production in Limpopo Province

Limpopo Province lies within the semi-arid environment. A greater portion of the region receives less than 600 mm of annual summer rainfall with high summer temperatures mostly between October and March; peaking in January (Thomas, 2004). Despite the harsh limitations imposed by the environment on agricultural productivity, several small-scale farming activities occur throughout the Province. Crop yields are marginal and continue to decline in most parts of the region (Machethe *et al*., 2004). Maize (*Zea mays* L.) is the most important grain crop in South Africa (Department of Agriculture, 2003), it constitutes a major staple food in many households; and also largely used in the production of animal feeds. The crop is a heavy feeder requiring large quantities of nutrients to guarantee a high yield; and often grows well under diverse environments. However, increased and sustainable maize production depends on the correct application of fertiliser so as to preserve soil fertility, ensure environmental sustainability and also guarantee increased productivity. On the basis of the area and volume of production, it remains the most important dry-land crop in South Africa (Thomas, 2004). Available statistics revealed that the total arable farmlands in Limpopo Province occupy 1 054 829 ha with maize being produced on only 25 000 ha (Thomas, 2004).

2.2 A review of soil fertility situation and management in South Africa

In South Africa, low soil fertility is the most limiting factor in crop production after drought, particularly on smallholder farmlands. Farmers working in areas with fertile soils also need to maintain the fertility of their soils, as frequent cropping depletes the soil of nutrients (Goldblaat, 2011). South African soils are extremely susceptible to degradation and have a low recovery potential (Blom, 2013). Soil degradation is a result of land use and it poses a threat to sustainable agriculture in South Africa (Du Preez *et al*., 2011). According to Maqubela *et al*. (2008), many soils in South Africa have low nutrient supply, poor structural firmness and are susceptible to soil erosion due to vulnerability to surface sealing and crusting. It is estimated that 25% of South Africa's soils are highly prone to wind erosion. This is particularly true of sandy soils of the North West and Free State, which produce 75% of the country's maize (Goldblaat, 2011). South African soils have low organic matter levels. About 58% of soils contain less than 0.5% organic carbon and only 4% contain more than 2% organic carbon (Du Preez *et al*., 2011; Maqubela *et al*., 2008). Similarly, most of arable lands in Limpopo province are described as inherently infertile (Ramaru *et al*., 2000). According to Odhiambo (2004), poor soil fertility on smallholder farmlands in Limpopo province is the result of inherently poor soil types, continuous cultivation, soil erosion and high cost of inorganic fertiliser that compelled under-resourced smallholder farmers to rely solely on the use of animal manures and intercropping/crop rotation for soil fertility management. Mulvany *et al*. (2009) reported that poor application of fertiliser such as synthetic fertilisers also reduces soil fertility and promotes soil degradation while the exclusive use of synthetic fertiliser leads to decline in soil organic matter and soil life.

2.3 The role of phosphorus and its deficiency symptoms in maize

Phosphorus is a nutrient that is required in relatively large amounts by plants. It is considered as an immobile nutrient compared with N since it has a relatively short range of movement in the soil (McKenzie and Middleton, 1997). Efficiency of P uptake is enhanced by the availability of soil moisture (Monsato, 2010); hence, dry soil conditions can negatively impact on P uptake by the root system. Plants need P for growth throughout their life cycle, especially during the early stages of growth and development. The primary role of P compounds in plants is to store and transfer energy produced durig photosynthesis for use in growth and reproduction. Early-season P uptake is often useful for crop establishment but later redirected for reproduction (McKenzie and Middleton, 1997). Adequate P levels are required to enhance shoot and root growth, promote early maturity, increase water-use efficiency and yield potential. When P level is inadequate, maize cannot grow, produce or sufficiently tolerate stresses (Monsato, 2010). On well fertilised soils, skipping or reducing P fertiliser application for one year may have minimal impact on yield potential in many cases due to the “banked” levels of P (Dekalb, 2011). Corn plants increase P uptake rapidly after the V6 growth stage of development, which is about four to six weeks after corn planting. The uptake can continue until near maturity (Ritchie *et al*., 1997). The symptoms of P deficiency in maize include stunted plants and lower maize leaves turn purple (Monsato, 2010). The symptoms appear first on the lower leaf tips and extend down the margins toward the leaf base. Leaf edges may become brown and lower leaves often die when P deficiency is severe, especially during hot, dry, and windy conditions. In addition, stalks may be thin and short and maturity can be delayed (Draper *et al*., 2009).

2.4 Characterisation and utilisation of poultry manure as plant nutrient source

The utilization of poultry manure as an organic fertiliser is essential in improving soil productivity and crop production (Dikinya and Mufwanzala, 2010). Poultry manure is an excellent source of nutrients and can be incorporated into most fertiliser programmes (Zublena *et al*., 1997). The nutrient composition of poultry manure varies with the type of bird, the feed ration, the proportion of litter to droppings, the manure handling system, and the type of litter (Zublena *et al*., 1997). The need and utilisation of poultry manure has overtaken the use of other animal manure (e.g. pig manure, kraal manure) because of its high content of nitrogen, phosphorus and potassium (Dikinya and Mufwanzala, 2010). Besides its important nutrient content, it represents a cheaper alternative to the conventional inorganic fertilisers used in crop production. The efficient use of poultry litter also helps to reduce the environmental problems that are normally associated with its disposal near poultry production farms (Hirzel and Walter, 2008). It is a potential source of plant available P and thus presents a viable option for supplying P to sustain maize plants in the smallholder farming sector of South Africa (Materechera and Morutse, 2009).

2.5 Characterisation and utilisation of sewage sludge as plant nutrients source

Composts from organic wastes, such as sewage sludge, can improve the availability of nutrients; moreover, it increases the soil’s cation exchange capacity (Vaca *et al*., 2011). Sewage sludge obtained from the treatment of municipal wastewater is characterised by a high content of organic matter, N, P, K, Ca and Mg as well as the presence of some potentially toxic compounds particularly heavy metals or trace elements that may potentially cause toxicity in the food chain (Kidd *et al*., 2007). Nonetheless, sewage sludge had been reported to contain important trace elements such as Zn, and Cu that are considered very essential nutrients for plants (Vaca *et al*., 2011).

The variation in P composition of sewage sludge is explained largely by the combination of treatment processes (Gestring, 1982; Frossard, 1996). Yet, limited studies have conducted to provide a quantitative evaluation of differential P sorption and availability characteristics of sewage sludge as sources of P in soil (Siddique and Robinson, 2003). Most of the earlier reported studies have revealed that soil amendments of sewage were often based on N content and/or at excessive rates (Reddy, 1980). A study by Siddique (2000) correlated the relatively low rate of P leached from sludge-amended soils to the low rate of P saturation of sorption sites in the soil and the relatively low (8%) water solubility of P in the sludge. Earlier researchers have reported that organic sources can modify the P sorption characteristics of soils around the application zone with implications for the P movement to greater soil depths (Reddy, 1980; Gerritse, 1981). Consequently, there is increasing concern about soil-P enrichment and the subsequent potential losses following repeated and long-term application of sewage sludge to agricultural land (Rydin, 1997; Siddique, 2000).

2.6 Phospho-composting technology for increasing P solubility in non-reactive GPR

Phospho-composting is based on the sound scientific principles of thermophilic composting process through intense microbial activities that take place during decomposition of organic materials (FAO corporate document repository, 2003a). The process results in the proliferation of numerous types of bacteria and fungi that produce a large number of organic acids and humic substances and helps in the mineralisation and release of P in the GPR (Stevenson, 1967). However, the effectiveness of the composts in solubilising GPR differs with the kind and composition of waste materials and with the rate of decomposition (Mahimairaja *et* *al*., 1995). It is a function of the magnitude of production of organic acids and the chelating substances in the compost that result from the metabolic activities of microorganisms present in the compost heap, which include bacteria, fungi and actinomycetes (Mahimairaja *et al*., 1995). Thus, treating GPR with organic materials through composting them is a promising technique for enhancing the solubility and the subsequent availability to plants of P from the GPR (Bangar *et al*., 1985). Though technologies for the direct application of GPR have already been proved under a variety of agro-ecological conditions, their agronomic effectiveness depends largely on a range of factors and their interactions (FAO corporate document repository, 2003a).

2.7 Chemical composition of organic materials in relation to their nutrient release

Composting is the natural process of decomposition of organic materials by the action of microorganisms under controlled conditions. The chemical compositions of raw organic materials such as crop residues, animal wastes, food garbage, treated municipal and industrial wastes affect their suitability for application to the soil as a fertilising resource after composting (FAO corporate document repository, 2003b). Micro-organisms require carbon (C), N, P and potassium (K) as the primary nutrients. Of particular importance is the C:N ratio of the raw materials, which is considered optimum at between 25:1 and 30:1; although ratios between 20:1 and 40:1 are also acceptable (Raabe, 2001). The growth of micro-organisms is limited when the ratio is higher than 40:1 and often results in a longer composting time while a ratio of less than 20:1 leads to underutilisation of N and the excess may be lost to the atmosphere (Raabe, 2001). The C:N ratio of the final product should be between about 10:1 and 15:1 (Raabe, 2001).

Aerobic composting can be affected by polyphenols, hydrolysable and condensed tannins (Schorth, 2003), which are considered as inhibiting factors. The presence of insoluble condensed tannins bind the cell walls and proteins and make them physically or chemically less accessible to decomposers. Soluble condensed and hydrolysable tannins react with proteins and reduce their microbial degradation and thus N release (Zhang *et al*., 2013). Thus, Palm *et al*. (2001) suggested that the contents of these chemical substances can be used to classify organic materials for more efficient on-farm natural resource utilization, including composting.

2.8 Organic phosphorus mineralisation studies and bioavailability

Soil organic P occurs in different chemical forms. Soil microorganisms play an important role in recycling many of the organic P compounds in soils (Helmke *et al*., 2000). During P cycling, once in solution, the P incorporated into the system is converted to secondary inorganic P and organic P forms, some of which are of limited availability to plants and microbial communities. These forms can be affected by chemical and biochemical processes including sorption-desorption (oxidation-reduction) and mineralisation-immobilization (Chirino-Valle, 2013). Soil organic P mineralisation is an important microbiologically controlled process in P cycling (Oehl *et al*., 2001). Early research reports indicated that most of the mineralisable organic P in soils is in the form of phytic acid (Helmke *et al*., 2000) which is the main compound that plants use to store P in seeds to support early seedling growth upon germination. The complexity of this mixture of compounds and the interaction of soil microorganisms with soil organic compounds has prevented the development of an analytical procedure than can measure the quantity and availability of organic P in soils (Helmke *et al*., 2000; Oehl *et al*., 2001). The current approach used to estimate the amount of organic P in soils subtracts the amount of inorganic from the total P (He, 1998). The absence of suitable analytical procedures for the quantification of soil organic P coupled with the limited knowledge on the rates and mechanisms for the mineralisation of soil organic P has resulted in fertility management practices that often ignore or minimize the contributions made by this fraction of the total phosphorus in soils (Helmke *et al*., 2000).

CHAPTER 3

RESEARCH METHODOLOGY

3.1 Description of the study site

The study involved three different stages namely phospho-composts preparation, laboratory incubation for P mineralisation study and agronomic evaluation of the phospho-composts produced through a greenhouse study. The phospho-compost preparation was done at the experimental farm of School of Agriculture and Environmental Sciences Syferkuil (23°50’36.86”S and 29°40’54.99”E), University of Limpopo.

3.2 Preparation of phospho-composts and sampling for laboratory determinations

Materials used for the phospho-composting included poultry manure, sewage sludge and GPR. Poultry manure was obtained from a nearby poultry farm while the sewage sludge was collected from Polokwane Municipality waste treatment plant. The GPR used (36.5% P_2O_5) was obtained from Foskor mining company, Phalaborwa. Different mix ratios (5:5, 7:3, 8:2 and 9:1) of the sewage sludge and poultry manure with the GPR were prepared on a concrete floor based on the dry weight of the organic materials. The control compost (10:0) for each organic material with no ground phosphate addition was also included. However, sewage sludge phospho-compost with a mix ratio of 5:5 was not included in this study due to insufficient ground P rock. Thus, a total of nine phospho-composts were produced through the thermophilic process using the windrow composting. The composts were turned every two weeks to provide satisfactory aeration. The moisture content of the composts was maintained beneath the water-holding capacity during the composting period so as not to slow down microbial activities. The co-composting process was continued for 3 to 4 months to achieve proper curing.

Samples from the phospho-composts taken when cured together with the organic wastes used for the composting process were subjected to detailed chemical characterisation and quality indices determinations. Such determinations included total C and N using the LECO C/N analyser (LECO Corporation 2003), P content as described by Okalebo et al. (2002), tannin, lignin, cellulose and polyphenols using the neutral detergent fibre (NDF) and acid detergent fibre (ADF) methods (Goering and Van Soest 1970). The materials were also subjected to trace element determinations (Zn, Cu, Fe, Mn, Cr, Ni and Pb) following nitric acid digestion method according to the procedure described by Hseu (2004).

3.3 Incubation and P mineralisation of the phospho-composts

The different phospho-composts were each weighed and thoroughly mixed with 1.2 kg surface soil with no recent history of organic amendment at an equivalent rate of 100 kg P ha^{-1} soil. Prior to the mixing, the soil was passed through a 2 mm sieve so as to remove all foreign materials including stones. Thereafter, the soil was transferred into individual well labelled small plastic pots for incubation in the laboratory under a controlled temperature of between 15 and 25^{0}C. Additional 1.2 kg soil without organic amendment was also incubated as control for the purpose of comparison. Prior to the placement of the phospho-compost amended soils in the incubation chamber, calculated amount of water was added just to keep the amended soil moist. This was maintained throughout the incubation period by checking the weight of the pots on weekly basis and adding water as needed to adjust the weight back to the original level. The pots were, however, left opened to allow for free air exchange while the incubation process lasted for 42 days. Soil sampling for P determination was done at 7, 14, 21, 28, 35 and 42 days after incubation (DAI).

3.3.1 Determination of net P mineralisation and/or immobilisation

The amount of extracted P during each sampling date was measured as Bray-P1. The net P mineralisation and/or immobilisation indicated by positive and negative values, respectively from amended soil were estimated as the difference between the extracted P in the amended and control or unamende soil. On the other hand, the cumulative P mineralised was calculated as the sum of all previous measurements over the incubation period.

3.4 Procedure for Bray-P1 extraction and colour development for P determination

3.4.1 Preparation of Bray-P1 solution for soil P extraction

Available P in 2 mm sieved soil samples was determined from 6.67g sub-sample in each representative sample using the Bray-P1 procedure (Bray and Kurtz, 1945). Prior to weighing the soil sub-sample, Bray-P1 solution was prepared by mixing 30 mℓ of NH_4F solution (37 g of NH_4F dissolved in one litre distilled water) with 50 mℓ of HCl in a 1000 mℓ volumetric flask; and then it was filled to the mark using deionised water. The weighed soil was then transferred into a 250 mℓ Erlenmeyer flask and 50 mℓ of Bray-P1 solution added. The mixture was shaken manually for 60 seconds then the extract was filtered through 42 mm Whatman filter paper. The extraction for P determination was done in duplicate.

3.4.2 Preparation of Reagents A and B for colour development

The preparation of reagent A was achieved by first dissolving 12 g of ammonium molybdate in 250 mℓ of distilled water. Similarly, 0.2908 g of antimony potassium tartrate was dissolved in a separate 100 mℓ of distilled water. Both reagents were mixed with 2.5 N sulphuric acid (148 mℓ concentrated sulphuric acid to 1 ℓ) in a 2 ℓ volumetric flask and distilled water was added to make the mark. Preparation of Reagent B was done by dissolving 1.056 g of ascorbic acid into 200 mℓ of reagent A.

3.4.3 Preparation of stock and standard P solutions and reading of P concentration

A P-stock solution of 250 ppm was prepared using 0.549 g KH_2PO_4 in a 500 mℓ volumetric flask and distilled water added to the mark. Standard solutions containing various P concentrations (0, 0.5, 1, 2.5, 5, 10 and 12.5 ppm) were prepared using the stock solution. Approximately 100 mℓ Bray-1 solution were added to 0, 1, 2, 5, 10, 20 and 25 mℓ of the standard P stock solution and made to 500 mℓ mark with distilled water. The colour development in standard P solutions and samples were done by mixing 5 mℓ of each of the standard solutions and sample extract, 3 mℓ distilled water and 2 mℓ reagent B; and thoroughly mixed together. These were left to stand for 30minutes so as to allow for the full development of the molybdenum blue colour and the absorbance subsequently read on T60 UV-visible spectrophotometer at a wavelength of 882 nm.

3.5 Greenhouse and bioavailability study on the phospho-composts

Bioavailability of P from the different phospho-composts produced was assessed in a greenhouse study using maize as the test crop. The various phospho-compost treatments were applied at 60 kg P ha^{-1} with a control (P0) and reference standard inorganic P check treatment (Pi) included. Inorganic N fertiliser was applied at 80 kg N ha^{-1} using urea to balance N variation in the phospho-composts. Two well characterized surface soils (0–20 cm depth) with different characteristics (medium and low clay-content; strongly acidic to basic condition but low in P) were used for the study. The soils were air-dried, homogenized and sieved through a 4 mm size sieve and transferred into 12 kg pots. Soil-filled pots containing the various treatments were thoroughly mixed and arranged in a completely randomized design (CRD) with four replicates. Four maize seeds were sown per pot but thinned to two at two weeks after plant emergence. Growth and plant tissue P were determined from the maize plants while residual soil P was also determined after crop harvest. The trial was terminated after 42 days.

3.6 Procedure for plant tissue P extraction and colour development

3.6.1 Sample preparation and dry ash procedure for plant tissue P analysis

The plant tissue samples were finely ground after drying and 1 g of each dried plant tissue weighed into a porcelain crucible for ashing in a muffle furnace at 500 ºC for 2 to 4 hours. Ashed samples were allowed to cool and dissolved (extract) in 5mℓ of 20 % 2 M HCl. The 2 M HCl solution was prepared from 32 % HCl (stock solution) by adding 95 mℓ of stock HCl to 125 mℓ de-ionised water in a 500 mℓ volumetric flask then filled to the mark with de-ionised water.

Table 1: Selected chemical properties of the soil used for greenhouse study

Chemical characteristics	HP soil	LP soil
% sand	68	93
% Clay	11	3
% Silt	21	4
Soil texture	Sandy loamy	Sandy
% Organic carbon	0.48	0.32
pH (H_2O; 1:2.5)	8.00	7.50
Phosphorus (mg/kg)	6.35	4.58
Mineral N (mg kg^{-1})	35.95	39.87

HP= High potential,   LP = Low potential

3.6.2 Colorimetric determination of P in plant digest

3.6.2.1 Preparation of reagents

Two separate solutions (1 & 2) were prepared and used for colour development. Solution 1 was prepared by dissolving 20 g NH_4-molybdate [$(NH_4)_6$ $Mo_7O_24.H_2O$] in 200 mℓ hot water and left to cool. Solution 2 was prepared by dissolving 1 g of NH_4-metavanadate separately in 120 mℓ hot water, cooled, and 140 mℓ of concentrated HNO_3 was gradually added under fume cupboard. The molybdate solution (solution 1) was gradually mixed with the metavanadate solution in a 1000 mℓ volumetric flask, diluted to the mark with distilled water and used for the colour development.

3.6.2.2 Preparation of P-stock and standard P solutions

Phosphorus stock solution of 100 ppm P was prepared by dissolving 0.4394 g of dry anhydrous KH_2PO_4 in distilled water and then made to 1ℓ in a volumetric flask. Phosphorus standard solution of 25 ppm P was thereafter prepared by pipetting 25 mℓ of the 100 ppm P stock solution into a 100 mℓ volumetric flask and made up to the 100 mℓ mark using distilled water.

3.6.2.3 Preparation of standard curves

An amount of 0, 2, 4, 5, 10, 15, and 20 mℓ of the 25 ppm P standard solution were pipetted into a series of 100 mℓ volumetric flasks, and 20 mℓ of Vanado molybdate reagent was added. These were made to a mark using distilled water with thorough mixing; and thereafter left to stand for 10 minutes for colour development. The percent transmittance at 400 nm was thereafter determined using the T60 UV-visible spectrophotometer.

3.6.2.4 Phosphorus determination in sample digests

Five milliliters of sample digest was transferred into a 100 mℓ volumetric flask and 20 mℓ of vanado molybdate reagent was added and made to the mark by using distilled water. The mixture was well shaken and allowed to stand for 10 minutes and the percentage transmittance read as specified above. The percent P content in the sample was thereafter calculated from the standard curve using the following formula:

% P in sample = (CxVxf)/W

where: C = concentration obtained using the equation derived from the graph for the standard curve, V = volume after ashing, f = dilution factor used for colour development i.e. 5 mℓ extract made up to 100 mℓ mark (100/5) = 20); W = weight of sample that was ashed, V = final volume used for ash solubilisation, which was 50.

3.7 Data analysis

Growth and yield data on maize, soil available P and P mineralisation data as well as plant tissue-P data generated from the different phospho-composts were subjected to analysis of variance (ANOVA) using Statistix 8.1 software. This was followed by the use of Tukey HSD post-hoc test ($\alpha \leq 0.05$) to carry out the mean comparison. Simple and multiple correlation and regression analyses were run between the net cumulative mineralised and/or immobilised P after the 42-day incubation period and the various chemical constituents and quality parameters of the different phospho-composts.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Chemical characterisation of the wastes and different phospho-composts

The total P content of the various phospho-composts produced increased with the increasing GPR addition, while the total N content decreased with an increase in GPR addition (Table 2). The content of total P ranged from 3.48% to 8.92% in PM-based phospho-composts but varied between 0.77% and 6.28% in SS-based phospho-composts. The total N content ranged from 0.04% to 0.1% in PM-based phospho-composts and from 0.15% to 0.22% in SS-based phospho-composts. The total P content was quantitatively higher in PM-based than in the SS-based phospho-composts while the reverse was the case with the total N content. There was a decrease in the content of lignin, cellulose, tannin and polyphenols of the various phospho-composts after the co-composting process relative to the contents of the composted original organic wastes. Total N content increased with the decrease of both condensed tannins and polyphenols, it also increased with the increase of lignin and cellulose. Hellal *et al*. (2012) reported that the total P content increases due to the addition of rock phosphate as compared to untreated compost. The higher total P content in the PM-based than SS-based phospho-composts reported in this study may be attributed to the higher P content in poultry manure than sewage sludge. This is in agreement with the earlier study reported by Dikinya and Mufwanzala (2010) who indicated that the need for and utilization of poultry manure has overtaken the use of other animal manures such as pig and kraal manures due to its higher N, P and K contents.

The presence of high polyphenol and tannin contents bind the cell walls and proteins and thus make them physically or chemically less accessible to decomposers (FAO corporate document repository, 2003b). Soluble condensed and hydrolysable tannins react with proteins and reduce their microbial degradation and thus N release (Zhang *et al*., 2013). The co-composting process reduced the content of polyphenols and tannin, thus resulted in increased levels of N release. Lignin complex chemical structure makes it to be highly resistant to microbial degradation and it reduces the bioavailability of other cell wall constituents making the C:N ratio lower (FAO corporate document repository, 2003b). Thus, the low value of C/N and C/P ratios in any of the phospho-composts confers superiority in terms of N and P mineralisation potentials. The polyphenol and lignin contents appeared to be the most inhibiting factors during aerobic composting; hence, Palm *et al*., (2001) suggested that their content must be used to classify organic materials for more efficient on-farm natural resource utilization, including composts.

The different phospho-composts contain variable levels of trace elements (Table 3). The level of Arsenic (As), Hg, Cu, Au and Ni elements in phospho-compost were low and fall within the range for compost described by European virtual institute for specification analysis as reported by Bolan *et al* (2010). Nonetheless, low concentration of Hg, Au, Ag and uranium was reported to be toxic to plant (Lambers *et al*., 1998). Accumulation of trace element has been reported to retard seedlings and growth in corn (Singh and Mishira, 1987). Elevated level of Cu, Ni and Pb was observed in SS-based than PM-based phospho-composts while a quantitatively higher level of Mn and Cu was obtained in PM-based than SS-based phospho-composts. High concentration of Pb in soil has been reported to exert an antagonistic effect on mineral uptake and physiological function of plants (Epistein, 1972). These could exert a negative effect on plant growth, dry matter accumulation and yield (Wyszkowski *et al*., 2004).

The concentration of trace elements in phospho-composts play an important role in the nutrition of maize due to the potential toxic effect (Lambers *et al*., 1998) and the consequence negative implication on growth and yield. For instance, Black (1957) reported that as little 4 mg kg^{-1} of Mn could results on maize yield depression. However, the high level of Mn in the phospho-composts did not exert such negative impact on maize plants. The detection limit of As concentration was poor possibly due to interference by the presence of high Fe concentration in all the compost samples (Hartley *et al*., 2009). A generally high content of Fe, Mn and Zn was obtained in all the phospho-composts and they are considered as essential nutrients for plants. The value of Zn obtained in this study was comparable to that reported by Vaca *et al*. (2011) in the sewage sludge and its phospho-composts considering the maximum permissible limit of 420 mg kg^{-1} set as Mexican standard.

4.2 Incubation and P mineralisation study of the phospho-composts

The amount of P measured in amended and un-amended soil following 42 days incubation period differed significantly ($P<0.05$) on days 14, 21 and 42 (Table 4). The highest amount of 15.12 mg P kg^{-1} was measured at 7 DAI while the lowest amount of 5.28 mg P kg^{-1} was measured at 21 DAI. The highest amount of 15.12 mg P kg-1 was measured at 7 DAI from soil amended with PM 8:2 mix ratio, while the lowest amount of 5.28 mg P kg^{-1} was measured at 21 DAI from un-amended soil. Soil amended with 8:2 PM and SS-based phospho-composts gave the highest P throughout the incubation period.

The amount of P mineralised from each phospho-composts during the 42 days incubation period did not differ significantly ($P<0.05$) but the total cumulative mineralised P at 42 DAI differed significantly ($P<0.05$). The Amount of P mineralised from each phospho-compost decreased with increase in time (Figure 1). The maximum amount of P mineralisation was obtained during the first 21 days of incubation; although P immobilization was observed at 28 and 35 DAI although the P immobilization of -0.68, -0.04 and -0.05 was observed at 28 DAI from PM 10:0, 7:3 and SS 7:3 mix ratios respectively and -0.09 and -0.1 was observed at 35 DAI from PM and SS 10:0 mix ratios respectively. The hghest cumulative P mineralised of 16.06 and 9.98 mg kg^{-1} in PM and SS-based phospho-compost respectively were obtained from the 8:2 mix ratios during the 42 days of incubation (Figure 2).

Table 2: Percent chemical composition of the different phospho-composts produced

Phospho-composts mix ratio	Total organic carbon	Total P	Total N	Tannin	Total Polyphenols	NDF	ADF	Lignin	Cellulose	C:N	C:P
PM10:0	5.83	3.48	0.14	0.06	0.08	33	25	5	21	42	1.68
PM5:5	6.74	8.92	0.04	0.06	0.05	59	9	2	7	169	0.76
PM7:3	1.55	8.84	0.08	0.03	0.05	54	14	4	9	19	0.18
PM8:2	2.66	6.58	0.06	0.02	0.16	40	19	4	14	44	0.40
PM9:1	3.71	5.53	0.10	0.21	0.11	33	19	3	15	37	0.67
SS10:0	12.68	0.77	0.24	0.00	0.01	46	48	18	30	53	16.45
SS7:3	9.68	6.28	0.22	0.12	0.08	50	23	8	16	44	1.54
SS8:2	6.31	3.96	0.15	0.12	0.07	53	42	14	29	43	1.59
SS9:1	10.42	2.51	0.17	0.08	0.02	49	46	11	34	61	4.15

PM= Poultry manure, SS= Sewage sludge, NDF = Neutral detergent fibre, ADF = Acid detergent fibre

Table 3: Selected trace element concentration (mg kg^{-1}) in the different phospho-composts

Phospho-composts mix ratio	As	Hg	Co	Au	Ni	Zn	Cu	Fe	Mn	Cr	Pb
PM10:0	< 10	< 0.8	3.81	< 0.2	43	302	73	2242	921	69	13
PM5:5	<4	< 0.15	1.83	< 0.1	38	180	41	2034	493	57	35
PM7:3	<7	< 0.3	2.16	< 0.15	42	210	39	2081	589	63	33
PM8:2	< 7	< 1	2.74	< 0.2	40	239	49	2167	680	77	34
PM9:1	< 10	< 0.8	3.43	< 0.2	43	268	60	2245	804	82	33
SS10:0	< 10	0.99	4.10	< 0.15	58	334	95	2501	218	10	47
SS7:3	< 10	< 0.8	2.27	0.19	52	284	74	2401	213	11	49
SS8:2	< 15	< 1	2.87	0.23	51	285	73	2395	179	12	52
SS9:1	< 6	< 1	2.38	0.20	52	285	76	2396	179	13	62

PM= Poultry manure *SS= Sewage sludge*

Table 4: Amount of P (mg/kg) measured in amended and un- amended soil during the 42-day incubation period

Phospho-composts mix ratio	Day after incubation					
	7	14	21	28	35	42
PM10:0	10.51a	7.98ab	5.47ab	8.23a	7.01a	7.79ab
PM5:5	11.92a	8.44ab	6.37ab	10.13a	8.89a	9.77a
PM7:3	12.65a	9.42a	5.89ab	8.87a	8.73a	8.26ab
PM8:2	15.12a	9.58a	7.18a	9.76a	8.52a	9.58ab
PM9:1	10.42a	9.10ab	6.29ab	9.31a	7.44a	8.87ab
SS10:0	10.90a	8.03ab	5.69ab	10.19a	6.96a	7.77ab
SS7:3	9.01a	9.22a	5.94ab	8.86a	7.97a	8.17ab
SS8:2	11.14a	9.74a	6.18ab	9.35a	8.30a	8.95ab
SS9:1	11.76a	9.23a	6.30ab	8.99a	7.31a	8.02ab
Control	7.88a	7.33b	5.28a	8.91a	7.11a	7.17b

Means followed by the same letter in each column for each time duration are not significantly different at P<0.05; PM= Poultry manure, SS= Sewage sludge

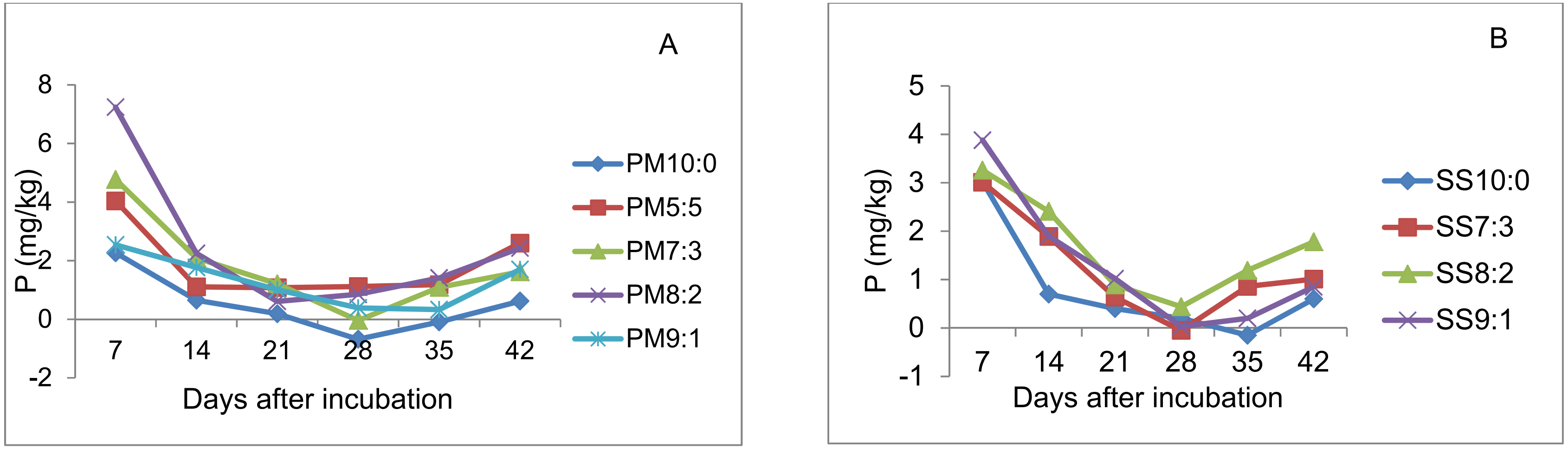

Figure 1: Concentration of P (mg/kg) mineralised from (A) poultry manure (PM)- and (B) sewage sludge (SS)-based phospho-composts during each sampling date over the 42 days incubation period

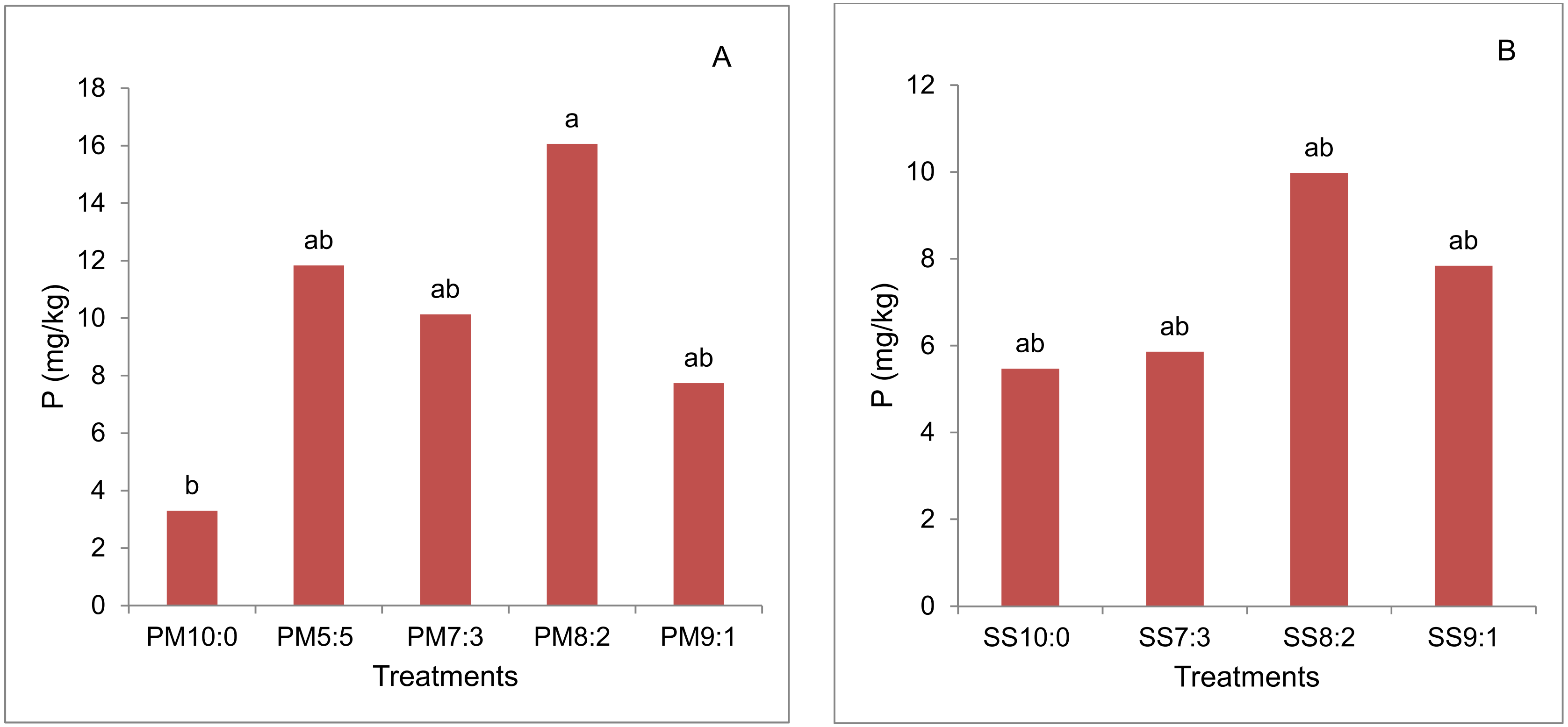

Figure 2: Concentration of cumulative P (mg P kg-1) mineralised from (A) poultry manure (PM)- and (B) sewage sludge (SS)-based phospho-composts over 42 DAI

4.3 Correlation and regression analyses of the net cumulative P mineralised with compost chemical composition

A significant and positive linear relationship ($p<0.05$) was obtained for the total cumulative P mineralised with neutral detergent fibre (NDF) as well as the total polyphenol content of the various phospho-composts; with a regression coefficient (R^2) value of 0.654 (Table 5). The observed P mineralised values from the various mix ratios were higher in the PM-based than the SS-based phospho-composts. This was confirmed by a slightly lower R^2-values (PM = 0.731; SS = 0.613) obtained from the polynomial relationship between cumulative P mineralised and the various phospho-compost mix ratios (Figure 3). The total P content of the phospho-composts showed negative but significant correlation with ADF, cellulose, C:P ratio and lignin contents while total organic carbon correlated positively with ADF, cellulose, C:P ratio and lignin contents (Table 6). The content of TOC also showed negative but significant correlation with the total polyphenol and total P content. Hellal *et al*. (2012) reported that the total P content mineralised increased on decomposition and the increase was proportional to loss in organic matter during decomposition. There was a positive significant correlation between ADF and cellulose, lignin and TOC while cellulose showed significant and positive correlation with lignin and TOC. The results further showed a positive and significant ($p\leq0.05$) correlation between TOC and cellulose, C:P ratio and lignin content (Table 6).

Table 5: Linear regression analysis for cumulative P mineralised with NDF and total polyphenol contents of the different phospho-composts

Predictor variables	Coefficient	Standard error	T-statistic	P-value
Intercept	-10.7420	6.41009	-1.68	0.1448
NDF	0.30969	0.11578	2.67	0.0368
Total Polyphenol	72.6115	23.2935	3.12	0.0207

NDF= Neutral detergent fibre

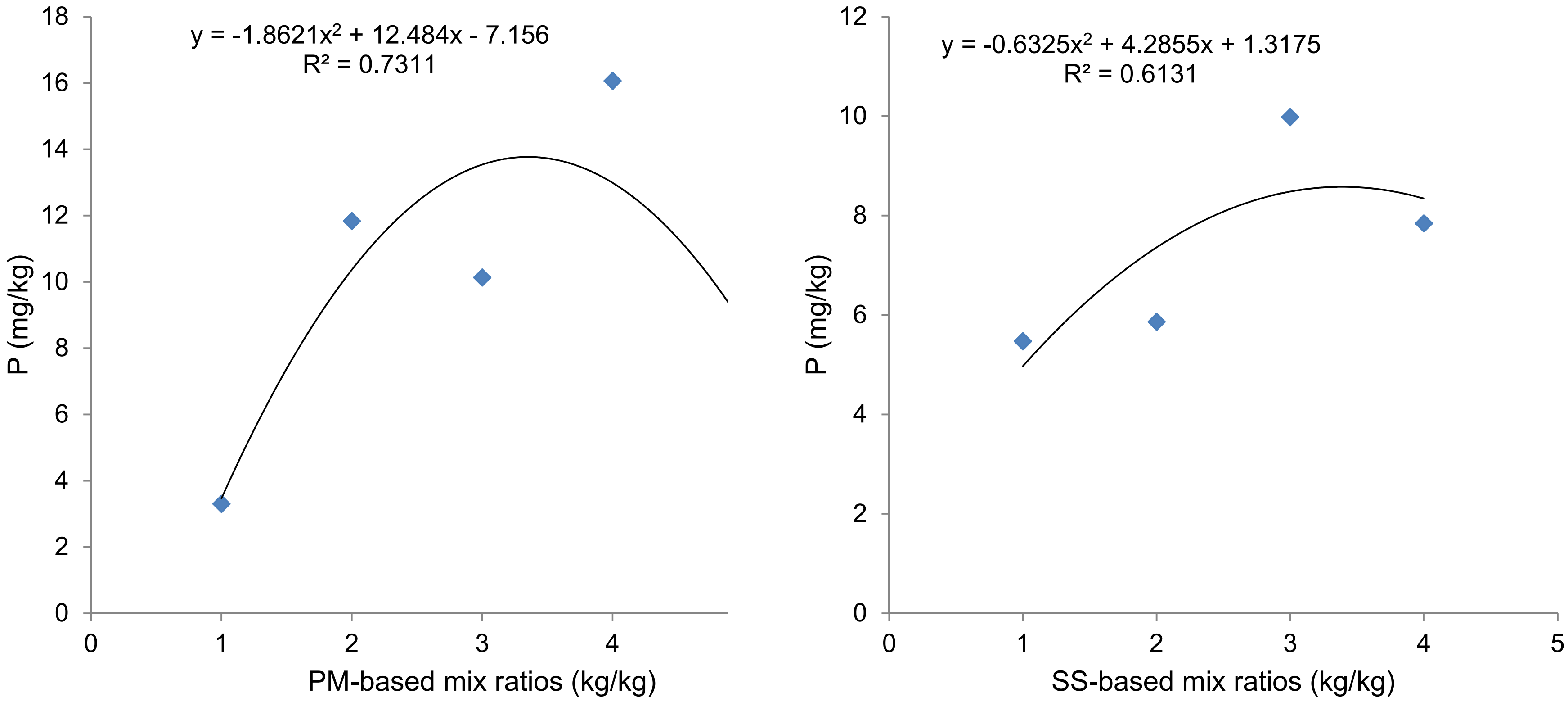

Figure 3: Optimum phosphorus (P) mineralised from the various phospho-compost mix ratios

(*Poultry manure, PM: 1 = 10:0; 2 = 5:5; 3 = 7:3; 4 = 8:2 & 5 = 9:1; Sewage sludge, SS: 1 = 10:0; 2 = 7:3; 3 = 8:2 & 4 = 9:1*)

Table 6: Pearson correlation matrix for different chemical properties of phospho-composts, total P and cumulative P mineralised (mg/kg)

Parameters	ADF	Cellulose	C:N	C:P	Lignin	NDF	TOC	Tannin	TPOL	Cum P
ADF										
Cellulose	0.981***									
C:N	-0.277	-0.278								
C:P	0.684	0.578	-0.030							
Lignin	0.930**	0.848**	-0.2235	0.787						
NDF	-0.013	-.0110	0.481	-0.003	0.171					
TOC	0.704*	0.663*	0.218	0.741*	0.741*	0.198				
Tannin	-0.100	-0.022	-0.117	-.0.422	-0.208	-0.270	-0.129			
TPOL	-0.508	-0.450	-0.231	-0.591	-0.561	-0.509	-0.662*	0.262		
TP	-.0.910***	-0.923***	0.300	-0.726*	-.0.801**	0.366	-0.682*	0.060	0.378	
Cum P	-0.383	-0.416	0.247	-0.398	-0.355	0.304	-0.534	-0.201	0.490	

ADF= Acid detergent fibre; NDF = Neutral detergent fibre; TOC= Total organic carbon; TPOL= Total polyphenols; TP= Total Phosphorus; Cum P = Cumulative P mineralised

4.4 Greenhouse and bioavailability assessment of the various phospho-composts

4.4.1 Effect on maize growth and productivity

There was no significant difference in the mean number of functional leaves across the two soil types used in this study (Figure 4) differed significantly ($P<0.05$) across the different phospho-compost mix ratios (Figure 5). The mix ratio of 8:2 for both poultry manure and sewage sludge-based phospho-composts gave the highest mean number of functional leaves but did not differ significantly from that of the composted sewage sludge without GPR addition (i.e. SS 10:0). The control and GPR treatments gave the lowest number of functional leaves.

There was a significant ($p<0.05$) soil types x phospho-composts interaction effects on the mean number of functional leaves per plant (Table 7). The highly significant interaction effect was observed on low clay content soils between SS 10:0, PM 8:2, SS 8:2 and PM 5:5 and GPR, control. However, there was a higher release of nutrients from the low potential than the high potential soils; and a significant interaction effect of soil types x phospho-composts on number of functional leaves.

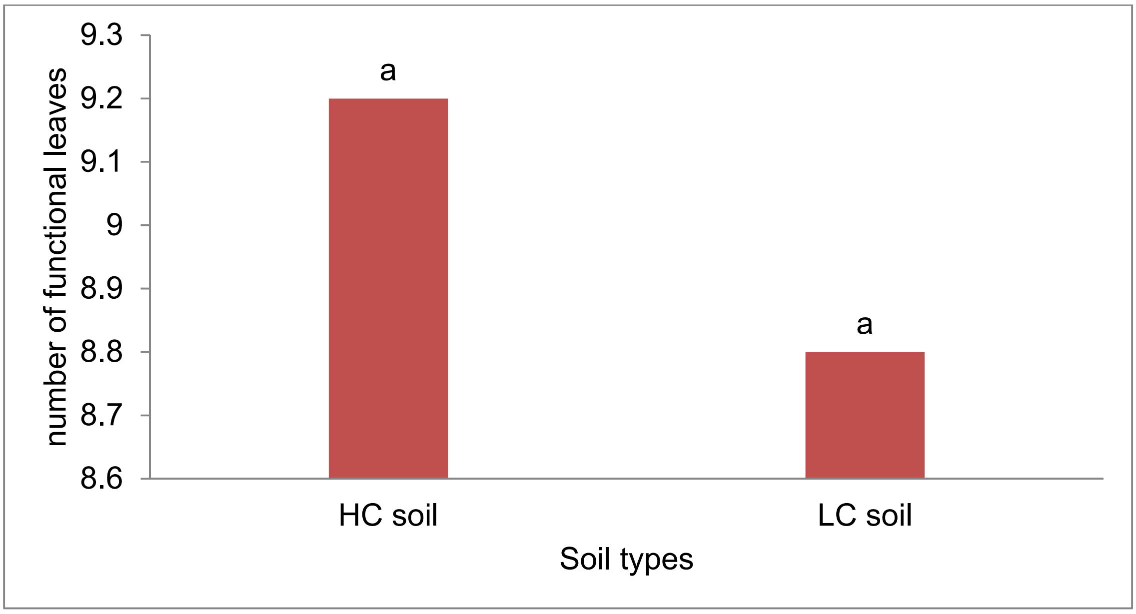

Figure 4: Effect of soil types used on the number of functional leaves of maize
(HP and LP implies high potential and low potential soil, respectively)

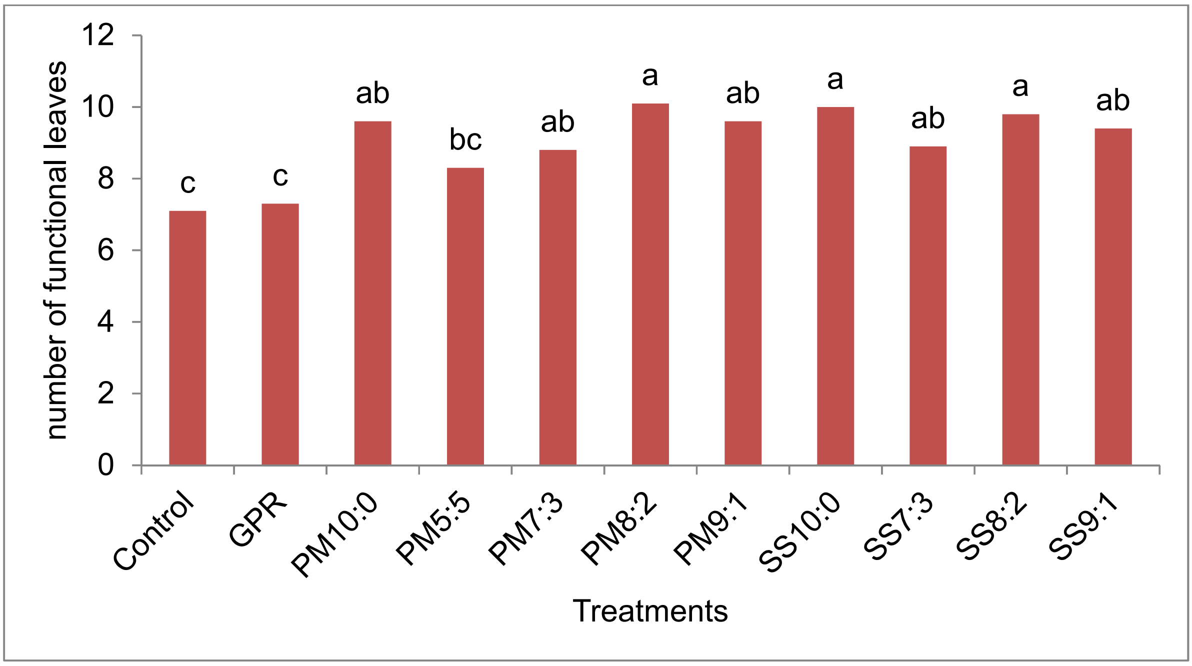

Figure 5: Effect of phospho-composts applied on number of functional leaves of maize *(PM= poultry manure, SS= sewage sludge, GPR= ground phosphate rock)*

Table 7: Soil type x phospho-compost interaction effect on the number of functional leaves per plant in maize

Phospho-compost treatments	HP Soil	LP Soil
PM10:0	9.63ab	9.63ab
PM5:5	8.50ab	8.13b
PM7:3	8.63ab	9.00ab
PM8:2	9.75ab	10.54a
PM9:1	9.75ab	9.38ab
SS10:0	9.38ab	10.63a
SS7:3	9.00ab	8.88ab
SS8:2	9.25ab	10.38a
SS9:1	9.00ab	9.75ab
GPR	8.88ab	5.63c
Control	9.09ab	5.09c

Means followed by the same letter do not significantly differ at $P<0.05$; PM= Poultry manure, SS= Sewage sludge; HP= High potential, LP = Low potential

The measured plant height from maize differed significantly (P<0.05) across the two soil types used (Figure 6) but showed no significant difference across the phospho-compost applied (Figure7). The highest plant height was obtained in low potential soil with lower clay content. Therefore, the soil type used had much effect on plant height.

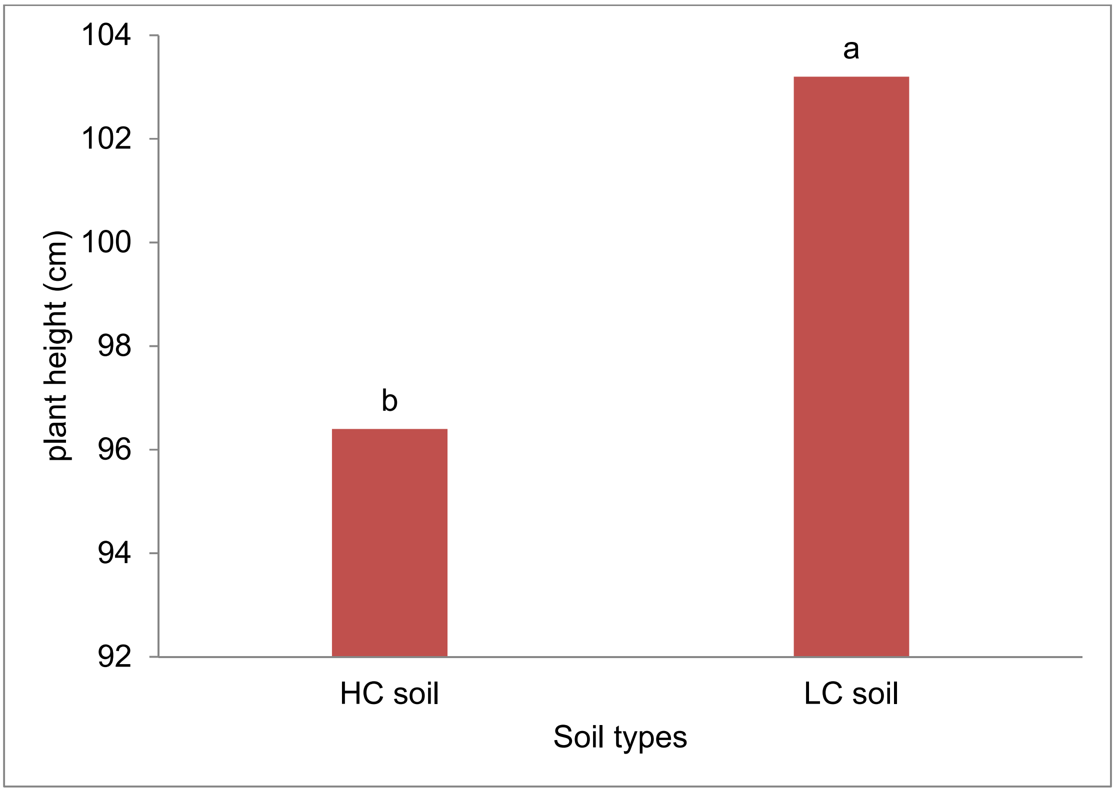

Figure 6: Effect of soil types used on maize plant height (cm)
(HP and LP implies high potential and low potential soil, respectively)

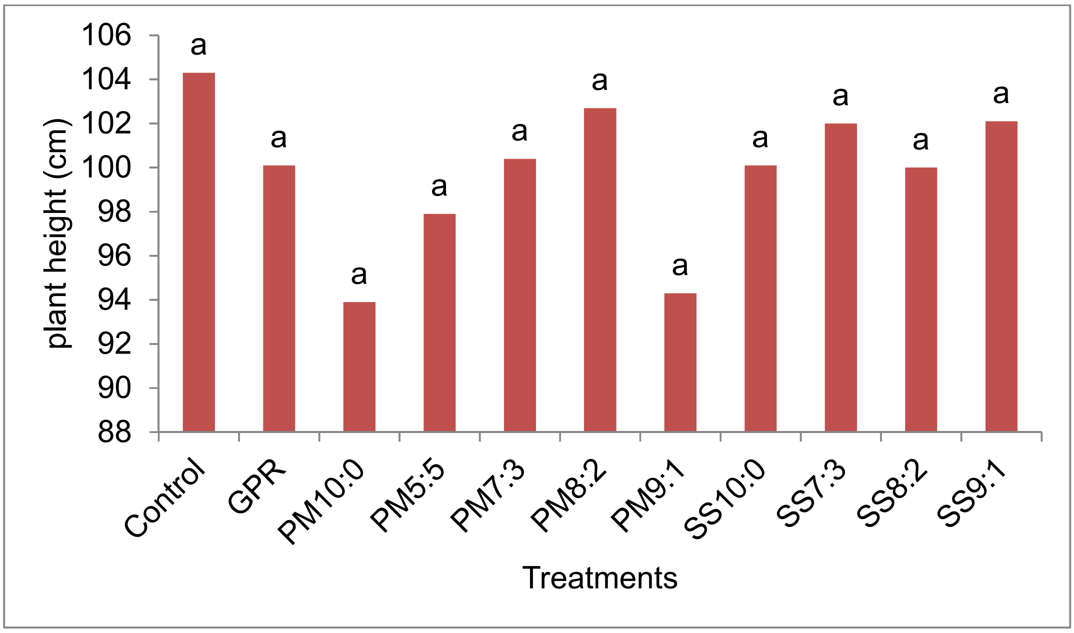

Figure 7: Effect of phospho-composts applied on plant height of maize (cm)
(PM= poultry manure, SS= sewage sludge, GPR= ground phosphate rock)

The weighed maize dried biomass obtained differed significantly (P<0.05) across soil types used (Figure 8) and also the various phospho-compost mix ratios (Figure9). However the high potential soil with higher percent clay content gave higher dried biomass compared to low potential soils. Similarly, the PM7:3 mix ratio gave the highest dried plant biomass while GPR and control gave the least. Therefore, the soil types used and phospho-compost mix ratios applied had significant effects on the dried biomass of maize plants after the trial. A significant (P<0.05) soil types x phospho-compost interaction effect on maize dried biomass was obtained. A highly significant difference existed between the dried biomass yield observed in low potential soil amended with SS9:1 mix ratio and those amended with sole GPR and control (Table 8).

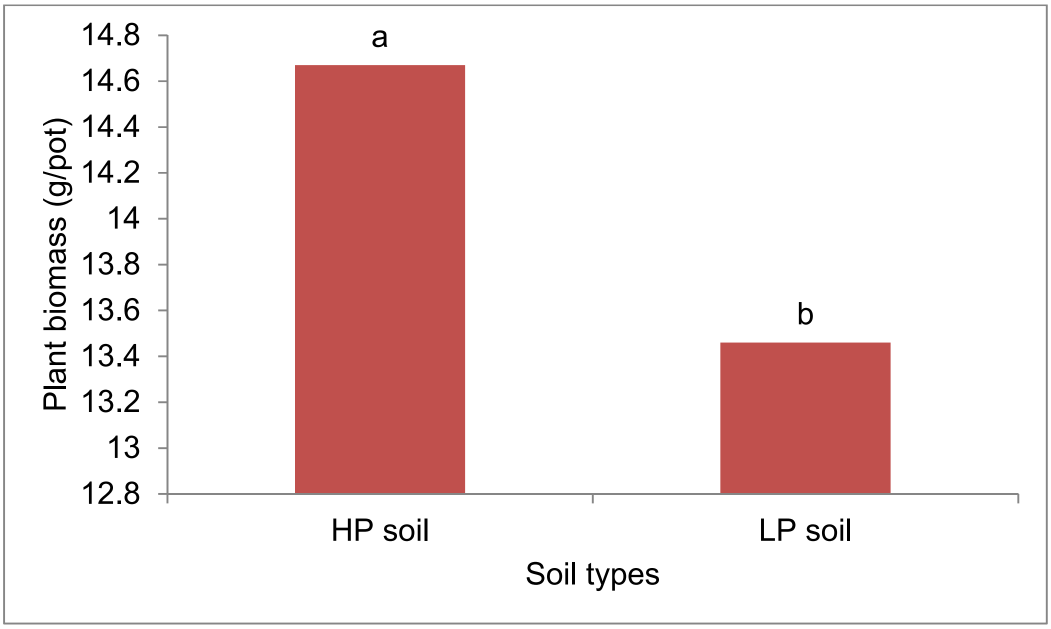

Figure 8: Effect of soil types used on dried plant biomass of maize (g/pot)
(HP and LP implies high potential and low potential soil, respectively)

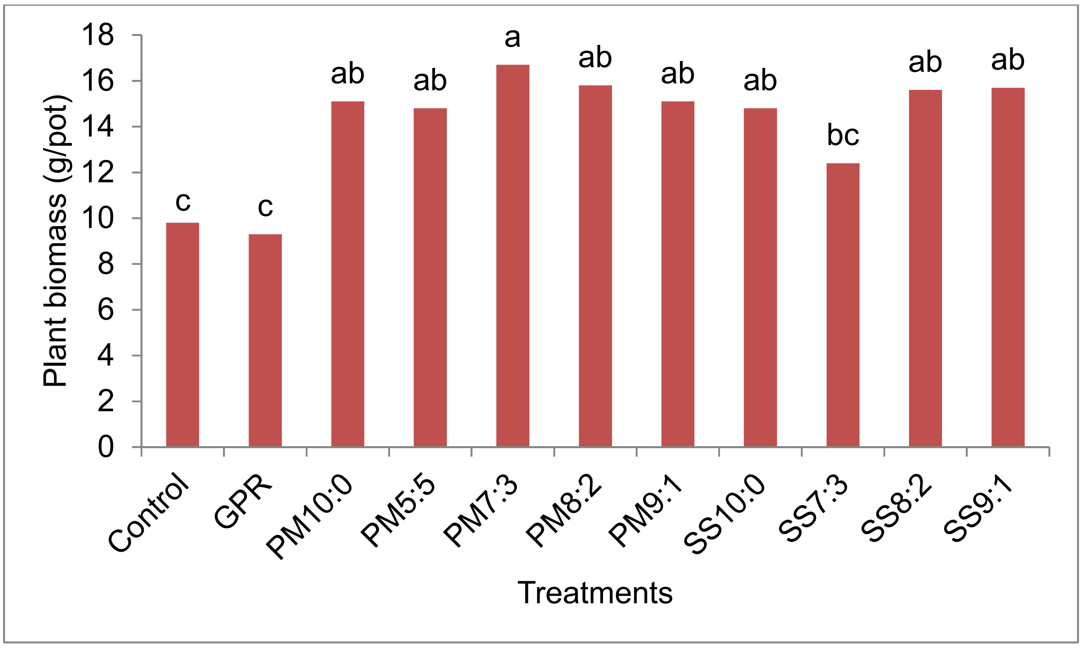

Figure 9: Effect of phospho-composts applied on maize dried plant biomass (g/pot)
(PM= poultry manure, SS= sewage sludge, GPR= ground phosphate rock)

Table 8: Soil type x phospho-compost interaction effect on dried plant biomass (g/pot) of maize

Phospho-compost treatments	HP Soil	LP Soil
PM10:0	17.05ab	13.18abc
PM5:5	14.00ab	15.58ab
PM7:3	16.14ab	17.18ab
PM8:2	16.23ab	15.30ab
PM9:1	16.05ab	14.05ab
SS10:0	14.80ab	14.70ab
SS7:3	12.18abcd	12.68abc
SS8:2	16.75ab	14.38ab
SS9:1	13.73ab	17.60a
GPR	11.75bcd	6.78d
Control	12.65abcd	6.85cd

Means followed by the same letter do not differ significantly at P<0.05; PM= Poultry manure, SS= Sewage sludge; HP= High potential, LP = Low potential

4.4.2 Effect on plant tissue nutrients content and P uptake

Bray1 P measured on plant tissues differed significantly (P<0.05) across soil type used (Figure 10) and as well as across phospho-compost applied (Figure 11). HP soils gave high plant tissue P when compared to low potential soils.Therefore the soil types had much effect on plant tissue P. PM 8:2 mix ratio gave higher plant tissue P while GPR and control gave the lowest. Therefore, phospho-composts applied had much effect on the plant tissue P. The interaction between soil type used and phospho-compost applied had significant influence(P<0.05) on bray1 measured P on plant tissue (Table 9). PM 8:2 mix ratio of HP soils gave high plant tissue P while control of low potential soils gave the lowest plant tissue P. However, there was a high release and measurement of P from high potential soils amended with PM-based phospho-compost. The interaction between soil type used and phospho-compost applied had much effect on plant tissue P.

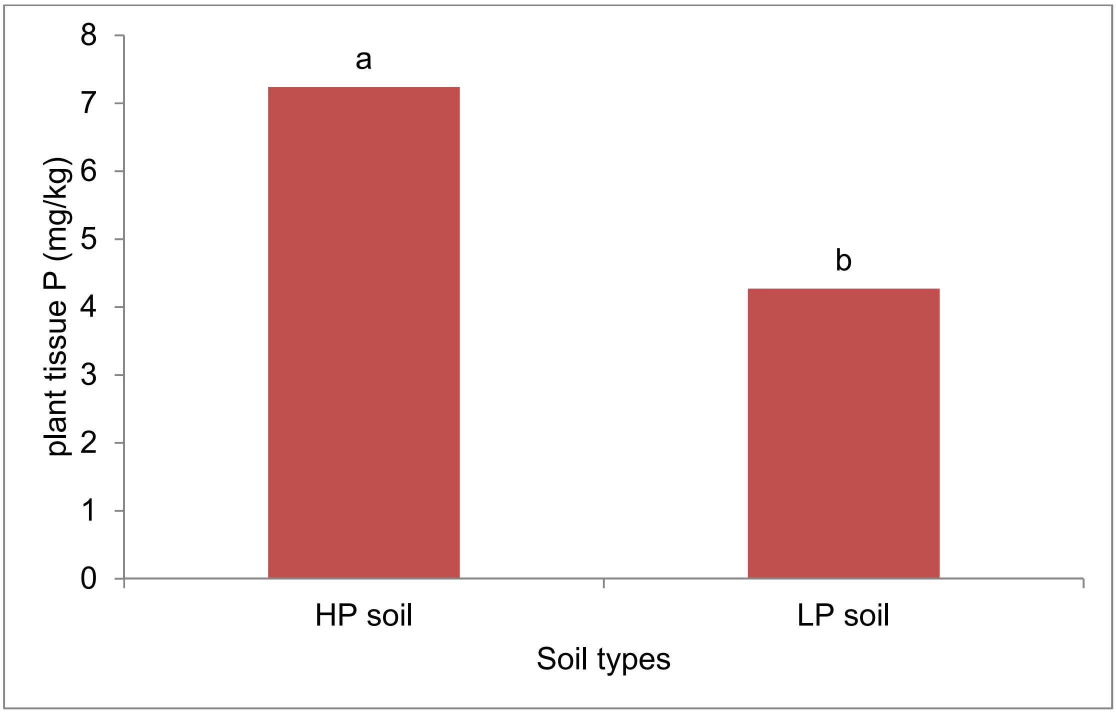

Figure 10: Effect of soil types used on maize plant tissue P (mg/kg)
(HP and LP implies high potential and low potential soil, respectively)

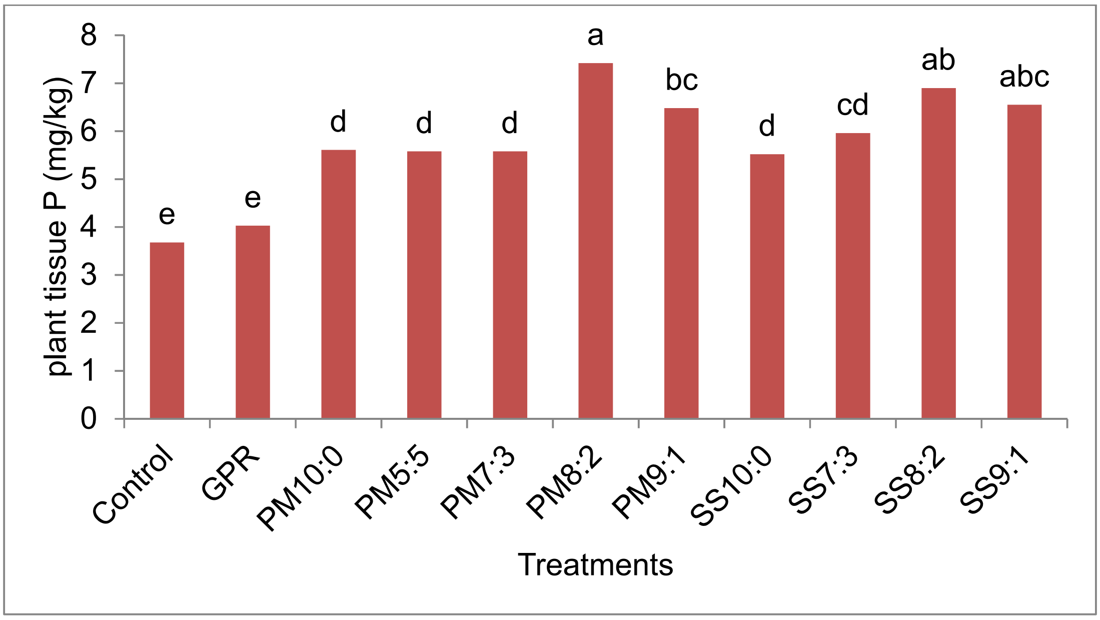

Figure 11: Effect of phospho-composts applied on maize plant tissue P (mg/kg)
(PM= poultry manure, SS= sewage sludge, GPR= ground phosphate rock)

Table 9: Soil type x phospho-compost interaction effect on maize plant tissue P (mg/kg)

Phospho-compost treatments	HP Soil	LP Soil
PM10:0	7.11cde	4.11ghi
PM5:5	7.60bcde	3.57hi
PM7:3	6.87def	4.30ghi
PM8:2	9.41a	5.43fg
PM9:1	8.06bcd	4.91g
SS10:0	6.63ef	4.42ghi
SS7:3	7.55cde	4.37ghi
SS8:2	8.90ab	4.91g
SS9:1	8.36abc	4.74gh
GPR	4.66gh	3.41hi
Control	4.52ghi	2.85i

Means followed by the same letter do not differ significantly at P<0.05; PM= Poultry manure, SS= Sewage sludge; HP= High potential, LC= Low potential

The plant tissue uptake P differed significantly (P<0.05) across soil types used (Figure 12) and across different phospho-compost applied (Figure 13). HP soils gave higher plant tissue uptake P compared to low potential soils while PM 8:2 mix ratio gave the highest plant tissue uptake P while control and GPR gave the lowest. Therefore the soil type and phospho-compost applied had much effect on the plant tissue uptake P. There was a significant difference in soil type x phospho-compost interaction effect on plant tissue uptake P (p<0.05). However, the high P level was obtained in high potential soil amended with PM-based phospho-compost 8:2 mix and bioavailability P was improved

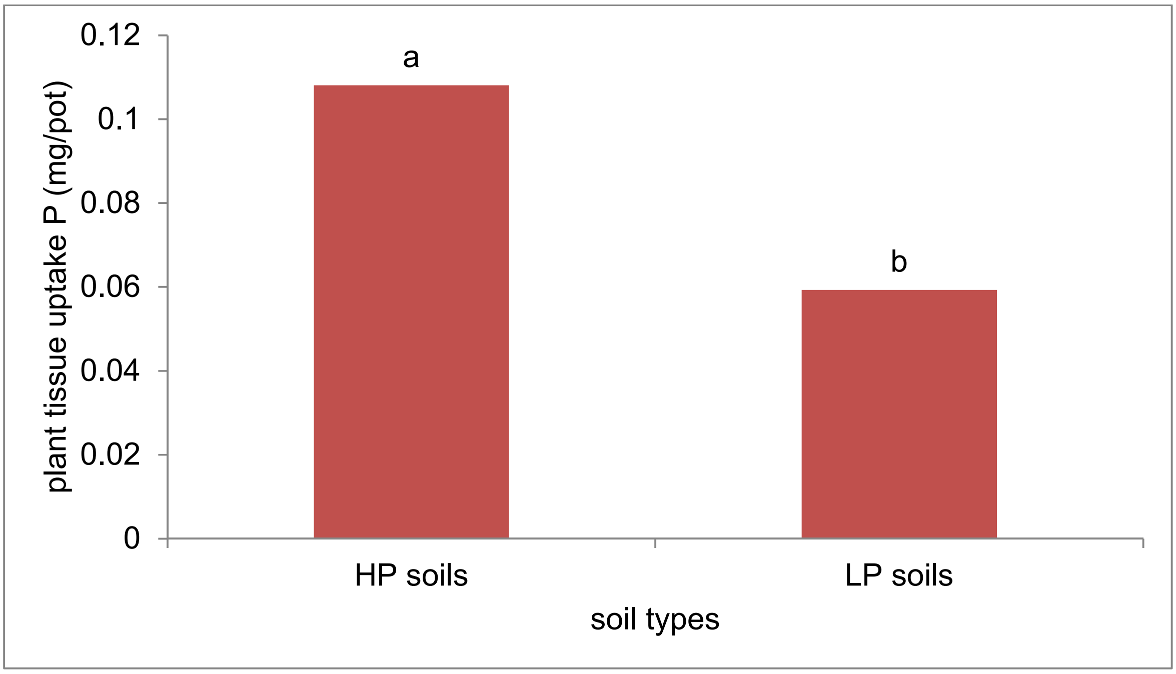

Figure 12: Effect of soil type used on plant tissue uptake P (mg/pot) by maize plants

(HP and LP implies high potential and low potential soil, respectively)

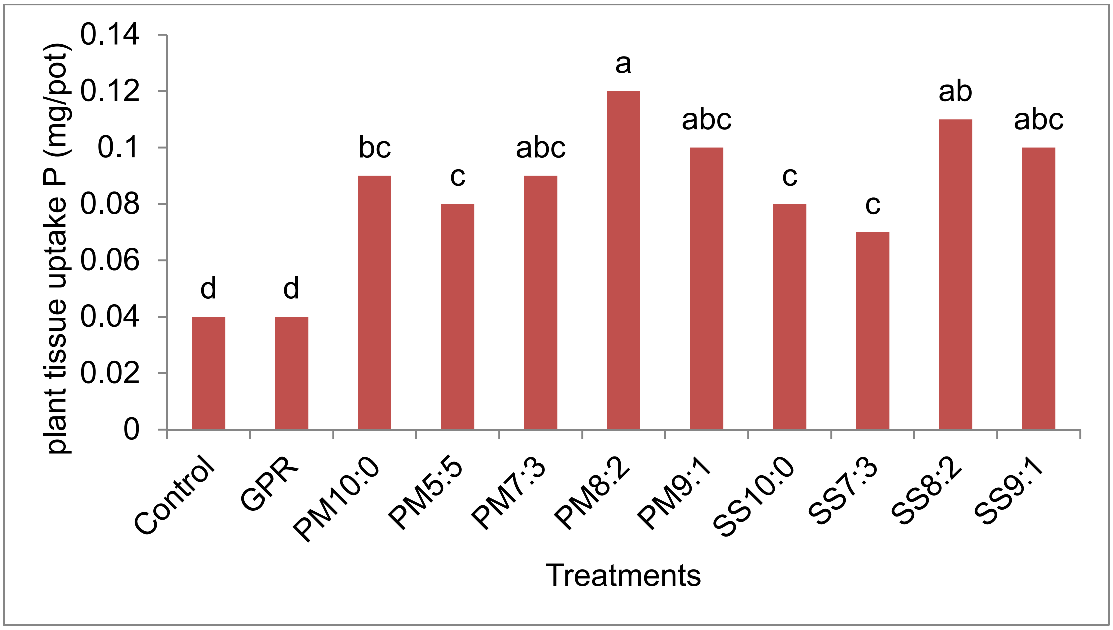

Figure 13: Effect of phospho-composts applied on maize plant tissue uptake P (mg/pot)

(PM= poultry manure, SS= sewage sludge, GPR= ground phosphate rock)

4.4.3 Effect on selected residual soil chemical properties

The residual organic carbon measured differed significantly (P<0.05) both across the soil types used (Figure 14) and the phospho-compost applied (Figure 15). The high potential soils gave high residual organic carbon when compared to low potential soils while SS 10:0 mix ratio gave higher residual organic carbon while GPR gave the lowest. Therefore the soil types and different Phospho-compost applied had much effect on residual organic carbon. The interaction between soil type used and phospho-compost applied had significant influence (P<0.05) on residual organic carbon (Table 10). PM 5:5 and 7:3 mix ratios of HP soils gave high residual organic carbon while PM 7:3 of low potential soils gave the lowest residual organic carbon. The phospho-compost applied increased the organic carbon of both HP low potential soils. The increase inorganic matter of the soil reduces the soil erosion as it improves the structure of the soil. The interaction between soil type used and phospho-compost applied had much effect on residual organic carbon.

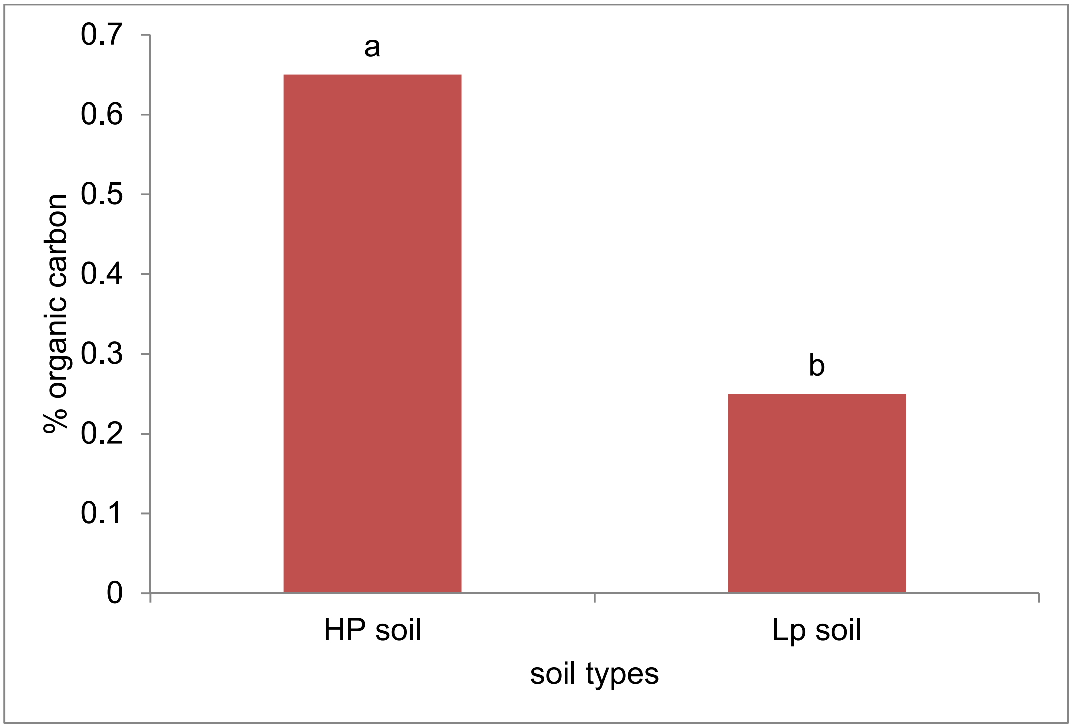

Figure 14: Effect of soil types on percent residual soil organic carbon
(HP and LP implies high potential and low potential soil, respectively)

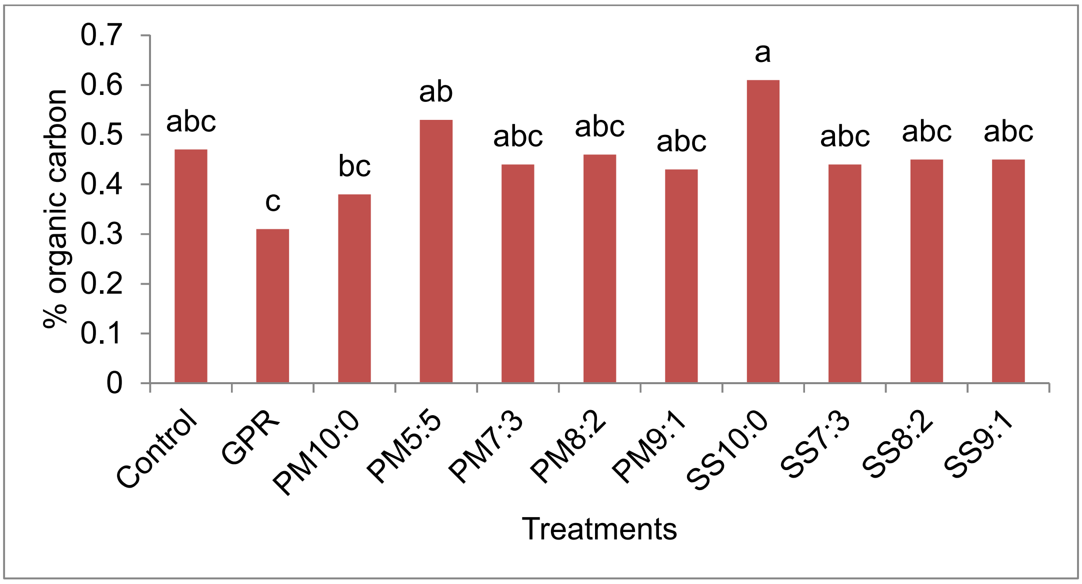

Figure 15: Effect of phospho-composts on percent residual organic carbon

(PM= poultry manure, SS= sewage sludge, GPR= ground phosphate rock)

Table 10: Soil type x phospho-compost interaction effect on residual percent organic carbon

Phospho-compost treatments	HP Soil	LP Soil
PM10:0	0.59abc	0.18fg
PM5:5	0.83a	0.23efg
PM7:3	0.78a	0.10g
PM8:2	0.73ab	0.19fg
PM9:1	0.66abc	0.21efg
SS10:0	0.66abc	0.55abcd
SS7:3	0.66abc	0.23efg
SS8:2	0.68abc	0.22efg
SS9:1	0.47bcde	0.43cdef
GPR	0.44cdef	0.17fg
Control	0.78abc	0.24defg

Means followed by the same letter do not differ significantly at P<0.05, PM= Poultry manure, SS= Sewage sludge; HP= High potential, LP = Low potential

The measured residual soil Bray1 P differed significantly ($P<0.05$) across the soil types used (Figure 16) and as well as across different phospho-composts applied (Figure 17). The high potential soils gave high residual soil P when compared to low potential soils, while PM and SS 8:2 mix ratio gave higher residual soil P while GPR and control gave the lowest. 8:2 mix ratio for both PM and SS have shown the highest residual soil P after extraction of P by Bray1 method over all other treatments. Therefore, the soil types used and phospho-composts applied had much effect on the residual soil P. The interaction between soil type used and phospho-compost applied had significant influence ($P<0.05$) on residual soil P (Table 11). The PM and SS 8:2 mix ratio in high potentla soils gave high residual soil P while GPR and control of low potential soils gave the lowest residual soil P. However, the application of both PM and SS-based phospho-composts improved the soil available soil-P. The interaction between soil type used and phospho-compost applied had much effect on residual soil P.

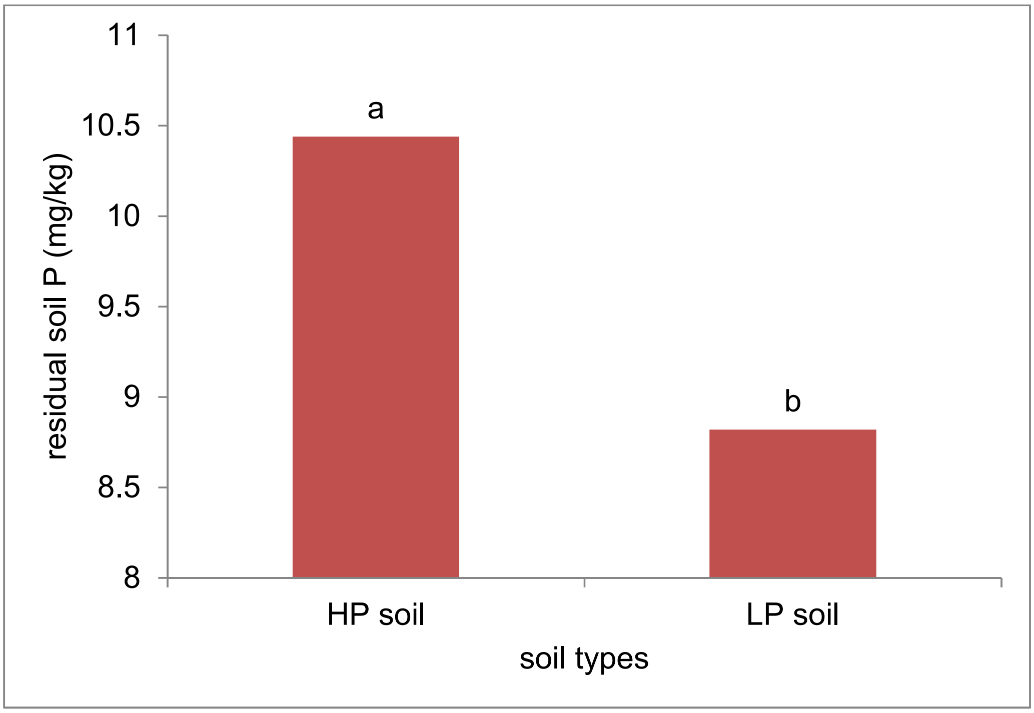

Figure 16: Effect of soil types used on residual soil P (mg/kg)
(HP and LP implies high potential and low potential soil, respectively)

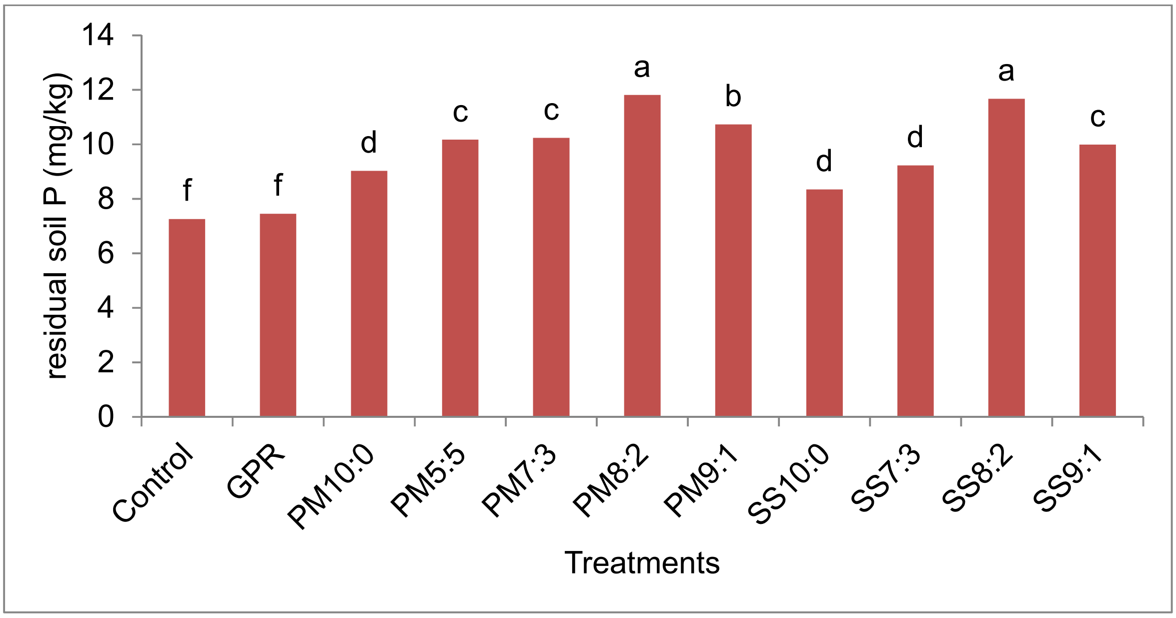

Figure 17: Effect of phospho-composts applied on residual soil P (mg/kg)

(PM= poultry manure, SS= sewage sludge, GPR= ground phosphate rock)

Table 11: Soil type x phospho-compost interaction effect on residual soil P (mg/kg)

Phospho-compost treatments	HP Soil	LP Soil
PM10:0	9.70ef	8.35i
PM5:5	10.59c	9.76ef
PM7:3	10.71bc	9.76ef
PM8:2	13.06a	10.56cd
PM9:1	11.20b	10.26cde
SS10:0	8.96gh	7.75j
SS7:3	9.98de	8.49hi
SS8:2	12.61a	10.72bc
SS9:1	10.68bc	9.29fg
GPR	8.79ghi	6.10k
Control	8.52hi	6.01k

Means followed by the same letter do not differ significantly at P<0.05; PM= Poultry manure, SS= Sewage sludge; HP= High potential, LP = Low potential

The two soil types used for the greenhouse study had a significant influence on plant-height, plant dried biomass, plant P uptake, plant tissue P, residual organic carbon and soil P, but did not have an influence on the number of functional leaves. Plant height was significantly higher on low potential soils, while the other parameters were significantly higher on high potential soils.

The different phospho-compost mix ratios applied had significant influence on the number of functional leaves, plant dried biomass, plant P uptake, plant tissue P, residual organic carbon and soil P but there was no significant influence on plant-height. The high plant P uptake could be attributed to the greater leaf biomass yield in applied phospho-compost soil compared to GPR. Hellal *et al.* (2013) reported that phospho-compost applied gave higher P uptake and residual soil P compared to sole application of ground phosphate rock. Progressive application of compost produced a better vegetative growth of maize in all pots where compost was applied than where GPR was directly applied without composting it (Nyirongo *et al*., 1999). Hellal *et al*. (2013) reported that GPR usually does not perform as well as water soluble P fertilisers with annual crops in terms of yield response. Gilkes and Bolland (1990) reported that it has been observed that the differences in plant response could be explained by the different dissolution behaviours of ground phosphate rock.

Akande *et al.* (2005) studied the effect of rock phosphate amended with poultry manure on soil available phosphate and yield of maize grown sequentially for four cropping seasons. Their results showed that the effectiveness of rock phosphate as a P source for crop production was remarkably enhanced by the solubilizing effect of the poultry manure. Mahimairaja *et al*. (1995) reported that composting of rock phosphates with agricultural wastes is known to increase solubility of rock phosphates. The Institute of Organic Training and Advice (2010) concluded that, co-composting maintains P in a potentially plant-available form through the uptake and storage of P in the microbial biomass, which is subsequently turned over making the P available. When co-composting RP, the initial dissolution or decomposition phase is followed by uptake, transformation and storage of solubilised P within the microbial biomass, and finally a variable period of stabilisation and humification of organic P-containing compounds, the extent of which will depend on storage conditions and duration.

The interaction between soil types and phospho-compost had significant influence on the number of functional leaves, plant dried biomass, maize plant tissue P content and uptake, the residual soil organic carbon and P contents but exerted no significant effects on maize plant height. The results of P enriched compost and its effect on maize crop clearly demonstrated that Phalaborwa GPR is solubilised, during the co-composting process. The findings also demonstrated that the available soil-P and soil organic matter was improved following application of the phospho-composts in the two soil types. Thus these results clearly revealed that the continuous use of phospho-composts has a potential to overcome the current low soil P problem in smallholder farmlands and sustain the conservation of soil and high crop productivity.

CHAPTER 5

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

The inherent problems associated with the use of organic manures and direct application of the non-reactive Phalaborwa ground phosphate rock (GPR) in relation to managing phosphorus deficiency problems on farmlands necessitated the search for a viable solution. The co-composting technology process has been recognised as a viable and cost effective strategy to achieve increased P solubility in non-reactive GPR typical of Phalaborwa ground phosphate rock. In an attempt to develop a comprehensive strategy to deal with the available soil P problem on, particularly smallholder farmers' fields, the co-composting of Phalaborwa GPR with poultry manure and sewage sludge followed by laboratory incubation and greenhouse study were undertaken with the following objectives:

i. Quantify the extent of P solubility and bioavailability from the different mix ratios of co-composted GPR, poultry manure and sewage sludge.

ii. Compare the rates and patterns of P release from the resulting different phospho-composts.

iii. Evaluate maize performance and the residual soil-P content following application of the different phospho-composts.

The different phospho-composts produced contained different levels of nutrient and trace elements that did not exert any toxic symptoms on the maize plants grown. The amount of P mineralized during each sampling date from various phospho-compost mix ratios differed significantly ($P<0.05$). Quantitatively higher P concentration was mineralized from poultry manure-based phospho-composts than in sewage sludge-based phospho-compost. The 8:2 phospho-compost mix ratio gave higher maize tissue P uptake and cumulative mineralized P than any other mix ratios. The different soils used had significant influence on maize tissue P uptake following the phospho-compost application. Maize tissue P uptake was significantly enhanced in soil with medium clay content. The dry matter yield had positive correspondence with soil residual P and plant uptake P by maize. The different phospho-composts showed great potential for amelioration of P deficiency problems in crops while thermophilic co-composting improved the solubility and bioavailability of P from GPR. The 8:2 mix ratio is the minimum amount of compost required to solubilize GPR.

Results of this study revealed that phospho-compost application increased P availability in soil and the dry matter yield of maize. Both poultry manure and sewage sludge can be used to solubilise the non-reactive Phalaborwa ground phosphate rock. Although the choice of which of these two organic wastes to use might depends on which material is available to the individual farmer, but preference could be given to poultry manure due to its higher P content and release. Finally, further research is recommended for assessment of the various phospho-composts along with the GPR and inorganic P fertilizer source under field conditions for the comparison of mineralisation and bioavailability of these different P sources. The same thermophilic co-composting of GPR should be done with poultry manure using different types of bedding. Similarly, possibility making bigger compost heaps with the addition of more carbon sources should be considered so as to achieve increased microbial activities, more heat generation during the co-composting process and possibly higher P solubilisation. Finally, extension staff could be involved in the future research given its potential to improve and sustain field crops production, especially among smallholder farmers.

REFERENCES

AKANDE M.O., ADEDIRAN J.A. and OLUWATOYINBO F.I. 2005. Effects of rock phosphate amended with poultry manure on soil available P and yield of maize and cowpea. African Journal of Biotechnology 4: 444-448.

BANGAR K.C., YADAV K.S. and MISHRA M.M. 1985. Transformation of rock phosphate during composting and the effect of humic acid. Plant Soil, 85: 259 - 266.

BARNARD R.O and DU PREEZ C.C. 2004. Soil fertility in South Africa: The last twenty five years. South African Journal of Plant and Soil 21: 301-315.

BINH T. and ZAPATA F. 2002. Assessment of soil phosphorus status and management of phosphatic fertilisers to optimise crop production. Soil and water &crop nutrition management section, International Atomic Energy Agency Austria.

BLACK C.A. 1957. Soil-plant relationships. New York, John Wiley and Soils Incorporated, 332pp.

BLOM N. 2013. Greater demand for food fuels need for sustainability. KwaZulu-Natal Agricultural Union, Kwanalu.

BOLAN N.S., SZOGI A.A., CHUASAVATHI T., SESHADRI B., ROTHROCK JR. M.J. and PANNEERSELVAM P. 2010. Uses and management of poultry litter. World's Poultry Science Journal 66: 673-698.

BRAY R.H. and KURTZ L.T. 1945. Determination of total, organic, and available forms of phosphorus in soils. Soil Science 59: 39-45.

CHIRINO-VALLE I. 2013. Soil phosphorus dynamics and bioavailability in New Zealand forest ecosystems. PhD thesis Lincoln University.

DEKALB. 2011. Importance of P and K applications in corn plant development. agronomic spotlight. Growing knowledge. Available at www.DEKALB.ca. Accessed on 27/02/2012.

DEPARTMENT OF AGRICULTURE. 2003. Maize production. National Department of Agriculture, Pretoria RSA. Available online at www.nda.agric/publications. Accessed on 07/11/2011.

DIKINYA O. and MUFWANZALA N. 2010. Chicken manure-enhanced soil fertility and productivity: Effect of application rate. Journal of Soil Science and Environmental Management 3: 46-54

DRAPER M.A., LANGHAM M.A., CLAY S.A. and RUDEN B.E. 2009. Best management practices for corn production in South Dakota. Available online at http://agbiopubs.sdstate.edu. Accessed on 05/07/2011.

DU PREEZ C.C., VAN HUYSSTEEN C.W. and MNKENI P.N.S. 2011. Land use and soil organic matter in South Africa 1: A review on spatial variability and the influence of rangeland stock production. South Africa Journal Science 107: 1-8.

EPISTEIN E. 1972. Mineral nutrition of plants: Principles and Perseptives. New York, John Wiley and Sons, Incorporated.

FAO CORPORATE DOCUMENT REPOSITORY. 2003a. Ways of improving the agronomic effectiveness of phosphate rocks. Use of phosphate rock for sustainable agriculture. Natural Resources Management and Environmental Department.

FAO CORPORATE DOCUMENT REPOSITORY. 2003b. On-farm composting methods. Land and water discussion paper 2. Natural Resources Management and Environmental Department.

FROSSARD E. 1996. Phosphorus in urban sewage sludge as assessed by isotopic exchange. Soil Science Society of America Journal 60: 179 - 182.

GERRITSE R.G. 1981. Phosphorus in sewage sludge and animal wastes. Journal of Plant Nutrition 20: 347 - 366.

GESTRING W.D. 1982. Plant availability of phosphorus and heavy metals in soils amended with chemically treated sewage sludge. Journal of Environmental Quality 11: 669 - 675.

GILKES R.J. and BOLLAND M.D.A. 1990 The Australian experience with rock phosphate: Limitations and explanations. Phosphate sources for acid soils in the humid tropics of Asia. Proceedings of the workshop, Kuala Lumpur, pp. 177-205.

GOERING H.K. and VAN SOEST P.J. 1970. Forage fiber analysis (apparatus, reagents, procedures and some applications). USDA Agriculture Handbook No. 379

GOLDBLATT A. 2011. Agriculture: facts and trends in South Africa.

HARTLEY W., DICKINSON N. M., RIBY P. and LEPP N. W. 2009. Arsenic mobility in brownfield soils amended with green waste compost or biochar and planted with *Miscanthus*. Environmental Pollution 157: 2654–2662.

HE X. 1998. Mineralisation and bioavailability of phosphorus bound to soil organic matter by enzymes from *Lupinus albus*. PhD thesis. University of Wisconsin-Madison. 145pp.

HELLAL F., NAGUMO F. and ZEWAINY R. 2013. Influence of phospho-compost application on phosphorus availability and uptake by maize grown in red soil of Ishigaki Island, Japan. Agricultural Sciences 4: 102-109.

HELLAL F., NAGUMO F. and ZEWAINY R. 2012. Influence of phospho-composting on enhancing phosphorus solubility from inactive rock phosphate. Australian Journal of Basic and Applied Sciences 6: 268-276.

HELMKE P.A., ROERTH T.J. and HE X. 2000. Bioavailability of organically-bound soil phosphorus. College of Agricultural and Life Sciences, University of Wisconsin-Madison, USDA National Research Initiative Competitive Grant 94-37107-0356 and Hatch Project 3940.

HIRZEL J. and WALTER I. 2008. Availability of nitrogen, phosphorus and potassium from poultry litter and conventional fertilisers in a volcanic soil cultivated with silage corn. Chilean Journal of Agricultural Research 68: 264 – 273.

HSEU Z.-Y. 2004. Evaluating heavy metals content in nine compost using four digestion methods. Bioresource Technology 95: 53-59.

KIDD P.S., DOMINGUEZ-RODRIGUEZ M.J., DIEZ J. and MONTERRROSO C. 2007. Bioavailability and plant accumulation of heavy metals and phosphorus in agricultural soils amended by long term application of sewage sludge. Chemosphere 66, 1458-1467.

KUTU F. R. 2008. Survey of fertility status and nutrient management practices on selected small-scale farmers' fields in North West and Limpopo provinces, South Africa. Paper presented at the Combined Congress held at Rhodes University, Grahamstown during 21 – 24 January 2008.

LAMBERS H., CHAPIN F.S. and PONS T.L. 1998. Plant physiological ecology. Heidelberg, Germany. Springer Verlag. New York, 540 P.

LECO COOPERATION 2003. Truspec carbon/nitrogen determinator. Leco Cooperation 3000. Lakeview Avenue St Joseph, M149085-2396, USA.

MACHETHE C.L., MOLLEL N.M., AYISI K., MASHATOLA M.B., ANIM F.D.K. and VANASCHE F. 2004. Smallholder irrigation and agricultural development in the Olifants River Basin of Limpopo Province: Management transfer, productivity, profitability and food security issues. University of the North, Limpopo RSA.

MAHIMAIRAJA S., BOLAN N.S. and HEDLEY M.J. 1995. Dissolution of phosphate rock during the composting of poultry manure: an incubation experiment. Fertiliser Research 40: 93 - 104.

MAQUBELA M.P., MNKENI P.N.S., MALAM ISSA O., PARDO M.T. and D'ACQUI L.P. 2008. Nostoc cyanobacterial inoculation in South African agricultural soils enhances soil structure, fertility, and maize growth. Plant Soil Journal 315: 79-92.

MATERECHERA S.A. and MORUTSE H.M. 2009. Response of maize to phosphorus from fertiliser and chicken manure in a semi-arid environment of South Africa. Experimental Agriculture 45: 261 - 273.

MCKENZIE R. and MIDDLETON A. 1997. Phosphorus fertiliser application in crop production. Agriculture Information Services, Alberta, Canada. Available at http://www.1.agric.gov. Accessed 10/07/2011.

MILLS A.J. and FEY M.V. 2003. Declining soil quality in South Africa: Effects of land-use on soil organic matter and surface crusting. South African Journal of Science 99: 429 – 436.

MONSATO. 2010. Importance of P and K in corn and soybean development. Agronomic spotlight. Technology Development. Available online at http://www.krugerseed.com/images/pdf/soybean041310.pdf. Accessed 10/07/2011

MULVANY R.L., KHAN S.A. and ELLSWORTH T.R. 2009. Synthetic nitrogen fertiliser depletes soil nitrogen: A global dilemma for sustainable cereal production. Journal of Environmental Quality 38: 2295–2314.

NYIRONGO J.C.V.B., MUGHOGHO S.K. and KUMWENDA J.D.T.1999. Soil fertility studies with compost and igneous phosphate rock amendments in Malawi. African Crop Science Journal 7: 415-422.

ODHIAMBO J.O. 2011. Potential use of green manure legume cover crops in smallholder maize production system in Limpopo Province, South Africa. African Journal of agricultural Research 6: 107 – 112.

ODHIAMBO J.O. 2004. Physical features, soils and land utilization in Limpopo Province. Department of Soil Science, Limpopo, South Africa.

OEHL F., OBERSON A., SINAJ S. and FROSSARD E. 2001. Organic phosphorus mineralisation studies using isotopic dilution techniques. Soil Science Society of America Journal 65: 780-787.

OKALEBO J.R., GATHUA K.W. and WOOMER P.L. 2002. Laboratory methods of soil and plant analysis. A working manual (2nd edn.). SACRED Africa, Nairobi Office, P. O. Box 79 The Village Market, Nairobi, Kenya.

PALM C.A., GACHENGO C.N., DELVE R.J., CADISCH G. and GILLER, K.E. 2001. Organic inputs for soil fertility management in tropical agro-ecosystems: application of an organic resource database. Agricultural Ecosystem Environment 83: 27-42.

RAABE R.D. 2001. The rapid composting method. University of California, US, Co-operative Extension, Division of Agriculture and Natural Resources.

RAMARU J., MAMABOLO Z. and LEKGORO J. 2000. Improving soil fertility management in South Africa: Learning through participatory extension approaches. Managing Africa's soils No. 19. Russell Press, Nottingham, UK.

REDDY K.R. 1980. Phosphorus adsorption–desorption characteristics of two soils utilized for disposal of animal wastes. Journal of Environmental Quality 9:86–92.

RITCHIE S.W., HANWAY J.J. and BENSON G.O. 1997. How a corn plant develops. Iowa State University Cooperative Extension Service specification representation. 48pp.

ROSEN C.J. and BIERMAN P.M. 2005. Using manure and compost as nutrient sources for fruit and vegetable crops. Department of Soil, Water, and Climate University of Minnesota.

ROUX E.H., DE JAGER D.H., DU PLOOY J.H., NICOTRA G.J., VER DER LINDE G.J. and STEYN J.H.F. 1998. South African phosphate reserves and production. Proceedings of Phosphate Symposium, 21-28. Department of Agriculture and Water Supply & Fertilizer Society of South Africa, South Africa.

RYDIN E. 1997. Potential release of phosphorus from soil mixed with sewage sludge. Journal of Environmental Quality 26: 529–534.

SCHORTH G. 2003. Decomposition and nutrient supply from biomass. *In*: Schorth G. and Sinclari F.L, (eds.), Trees, crops and soil fertility: concepts and research methods. CABI Publishing, ISBN - 0851995934.

SIDDIQUE M.T. 2000. Phosphorus reactions and leaching potential in soils amended with sewage sludge. Journal of Environmental Quality 29: 1931–1938.

SIDDIQUE M.T. and ROBINSON J.S. 2003. Phosphorus sorption and availability in soil. Amended with animal manures and sewage sludge. Journal of Environmental Quality 32: 1114-1121.

SINGH K.K. and MISHIRA L.C. 1987. Effect of fertilizer factory on soil and crop productivity. Water Air Soil pollution 33: 309-320.

STEVENSON F.J. 1967. Organic acids in soil. In: D.A. McLaren and G.H. Peterson, (eds.) Soil biochemistry. New York, USA, Marcel Dekker Inc. pp. 119-146.

THE INSTITUTE OF ORGANIC TRAINING AND ADVICE 2010. Composting with rock phosphate: Increasing plant-available P. Institute of Organic Training & Advice, Shropshire. Available online at www.organicadvice.org.uk.

THOMAS R. 2004. Crop production in Limpopo Province. Department of Plant Production. Limpopo Department of Agriculture, RSA.

VACA R., LUGO J., MARTINEZ R., ESTELLER M.V. and ZAVALETA H. 2011. Effect of sewage sludge and sewage sludge compost amendment on soil properties and *Zea mays* L. plants (heavy metals, quality and production). Revistas International Contamination Ambient 27: 303-311.

VAN STRAATEN P. 2002. Rocks for Crops: Agrominerals of sub-Saharan Africa. ICRAF, Nairobi, Kenya, 338pp. NISC Publishing, ISBN 0-88955-5125.

WYSZKOWSKI M., WYSZKOWSKI S. and ZOILKONSKA A. 2004. Effect of soil contamination with diesel oil on yellow lupine yield and macro elements contents. Plant, Soil and Environment 50: 215-226.

ZHANG L.H., ZHANG S.J., YE G.F., SHAO H.B., LIN G.H. and BRESTIC M. 2013. Changes of tannin and nutrients during decomposition of branchlets of *Casuarina equisetifolia* plantation in subtropical coastal areas of Chaina. Plant Soil Environmental 59:74-79.

ZUBLENA J.P., BARKER J.C. and CARTER T.A. 1997. Poultry manure as a fertiliser source. Soilfacts publication. North Carolina Cooperative Extension Service.

APPENDICES

Appendix 1: Variance ratio of testing differences in P released from the various phospho-compost treatments during each sampling date over the incubation period

Sources of variance	7DAI	14DAI	21DAI	28DAI	35DAI	42DAI
Rep	8.9502	0.1296	0.011	8.739	1.658	5.020
Treatment	11.7463ns	1.961***	0.873ns	1.160ns	1.672ns	2.098***
Error	8.2351	0.390	0.389	2.027	0.802	0.787

ns= not significant; *** implies significant at P<0.05 probability; DAI = days after incubation

Appendix 2: Combined ANOVA table for amount of P released from each incubated phospho-compost sample

Sources of variance	Sum of Squares	Mean Square	Probability
Sampling date (SD)	418. 88	83.78	0.00
Treatments (Trst)	92.47	10.27	0.00
SD ×Trts interaction	83.14	1.85	0.71
Error	252.28	2.134	

Appendix 3: ANOVA for Linear regression of cumulative P mineralised with NDF and total polyphenol contents

Sources of variance	Sum of Squares	Mean Square	Probability
Regression	76.44	38.22	0.0416
Residual	40.53	6.75	
Total	116.97		

Appendix 4: Summary of ANOVA tables for greenhouse study

Sources of variance	Number of functional leaves	Plant height	Plant dried biomass	Plant tissue P uptake	Residual organic carbon	Residual soil P	Plant tissue P
Soil types (St)	4.845ns	1845.01***	28.7246***	0.04738***	3.28560***	52.3922***	174.989***
Compost treatments (Ct)	14.144***	152.75ns	40.7610***	0.00422***	0.04480***	16.2741***	7.917***
St*Ct interaction	9.017***	124.52ns	15.1985***	0.00059***	0.07707***	0.8403***	1.614***
Error	1.52	148.38	4.42	0.0002	0.012	0.049	0.253

ns= not significant; *** implies significant at P<0.05 probability

Appendix 5: Selected pictures of maize plants taken during greenhouse experiment showing effect of different phospho-composts

Plate 1: Maize plant at the three leaves (V3) stage

Plate 2: Comparison of poultry manure (PM)-based phospho-compost and GPR treatments in amended and un-amended high potential (HP) soils on maize plants

Plate 3: Comparison of sewage sludge (SS)-based phospho-compost and GPR treatments in amended and un-amended high potential (HP) soils on maize plants

Plate 4: Comparison of poultry manure (PM)-based phospho-compost and GPR treatments in amended and un-amended low potential soils on maize plants

Plate 5: Comparison of sewage sludge (SS)-based phospho-compost and GPR treatments in amended and un-amended low potential soils on maize plants