



Research Article

Effects of Municipal Phosphocomposts on Groundnut Growth, Yield and Residual Soil Phosphorous

Tavagwisa Muziri^{1,3,*} , Innocent Pahl¹ , Fanuel Tagwira²

¹Department of Horticulture and Agronomy, Midlands State University, Gweru, Zimbabwe

²Faculty of Natural Resources and Agriculture, Africa University, Mutare, Zimbabwe

³Department of Horticulture and Sustainable Agriculture, Women's University in Africa, Marondera, Zimbabwe

Abstract

Smallholders crop production systems in Africa are constrained by a variety of factors: among them nutrient deficiency and low soil organic matter status. Groundnut (*Arachis hypogea* L) production in these areas is usually practiced with no artificial fertilisers or cattle manure as fertilizers are preferably used for staple crops production like maize. Organic composts from municipal landfills provide an alternative source of organic amendment for peri-urban groundnut production. Greenhouse and field studies were conducted during the 2006-07 season to determine whether municipal phosphocomposts can increase groundnut productivity as measured by dry matter, P uptake and yield. The field studies were carried out at two sites, namely Africa University farm and Nyamazura, both in Manicaland province of Zimbabwe. The studies were carried out during the 2006/2007 seasons. Municipal phosphocomposts used in the experiment were made from sewage sludge (SL), vegetable vending waste (VW) and wood processing waste (WW) collected from various sites in the city of Mutare. The wastes were composted with Zimbabwe (Dorowa) phosphate rock (DPR) and sulphur for a period of 56 days before being used for the experiments. Application of the three-municipal organic phosphocomposts produced comparable dry matter with inorganic fertilisers (SSP). Addition of sewage sludge/DPR composts improved dry matter of groundnuts. Leaf P and residual P_2O_5 were significantly ($P<0.05$) higher with organic amendments than with other soil ameliorants, except for SSP. The amount of residual phosphorous from sewage sludge compost amended plots was enough to support a succeeding crop of maize (>30 ppm resin extractable). Municipal composts significantly ($P<0.001$) improved groundnut pod yield compared to control and sole DPR. The study showed that the use of municipal phosphocompost is beneficial in improving groundnut nutrition and productivity. They can therefore be used for groundnut production in areas where soil nutrient sources are scarce and have potential for building phosphorous stocks. Apart from increasing current crop growth, the composts can also help build soil organic matter.

Keywords

Groundnuts, Municipal Phosphocomposts, DPR, Yield and Residual Phosphorous

*Correspondence: Tavagwisa Muziri (tavamuziri@gmail.com), Tavagwisa Muziri (tmuziri@wua.ac.zw)

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1. Introduction

Groundnuts (*Arachis hypogaea. L*) is an important food security buttress crop and a vital cash crop in most rural economies. Like many other crops, its production in most of the African countries is constrained by lack of mineral and/or organic fertilizers [1]. Farmers in Zimbabwe and other resource poor countries normally grow groundnuts with no basal fertiliser, relying on residual nutrients for early growth of the crop [1]. This is mainly because of the limited availability of inorganic fertilisers and manure as well as the prohibiting costs of acquiring fertilisers [2-4].

Composts have been in use for centuries and have been found to improve crop yields, soil physical and chemical properties [2]. In developing countries with rapidly growing urban populations like Zimbabwe, municipal organic composts are a potential source of organic inputs for farmers in the peri-urban areas. However, municipal composts, like manure, are not capable of fully satisfying the complete nitrogen, phosphorous and potassium requirements of crops since they are dilute sources of nutrients [5]. When composted with additional nutrient sources, municipal wastes can be converted into biofertilizers that can be used to boost fertility of most agricultural soils.

Research has shown that, when composted with phosphate rock, organic amendments such as yard waste, compost and bio solids can enrich the soil by their direct contribution and by altering the P sorption capacity of the soil [4]. The fertilising value of municipal composts can be boosted considerably by the addition of phosphate rock, mineral fertilisers or other special material [18]. The use of phosphate rock additives can be particularly important if for example, the soil to be treated with

the compost is known to be low in phosphorous, as is the case with most Zimbabwean soils [3].

The use of beneficiated composts has been demonstrated extensively with different phosphate rocks and inorganic fertilisers. In Zimbabwe, such beneficiation studies have been done with cattle manure and Dorowa phosphate rock or inorganic fertilisers [6-8]. Few studies have been done to show the benefits of using beneficiated municipal composts on the growth and yield of field crops. The research was therefore carried out to determine whether municipal organic waste composted with Dorowa phosphate rock (DPR) and sulphur can increase crop growth as measured by dry matter, P uptake and yield of groundnuts. A secondary objective was to determine the effect of applying municipal composts on residual phosphorous after growing the test crop.

2. Materials and Methods

2.1. Organic Wastes and Dorowa Phosphate Rock Used in the Experiment

Municipal organic wastes used in the study were collected from the city of Mutare's industrial areas, vegetable market places, dumping sites and from the sewage treatments works. Three major organic wastes were used in this experiment: sewage sludge (SL), wood processing waste (WW) and vegetable vending waste (VW). Chemical characteristics of the organic wastes and composts used in the experiments are shown in Table 1.

Table 1. Analysis of sludge, vegetable vending waste and wood processing waste obtained from Mutare city and their phosphocomposts.

Compost type	pH 0.01 M CaCl ₂	Total N %	Total P ppm	Mehlich extractable P ₂ O ₅ of uncomposted wastes	Mehlich extractable P ₂ O ₅ of the beneficiated composts		
				ppm	0 kg DPR	50 kg P ₂ O ₅ (DPR)	100 kg P ₂ O ₅ (DPR)
Sludge	4.88	1.8	1068	77	270	313.3	303.3
Vending Waste	5.91	0.5	780	53	283.3	303.3	233.3
Wood P Waste	4.85	0.7	130	21.5	60	70	83

2.2. Dorowa Phosphate Rock (DPR)

Dorowa phosphate rock (DPR) used in the experiment is an igneous phosphate reserve mined at Dorowa (190041; 310411E) in Manicaland province of Zimbabwe. The International Fertiliser Development Centre (IFDC) identified DPR

(33% P₂O₅) as a hydroxyl- fluorapatite with an ammonium citrate solubility of 0.8% P₂O₅ and approximately the following composition: Ca₁₀(PO₄)₆(F1.08OH0.92) [9]. With a citrate solubility of 0.8%, DPR is considered to be very low in reactivity and its igneous nature makes it unsuitable for direct application.

2.3. Composting

Sewage sludge, vegetable vending waste and wood waste were composted with three levels of DPR supplemented with sulphur (0 kg; 50 and 100 kg P₂O₅ (DPR) + 20 kg S/ t of each organic waste). Composting was done in six (6) aerated brick cubicles measuring 200 cm long x 90 cm high x 44 cm wide (Figure 1) for a period of 56 days. The composting cubicles

were lined with impermeable polyethylene plastic to prevent leakage of nutrient laden water. Deionised water was used to keep the moisture at field capacity. Sulphur was added to the compost to improve dissolution of the phosphate rock through its acidulation effects [10].

The composts were compared with two levels of sole DPR; two levels of single super phosphate (SSP), a control and farmer practice, giving a total of 14 treatments (Table 2).

Table 2. Treatment descriptions for the field and greenhouse experiments.

Treatment	Composition
VW	Vegetable vending waste
WW	Wood waste
SL	Sewage sludge
CVW-L1	4t VW /ha containing 50kg P ₂ O ₅ (DPR) +20kg S compost
CWW-L1	4t WW /ha containing 50kg P ₂ O ₅ (DPR) +20kg S compost.
CSL-L1	4t SL /ha containing 50kg P ₂ O ₅ (DPR) +20kg S compost.
CVW-L2	4t VW /ha containing 100kg P ₂ O ₅ (DPR) +20kg S compost.
CWW-L2	4t WW /ha containing 100kg P ₂ O ₅ (DPR) +20kg S compost.
CSL-L2	4t SL /ha containing 100kg P ₂ O ₅ (DPR) +20kg S compost.
DPR-L1	50 kg P ₂ O ₅ (DPR) (ground)
DPR-L2	100kg P ₂ O ₅ (DPR) (ground)
SSP-50	SSP at 50kg P ₂ O ₅ /ha.
SSP-100	SSP at 100kg P ₂ O ₅ /ha.
Farmer Practice/ (Control)	No soil ameliorant applied

2.4. Methodology for the Greenhouse Experiment

2.4.1. Soils

The soil used in the greenhouse experiment was collected

from Marange, a typical communal area with highly weathered granite soils. According to the Zimbabwean soil classification system, Marange soils are classified as fersiallitic, 5G soils [11, 12], also classified as Typic Ustipsament in the USDA system of classification. The soils were collected from the top 20 cm and analysed for physical and chemical properties (Table 3).

Table 3. Chemical characteristics of Marange soils, Zimbabwe.

Soil Type	Texture	pH 0.01M CaCl ₂	Mineral N (ppm)	Available P (ppm)	Ca meq (%)	Mg	Zn	Cu
Marange soil	Sandy loam	4.92	23	15	0.14	0.11	0.218	Trace

2.4.2. Soil Preparation, Treatment Application and Planting

The soil was air-dried and packed in 10 kg plastic pots. Gypsum was added at the rate of 1200 kg.ha⁻¹ (5.455 g.pot⁻¹) and allowed to incubate for four weeks. Treatments shown in Table 1 were applied to the plastic pots. Composts were applied to the pots at 18.18 g.pot⁻¹ (equivalent to 4tha⁻¹). SSP and sole DPR were applied at 0, 50 and 100 kg P₂O₅ ha⁻¹ (0, 1.25, and 2.5 g.pot⁻¹ for SSP and 0, 0.69 and 1.38 g.pot⁻¹ for DPR). A treatment with no basal fertilizer application was considered to reflect farmer's practice.

2.4.3. Design of the Experiment, Planting and Measurements

The pots were arranged in completely randomized blocks with three replicates. Four groundnut seeds were sown and thinned to two (2) plants two weeks after emergence. Dry matter yield and plant tissue phosphorus were measured at 42 days after emergence. Above ground biomass was collected, oven dried at 60°C for 48hrs and weighed for dry weight. Samples were ground and digested in selenium / sulphuric acid mixture for the determination of total P. After removing the dry above

ground parts, residual available P was analysed from soils using Mehlich-3 method [13].

2.4.4. Data Analysis

Dry matter, tissue P and soil available P data were analysed using analysis of variance. The statistical package used was GenStat Release 7.1 (2003). Means were separated using the least significant difference (LSD).

2.5. Field Experiment

2.5.1. Study Site and Soils

The field experiments were conducted at Africa University (AU) and Nyamazura farms in Manicaland Province of Zimbabwe. Nyamazura is located 180 50' S 320 25' E, 1036 meters above sea level (m.a.s.l). It receives an annual average rainfall of 660mm and the soils at the site are Orthoferrallitic 7G soils [11]. Africa University farm is located at 320 36' E 180 53' S, at an elevation of 1063 m.a.s.l and receives an annual average rainfall of 920mm. The soils at Africa University are classified as Fersiallitic 5E.2 according to the Zimbabwean system of soil classification [11]. The chemical characteristics of the soils are shown in Table 4.

Table 4. Chemical characteristics of soils from farms in the Africa University (AU) and Nyamazura in Zimbabwe.

Soil Type	Texture	pH 0.01M CaCl ₂	Mineral N (ppm)	Available P (ppm)	Ca meq (%)	Mg	Zn	Cu
AU soil	Sandy clay	4.96	57	52	8.83	2.42	0.372	Trace
Nyamazura soil	Sandy loam	5.82	24	25	0.18	0.13	0.14	Trace

2.5.2. Field Layout, Treatment Application and Planting

The experiments were arranged as randomised complete block designs with three replicates. Plots were marked measuring 4m x 3m. DPR was applied at 0, 50 and 100 kg P₂O₅ ha⁻¹ (0, 181.82 and 363.64 g.plot⁻¹). Single super phosphate was applied at 0, 50 and 100 kg P₂O₅ ha⁻¹ (0, 329.67 and 659.34 g). Composts were applied at 4tha⁻¹ dry matter (4.8 kg per pot). No basal fertiliser was adopted as the farmer practice and this acted as the control. Treatments were banded in the furrows and covered slightly with soil before sowing the seed. Groundnuts were sown at a spacing of 45 cm x 5 cm and a depth of 5 cm, giving a plant population of 350 000 plants.ha⁻¹. Gypsum was applied to the groundnuts at 200 kg.ha⁻¹ at 56 days after emergence (DAE).

2.5.3. Measurement of Above Groundnut Dry Matter Accumulation

Dry matter was measured at 56 days after emergence (DAE) by sampling three plants from the second row and collecting the whole above ground parts. Whole above ground parts were dried in an oven for 48 hours at 60°C and then weighed. Dry matter was expressed in tonnes per hectare.

2.5.4. Measurement of Groundnut Leaf P

Groundnut leaves were collected from the dry matter samples and ground to pass through 0.18 mm sieve. Total leaf P was extracted by digesting the ground samples in selenium/ sulphuric acid mixture and the total P was measured in the extracts using-VIS Spectrophotometer.

2.5.5. Groundnut Kernel Yield, Pod Yield and Shelling Percentage

Groundnut kernel and pod yield were determined by harvesting net plot plants i.e. 3.375 m² in the centre of the plot. Kernel yield was measured by weighing kernels after drying the harvested nuts to 17% moisture content. Pod yield was determined by shelling the net plot kernels and weighing the resultant pods. Shelling percentage was determined by calculating the percentage of pod yield relative to kernel yield i.e,

$$\text{Shelling percentage} = \text{pod weight} / \text{kernel weight} \times 100\%$$

2.5.6. Data Analysis

Analysis of variance for dry matter, P accumulation, yield and shelling percentage data was done using GenStat release 7.1 (2003). Mean separation was done using LSD pair wise comparisons at $P < 0.05$.

3. Results and Discussion

3.1. Effect of Municipal Phosphocomposts, SSP and DPR on Groundnut Dry Matter

Table 5. Groundnut dry matter production as affected by municipal organic wastes composted with DPR and sulphur.

Treatments	Groundnut Dry Matter		
	GH (42 days)	AU (56 days)	NY (56 days)
SL	2.66	6.37	5.39
SL50	3	6.38	5.48
SL100	3.45	7.42	5.57
WW	2.44	6.53	4.61
WW50	2.84	6.82	4.53
WW100	2.8	6.28	4.95
VW	2.8	6.56	4.41
VW50	2.55	6.13	4.31
VW100	3	6.52	6.58
SSP50	3.1	4.45	5.07
SSP100	2.47	8.44	4.9
DPR50	2.53	5.54	5.25
DPR100	2.94	5.01	5.41
Control (Farmer Practice)	2.21	5.46	4.32
CV%	20.1	14.9	14.1
LSD _{0.05}	0.8943	1.309	1.18
Mean	2.73	5.91	5.01
P-value	>0.05	<0.05	<0.05

GH=Greenhouse, AU=Africa University, NY= Nyamazura

Table 5 shows the effects of municipal phosphocomposts, SSP, sole DPR, and control/ farmer practice on groundnut dry matter yield at 42 days after emergence (DAE) in the greenhouse and 56 DAE in the field experiments.

Results from the Table 5 show that application of treatments resulted in significant yield changes at both Africa University and Nyamazura sites ($P < 0.05$). The sewage sludge composted with 100kg DPR produced the highest dry matter results. This could probably be due to that at the highest level of DPR; the amount of

P released was significant enough to cause an increase in yields whereas with other applications the composting time was not enough to produce sufficient P. Plots which were treated with sole DPR did not produce better dry matter when compared with the control indicating no benefit derived from applying DPR alone.

The positive effects of sewage sludge phosphocompost on groundnuts dry matter suggest farmers can benefit from improved early establishment of their groundnut crops through addition of this type of organic amendment [17]. Indeed, early accumulation of dry matter produces a vigorous plant less susceptible to adverse effects of competition from weeds and capable of withstanding minor attack from pests and diseases.

3.2. Groundnuts Leaf P Uptake

The effects of sewage sludge, wood waste and vegetable vending waste composts, sole DPR, SSP and farmer practice on the levels of P in groundnut leaves at 42 DAE are shown in Figure 1.

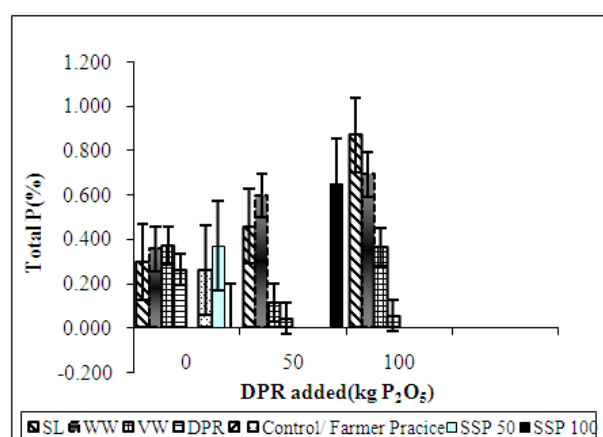


Figure 1. Groundnut leaf P content as affected by different municipal phosphocomposts, sole DPR, SSP, farmer practice/control (%) from greenhouse experiment.

The application of treatments produced significantly different leaf P (%) in the test plants ($P < 0.05$). SSP and wood waste and sewage sludge phosphocomposts produced the highest leaf P. In non-beneficiated composts, there were no significant differences between the leaf P contents of groundnuts plants ($P > 0.05$). The level of leaf P increased in groundnuts grown in beneficiated compost pots as the level of DPR was increased (Figure 1). The responses by groundnuts to application of the different treatments show that organic amendments were beneficial in improving leaf P and addition of DPR was beneficial in improving the P status of leaves. The amount of leaf P reflects the phosphorous nutrition of the crop [14]. Apart from improving other soil properties, results suggest that the use of beneficiated composts is beneficial in improving P status in the soil.

The levels of leaf P produced by groundnuts plants grown to DPR amended soils were lower than the critical leaf P_2O_5 levels of 0.15% P and considered acutely low [14]. This indicates that

DPR alone did not release enough available P to improve the amount of available P in the soil, hence low uptake by plants reflected in the leaves. The low P contents of plants grown to sole DPR and control could also have been compounded by the limited supply of N in the soil, as N nutrition indirectly influence P uptake through its effects on root growth [14]. These findings conform to other findings made in earlier research, which showed that DPR has poor agronomic effectiveness when applied alone owing to its low citrate solubility [9, 7].

3.3. Effects of Municipal Phosphocomposts on Residual Soil P After Planting Groundnuts for 42 Days

The amount of available P_2O_5 remaining in the soil after applying the different soil ameliorants and planting groundnuts for a period of 42 days was determined from the greenhouse experiment (Figure 2).

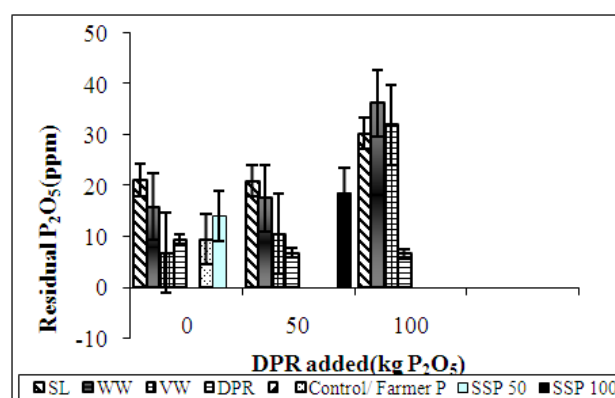


Figure 2. Residual soil phosphorous after planting groundnuts under different municipal phosphocomposts, sole DPR, SSP, farmer practice/control.

Results from Figure 2 show that application of municipal phosphocomposts had a significant effect on residual phosphorous ($P < 0.05$). The amount of available P_2O_5 left in the soil by the three phosphocomposts (at 100 kg P_2O_5 as DPR) after 42 days of growing groundnuts were adequate for growing a maize crop (> 30 ppm resin P_2O_5) [15]. Spectacular from these results is that in all cases, municipal phosphocomposts left behind significantly more P_2O_5 than SSP at both levels ($P < 0.05$). The rest of the municipal phosphocompost treatments left behind less than 30ppm (resin P_2O_5), an amount lower than what is critical for growing crops but significantly higher than that found in the control/farmer practice plot.

Although 42 days are not enough to determine the total uptake of P by a plant, most of the roots would have formed by then and most vegetative material would have been created hence it gives a rough estimate of what is taken up by the plant. This gives a clue of what can be left behind in soil, implying therefore that beneficiated composts can be used for growing

groundnuts leaving enough residual P for subsequent crops.

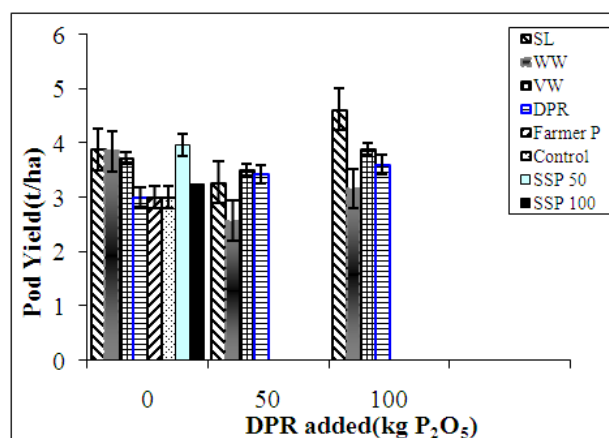


Figure 3. Groundnut pod yield as affected by municipal organic waste phosphocomposts, SSP and sole DPR on at Africa University site in Zimbabwe.

The three unbeneficiated composts produced yields that were significantly higher than those produced by farmer practice/ control and those produce by DPR alone. Yields attained in municipal compost treated plots were comparable with those produce by SSP. Except for vending waste compost which produced better results at 100kg DPR added, results showed that the addition of DPR did not have any significant effect on yield. Yield results from organically amended plots were comparable with those obtained in SSP plots. Although leaf P results (Figure 1) were significantly different between the different wastes, this was not observed for the yields. A number of factors could have affected yield increase. Shortage of other nutrients in some compost for example, may have affected yield response to higher phosphate levels.

The high groundnut yields produced in sewage sludge plots could have been due to its relatively higher contents of P and other nutrients and its buffering effect on pH rather than P alone. Numerous studies have also shown that when P is applied, other factors become limiting, notably nitrogen [16]. Recognition of other plant growth limiting factors is therefore important in making conclusions about the effects of organic amendments on crop yields.

4. Conclusion

Residual P results show that beneficiated municipal composts are capable of supplying phosphorous to the groundnut crop and to a subsequent crop following groundnuts. Sequential cropping is therefore possible when beneficiated municipal organic composts are adapted for growing crops. The positive residual effects of applying beneficiated organic wastes also suggest P build-up in soils, an important aspect in P replenishment strategies.

Yield results from the current study therefore showed that

municipal composts perform comparatively well with inorganic soil ameliorants. Although the use of municipal composts was shown to increase yields significantly, the use of DPR to beneficiate the composts did not produce any incremental benefits on yield. Sewage sludge phosphocomposts were shown to consistently produce better yields than the other two composts. The reason could be that sewage sludge has high P and other nutrients in the available form than the other wastes. The lack of positive results on yield is however outweighed by the positive residual P results emanating from addition of DPR in composts. This shows that municipal composts are good alternatives for smallholder farmers where fertilizer is a scarce commodity. Results however indicate that beneficiating municipal wastes with DPR and sulphur may not be beneficial in the short term as the effects on yield were not significant. However, since residual P results show benefits of beneficiating, composting with DPR and sulphur would be recommended where sequential cropping is done for the benefit of succeeding crops. It is also recommended for building up soil stocks of phosphorous.

These results point to the conclusion that municipal organic composts can be used to bridge the urban- rural nutrient divide with additional benefits of building up phosphorous stocks and soil organic matter.

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Abbreviations

DPR	Dorowa Phosphate Rock
SSP	Single Super Phosphate
SL	Sewage Sludge
VW	Vegetable Vending Waste
WW	Wood Waste

Author Contributions

Tavagwisa Muziri: Data curation, Formal Analysis, Investigation, Methodology, Writing – original draft, Writing – review & editing

Innocent Pahla: Methodology, Visualization, Writing – review & editing

Fanuel Tagwira: Conceptualization, Funding acquisition, Methodology, Project administration, Resources, Supervision

Conflicts of Interest

The authors declare no conflicts of interest.

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