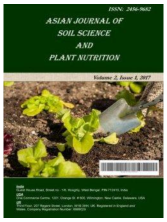

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Effects of Cowpea Residues, Chicken Manure and Partially Acidulated Phosphate Rock on the Fertility of Two Acid Soils for Maize Production in Lusaka-Zambia

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Authors' contributions

This work was carried out in collaboration between both authors. Author MN managed the literature searches and wrote the first draft of the manuscript. Author VS designed the study and performed the statistical analysis. Both authors read and approved the final manuscript.

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ABSTRACT

Aim: To assess the use of chicken manure pellets, partially acidulated phosphate rock (PAPR) and cowpea residues to enhance the fertility and productivity of two Kandiustalfs in Zambia.

Methodology: Six treatments; chicken manure, PAPR, cowpea residues, chicken manure with PAPR, cowpea residues with PAPR and no amendment (control) were assigned to 4 m x 4 m plots on each soil. The PAPR was applied at a rate of 40 kg P_2O_5/ha, chicken manure at 20 kg N/ha and cowpea was planted in rows 45 cm apart. Cowpeas or weeds were allowed to grow on each plot for four months when cowpea pods matured. Plants were cut, incorporated into the soil and left to decompose for six weeks. Soil samples were then collected for analysis of organic matter, N, P, K and greenhouse maize trials.

Results: Cowpea residues, chicken manure and chicken manure with PAPR significantly increased levels of organic matter. Cowpea residues and cowpea residues with PAPR significantly increased levels of available N than the control. Available P levels significantly increased with

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application of cowpea residues and chicken manure with PAPR. Application of cowpea residues, cowpea residues with PAPR and chicken manure significantly increased levels of K than the control. Cowpea residues and cowpea residues with PAPR significantly increased maize dry matter yields than the control. The relative agronomic effectiveness (RAE) of cowpea residues was 66% on Chakunkula soil and 37% on Choma soil respectively.

Conclusion: Cowpea residues are potential means of improving the fertility and productivity of acidic Alfisols especially for resource poor farmers with limited access to chemical fertilizers.

Keywords: Amendment; soil organic matter; nitrogen; phosphorus; residue.

1. INTRODUCTION

Many soils in sub-Saharan Africa are acidic and have low levels of organic matter (OM), nitrogen (N) and phosphorus (P) [1]. Deficiency of any plant nutrient results in poor crop establishment, reduced plant growth and sometimes, total crop failure. To achieve acceptable yields on degraded land, farmers apply chemical fertilizers to supply the deficient nutrients. In Zambia, majority of farmers are small scale farmers and resource poor who cannot afford to purchase adequate quantities of chemical fertilizers to sustain acceptable crop yields [2]. Continuous cultivation of land without adequate replenishment of nutrients removed through crop harvest results in reduced levels of nutrients and organic matter in soils [3].

Under traditional farming systems, farmers relied on 10 – 15 year fallows to restore the fertility of soils. Because of the increase in population and its associated increased demand on land, fallow periods have reduced to 1 - 2 years resulting in soil degradation and its associated reduction in productivity [4]. If this trend is to be arrested, there is need to find ways of improving the fertility of fields left fallow using potential locally available soil amendments. The need to use amendments such as phosphate rocks, animal manures and annual leguminous crops such as cowpea is quite necessary.

Cowpea is a crop widely grown by small scale farmers in Zambia. It is known to form mycorrhizal associations with fungi in the soil that enhances the uptake of phosphorus [5]. It also forms symbiotic relationships with *Rhizobium* bacteria that enable it to fix nitrogen [6]. When cowpea is used as a cover crop, it can contribute as much as 145 kg N/ha into a cropping system [7]. After harvesting cowpea grain, the stover can be incorporated into the soil, where the nitrogen and other nutrients contained in the stover can be mineralized into the soil, since it has a low C/N ratio. Recent studies have shown that the effect of incorporating cowpea stover into the soils on maize yield is similar to that of applying chemical fertilizer [8,9]. Incorporating cowpea residues was also reported to significantly increase soil nitrogen levels in the soil and rice yields [10].

According to [11] Poultry manure is the most easily decomposable animal manure, because it contains uric acids which are easily decomposed. It is a readily available source of nitrogen for plants when applied to soils. Poultry manure has been reported to increase N, moisture, exchangeable bases and to reduce the bulk density when applied to soils [12]. It has also been cited to significantly increase levels of organic matter, total and available N, available P and exchangeable K in soils [13,14,15].

Phosphate rocks (PR) are an important source of P, a nutrient which is commonly deficient in most highly weathered soils. There are a number of PR deposits in Zambia which are not currently utilized as sources of P for crop production. These deposits are at Chilembwe, Mumbwa, Nkombwa Hill, Kaluwe Hill [16] and Sinda (V. Shitumbanuma, University of Zambia, Unpublished results). The use of PR as sources of P for crop production has been well investigated across the world [17]. In Zambia, trials have been conducted on the agronomic effectiveness of some PR products.

The suitability of Partially Acidulated Phosphate rock (PAPR) from Mumbwa and Chilembwe as sources of P for growing soya beans, finger millet and maize was assessed by [18]. They found that PAPR from both Mumbwa and Chilembwe were effective sources of P for the three crops. Chilembwe PAPR had greater soil residual P than mono-ammonium phosphate and was recommended as a suitable amendment for improving levels of P in deficient soils [19]. The PAPR from Sinda was as effective as Single

Super Phosphate fertilizer in providing P to maize (V. Shitumbanuma, University of Zambia, unpublished results).

The above cited benefits of applying cowpea residues, chicken manure and phosphate rock to soils intended for crop production prompted an investigation to assess the potential of using these materials alone and in combination as amendments for improving the fertility and productivity of degraded cultivated soils. This paper presents results of a study that was conducted to assess the effects of incorporating cowpea residues, chicken manure and PAPR into the soil, on the levels of organic matter, available N, available P and exchangeable K in the soil and on the dry matter yield of maize on two cultivated acid soils.

2. MATERIALS AND METHODS

2.1 Location

The study was carried out in the 2015/2016 cropping season. It involved field studies and greenhouse pot trials. The field studies were conducted on two sites at the University of Zambia Farm in Lusaka, Zambia. The sites were Agricultural Technology Demonstration Centre (ATDC) located at 15° 21′ 25.2″ S and 28° 27′ 25.2″ E, at 1140 m above sea level and Liempe Farm located at 15° 23′ 13.2″ S and 28° 29′ 13.2″ E at 1160 m above sea level. Both sites are located in Agro-ecological zone II of Zambia. This zone has a subtropical continental climate that receives unimodal rainfall between the months of November and April. The long term mean annual rainfall is between 800 and 1200 mm while the mean annual air temperature is around 19°C. During the study period, the sites received 729 mm of rainfall while the average monthly temperature was 21.9°C indicating that the season had lower than normal rainfall and was hotter than the long term average. The soil at the ATDC was a Typic Kandiustalf [20] locally classified as Choma Soil Series, while the soil at Liempe was also a Typic Kandiustalf [20] belonging to Chakunkula Soil Series.

Greenhouse pot trials were carried out at the School of Agricultural Sciences University of Zambia in Lusaka, Zambia is at latitude 15° 23′ 40.4″ S and longitude 28° 20′ 04″ E at an altitude of 1260 metres above sea level.

2.2 Soil Sampling and Analysis

At each study site, suitable locations with cultivated acid soils were selected. Selected locations at both sites were generally uniform in terms of their slope and surface properties. The land at each site was demarcated into rectangular quadrats. Surface (0-20 cm) soil samples were randomly obtained using an auger and mixed to make composite samples. Four composite samples were taken from each site for the initial characterization of soils.

Soil samples from the field were air dried, disaggregated and passed through a 2 mm sieve. Portions passing through the 2 mm sieve were retained for laboratory analysis of selected properties. The properties tested included; particle size analysis using the hydrometer method [21]; soil pH in 0.01M $CaCl_2$ at a soil to solution ratio of 1:2.5 [22]; organic carbon content by the Walkely and Black method [23]; available N extracted in 2M KCl and determined by distillation [24]; available P extracted using the Bray 1 method [25] and determined colorimetrically by measuring at a wavelength of 882 nm after developing molybdenum blue colour; exchangeable bases extracted in 1N NH_4O_{AC} buffered at pH 7.0 using a 1:5 (w/v) suspension and the concentrations in the extracts determined on Atomic Absorption Spectrophotometer (AAS) [26].

2.3 Production of PAPR and Analysis of Nutrient Contents of PAPR and Chicken Manure Pellets

Partially acidulated phosphate rock (PAPR) was produced by adding concentrated commercial grade sulphuric acid to finely ground phosphate rock from Sinda district. The amount of acid used was calculated to be sufficient to convert 50 % of the phosphates in the rock into water soluble form. The calculation used was based on the following stoichiometric equation:

$$2Ca_5(PO_4)_3F_{(s)} + 7H_2SO_{4(aq)} + 3H_2O_{(l)} \Leftrightarrow 7CaSO_{4(s)} + 3Ca(H_2PO_4)_{2(s)} + 2HF\uparrow$$

About 5 kg of phosphate rock powder was reacted with 250 mL of 10M H_2SO_4 and two litres of tap water and mixed under open air. The acid-rock mixture was left to cure for three days and then allowed to dry. After drying, the product was ground into a powder.

To determine the concentrations of total P and Ca in the PAPR, samples of the PAPR were digested in Aqua-Regia for 30 minutes. Aqua regia was prepared by mixing one part concentrated HNO_3 to three parts concentrated

HCl. The concentrations of P and Ca in the extract were determined colorimetrically and by AAS respectively.

To determine concentrations of Ca, Mg, K, Mn, Fe, Cu and Zn in the chicken manure pellets, the manure samples were ashed at 500°C for 3 hours. The ash was then digested in 1N HNO_3. Concentrations of the metals in the extract were determined by AAS. The total N content of the chicken manure was determined using the modified macro Kjeldhal method [27]. The total P content was determined using the dry ashing method [28] and concentrations determined colorimetrically at a wavelength of 882 nm after developing the molybdenum blue colour.

2.4 Experimental Set Up

At each site, the land was ploughed and disced with tractor drawn equipment after which six 4 m x 4 m plots were demarcated. The treatments (i) a control where no amendment was applied, (ii) PAPR, (iii) chicken manure pellets (CM), (iv) Cowpea residues (CP), (v) CM with PAPR and (vi) CP with PAPR were randomly assigned to each plot without replication. For the treatments with cowpea residues, a cowpea variety, LT 11-3-3-12 from the Department of Plant Science, University of Zambia was used. The cowpea was planted in rows 45 cm apart with an intra row spacing of 20 cm. Four seeds were planted per planting station and thinned to two plants per station two weeks after emergence. Chicken manure pellets and PAPR were banded in rows 45 cm apart similar to those used for planting cowpea. On each of the plots, weeds were allowed to grow.

At the ATDC, plots in which cowpeas were grown were weeded 3 weeks after planting, following a severe infestation of the weed *Richardia scabra*. Four months after planting; when cowpea pods had formed and matured, plants growing on each plot were cut, spread across the surface of the plots and left to dry for three days. The plant residues on each plot were then arranged into four rows and covered with surface soils to form ridges using hand hoes. The ridges were left for six weeks to allow the organic residues to decompose. The ridges were then dismantled and the soils were thoroughly mixed with the decomposed plant residues. Soil samples were collected from each plot for use in greenhouse maize trials and for further soil analysis to determine the levels of organic matter, available N, available P and exchangeable K using the methods outlined earlier.

A greenhouse pot trial was conducted to assess the effects of the treatments used in the field study on the dry matter yield of maize. The experiment was laid out as a Completely Randomised Design with 7 treatments and four replicates on each of the two soils. The extra treatment to the six used in the field study, was the addition of chemical fertilizer; compound D (10% N : 20% P_2O_5 : 10% K_2O) at the rate of 4.5 g fertilizer per pot corresponding to the local recommended basal fertilizer application rate of 200 kg Compound D per hectare for maize. Three kilograms of soil was weighed into 3 litre plastic pots in which four ZMS 402 maize seeds were planted and thinned to one plant per pot a week after emergence. The maize plants were grown for six weeks after which the above ground biomass was harvested, air-dried and weighed to determine the dry matter yield.

The Relative Agronomic Effectiveness (RAE) of the amendments used was then calculated using the formula:

$$RAE(\%) = \frac{(yield\ from\ amendment) - (yield\ from\ control)}{(yield\ from\ fertilizer) - (yield\ from\ control)} * 100$$

Where:

- Yield from control is dry matter yield of maize grown on soils from control plots and NPK fertilizer was not added
- Yield from fertilizer is dry matter yield of maize grown on soils from control plots and NPK fertilizer was added
- Yield from amendment is dry matter yield of maize grown on soils obtained from plots treated with different amendments

2.5 Statistical Analysis

To determine whether there were significant differences due to the effect of the amendments on selected soil properties and maize dry matter yield, an Analysis of Variance was conducted. Mean separation was carried out using Duncan's Multiple Variance Range Test. All tests were compared at a significance level of 0.05. The statistical analyses were conducted using SAS software version 9.0 for windows [29].

3. RESULTS AND DISCUSSION

3.1 Characteristics of Soils Used in the Study

Results of selected initial chemical and physical properties of the soils used in the study are presented in Table 1. Both soils were very strongly acid. Chakunkula soil was a sandy loam soil and Choma soil was loamy sand.

The critical levels for maize production in tropical soils have been reported to be 12 mg/kg for available P [30], 0.15% for total N [31] and 0.12 cmol/kg for K [32]. Based on these levels, Chakunkula soil had low levels of organic matter, total N, available P and K. On the other hand, Choma soil had low levels of N and K and moderate levels of organic matter and available P. This implied that the productivity of the two soils for maize was thus likely to be low if amendments were not applied to remedy the identified limitations to crop production.

The compositions of chicken manure and PAPR are presented in Table 2. The PAPR used in this study was produced from a PR that was predominantly composed of the phosphate mineral fluorapatite ($Ca_5(PO_4)_3F$. It therefore contained relatively high amounts of Ca and P. The PR was an inorganic material in which carbon, N and most other nutrients found in chicken manure were not expected to occur in appreciable amounts. The PAPR was therefore not analysed for N, K and the micronutrients determined in the chicken manure. It was applied as a source of Ca and P, but not N and K.

The chicken manure had relatively high levels of C, N, P, K, Ca and the metal micronutrients Cu, Zn, Fe and Mn. The C:N ratio of the chicken manure was 14:1 which is lower than 20:1 below which nitrogen present in organic materials is expected to be mineralized upon decomposition of the organic materials in the soil. Similarly, the P in the manure was readily mineralizable as the carbon to phosphorus (C:P) ratio of the manure was 8:1, which was much lower than 200:1 below which P in organic materials is expected to be mineralized upon decomposition of the organic materials [33].

3.2 Effects of Amendments on Selected Soil Properties

The mean values of organic matter, available N, available P, and K in plots treated with different amendments are presented and discussed in this section.

3.2.1 Organic matter

The levels of SOM in plots treated with different amendments on the two soils are presented in Fig. 1. On Chakunkula soil, plots with cowpea residues and CM with PAPR had significantly (*P* < .001) higher levels of organic matter than the control while on Choma soil, only plots with CM had significantly higher levels of organic matter than the control.

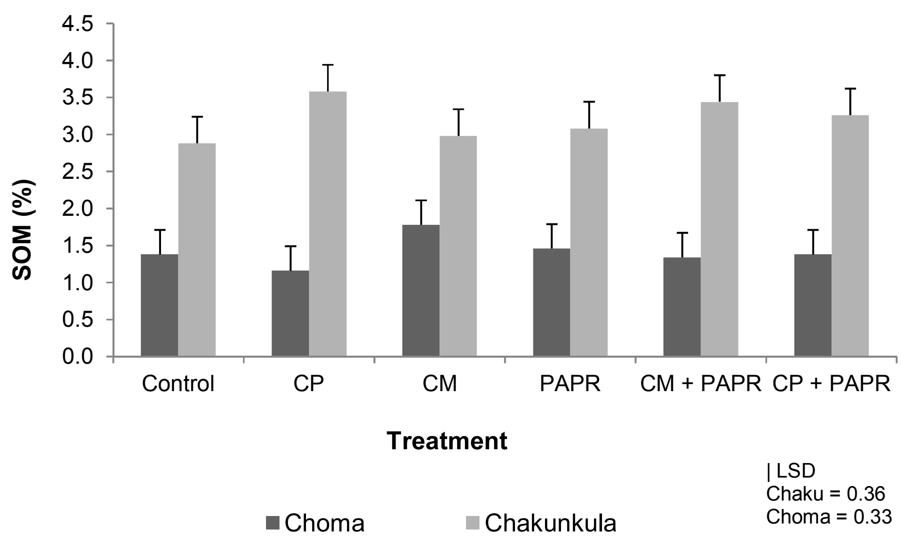

Fig. 1. SOM levels in plots treated with different amendments on the two soils

Table 1. Selected physical and chemical properties of the soils used in the study

Soil	pH 0.01MCaCl$_2$	OC	N	Avail N	Avail P	Ca^{2+}	Mg^{2+}	K^+	Sand	Silt	Clay
		%		mg/kg soil		cmol+/kg soil			%		
Chakunkula	4.02	1.08	0.06	180	6.55	0.92	0.37	0.11	53.5	13.2	34
Choma	4.32	0.49	0.03	161	22.19	0.26	0.04	0.13	77	6	17

Avail = available; OC = Organic Carbon

Table 2. Composition of chicken manure and PAPR used in the study

Amendment	OC	N	P	K	Ca	Mg	Cu	Zn	Fe	Mn
	%						mg/kg			
Chicken manure	28.8	2.1	3.59	1.78	6.18	0.86	23	105	592	111
PAPR	-	-	5.95	-	22.74	-	-	-	-	-

OC = Organic Carbon

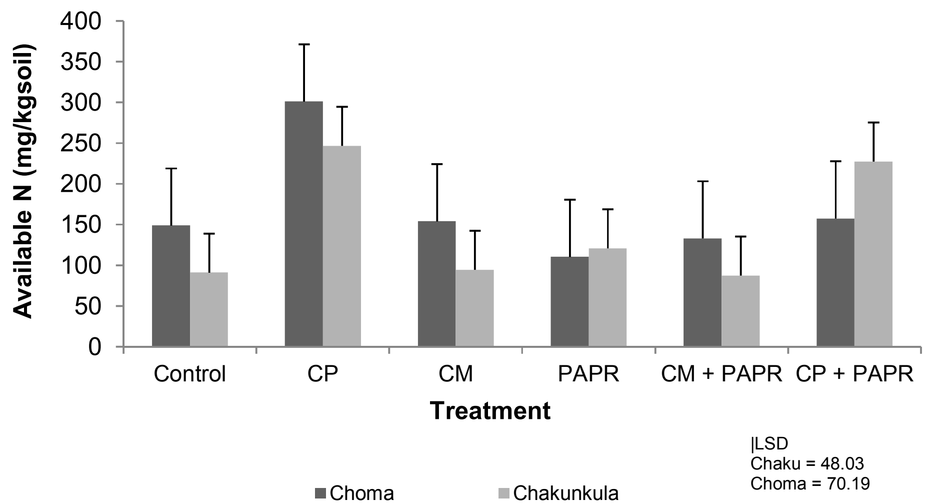

Fig. 2. Available N levels in plots treated with different amendments on two soils

Generally, soils from all the plots in the experiments including the control showed increases in the levels of organic matter compared to the initials levels in both soils. A significant amount of the organic matter measured in the soils at the end of experiment most likely originated from organic residues from plants that grew on the plots. According to [34], retaining plant residues and incorporation them into the soil increases the levels of soil organic matter. This may explain why levels of organic matter in all plots at the end of the field experiment were generally higher than the initial levels of organic matter in soils at the two sites.

On Chakunkula soil, the levels of N, P and K were initially low for maize growth. It was therefore anticipated, that adding amendments containing these nutrient would result in enhanced plant growth. Results of correlation analysis showed highly significant ($p < 0.0001$) positive linear relationships between SOM and available P ($r = 0.83$). This could explain the significantly high levels of SOM associated with treatments like cowpea residues and chicken manure with PAPR which had significantly higher levels of available P than the control.

On Choma soil where K was low, significant ($p < 0.005$) positive relationships were also established between SOM and K. This means application of K containing amendments probably enhanced plant growth. This probably explains the highest levels of SOM observed in plots amended with chicken manure which had high levels of K in addition to other nutrients. These results are consistent with findings of other researchers on the effect of poultry manure on SOM levels in African soils which indicate that applying poultry manure increases the levels of soil organic matter [13,14,15].

3.2.2 Available nitrogen

The levels of available N associated with different treatments on the two soils are presented in Fig. 2. On Chakunkula soil, plots with cowpea residues and cowpea residues with PAPR had significantly higher levels of available N than the control while on Choma soil; only plots with cowpea residues had significantly higher levels of available N than the control. These results are in agreement with findings of other researchers [10,35] who reported significant increases in the levels of total N in the soil following the incorporation of cowpea residues into the soil. Cowpea is a legume that fixes nitrogen biologically and therefore accumulates N in its biomass [6]. According to [36], cowpea biomass has an average N content of 1.4% and a C:N ratio of 21:1 which makes it a suitable source of N in soil.

Plots that received CM did not have higher levels of N than the control. This could be attributed to the fact that N in chicken manure is usually in a form that is readily available for plant uptake and also susceptible to leaching [12] especially on sandy soils. On medium to heavy soils, the N mineralized from the manure may be retained if it is not nitrified.

3.2.3 Available phosphorus

Fig. 3 presents the levels of available P in plots treated with different amendments on the two soils. On both soils, plots on which cowpea residues and chicken manure with PAPR were applied had significantly ($P < 0.05$) higher levels of available P than the control plots. The high levels of available P in soils treated with chicken manure with PAPR could be attributed to the fact that the two amendments making up this treatment contained relatively high amounts of P as shown in Table 2.

The high amounts of P in soils from plot where cowpea residues were applied could be attributed to the fact that cowpeas are known to take up significant amounts of P from soils. According to [5], cowpea forms mycorrhizal associations with soil fungus which increase the uptake of P from the soil. The P taken up accumulates in the cowpea biomass and is mineralized when the biomass is decomposed in the soil. This view is corroborated by the findings of [35] who observed an increase in levels of available P in soils as a result of incorporating crop residues from food legumes in the soil.

Plots where PAPR was applied seemed to have lower available P. The PAPR was applied in bands, soil from the whole plot was mixed after fallow period and available P was determined from the mixed soil. This implies that the dilution effect could have had an effect on the available P.

3.2.4 Exchangeable potassium

The levels of K in plots treated with different amendments on the two soils are presented in Fig. 4. Generally, all the treatments resulted in a significant increase in levels of K compared to

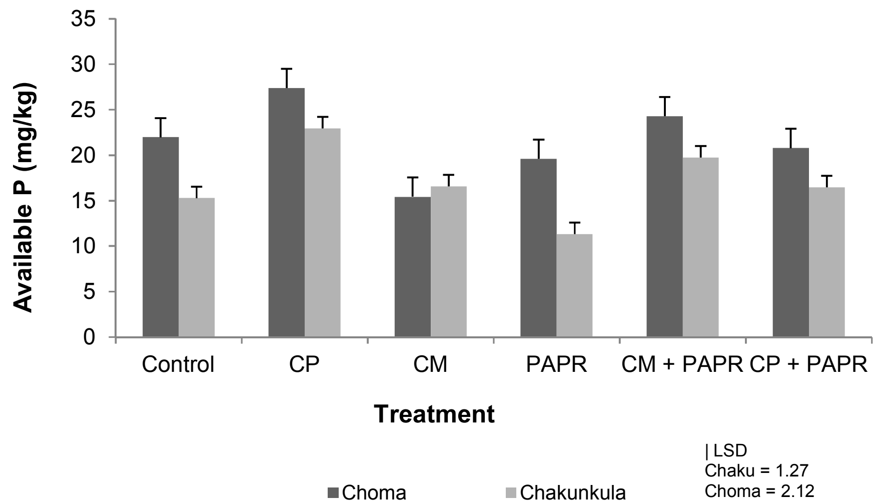

Fig. 3. Available P levels in plots treated with different amendments on the two soils

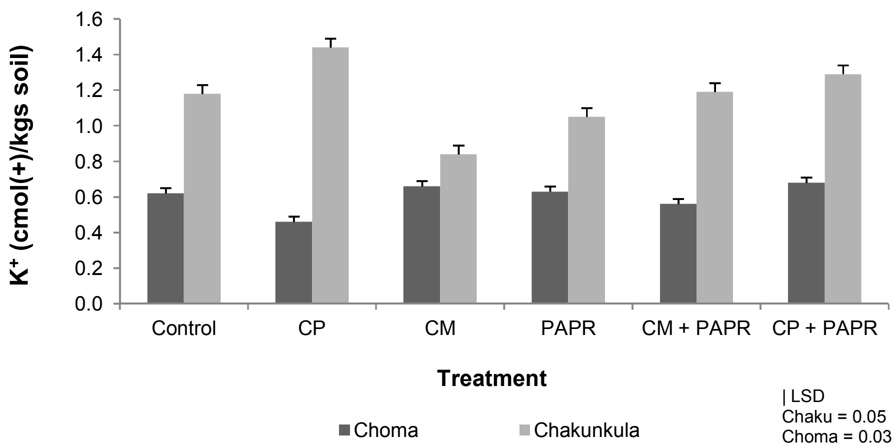

Fig. 4. K levels in plots treated with different amendments on the two soils

the levels of K before application of the treatments to the soil. The treatments that had significantly higher levels of K than the control plot were cowpea residues alone and cowpea residues with PAPR on Chakunkula soil and chicken manure and cowpea residues with PAPR on Choma soil.

On both soils, cowpea residues with PAPR had high levels of K. According to [37], phosphorus enhances root development which in turn possibly increased K uptake by the plant. Legumes take up a lot of K for nodule development and functioning [38]. This increases K accumulation in the crop biomass which is released into the soil upon decomposition of the plant residues. This could explain the increased K levels observed in plots with cowpeas residues. These results are in agreement to the findings of [35] who reported that incorporation of residues from food legumes significantly increased levels of Mg, Ca and K compared to natural fallow plots.

Generally, cowpea residues improved most of soil properties used to assess the fertility status of both soil. This indicates that cowpea residues were the best amendment in improving soil fertility of both soils.

3.3 Effect of Soil Amendments on the Dry Matter Yield of Maize

The dry matter yields of maize from soils treated with different amendments on the two soils without the application of chemical fertilizer are

Table 3. Mean dry matter yield of maize on choma and chakunkula soil series with different treatments without application of compound D fertilizer

Amendment	Maize dry matter yield (g/pot)	
	Chakunkula	Choma
Control	2.37[d]	3.14[c]
Cowpea residues	8.47[a]	5.58[a]
Chicken manure	2.43[d]	4.23[b]
PAPR	3.92[c]	3.63[bc]
Chicken manure + PAPR	3.73[cd]	3.07[c]
Cowpea residues + PAPR	5.58[b]	5.42[a]
LSD (0.05)	1.29	0.89

***Means followed by the same letter in a column are not significantly different from each other at 5 % significant levels*

Table 4. Relative agronomic effectiveness of the amendments relative to compound D on the two soils

Amendment	RAE (%)	
	Chakunkula	Choma
Cowpea residues	66.4[a]	36.6[a]
PAPR	16.9[c]	7.3[bc]
Chicken manure	0.7[d]	16.4[b]
Chicken manure + PAPR	14.6[cd]	-1.2[c]
Cowpea residues + PAPR	35.1[b]	34.3[a]
LSD (0.05)	15.35	13.94

***Means followed by the same letter in a column are not significantly different from each other at 5 % levels of significance*

presented in Table 3. On both soils, plots with cowpea residues and CP with PAPR had significantly ($p < 0.05$) higher maize dry matter yields than the control. On Chakunkula soil, PAPR also had significant higher yields than the control plots, while on Choma soil, chicken manure also had significantly higher dry matter yield of maize compared to the control.

It was observed that available N had the greatest influence on maize dry matter yield, indicating that N was probably the most limiting nutrient to maize growth on both soils. There were highly significant ($p < 0.005$) linear relationships between available N and maize dry matter on both soil. This may explain the high dry matter yield associated with plots treated with cowpea residues and CP with PAPR which had higher levels of available N on both soils. Evidence in support of this, was that, no symptoms of N deficiency were observed on maize plants grown on soils with treatments of cowpea residue and CP with PAPR. Similar observations have been reported by [8,9] who observed significant increases in maize grain yields on plots that received applications of cowpea residues compared to control plots. [10] also reported significant increases in rice yields in plots where cowpea residues were incorporated into the soil compared to natural traditional fallows plots.

On the other hand, very low maize dry matter yields were obtained where chicken manure was applied. Maize plants grown on soils treated with chicken manure also showed deficiency symptoms of N and P three weeks after emergence. It is probable that in these plots, most of the N released from the chicken manure may have been leached and partially utilised by the plants that grew on the plots during the fallow period.

3.4 Relative Agronomic Effectiveness of the Amendments

Results of the Relative Agronomic Effectiveness (RAE) of the amendments on the two soils relative to Compound D fertilizer are presented in Table 4. On both soils, cowpea residues had the highest RAE followed by the treatments with CP with PAPR. On Chakunkula soil, the RAE of cowpea residues was 66%, while on Choma soil it was 36.6%. These results are similar to those of [35], who found that grain yield of maize on plots on which stover of food legumes was incorporated into the soil ranged from 42.5 to 61.4% of that obtained from plots that received applications of chemical fertilizers.

It is evident from the results of this study that cowpea residue was the most effective treatment in increasing the productivity of the two soils for maize production. Results of the RAE of the amendments are consistent with those of the effects of the amendments on the fertility of the soils, which showed that on both soils cowpea residues improved the status of more soil fertility parameters than any other amendment. It is therefore not surprising that results of the agronomic effectiveness also showed cowpea residues to be superior to the other amendments. It should be noted that the evaluation of the agronomic effectiveness of the amendments used in this study was carried based on a pot study under greenhouse conditions and on the dry matter yield of maize rather than on the grain yield. It would therefore be necessary to carry out the same study under field conditions where maize would be grown to maturity and where the grain yield would be used to calculate the agronomic effectiveness. This however does not diminish the value of the present findings based on the greenhouse pot study.

4. CONCLUSION

Results of this study show that cowpea residues were the most effective amendment in increasing the fertility status of the soils as indicated by greater number improvements in the fertility indicators used on both soils. Furthermore, cowpea residues were most effective in increasing the productivity of the two soils for maize production. It was therefore concluded that among the amendments used, cowpea residues had the greatest potential for improving the fertility and productivity of the two acidic, low fertility Kandiustalfs for maize production. Growing cowpea and incorporating its residues into the soil after harvest could therefore be a means of restoring the productivity of soils with low fertility for maize production that resource poor resource farmers with limited access to chemical fertilizers can use in agro-ecological environments similar to those used in this study.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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