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Full Length Research Paper

The effects of superphosphate application and mucuna *(Mucuna pruriens)* management options on chemical characteristics of a sandy loam soil in Zimbabwe

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Low soil fertility due to monoculture crop production systems is recognized as one of the major biophysical causes for declining per capita food production in sub-Saharan Africa. The major objective of this research was to investigate the effect of two superphosphate levels and four mucuna management options on soil chemical properties on a depleted kaolinitic sandy soil in Zimbabwe. The two phosphorous treatments were P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1} and the four mucuna treatments were MF = mucuna incorporated at flowering, MAR = mucuna above ground biomass removed at maturity and only roots incorporated, MPR = above ground biomass except pods incorporated at maturity and F = Fallow (control). The following soil nutrients were investigated; Nitrogen, Phosphorus, Potassium, Calcium, Magnesium and Zinc. The MF and P40 treatment combination resulted in the highest N, P, K, Ca and Mg levels. However the P40 and mucuna treatment combinations had significantly lower Zn levels than the P0 and mucuna treatment combinations.

Key words: Exchangeable bases, major nutrients, mucuna.

INTRODUCTION

Low soil fertility due to monoculture crop production systems is recognized as one of the major biophysical causes for declining per capita food production in sub-Saharan Africa (Sanginga, 2003). Nutrient balance studies in this region have shown that on average 22 kg N, 2.5 kg P, and 15 kg K per hectare are lost annually and losses can be as high as 112 kg N, 3 kg P, and 70 kg K per hectare in the intensively cultivated highlands of Africa (Van den Bosch et al., 1998). These losses are much higher than the estimated inorganic fertilizer use in Africa (Heisey and Mwangi, 1996). This emphasizes the need for soil fertility replenishment through the use of organic sources such as herbaceous legumes like mucuna.

Most smallholder farmers in Zimbabwe practice monoculture crop production systems. Maize is one of the crops which are commonly used in these systems. Monoculture can lead to depletion of inherent soil fertility (Franke et al., 2004). This results in a serious threat to sustainability of maize production in Zimbabwe.

The use of legume crops such mucuna has the potential to improve the chemical and physical characteristics of inherently poor soils such as sands (Carsky et al., 2001). The improvement of the soil structure helps to reduce the adverse effects of soil erosion and decreasing cation exchange capacity. Application of organic materials such as herbaceous legumes like mucuna may increase crop-available N, P, K, Ca and Zn either directly by the process of decomposition of the biomass or indirectly by the production of organic acids (products of decomposition) that chelate Fe or Al and thus improving the CEC of the soil (Nziguheba et al., 1998).

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Abbreviations: F, Fallow; **MAR,** mucuna above ground biomass removed at maturity and only roots incorporated; **MF,** mucuna incorporated at flowering; **MPR,** above ground biomass except pods incorporated at maturity.

Carsky et al. (2001) showed that whereas mucuna contains sufficient N in 2 or 3 t of leafy material to match the requirement of a 2 t crop of maize, it cannot meet the P requirements and must be supplemented by inorganic P in areas where P is deficient. Judicious application of inorganic fertilizers is recognized as an indispensable means of overcoming soil fertility decline and decreasing food production per capita (Carsky et al., 2001). It is estimated that N fixation ranging from 0 to 250 kg N ha^{-1} with a median of 110 kg N ha^{-1} can be achieved from annual legumes with growth periods of 100 to 150 days (Ibewiro et al., 2000).

The contributions of legume residues to soil improvement and crop production depend largely on the amount of biomass produced, chemical composition and method of application (Tian et al., 2000). The decomposition and nutrient release by these residues are also affected by both climatic and edaphic factors, including the biological activity and availability of nutrients in the soil (Mugendi and Nair, 1997). It is estimated that nodulated legume roots contain from 15 kg to 50 kg N ha^{-1} (Tian and Kang, 1998). This amount of root N represents a minimum of 15% of total plant N (Peoples et al., 1995).

The major objective of this study was to assess the role played by mucuna management options and superphosphate application on the chemical characterization of the soil. This is important because mucuna was identified as a potential rotational cropping legume in maize production systems in these areas.

MATERIALS AND METHODS

Experimental site

The experiment was carried out at the Grasslands Research Station (18° 11[1] S; 31°30[1] E; alt. 1200 m.a.s.l.) in Marondera in Zimbabwe during 2007 and 2008. Marondera receives on average > 86% of the annual rainfall of 850 mm during the hot summer months (November to March). During the experimental period, a total of 1067 and 867 mm were received during 2007 and 2008 respectively. Mean monthly daily minimum temperature ranges from a lowest of 5.3°C in July to 15.3°C in January and mean monthly daily maximum temperature ranges from a lowest of 18.3°C in June to a highest of 26°C in October.

The soils are classified as humic Ferralsols based on the FAO/UNESCO system (FAO UNESCO, 2003) and are equivalent to a Kandiudalfic Eutaudox in the USDA soil taxonomy system (Soil Survey Staff, 1991). The loamy sandy soils are predominantly of the kaolinitic order and of low fertility (Nyamapfene, 1991). In general these soils are slightly acid (pH CaCl = 5.2) with organic matter content of 0.33%.

These soils have inherent low weather-able minerals and are deficient in nutrients such as P (Grant, 1981). The P levels of these soils range from as low as 5 to 15 mg kg^{-1} (Mehlic 3 method) (Grant, 1981). Soil analyses performed on soil samples taken before the trial started showed a mineral N content of 15 mg kg^{-1} at the time of sampling as well as a P content of 15.8 mg kg^{-1}, K content of 0.15 cmol kg^{-1}, Ca content of 0.2 cmol kg^{-1} and Mg content of 0.03 cmol kg^{-1}. The P test used was Mehlic 3. A P level of 30 mg kg^{-1} is regarded as sufficient for crop production and therefore this soil clearly showed deficient P levels.

Crop establishment

The experimental area was ploughed, harrowed and planted to *Mucuna pruriens* var. *utilis* in August 2007 (first season crop) and July 2008 (second season crop) using an inter row spacing of 45 cm and intra row spacing of 10 cm. Weed control was done twice using mechanical methods. A supplementary irrigation of 35 mm per application was supplied during drought periods to supplement the rainfall of 242.7 and 148.4 mm that occurred during the growth period of the mucuna crop (July to November) during 2007 and 2008 respectively. This resulted in the crops receiving relatively similar amounts of moisture in both seasons. Although this is not a normal practice with the smallholder farmers, this was done during the experimental phase so that the mucuna crop would not fail.

Experimental design and treatments applied

The experimental design was a randomized complete block design (RCBD) with 2 P treatments [P0 = 0 kg P ha^{-1} and P40 = 40 kg P ha^{-1}] applied prior to planting the mucuna crop. Single superphosphate (19.25% P_2O_5, 12% S and 14% Ca) was used as pre-planting fertilizer for the P treatments. The P40 treatment was chosen because it is the rate of P generally recommended by extension officers in Zimbabwe for a mucuna crop, but which were not previously tested in this region of Zimbabwe.

Four mucuna treatments was the sub-plot factors [MF = mucuna incorporated at flowering, MAR = mucuna above ground removed at maturity and only roots incorporated, MPR = above ground biomass except pods incorporated at maturity and F = Fallow (control)]. The effect of superphosphate and mucuna management options was measured on the N, P, K, Ca, Mg and Zn content of the soils. The treatments were replicated 4 times.

Soil sampling

Soils were sampled before the planting of mucuna in 2007 and were also done two months after the incorporation of mucuna in 2007 and 2008, shortly before planting of the subsequent maize crop. Soil samples were collected at 0 to 30 cm depth by taking five cores per plot using a 50 mm diameter augur. The five sub samples were thoroughly mixed to obtain one composite sample per plot. Subsequently 500 g of soil were weighed from each composite sample and taken to the laboratory for analyses.

The collected soil was analyzed for N, P, K, Ca, Mg and Zn. For the analyses of the nutrients the following methods were used: the Micro-Kjeldahl method for total nitrogen, the Melich 3 extraction method for available phosphorus, the 1 M ammonium acetate method for calcium, magnesium and potassium and the 0.01 M CaCl method for the soil pH. The details of the methods are outlined by AOAC (1990).

RESULTS

The data largely showed the same trends in 2007 and 2008. Therefore, only the combined data of the 2007 and 2008 seasons will be discussed although the data for the separate seasons is also given in Tables 1 to 6.

Mineral nitrogen (N)

The significant interactions ($P < 0.05$) between mucuna management options and P treatments on mineral N

Table 1. Mineral nitrogen content (ppm) of a sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied) (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control)).

Treatment	2007 season		2008 season		2 seasons mean	
	P0	P40	P0	P40	P0	P40
Before planting mucuna	15.03					
F	15^{a}	15^{a}	15.01^{a}	15.01^{a}	15$^{\mathbf{a}}$	15$^{\mathbf{a}}$
MF	23.25^{c}	24.25^{c}	23.28^{e}	24.32^{f}	23.26$^{\mathbf{d}}$	24.29$^{\mathbf{e}}$
MAR	15.9^{a}	15^{a}	15.8^{b}	15.01^{a}	15.8$^{\mathbf{a}}$	15$^{\mathbf{a}}$
MPR	20.25^{b}	21^{b}	17^{c}	21.10^{d}	20.21$^{\mathbf{b}}$	21.42$^{\mathbf{c}}$

Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

Table 2. Phosphorus content (ppm) of a sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied) (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control)).

Treatment	2007 season		2008 season		2 seasons mean		Mucuna management option (2 seasons mean)
	PO	P40	P0	P40	P0	P40	
Before planting mucuna	16						
F	17.90^{b}	17.75^{b}	18^{b}	19^{b}	17.95$^{\mathbf{a}}$	18.35$^{\mathbf{a}}$	**18.15**^{a}
MF	20.50^{c}	22.50^{d}	20.15^{c}	23.75^{f}	20.3$^{\mathbf{b}}$	23.1$^{\mathbf{c}}$	**21.7**^{c}
MPR	16.25^{a}	18^{b}	18.9^{b}	18.56^{b}	16.58$^{\mathbf{a}}$	17.5$^{\mathbf{a}}$	**17.04**^{a}
MAR	18^{b}	20^{c}	18^{b}	21^{d}	18$^{\mathbf{a}}$	20.5$^{\mathbf{b}}$	**19.25**^{b}
P treatments (mean)					**18.21**^{a}	**19.9**^{b}	

Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05. Values followed by the same italicized letter are not significantly different at P = 0.05.

Table 3. Potassium content (meq %) of a sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied) (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control)).

Treatment	2007 season		2008 season		2 seasons mean	
	P0	P40	P0	P40	P0	P40
Before planting mucuna	0.15					
F	0.15^{a}	0.15^{a}	0.15^{a}	0.15^{a}	0.15$^{\mathbf{a}}$	0.15$^{\mathbf{a}}$
MF	1.09^{e}	1.17^{f}	1.07^{d}	1.15^{e}	1.08$^{\mathbf{d}}$	1.16$^{\mathbf{e}}$
MAR	0.82^{b}	0.85^{b}	0.80^{b}	0.83^{b}	0.81$^{\mathbf{b}}$	0.83$^{\mathbf{b}}$
MPR	0.99^{c}	1.04^{d}	1.00^{c}	1.04^{d}	1.00$^{\mathbf{c}}$	1.05$^{\mathbf{d}}$

Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

content of the soil over two seasons are illustrated in Table 1. The soil in the MF and MPR management options had significantly ($P < 0.05$) higher mineral N contents in the soil as result of the P40 treatment but there were no significant differences in the mineral N content of soil between the P0 and P40 treatments in the F and MAR management options. The MF management option had 55% (P0) to 61.9% (P40) more mineral N than both the F and MAR management options and 13.4% (P40) to 15.1% (P0) more N than the MPR management option.

Table 4. Calcium content (meq %) of a sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied) (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control)).

Treatment	**2007 season**		**2008 season**		**2 seasons mean**	
	P0	**P40**	**P0**	**P40**	**P0**	**P40**
Before planting mucuna	0.19					
F	0.19^{a}	0.20^{a}	0.20^{a}	0.22^{a}	$0.20^{\mathbf{a}}$	$0.21^{\mathbf{a}}$
MF	2.94^{e}	3.10^{f}	2.95^{d}	3.12^{e}	$2.94^{\mathbf{d}}$	$3.11^{\mathbf{e}}$
MAR	1.78^{b}	1.89^{c}	1.82^{b}	1.92^{b}	$1.80^{\mathbf{b}}$	$1.90^{\mathbf{b}}$
MPR	2.08^{d}	2.96^{e}	2.08^{c}	2.94^{d}	$2.08^{\mathbf{c}}$	$2.95^{\mathbf{d}}$

Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

Table 5. Magnesium content (meq %) of a sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied) (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control)).

Treatment	**2007 season**		**2008 season**		**2 seasons mean**		**Mucuna management option (2 seasons mean)**
	PO	**P40**	**P0**	**P40**	**P0**	**P40**	
Before planting mucuna	0.03						
F	0.03^{a}	0.03^{a}	0.04^{a}	0.03^{a}	$0.03^{\mathbf{a}}$	$0.04^{\mathbf{a}}$	**0.04**^{a}
MF	0.27^{d}	0.28^{d}	0.26^{c}	0.29^{c}	$0.27^{\mathbf{c}}$	$0.28^{\mathbf{c}}$	**0.28**^{c}
MPR	0.16^{c}	0.16^{c}	0.16^{b}	0.16^{b}	$0.16^{\mathbf{b}}$	$0.16^{\mathbf{b}}$	**0.16**^{b}
MAR	0.13^{b}	0.17^{c}	0.14^{b}	0.17^{b}	$0.14^{\mathbf{b}}$	$0.17^{\mathbf{b}}$	**0.16**^{b}
P treatments (mean)					**0.15**^{b}	**0.13**^{a}	

Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

Table 6. Zinc content (ppm) of a sandy soil under different management options of mucuna during the 2007 and 2008 seasons after two P treatments (P0 = No P applied (control) and P40 = 40 kg P ha^{-1} applied) (MF = mucuna incorporated at flowering, MAR = Mucuna above ground biomass removed and only roots incorporated, MPR = only pods removed and all the other above ground biomass was incorporated and F = Fallow (control)).

Treatment	**2007 season**		**2008 season**		**2 seasons mean**	
	P0	**P40**	**P0**	**P40**	**P0**	**P40**
Before planting mucuna	4.10					
F	4.13^{a}	4.09^{a}	4.12^{a}	4.10^{a}	$4.12^{\mathbf{a}}$	$4.10^{\mathbf{a}}$
MF	9.07^{f}	8.79^{e}	9.06^{e}	8.82^{d}	$9.06^{\mathbf{f}}$	$8.80^{\mathbf{e}}$
MAR	5.06^{b}	4.10^{a}	5.08^{b}	4.12^{a}	$5.07^{\mathbf{b}}$	$4.11^{\mathbf{a}}$
MPR	6.35^{d}	6.20^{c}	6.32^{c}	6.18^{c}	$6.33^{\mathbf{d}}$	$6.19^{\mathbf{c}}$

Values followed by the same unbold letter in a season and those followed by the same bold letter for the 2 season means are not significantly different at P = 0.05.

Phosphorus (P)

There were no significant interactions between P treatments and mucuna management options over the two seasons. However, significant differences ($P < 0.05$) in the phosphorus content (ppm) of the 0 to 30 cm soil profile were noted between the P0 (18.21 ppm P) and P40 (19.9 ppm P) treatments. The MF management option resulted in the highest P levels in the soil followed by the MPR management option (Table 2). There were no significant differences in the P content of the soil between the F and MAR mucuna management options.

Potassium (K)

Significant interactions ($P < 0.05$) between mucuna management options and the P treatments on exchangeable K content of the soil over two seasons are shown in Table 3. In the case of the MF and MPR management options the P40 treatment resulted in significantly ($P < 0.05$) higher K levels in the soil but this was not true for the F and MAR management options. The MF management option resulted in significantly ($P < 0.05$) higher K levels compared to the F, MAR and MPR management options regardless of the P treatment. The MF management option in the P0 treatment increased K levels with 620 and 33% compared to the F and MAR management options respectively. A similar trend was observed in the P40 treatment.

Calcium (Ca)

There were significant interactions ($P < 0.05$) between mucuna management options and P treatments on exchangeable Ca content of the soil over two seasons (Table 4). As in the case of N and K, the F and MAR management options did not have significantly different Ca contents under the P0 and P40 treatments. The P40 treatment however resulted in significantly ($P < 0.05$) higher exchangeable Ca content compared to the P0 treatment in the MF and MPR management options. The MF management option increased the exchangeable Ca content with between 1370 and 1380% compared to the F management option.

Magnesium (Mg)

No significant ($P > 0.05$) interactions between P treatment and mucuna management options could be observed. The P treatments did not significantly ($P > 0.05$) influence exchangeable Mg (Table 5). However the MF management option resulted in significantly ($P < 0.05$) higher Mg levels than the F, MAR and MPR management options. The MPR and MAR management options also resulted in a significantly ($P < 0.05$) higher Mg content than the F management option but there were no significant differences between the MPR and MAR management options.

Zinc (Zn)

Significant interactions ($P < 0.05$) between mucuna management options and the P treatments on Zn content of the soil over two seasons are shown in Table 6. In contrast to the other elements discussed the P0 treatment resulted in significantly ($P < 0.05$) higher Zn levels where mucuna was planted. No significant differences in Zn levels between the P0 and P40 treatments were noted in the F management option.

Again the MF management option resulted in the highest Zn levels followed by the MPR and MAR management options. The two seasons' average in the P0 treatment shows that the MF management option had 43 and 119.9% more Zn than the MPR and F management options respectively.

DISCUSSION

Mucuna has the potential to improve soil chemical characteristics for the smallholder resource-poor-farmers in Sub Saharan Africa. The results of the study indicated that smallholder farmers can add the equivalent of about 40 kg ha^{-1} N fertilizer by incorporating a mucuna crop at flowering (MF) compared to the traditional fallow system (F). The fallow (control) management option resulted in a soil N content of 15 ppm. Such a soil N level will need about 100 kg N ha^{-1} to allow farmers to harvest about 3 to 4 t ha^{-1} on sandy textured soils (Akinnifesi et al., 2006). However the application of the MF management option under the P40 treatment increased N content of the soil to 24.3 ppm. Such a soil will need only about 60 kg N ha^{-1} for farmers to realize a yield of 3 to 4 t ha^{-1} (Akinnifesi et al., 2006). However if farmers remove pods from the mucuna crop and incorporate the rest of the above ground biomass the soil will need about 80 kg N ha^{-1} to realize the same yield. The P0 and MF treatment combination will need a supplement of about 70 kg N ha^{-1}.

The soils in this study, similar to many other soils in sub Saharan Africa, may not sustain satisfactory maize production because of serious P deficiencies (Akinnifesi et al., 2006). According to the recommendations by Tagwira (1992) the results of this study showed that P in the soil was inadequate at all P and mucuna management treatment combinations. Phosphorus levels should be > 30 ppm for it to be adequate for a maize crop (Tagwira, 1992). The MAR and MPR management options in the P0 treatment will require a supplementation of 50 kg P ha^{-1} to meet the maize P requirements in Zimbabwe as stipulated by Tagwira (1992). However if farmers use the MF management option they only need to supplement with 40 kg P ha^{-1} to meet the maize P requirements in Zimbabwe. The P40 and MF treatment combination will improve soil P and farmers will need to supplement with about 35 kg P ha^{-1} to meet the maize P requirements in Zimbabwe compared to the MPR and P40 treatment combination which will need about 40 kg ha^{-1}. If only P is considered, it will be advantageous to use the P0 treatment and add 40-50 kg P ha^{-1} to the main crop.

The level of exchangeable bases in this study indicated that they have been improved by the mucuna management options. The application of the P40 and the MF treatment combinations may result in farmers needing to supply about 20 kg K ha^{-1} to meet the K requirements for sandy soils. However the application of P40 and other mucuna treatments may require of farmers to supplement with 30 kg K ha^{-1}. The fallow (F) management option will require supplementing with 40 kg K ha^{-1} (Tagwira, 1992; Tisdale et al., 1999). The availability of other exchange-able bases (Ca and Mg) can be enhanced by liming with Dolomite or quicklime at 800 kg ha^{-1} to raise the pH of the soil to ensure availability of these nutrients to maize crops. The optimum Ca and Mg requirements for maize production are less than 1.5 to 2 and 0.2 (meq%) respectively (Tisdale et al., 1999). The MF and MPR management options seem to have supplied adequate Ca for the subsequent maize crop. This could be attributed to the incorporation of Ca in the biomass of mucuna at flowering and maturity. For Mg it appears as if the MF management option provided adequate Mg.

The application of mucuna management options under the P40 treatment showed lower Zn contents than under the P0 treatment. This could be attributed to a more rigorous rooting system due to P application and hence a more effective removal of Zn from the soil. The acidifying effect of P on soil pH could also contribute to the low available Zn levels (Tisdale et al., 1999). This will lead to the extraction of inherent Zn in the soil (Tisdale et al., 1999). Maize requires 21 to 70 ppm of Zn in Zimbabwe (Tagwira, 1992). The results of this study indicated that P0 and MF treatment combination will supply about 50% of the optimum Zn requirements of a maize crop. However about 75% of Zn requirements needs to be supplemented when using other mucuna management options with either the P0 or P40 treatments.

Conclusion

Phosphorus treatments and mucuna management options showed some great impact on the availability of essential nutrients. Generally mucuna incorporated at flowering (MF) at the P40 treatment will result in a saving on N, P and K fertilizers. However Zn levels are somehow negatively affected by mucuna management options under the P40 treatment. The study also emphasized the need for farmers to supplement with inorganic fertilizers to realize better yields even when mucuna is used as a rotational crop. Mucuna treatments however reduce the inorganic fertilizer requirements.

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