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EFFICIENCY OF MINERAL FERTILIZERS AND MUCUNA ON THE IMPROVEMENT OF THE YIELD OF MAIZE IN ZIMBABWE

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In Zimbabwe farmers use sub-optimal amounts of fertilizers due to cash limitations and poor access to fertilizer markets, hence the need to integrate legumes like mucuna (*Mucuna pruriens*) into their cropping systems. In this study, the effect of P and N along with different mucuna management options was investigated on the yield and yield components of maize. The experimental design was a split - split- plot with two P rates (0 and 40 kg P ha^{-1}) applied to a preceding mucuna crop, four mucuna management options [1) fallow (F), 2) mucuna ploughed in at flowering (MF), 3) all mucuna above ground biomass removed at maturity and only roots were ploughed in (MAR) and 4) mucuna pods removed and the residues ploughed in (MPR)] and four N treatments [N0 = 0, N1 =40, N2 = 80 andN3 = 120 kg N ha^{-1}respectively] applied to a subsequent maize crop. The various crop parameters like grain yield, cob length, number of grains per cob, cob diameter, 1000 dry grain weight, stalk weight and harvest index of maize were determined. Phosphorous application improved mean maize grain yield from 2.29 t ha^{-1} to 2.34 t ha^{-1}. The MF and N3 treatment combination resulted in the highest maize grain yield. The MF and MPR and N0 treatment combinations resulted in similar grain yields when compared with F and MAR management options and N3. Other parameters followed similar trends. The MF and MPR management options could, therefore, save 80 and 120 kg N ha^{-1}for smallholder farmers without sacrificing yield.
Keywords: maize yield, mucuna management options, N and P rates, small holder farmer

INTRODUCTION

Positive residual effects of N-fixing legumes on subsequent cereals in rotations have been widely reported in both old and modern agriculture (Sanginga, 2003; Shah *et al*., 2003). The yield increases have been primarily attributed to an improvement in the N economy of the soils. Studies on the predominantly sandy soils of Southern Africa have shown the complexity of soil fertility problems on smallholder farms and the challenges in developing sustainable management options (Barthès *et al*., 2004; Robertson *et al*., 2005). There are limited opportunities for building soil organic matter mainly because of monoculture production systems (Giller and Wilson, 1991), rendering farmers to rely heavily on external nutrient inputs on a seasonal basis. However, most of the small holder farmers use sub-optimal amounts of fertilizers due to cash limitations and poor access to fertilizer markets (Ahmed *et al*., 1996).
This whole issue of nutrient supply to maize production systems calls for increased efficiency in use and recycling of both exogenous and endogenous nutrient pools in the cropping systems. Although work has been done on mucuna (*Mucuna pruriens*) as a rotational crop (Barthès *et al*., 2004; Robertson *et al*., 2005), not much has been focused on various management options of mucuna relative to the P and N applications in maize production systems on a kaolitic sandy loam soil in Zimbabwe.
The aim of this study was to determine the effects of P application to a preceding mucuna crop, mucuna management options and N fertilizer application rates on the yield and yield components of a subsequent maize crop on a sandy loam soil in Zimbabwe. Mucuna was chosen for this study because of its ability to grow on relatively poor soil and its tolerance to drought and other environmental stress factors (Maasdorp and Titterton, 1997; Muhr *et al*., 1999).

MATERIALS AND METHODS

***Experimental site*:** This study was carried out at the Grasslands Research Station in Marondera, Zimbabwe. The Grasslands Research Station is situated at approximately 18^{o} 11^{1}S latitude and 31^{o} 30^{1}E longitude at an altitude of 1200 m above sea level. At this site the average annual rainfall is 900 mm per annum (20-year mean), falling predominantly in the hot summer months (November to March). The winters are relatively cool and dry (Table 1). Soil characteristics at the time of planting are shown in Table 2.
***Crop establishment*:** After preparation of the selected field, early maturing maize variety (SC-13) was sown by hand each year on December 22, 2007 (first season crop) and December 08, 2008 (second season crop) with seed rate of 25 kg ha^{-1}. An inter-row spacing of 90 cm and intra- row spacing of 25 cm was maintained. A plant population of 48450 plants ha^{-1} was achieved. No basal fertilizer was

Table 1. Rainfall data for the experimental site for 2007 and 2008 (Grasslands Research Station, Marondera, Climatological Section) and long-term climatological data for Marondera

Month	Mean temperature (ºC)			Mean total rainfall (mm)		Mean number of rain days long term
	Daily minimum	Daily maximum	Long term	2007	2008	
Jan	15.3	23.6	193.4	333.1	352.5	14
Feb	13.1	24.5	149.1	48	10	12
Mar	15.8	23.9	90.3	14	74	9
Apr	12.5	22.8	48.7	0	0	5
May	11.9	21.0	10.1	0	0	2
Jun	6.2	18.3	5.4	0	0	1
Jul	5.3	18.4	3.0	0	0	1
Aug	6.3	25.0	3.0	0	0	1
Sep	12.5	25.5	6.8	0	0	1
Oct	13.5	26.0	40.3	85.5	11	5
Nov	14.8	25.9	113.1	157.2	137.4	10
Dec	14.5	24.3	187.7	429.2	282.6	15

http://www.worldweather.org/130/c00958.htm

Table 2. Soil characteristics of the study site at Marondera at time of sampling before the trial started

Parameter	Description/Value
Classification (FAO/UNESCO)	Humic Ferral sol
Texture	Loamy sand
pH $_{CaCl}$	5.20
Organic matter carbon (%)	0.33
P content (mg kg^{-1}) (Mehlic 3)	15.80
N content (mg kg^{-1})	15.00
K content (cmol kg^{-1})	0.15
Ca content (cmol kg^{-1})	0.20
Mg content (cmol kg^{-1})	0.03

applied to the maize crop to simulate the resource-poor farmers' practice. The N treatments were applied as a top dressing at 4 weeks after emergence (WAE)in both seasons. Weed control was done twice using mechanical methods. Irrigation was applied strategically to supplement rainfall when the crop started to show signs of moisture stress.

***Experimental design and treatments applied*:** The experiment was laid out according to a split-split plot design with two P treatments as main plot factors [P0 = 0 kg P ha^{-1} and P1= 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 P1 treatment was chosen because it is the rate of P generally recommended by extension officers in Zimbabwe for a mucuna crop, Four mucuna treatments were 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)] and 4 N treatments [N0 = 0 kg N ha^{-1}, N1 = 40 kg N ha^{-1}, N2 = 80 kg N ha^{-1} and N3 = 120 kg N ha^{-1} representing about 0, 33, 66 and 100 % of the recommended rate] were applied to the subsequent maize crop as sub-sub-plot factors. The treatments were replicated 4 times. The sub-sub plot size was 10 x 10 m^2.

After harvesting the crop different yield parameters like dry dehusked cob length, dry cob diameter, number of grains per cob, 1000 grain weight, grain yield and dry stalk weights were noted . A net plot of 5m x 5m (25 m^2) was used to determine the parameters. Harvest index was also calculated by using the following formula:

Harvest index = (Maize grain yield net $plot^{-1}$) / Stover weight net $plot^{-1}$

***Statistical analyses*:** Statistical analysis of the data was performed using the Statistica package (Statsoft, 2004). Analysis of variance (ANOVA) was conducted to determine the interaction of factors. Means were separated using Bonferroni adjustment for testing least significant differences at the 5% level when ANOVA revealed significant ($P<0.05$) differences among the treatments. The treatment factors which were compared were P and N rates and mucuna management options.

RESULTS AND DISCUSSION

The combined data for the years 2007-08 and 2008-09 were used because the data for separate seasons did not vary much in terms of maize yield and yield components. There were no significant seasonal effects.

***Cob length, cob diameter and number of grains per cob*:** The significant (P<0.05) 3-way interaction of P rate, mucuna management option and nitrogen rate in terms of cob length is shown in Table 3. Cob lengths significantly (P<0.05) increased with an increase in N and P rates across all the management options. The MF management option and N3 treatment combination generally produced the longest cobs. The MF and N0 treatment combination did not differ significantly from F and N2 treatment combination in both P treatments. The MPR management option was always second to the MF management option. The F and MAR mucuna management options did not show significant differences at N0 and N1 rates in both P treatments but in the P1 treatment, the N2 and N3 along with MAR treatment combinations produced longer cobs than F management option had.

The results of this study showed that the use of the MF management option with any P treatment applied to the mucuna and no nitrogen applied to the subsequent maize crop will give the same results as the F (control) management option with any P treatment applied and N2 rate applied in terms of cob length. This could be attributed to the N fixed by mucuna at flowering stage (Carsky *et al*., 1999). Therefore, farmers may save about 80 kg N ha^{-1} if they use these MF management options. If farmers decide to leave mucuna up to maturity (MPR), the results will be similar to using the F and N1 rate treatment combination. The total removal of above ground biomass of mucuna at maturity may yield the same as the F management option under all the P treatments and N rates. Legumes such as mucuna have a high harvest index (Giller and Wilson, 1991) and therefore, the removal of above ground biomass prevents addition of N reserves to the soil. There is a strong correlation between cob length and maize grain yield (Memon *et al*., 2007).

There was a significant (P<0.05) 2-way interaction between the mucuna management option and N rates in terms of cob diameters of maize (Table 5). The cob diameters increased with the increase in the N rates across all the mucuna management options. The MF and N3 treatment combination had significantly (P<0.05) bigger diameters than other treatment combinations. There were no significant differences between MF and N0 treatment combination and F and N2 and N3 treatment combinations. The F and MAR management options did not show any significant differences from each other.

The MF and N0 treatment combination resulted in the same cob diameter as the F and N3 treatment combinations. The MPR management option and the N0 combination may give the smallholder farmers the same diameter as the F (control) and N3 treatment combinations. Therefore, the same cob size can be attained by MF and MPR management options with little or no N supplementation as can be attained with the F and N3 treatment combination.

There were not significant (P>0.05) interactions between the three factors (P rate, mucuna management option and N rate) used in this study in terms of number of grains per cob. However there were significant (P<0.05) differences between treatments within factors of N rates and mucuna management options (Results not shown). There were no P treatment effects.

The MF mucuna management option had significantly (P<0.05) more grains (352) cob^{-1} than the other three [F (223), MAR (240) and MPR (286)] mucuna management

Table 3. Dry dehusked cob lengths (2007/08 and 2008/09 seasons combined) of maize as influenced by interactions of P rate, mucuna management option and N rate on a sandy loam soil in Zimbabwe

P treatments	Mucuna options	0	40	80	120
		Cob length (cm)			
P0[1]	F[2]	7.4a[3]	8.3b	11.1e	13.3g
	MF	10.8e	13.8g	16.8j	17.9k
	MPR	10.0d	11.5f	15.0i	15.5i
	MAR	7.5a	8.9b	11.5f	13.9g
P1	F	7.0a	9.3c	11.1e	14.3h
	MF	10.9e	14.5h	18.5k	20.2L
	MPR	9.9d	12.7f	16.8j	17.2k
	MAR	7.2a	9.2c	13.2g	15.1i

[1]P0 = No P applied (control) and P1 = 40 kg P ha^{-1} applied to the mucuna crop; [2]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); [3]Values followed by the same letter are not significantly different at P=0.05

options, which were not significantly different from each other. The number of grains cob^{-1} under the N3 rate (310) was significantly ($P<0.05$) more than the N2 (290), N0 (249) and N1 (251) rates. The N0 and N1 rates did not differ significantly.

The MF management option had more grains probably because of its ability to provide high N levels which is an essential nutrient for grain development and filling (Tisdale *et al.,* 1999). The N3 rate produced more grains than the other rates. This again can be attributed to the positive effect of N on grain development and cob-filling. Work carried out by Memon *et al*. (2007) showed that number of grains will add to the total yield per hectare, but the weight of the grains also plays an important role.

***1000 grain weight*:** A significant interaction ($P<0.05$) between P rate, mucuna management option and N rate in terms of 1000 grain weight were noted (Table 4). The MF and N2 and N3 treatment combination had a significantly ($P<0.05$) higher 1000 grain weight under both P treatments when compared with other combinations except for MPR and N3 treatment combination in the P40 treatment. No significant differences were noted between N2 and N3 rates under the MF management option for both P treatments. The MPR management option showed no significant differences between N0, N1 and N2 rates for P0 treatment. The MF and N0 treatment combination under P0 treatment did not differ

Table 4. Dry 1000 grain weight (2007/08 and 2008/09 seasons combined) of maize as influenced by interactions of P rate, mucuna management option and N rate on a sandy loam soil in Zimbabwe

P treatments	Mucuna options	N (kg ha^{-1}) 0	40	80	120
		1000 grain wt (g)			
P0[1]	F[2]	160.0a[3]	171.9b	184.8c	237.8e
	MF	226.4e	254.8e	260.9f	265.4f
	MPR	213.8d	246.4e	252.3e	254.0e
	MAR	160.6a	173.1b	251.5e	239.5e
P1	F	194.8c	217.9d	227.6e	232.8e
	MF	239.8e	262f	297.4h	311.6h
	MPR	256.1e	249.3e	284.0g	297.2h
	MAR	193.0c	210.7d	228.7e	227.7e

[1]P0 = No P applied (control) and P1 = 40 kg P ha^{-1} applied to the mucuna crop; [2]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); [3]Values followed by the same letter are not significantly different at P = 0.05

Table 5. Dry cob diameter, dry stalk weight and grain yield (2007/08 and 2008/09 seasons combined) of maize as influenced by interactions of mucuna management option and N rate on a sandy loam soil in Zimbabwe

Mucuna options	N (kg ha^{-1})	Cob diameter (cm)	Stover wt. (t ha^{-1})	Grain yield (t ha^{-1})
F[1]	0	4.5b[2]	2.0a	0.36a
	40	5.0c	2.3b	0.55b
	80	6.1e	4.6d	2.02d
	120	6.3e	5.5f	2.53e
MF	0	6.0e	3.3c	2.49e
	40	6.4e	5.1f	3.12f
	80	7.1e	6.5h	4.05h
	120	7.9g	7.1j	5.06j
MPR	0	5.0c	2.4b	0.63b
	40	5.6d	4.8d	2.06d
	80	6.3e	5.8g	3.40g
	120	7.1f	6.9i	4.12h
MAR	0	4.2a	2.5b	0.43a
	40	5.3c	3.1c	0.99c
	80	6.3e	4.6d	2.29d
	120	6.4e	5.5f	2.53e

[1]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); [2]Values followed by the same letter are not significantly different at P = 0.05

significantly from the F (control) and N3 treatment combination at both P levels. The MAR and F management options generally did not show significant differences between them across all the treatment combinations.

The 1000 grain weight is an important measurement as it determines the final grain yield (Memon *et al.*, 2007). The results showed that if a smallholder farmer does not apply P to the mucuna crop and ploughs under the mucuna crop at flowering (MF) and then applies no N fertilizer to the subsequent maize crop, he may attain the same 1000 grain weight as the F and N3 treatment combination at the P0 or P40 treatment in the subsequent maize crop. These results indicated the importance of N in protein synthesis which also helps in weight enhancement of the grain (Tisdale *et al*., 1999). The removal of the mucuna pods and incorporation of the rest of the mucuna biomass (MPR) in the P0 and P1 treatments may give the same weight as the F management option at any P treatment and N1. The removal of all above ground biomass (MAR) will have the same effect as the F management option under any P and N treatment.

***Grain yield*:** The significant ($P<0.05$) 2-way interaction between the mucuna management option and N rates on grain yield shown in Table 5 illustrates that the grain yield increased with increased N rates across all the mucuna management options. However, MF and N3 treatment combination produced significantly ($P<0.05$) higher grain yields followed by MPR and N3 treatment combination. No significant differences were observed between MF and N0 treatment combination and F and N3 treatment combination. Also MF and MPR management options did not differ significantly under N2 and N3 rates respectively. The F and MAR management options did not differ significantly across all the N rates except at the N1 rate. There were significant ($P < 0.05$) differences between the P0 (2.29 t ha^{-1}) and P1 (2.34 t ha^{-1}) treatments in term of the grain yield of maize.

Maize grain yield was higher in MF management option across all N rates. The MF and N0 treatment combination increased grain yield by almost 590% compared to F and N0 treatment combinations. The higher yield in the MF management option could partly be due to the higher 1000 grain weight parameter. These findings are supported by Mandimba (1995) who found that green manuring of mucuna gave a higher yield than natural fallows in the Congo. Sanginga *et al*. (1996) and Mausolff and Farber (1995) also found that green manuring with mucuna resulted in a subsequent maize yield which was equivalent to the yield of a crop receiving 120 kg N ha^{-1} inorganic fertilizer. The incorporation of root biomass (MAR) only gave the same yield as the F (control). These findings differ from findings by Smyth *et al*. (1991) who found that incorporation of the root biomass of legumes gave a higher yield than the control. However, their work was in an Amazon ecosystem with different soil and climatic regimes than those of this study.

***Dry stover weight*:** The significant ($P<0.05$) 2-way interaction between mucuna management option and N rate on dry stover weight is shown in Table 5. The stover weight increased with increase in N rates across all the mucuna management options. The MF and N3 treatment combination had a significantly ($P < 0.05$) higher stover weight than other treatment combinations. However, MF and N0 treatment combination did not differ significantly with F and N3 treatment combination. The F and MAR management options did not differ significantly at N2 and N3 rates.

The MF management option produced more stover than the other options under the same N rates. This could be attributed to the K incorporated with mucuna at flowering. Potassium is an essential nutrient for stalk development (Tisdale *et al*.,1999; Shoko *et al*., 2009).

The significant ($P < 0.05$) 2-way interaction between the P rate and N rate in terms of dry stover weight showed no

Table 6. Harvest index (HI) (2007/08 and 2008/09 seasons combined) of maize as influenced by interactions of P rate, mucuna management option and N rate on a sandy loam soil in Zimbabwe

P treatments	Mucuna options	N (kg ha^{-1}) 0	40	80	120
		Harvest Index			
P0[1]	F[2]	0.17a[3]	0.22b	0.44d	0.59e
	MF	0.45d	0.61e	0.62e	0.70f
	MPR	0.22b	0.44d	0.58d	0.60e
	MAR	0.15a	0.32c	0.50d	0.60e
P1	F	0.18a	0.24b	0.42d	0.60e
	MF	0.47d	0.61e	0.62e	0.70f
	MPR	0.29c	0.42d	0.59e	0.59e
	MAR	0.18a	0.33c	0.49d	0.59e

[1]P0 = No P applied (control) and P1 = 40 kg P ha^{-1} applied to the mucuna crop; [2]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); [3]Values followed by the same letter are not significantly different at P = 0.05

differences between the P0 and N0 (2.55 t ha^{-1}), N1 (3.80 ha^{-1}) and N3 (6.23 ha^{-1}) treatment combinations and the corresponding P1 and N0 (2.59), N1 (3.87) and N3 (6.27) treatment combinations (Results not shown). However there were significant ($P < 0.05$) differences between the P0 and N2 (5.33) treatment combination and the P1 and N2 (5.49) treatment combination.

***Harvest Index (HI)*:** A significant interaction ($P<0.05$) among P treatments, mucuna management options and N rates in terms of the HI of maize was noted (Table 6). The HI significantly ($P<0.05$) increased with increase in N rates across the mucuna management options in both P treatments. The MF and N3 treatment combination had a significantly ($P < 0.05$) higher HI under both P treatments when compared with other treatment combinations. However, no significant differences were noted between MF and NO treatment combinations and F and N2 treatment combination for both P treatments. The MAR and F management options did not show significant differences between P treatments across all N treatments except at the N1 rate.

The MF management option produced a higher HI throughout the treatment combinations. A higher HI indicates higher yield potential at the same vegetative biomass (Memon *et al*., 2007). Therefore, incorporation of mucuna green manure at flowering improved the ability of maize to produce grain yield from a given vegetative biomass.

***Conclusions*:** The results of this study clearly widened the scope for the smallholder farmers when it comes to manipulation of mucuna. Farmers can benefit from either mucuna at maturity being incorporated or incorporating mucuna at flowering. The findings have shown that the MF and MPR management options improves maize yield compared to the normal farmer practice of natural fallows (F). Implementation of these two mucuna management systems may increase the yield and profit of smallholder farmers whilst slowing down the rate of soil degradation in crop fields compared to the traditional maize monoculture systems.

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