African Journal of Agricultural Research Vol. 2 (10), pp. 521-527, October 2007
Available online at http://www.academicjournals.org/AJAR
ISSN 1991- 637X © 2007 Academic Journals

Full Length Research Paper

Use of pruning and mineral fertilizer affects soil phosphorus availability and fractionation in a gliricidia/maize intercropping system

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Accepted 26 September, 2007

Leguminous tree species are known to replenish soil nutrients through biological N fixation, mulch effect and recycling of other nutrients from the deeper soil layer to the topsoil, when managed in agroforestry systems. The soil available phosphorus (P) status and inorganic P-forms (fractionation) in a long-term gliricidia-maize trial was studied to understand the effect of additions of gliricidia prunings combined with and without inorganic fertilizers (N and P). Addition of gliricidia prunings and inorganic N and P fertilizers significantly increased phosphorus uptake by maize. Bray P1 had strong correlation with P uptake by maize in gliricidia/maize intercropping ($r = 0.81$, $p<0.001$). Both the Olsen and Bray P1 methods of extraction were strongly correlated ($r = 0.80$). Phosphorus fractionation data of the soils from the maize and gliricidia-maize plots indicated that the Fe-P fraction was the most dominant form of inorganic P. The addition of gliricidia prunings significantly reduced the Fe-P and Al-P forms. We conclude that iron phosphate acts as a sink for applied inorganic P in Lixisols and the increased soil organic matter through addition of gliricidia prunings solubilizes fixed P in the soil.

Key words: Agroforestry, fertilizer trees, available P, P-uptake, inorganic P fractions.

INTRODUCTION

Soil fertility depletion is the major cause of declining crop yields and subsequent food insecurity in sub-Saharan Africa (SSA) and phosphorus is one of the three most limiting nutrients (Sanchez et al., 1997). In Malawi, annual nutrient losses of not less than 40 kg N ha^{-1}, 6.6 kg P ha^{-1} and 33 kg K ha^{-1} have been indicated (Smaling et al., 1997). Soil fertility has declined as a result of continuous maize production, sub-optimal use of fertilizers and the abandonment of traditional fallow systems caused by increasing population densities (Snapp, 1998). Phosphorus (P) is an essential element for plant growth and its sufficient availability is necessary to maintain profitable crop production and increase food security (Buresh and Tian, 1997). Technologies to overcome phosphorus deficiency involve the use of soluble inorganic fertilizers and use of rock phosphate (Mathews et al., 1992; Sanchez et al., 1997; Nyirongo et al., 1999).

The use of fertilizers is a possible option to reverse soil fertility decline in Malawi but their high costs constitute a major handicap to resource-poor smallholder farmers. Correcting soil nutrient deficiency with large application of inorganic fertilizer maize cultivation is not profitable due to the high costs, difficult logistics of buying mineral fertilizers and the low market prices of maize (Carr, 1997). Even when subsidies are provided, the amounts available to farmers are less than half their requirement to meet both subsistence and cash needs. There is therefore a need for alternative sources of fertilizer to achieve food security in these marginal lands.

The World Agroforestry Centre (ICRAF) initiated a trial on intercropping of gliricidia with maize in the early 1990s as an alternative soil fertility replenishment option in Southern Malawi where average landholding size is less than 0.4 ha (Makumba, 2003; Akinnifesi et al., 2006). The long-term productivity of maize and tree biomass in the experiment has been reported by Akinnifesi et al. (2006). Various studies incorporating *Gliricidia sepium* prunings as green manure have reported an increase in maize

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yield (Rao and Mathuva, 2000; Makumba 2003; Akinnifesi et al., 2006). The success of the gliricidia-maize has been attributed to increased nitrogen supply to plants and improvement of other soil chemical and physical parameters in long-term applications (Ikerra et al., 1999; Makumba et al., 2001). Research has shown that addition of green manure into the soil improves P availability to plants (Yashpal et al., 1993; Haggar et al., 1991) through the total nutrients added and reduced phosphate sorption capacity of the soils (Nziguheba et al., 1998).

Although gliricidia pruning has been shown to improve yields through improved N supply to plants (Akinnifesi et al., 2006, 2007; Ikerra et al., 1999), there is no research data on P availability and the P forms system. Therefore, this study was undertaken to determine: (1) the effect of gliricidia pruning application on the soil available P, and (2) the forms of inorganic P in the gliricidia simultaneous intercropping system.

MATERIALS AND METHODS

Description of study site

The study was conducted in an ICRAF's long-term experimental trial at the Makoka Agricultural Research Station (15° 30' S; 35° 15'E; about 20 km from Zomba town along main road to Blantyre). The soils at the experimental site have been classified as Ferric Lixisols (FAO/UNESCO) or Oxic Haplustalf (USDA) (Ikerra et al., 1999). The top soils are sandy loam with pH (H_2O) ranging from 5.9 to 6.5; CEC of 6.2 to 10 cmol_c kg^{-1} and 30 mg kg^{-1} P (Olsen). The climate is characteristic of long dry season from April to October followed by short wet season from November to March. The total annual rainfall for the past 30 years varied between 540 and 1602 mm with an average of 1024 mm. Mean daily temperature varies from 16 to 24°C with daily maximum range of 21 - 34°C, and a minimum of 10 - 19°C.

Experimental design and management

The experiment is a randomized complete block design with 2 x 3 factorial arrangement with three blocks. Each treatment was replicated thrice within each block. The treatment factors were maize with or without intercropping with *G. sepium* trees and three rates of N and P fertilizers. The N fertilizer rate was applied at 0, 46 and 92 kg N ha^{-1}, applied at 4 weeks after planting. Inorganic fertilizer rates of 0, 46 and 92 kg N ha^{-1}, corresponding to zero (unfertilized), half (50%) and full (100%) of national fertilizer rates were applied from Calcium Ammonium Nitrate (CAN) fertilizer at four weeks after planting. The recommended N rate for southern Malawi is 92 kg N ha^{-1} by side dressing. Fertilizer was applied to the maize crop only. Initially, three levels of inorganic phosphorus were applied early in the trial (0, 20 and 40 kg P ha^{-1}, corresponding to fertilizer rates of 0, 50 and 100% of the recommended P dose). These P treatments were discontinued in 1993/94 as phosphorus had no effect on maize yield (Ikerra et al., 1999; Akinnifesi et al., 2006). Potassium was not applied because it is not a problem in Malawi soils and the initial soil analysis showed high levels at the site. The national fertilizer recommendation did not include K, so farmers generally do not apply it. The amount of maize stover applied during the period was approximately 3.5 tonnes for maize plot and 5 tonnes for gliricidia-maize plot, and these varied with fertilizer applications (Akinnifesi et al., 2007). *G. sepium* (Jacq.) Walp (ex Retalhaleu, Guatemala provenance, OFI seed No. 60/87) was used in view of its superior growth in Malawi and elsewhere in Southern Africa (Ngulube, 1994). The trees were established from seedling stock in December 1991, without cropping. *G. sepium* was planted in the furrows at 90 cm within tree rows and 150 cm between tree rows (7400 trees ha^{-1}s). In order to minimize tree root encroachment into adjacent plots or outside the experimental area, iron sheets were vertically installed to 1 m deep around plots (Akinnifesi et al., 2006). Plot size was 6.75 x 5.1 m, separated by 1 m wide path.

The *G. sepium* trees were first pruned in September 1992 to the height of 30 cm. In December 1992, the coppice regrowth was harvested incorporated into soil and maize planted in the same month. Tree coppices were harvested again in February 1993, and left to grow until September 1993 when trees were harvested again. The harvesting cycle of September-December-February was repeated continuously from 1991/2 to 1996/97 (Ikerra et al., 1999). The trees were pruned three times during each cropping season. However, because of the erratic rainfall patterns, the pruning re-gime was varied from 1997/98 to 2001/02, depending on the rain onset and also an additional pruning was included as follows: Pre-plant pruning in late October to early November (1st pruning), late December to early January (2nd), late February (3rd), and late August to early September (4th). This fourth pruning was necessary to encourage more leaf growth and reduce wood biomass (Makumba et al., 2001; 2006). The leaves and small green stems (twigs) were incorporated in the soil same day they were pruned and separated. Tree prunings were incorporated by splitting the ridges open, placing the leafy prunings and reconstituting the ridges burying the prunings to the depth of about 15 cm. The influence of the time of pruning application on N-uptake and maize yield has been reported elsewhere (Makumba et al., 2006).

Maize hybrid NSCM 41 was planted on ridges at a spacing of 30 cm within rows and 75 cm between rows (44,000 plants ha^{-1}), in both the maize as well as gliricidia-maize plots. Two weeks after emergence, the maize seedlings were thinned to one plant per hole. The maize was planted at least two weeks after incorporation of the October prunings. The maize population was maintained at 44,000 plants ha^{-1} in all the plots with and without trees. Maize was hoe-weeded twice during the cropping season typical of the traditional farming practice.

Soil sampling and analysis

From each plot soil samples were randomly collected from five points from 0 - 20 cm soil depth and bulked into a composite soil sample for each plot. The soil samples were air-dried and sieved to pass through a 2 mm-sieve, and were analysed for pH in 0.01 M $CaCl_2$, using glass electrode and soil to solution ratio of 1: 25 (Mc Lean, 1982); exchangeable cations, Ca^{2+}, Mg^{2+}, and K^+ by Mehlich-3 method. Organic C was determined by Walkley-Black method (Olsen and Sommers, 1982). Soil samples were analysed for P availability indices by Bray P1 (Bray and Kurtz, 1945) and Olsen P (Olsen and Sommers, 1982) methods.

Sequential extraction procedure was carried out as outlined by Zhang and Kovar (2000) to separate different P forms occurring in the soil P. The Method involves the use of a series of extractants to remove different pools of soil P. The extracting solutions used to extract various soil P fractions: 1 M NH_4Cl [Soluble P, sol-P)]; 0.5 M NH_4F at pH of 8.2 [Aluminium bound P (Al-P)]; 0.10 M NaOH [Iron bound P, (Fe-P)]; 0.3 M trisodium citrate and 1 M $NaHCO_3$ (reductant soluble P) and 0.25 M H_2SO_4 [Calcium bound P (Ca-P)]. Extracted P was measured colorimetrically by molybdate-ascorbic acid method (Murphy and Riley 1962).

Plant analysis

The annual maize yield from the trial over the last ten years has been reported elsewhere (Akinnifesi et al., 2006). Similarly, stover yield during 2003 to 2006 has been reported elsewhere (Akinnifesi et al., 2007). In June 2004, maize was harvested from the net plot of 6 x 4.1 m. Maize was harvested by cutting all the maize stover at the base just above the soil surface in the net plot. The maize cobs were removed from the stovers and then the stovers were weighed separately. A sample of stover was weighed, and then dried in an oven at 70°C for 48 h for the determination of the dry matter content. Maize grain yield was determined at 12% MC. The dried plant materials (stover and grain) were finely ground and analysed separately for total P in H_2SO_4-Se mixture. The total P uptake by the maize reported is the sum of P uptake by stover and grain. Total maize P uptake was correlated with soil available P extracted using Bray P 1 and Olsen P methods.

Data analysis

The data was analyzed by the General Treatment Structure (Randomised blocks) using the Genstat Discovery Edition (Genstat for Windows, 1999). Statistical significance was tested at $P < 0.05$. Simple correlation between soil P and total P uptake was performed using the Statistical Package for Social Scientists (SPSS) (Madsen and Taylor, 2001).

RESULTS AND DISCUSSIONS

Soil properties in the treatments

Table 1 shows the soil chemical properties under maize and gliricidia/maize after 12 years of continuous cropping in Makoka. Continuous application of gliricidia prunings increased the mean soil pH from 5.87 in maize cropping to 6.15 in gliricidia-maize plot ($p<0.001$). This may be ascribed to increase in soil organic matter, exchangeable cations and the nutrient recycling effect of Gliricidia from the deeper soil layers. However, a negative effect was observed in the treatment with application of inorganic fertilizer. Increasing N and P fertilizer rates reduced the soil pH in the gliricidia plot. The decrease of pH could have been induced by increased removal of exchangeable cations in maize harvests due to increased maize yields. Optimum P rate was shown to be at 20 kg ha^{-1} for both maize and gliricidia-maize while N application did not increase soil pH level. The reduction of soil organic carbon in the fertilized plots leads to the pH decline. Also oxidation of ammonium nitrates from the inorganic fertilizers may influence the soil acidity (Barber, 1984).

Pruning application had increased the mean soil organic C by 82% in gliricidia-maize compared to maize plot ($p<0.001$). These results are consistent with the findings of Makumba (2003) who reported increase in soil organic carbon in the topsoil (0 - 20 cm) due to addition of gliricidia tree prunings. Jones et al. (1996) found that plots receiving Leucaena leaves had high organic carbon, total nitrogen, pH, and exchangeable Ca, Mg, K and S. Addition of inorganic P and N fertilizers did not have consistent effect on the soil organic carbon content, but there was an interaction effect at $p = 0.01$.

Addition of gliricidia prunings consistently increased exchangeable cations (Ca, Mg and K) in the topsoil compared to the maize ($p<0.001$). The increase in exchangeable cations is attributed to recycling of nutrients from deeper soils to topsoil through application of gliricidia prunings (Makumba, 2003). Inorganic nitrogen fertilizer application significantly ($p<0.01$) increased exchangeable cations. The exchangeable cations consistently increased by the application of 46 kg N ha^{-1} (Table 1). This could be explained by the increased production of biomass that was recycled in the system. However, addition of a higher rate of 92 kg N ha^{-1} showed a slight decrease, and this could be explained by high grain yield that might have resulted in high exchangeable cations removal, hence net mining of nutrients in the soil

The Olsen and Bray P1 methods were strongly correlated ($r = 0.80$), indicating that both methods are equally efficient in extracting P in the study site. The two methods, Olsen P and Bray P, gave no significant difference in the mean soil P level in both maize and gliricidia-maize plots (Table 2), despite 12 - 20 kg P ha^{-1} reported to have been recycled annually in the gliricidia-maize (Makumba, 2003). This suggests that P removal during maize harvest and by tree uptake might have been higher than the P input through recycling. The application of inorganic P increased available P in the soil in both cropping systems. The two methods used to determine soil available P showed a general increase in topsoil P with increasing rates of inorganic P fertilizer added. Wendt et al. (1996) found in Malawi a similar response when he combined inorganic P and Leucaena leaves. Increase in extractable P following inorganic P addition confirms that soil P replenishment can be achieved through application of inorganic P fertilizers (Nziguheba et al., 1998). The mean soil available P decreased ($p< 0.05$) with the addition of inorganic N fertiliser, with the lowest levels occurring at 46 kg N ha^{-1}. This observation could have possibly resulted from increased P uptake by plants at the optimum level of inorganic N rate of 46 kg N ha^{-1} (Akinnifesi et al., 2006). Singh et al. (2002) observed a decrease in Olsen P with increasing rate of nitrogen fertilizer due to larger P exploitation by crops. Simple correlation analysis between extracted P (Bray P 1) and total P uptake showed significant ($P <0.01$) positive association in both maize and gliricidia-maize plot (Table 3). Correlation coefficients between soil extracted P and total P uptake by plant showed that Bray P 1 was highly correlated with P uptake in gliricidia/maize inter-cropping ($r = 0.61$, $p<0.01$) than in maize plot ($r = 0.46$, $p<0.01$) suggesting increased P uptake following addition of gliricidia prunings. The correlation coefficient (r) values were higher at harvest than at planting (Table 3), indicating that the soil available P extracted by Bray P1 was a good indication of the P actually taken up by the plant. Probably this indicates the accumulation effect of P in the soil after applying inorganic and organic P in the previous season.

Phosphorus fractionation

The inorganic phosphorus fractions of some treatments determined at time of maize planting in gliricidia-maize

Table 1. Soil properties (0 - 20 cm soil depth) in maize and gliricidia-maize plots after 12 years of continuous cropping in Makoka.

N-fert. Rate (kg/ha)	P-fert. Rate (kg/ha)	pH (H2O)		pH ($CaCl_2$)		Org. C (g/kg)		Exchangeable Mg ($cmol_c$/kg)		Exchangeable Ca ($cmol_c$/kg)		Exchangeable K ($cmol_c$/kg)	
N	**P**	**Sole**	**Gliricidia**	**Sole**	**Gliricidia**	**Sole**	**Gliricidia**	**Sole**	**Gliricidia**	**Sole**	**Gliricidia**	**Sole**	**Gliricidia**
Baseline data		5.9	-	-	-	8.8	-	1.6	-	4.40	-	0.30	-
0	0	5.97	6.30	4.77	5.29	4.3	10.2	1.37	1.42	3.52	3.86	0.47	0.74
0	20	6.17	6.33	4.77	5.20	6.0	14.2	1.34	1.37	3.52	3.92	0.42	0.81
0	40	5.93	6.23	4.73	5.13	6.3	11.2	1.29	1.43	3.41	3.78	0.46	0.69
46	0	5.73	6.13	4.47	5.07	6.7	16.9	1.40	1.41	3.68	4.06	0.49	0.91
46	20	5.77	6.13	4.50	4.90	7.2	10.0	1.38	1.40	3.58	4.05	0.43	0.78
46	40	5.97	6.30	4.40	4.90	7.0	10.1	1.37	1.43	3.72	3.94	0.36	0.86
92	0	5.70	6.13	4.49	5.13	8.2	11.6	1.37	1.32	3.39	3.84	0.36	0.81
92	20	5.67	5.90	4.63	5.13	5.5	11.6	1.26	1.41	3.11	3.72	0.28	0.77
92	40	5.93	5.90	4.57	5.10	7.9	11.4	1.27	1.37	3.20	3.67	0.28	0.55
Mean		5.87	6.15	4.59	5.09	6.6	11.9	1.34	1.40	3.46	3.87	0.39	0.77
LSD (0.05):													
Prod. Syst.(PS)		0.091		0.060		0.96		0.035		0.156		0.060	
N-Fert. rate (F)		0.111		0.073		1.17		0.043		0.192		0.073	
P-Fert. rate (P)		0.111		0.073		1.17		0.043		0.192		0.073	
PS x N rate		0.158		0.104		1.66		0.061		0.271		0.104	
PS x P rate		0.158		0.104		1.66		0.061		0.271		0.104	
N x P rate PS x N x		0.193		0.127		2.03		0.744		0.332		0.130	
P rate		0.273		0.180		2.07		0.105		0.469		0.179	
CV (%)		2.7		2.2		18.6		4.6		7.7		4.6	

Prod. Syst. = Production system, N Fert. = Nitrogen fertilizer rate; P-Fert.=Phosphorus fertilizer rate

Table 2. Available P status in 0 - 20 cm soil depth in sole and gliricidia-maize production systems

Production System	**P–fert. (kg/ha)**	**Olsen P (mg/kg)**			**Bray P (mg/kg)**		
		0	**20**	**40**	**0**	**20**	**40**
	N-fert. (kg/ha)						
Sole	0	26.51	29.78	37.73	57.03	62.40	78.89
	46	22.19	34.93	36.27	47.98	67.06	71.18
	92	22.05	28.52	30.63	52.01	64.55	69.57
	Mean	**23.58**	**31.08**	**34.88**	**52.34**	**64.67**	**73.21**
Gliricidia	0	24.86	29.94	27.98	55.59	69.21	71.00
	46	16.76	23.85	26.84	49.14	64.91	68.85
	92	19.40	21.52	29.81	51.65	66.70	74.50
	Mean	**20.34**	**25.10**	**28.21**	**52.13**	**66.94**	**71.45**
$LSD_{0.05}$							
Prod. Syst.(PS)			1.98			2.06	
N-Fert. rate (F)			2.42			2.53	
P-Fert. rate (P)			2.42			2.53	
PS x N rate			3.42			3.57	
PS x P rate			3.42			3.57	
N x P rate			4.19			4.34	
PS x N x P rate			5.93			6.17	
CV (%)			13.1			5.9	

Table 3. Correlation coefficient (r) of relationships between soil extracted P and total P uptake at planting and harvest.

Time of sampling	**Method of Extraction**	**Maize cropping**	**Gliricidia –maize cropping**
At planting	Bray 1	0.46^{**}	0.61^{**}
	Olsen	0.16^{NS}	0.53^{**}
At harvest	Bray 1	0.53^{**}	0.81^{**}
	Olsen	0.45^{NS}	0.82^{**}

Significant at 0.05 and 0.01 level respectively.

and maize plot provided in Table 4.

The P fractionation information reveals that iron P (Fe-P) was the dominant fraction and least soluble. The Fe-P fraction accounted for 53.52 to 58.41% of the total inorganic P fraction. Soluble P constituted the lowest fraction extracted (1.59 - 2.95%). The high Fe-P fraction could be explained by the presence of high levels of Fe in Ferric lixisol soils. The relative abundances of inorganic fractions increased in the following order soluble P, reductant soluble P, calcium bound P, aluminium P, iron bound P in both the gliricidia-maize and maize plot (Table 4).

Addition of gliricidia prunings did not significantly influence the soluble and reductant soluble P fractions, but had significant effect on the Al-P, Fe-P and Ca-P fractions (Table 5). Addition of gliricidia prunings significantly reduced the Al-P ($P<0.01$), Fe-P ($P<0.05$) and Ca-P ($P<0.05$) fractions. The decrease of Al-P, Fe-P and Ca-P fractions could suggest the increasing soil organic matter solubilized fixed P in Al, Fe and Ca stable compounds making P more available for plant uptake. Addition of inorganic P only significantly increased ($P<0.001$) the Al-P, Fe-P and Ca-P fractions, suggesting that Fe, Al and Ca fix applied inorganic P from external source. These results are in agreement with findings of Beck and Sanchez (1994) who found that NaOH- extractable P (Fe-P) inorganic pool acts a sink for P fertilized soils of pH ranging from 3.8 to 4.0. Szott and Mendelez (2001) also found that phosphorus fertilization of the annual cropping and alley cropping systems increased the NaOH-extractable inorganic fraction for soils of pH ranging from 3.5 to 4.9, suggesting that Fe was acting as a sink of applied inorganic P.

Conclusions

The results of the study indicated that iron phosphate was the most dominant form of inorganic P in the Lixisol

Table 4. Phosphorus fractions at planting in the soils under maize plot and Gliricidia-maize plot.

Production system	**Fertilizer rates (kg ha^{-1})**		**P-fractions in soil (mg kg^{-1})**				
	N	**P**	**Ca-P**	**Red.-P**	**Fe-P**	**Al-P**	**Sol-P**
Maize	0	0	10.26	5.60	41.89	13.45	1.33
	0	40	15.62	4.49	49.21	20.58	1.93
	92	0	9.91	5.11	40.12	11.32	2.06
	92	40	13.07	4.86	46.39	17.55	2.15
	Mean		**12.22**	**5.01**	**44.40**	**15.72**	**1.87**
Gliricidia/maize	0	0	13.31	5.35	42.13	13.75	1.33
	0	40	12.17	4.89	49.83	16.91	1.81
	92	0	9.79	5.11	39.30	11.00	1.81
	92	40	10.49	4.49	42.20	14.90	1.57
	Mean		**11.44**	**4.96**	**43.37**	**14.14**	**1.63**
LSD$_{(0.05)}$							
Prod. Syst.			0.25	0.55	3.95	1.08	0.37
N-Fertilizer			0.25	0.55	3.95	1.08	0.37
P-Fertilizer			0.25	0.55	3.95	1.08	0.37
Prod. Syst. x N-Fertilizer			0.36	0.77	5.59	1.53	0.52
Prod. Syst. x P-Fertilizer			0.36	0.77	5.59	1.53	0.52
N-Fertilizer x P-Fertilizer			0.36	0.77	5.59	1.53	0.52
Prod Syst x N- x P- Fert.			0.51	1.09	7.90	2.11	0.74

Table 5. Distribution of P in the soils under maize plot and gliricidia-maize plot at harvest.

Prod. system	**Fertilizer rates (kg ha^{-1})**		**P-fractions in soil (mg kg^{-1})**				
	N	**P**	**Ca-P**	**Red.-P**	**Fe-P**	**Al-P**	**Sol-P**
Maize	0	0	9.77	3.80	37.08	10.88	1.42
	0	40	14.22	4.25	45.98	15.73	2.26
	92	0	10.53	5.26	37.08	10.35	1.66
	92	40	11.42	4.26	43.75	17.43	2.62
	Mean		**11.49**	**1.39**	**40.97**	**13.60**	**1.99**
Gliricidia/maize	0	0	10.28	4.70	41.76	14.55	2.50
	0	40	14.34	4.25	39.89	16.38	1.90
	92	0	10.41	4.92	40.24	13.89	2.26
	92	40	13.07	4.25	37.78	14.29	2.50
	Mean		**12.03**	**4.53**	**39.92**	**14.78**	**2.29**
LSD$_{(0.05)}$							
Prod. Syst.			1.22	0.39	2.43	1.64	0.09
N-Fertilizer			1.22	0.39	2.43	1.64	0.09
P-Fertilizer			1.22	0.39	2.43	1.64	0.09
Prod. Syst. x N-Fertilizer			1.72	0.55	3.43	2.32	0.13
Prod. Syst. x P-Fertilizer			1.72	0.55	3.43	2.32	0.13
N-Fertilizer x P-Fertilizer			1.72	0.55	3.43	2.32	0.13
Prod Syst x N- x P- Fert.			1.72	0.77	4.85	3.29	0.18

and acted as the sink for added inorganic P in this site. Addition of gliricidia prunings reduced the iron phosphate fraction suggesting that increasing soil organic matter through application of gliricidia prunings released the fixed P as evidenced by the increase in P uptake following addition of gliricidia prunings. Bray P 1 was highly correlated with P uptake in gliricidia-maize than in maize plot indicating increased P availability with application of gliricidia prunings. We conclude that addition of gliricidia prunings improves the soil P availability by solubilizing the fixed P allowing more utilization by the plant.

ACKNOWLEDGEMENT

The funding for this research work has come from the African Network for Agroforestry Education (ANAFE) though scholarship support to the first author, and the Canadian International Development Agency (CIDA) through the CIDA/ICRAF Zambezi Basin Agroforestry Project in Southern Africa (Project No. 050, 19425; Agreement No. 23591). The field technician, Konisaga Mwafongo and laboratory technician Jane Mzungu are thanked.

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