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Research Article

The potential of legume tree prunings as organic matters for improving phosphorus availability in an acid soil

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Abstract: A study that was aimed to elucidate roles of *Gliricidia sepium* and *Tithonia diversifolia* prunings and their extracted humic and fulvic acids on improving phosphorus availability and decreasing aluminum concentration in an Ultisol was conducted in a glasshouse. Thirteen treatments consisting of two prunings, six rates of pruning application (5, 7.5, 10, 20, 40 and 80 t/ha) and one control (no added prunings) were arranged in a randomized block design with four replicates. Each mixture of prunings and soil was placed in a pot containing 8 kg of soil and maize of Srikandi cultivar was grown on it for 45 days. At harvest, soil pH, P content and aluminium concentration were measured. Results of the glasshouse experiment showed that application of *Gliricidia* and *Tithonia* prunings significantly increased soil pH, reduced Al_o concentration, increased Al_p content, increased P availability, and increased P taken up by maize grown for 45 days. The optimum rate of both *Gliricidia* and *Tithonia* pruning should be 40 t/ha. However, at the same rate, optimum production gained by *Tithonia* would be higher than that of *Gliricidia*.

Keywords: *acid soil, legume trees, phosphorus, prunings.*

Introduction

A major part of the tropics is characterized by acid soils of low inherent fertility known as Oxisols and Ultisols (Swift and Sanchez, 1984). In Indonesia, these soils are widespread throughout Kalimantan (21,938,000 ha), Sumatera (9,469,000 ha), Maluku and Papua (8,859,000 ha), Sulawesi (4,303,000 ha) and Java (1,172,000 ha) (Prasetyo and Suriadikarta, 2006). Such soils are generally characterized by low cation exchange capacity, low base saturation, high soluble aluminium, low pH and low organic matter content (Sri Adiningsih et al., 1988).

Improvement of Ultisol productivity can obviously be made through application of inorganic fertilizer and /or liming. However, fertilizer application is usually ineffective as such soils pose low buffering capacity due to low organic matter content. In addition, the high solubility of aluminium leads causes a greater part of applied phosphorus (around 70%) becomes unavailable for plant use due to adsorption by soluble aluminium (Bates and Lynch, 2001). Another practice commonly employed to solve acidity and aluminium toxicity problems in Ultisols is liming (Wawan, 2000). However, over liming can reduce availability of P and Mn (Radjagukguk, 1983).

It has been argued that the best way to improve productivity of soils having high content of soluble aluminium is organic matter application (Hairiah et al., 2000; Yusuf et al., 2004). This refers to previous findings that organic acids present in organic matters or produced during their decomposition can react with Al to form organic-Al complexes or Al-chelate (Stevenson, 1994; Tan, 1998). These complexes can reduce aluminium solubility to a certain level that will not hinder plant growth (Notohadiprawiro, 2006). It is widely known that organic matter is very useful for improving soil fertility, soil physical properties and ion exchange capacity. However, large amounts of organic matter are needed to maintain and improve soil organic matter content for a positive change in these properties. Such large amounts are usually beyond the reach of upland farmers. The relationship between organic matter application and nutrient release, especially nitrogen, has been enormously studied, but studies on the effects of organic matter application on improving phosphorus availability in Ultisols are relative few.

Besides the release nutrients, other short term beneficial effects of organic matter application have not been drawn to the attention of the users. Currently, very little information is available of these practical influences. In Ultisols, an increase in soil pH and the reduction of soil aluminium concentrations are very important at establishment to guarantee good germination and emergence after showing.

Organic acids present in the organic matters or produced during their decomposition have been shown to interact strongly with phosphorus adsorption as they compete for the same sites (Appelt et al., 1975; Hue et al., 1986). This increases phosphorus availability, which a consequent of soil property change also contributes to the improvement in crop production. Therefore, when organic matter management is considered in the context of shortage, both short-term and long-term benefits of organic matter amendment on beneficial changes other than nutrient release need to be taken into account.

Considering to the variable amount and quality of organic matters, selection of organic maters needs to consider their availability in the field, their potential use for organic fertilizers as well its common use by farmers. Amongst various sources of organic matter, prunings of *Gliricidia sepium* and *Tithonia diversifolia* are commonly used for improving soil productivity. *Gliricidia sepium* is a legume tree that can easily be found as living hedges and shelters in rural areas throughout Indonesia. This tree is also commonly used by villagers as fuel wood and animal feed. *Tithonia diversifolia* is a shrub type of vegetation that can also easily be found in rural areas. Prunings of those two organic matter sources are very potential for supplying nitrogen and phosphorus. They also contain substantial amounts of humic and fulvic acids that can reduce soil aluminium toxicity. Supriyadi (2003) reported that application of *Tithonia diversifolia* prunings in an Andisol increased Al-chelate from 1.30% to 1.49% during 30 days of incubation. Minardi et al. (2007a) reported that application of *Gliricidia sepium* prunings in an Andisol reduced Al_o by 29.85% which in turn released phosphate into soil solution.

In this study, a glasshouse experiment was conducted to judge the role of organic matter addition in decreasing aluminium toxicity and phosphorus availability of an Ultisol and their impact on crop growth.

Materials and Methods

Fresh Prunings of *Gliricidia sepium* and *Tithonia diversifolia* collected from Jatikerto Village of Malang, were oven dry at 60oC for 48 hours for organic-C, total N, and total P, humic acid and fulvic acid contents. Humic and fulvic acids from the prunings were extracted using 0.01 N NaOH. Chemical composition of *Gliricidia sepium* and *Tithonia diversifolia* prunings is presented in Table 1.

Each of the fresh prunings was chopped at 1-2 cm and applied soil in a 10 kg plastic pot. The soil used for this study was top soil of an Ultisol collected from Kentrong Village of Cipanas District, Lebak Regency, Banten Province. The soil has the following characteristics: pH 4.3, 38.1 mg total P/kg soil, 5.79 mg available P/kg soil, 68.18% Al saturation, 11.85 meq exchangeable Al/100g soil, 1,10 meq exchangeable H/100g soil, 1.99% organic-C, 0.20% total N, and C/N ratio of 9.99. Thirteen treatments (Table 3) were arranged in a randomized block design with three replicates. For each treatment, 8 kg of air dried top soil (0-30 cm depth) that passed through 2 mm sieve was mixed with pruning and placed in a 10 kg plastic pot. All pots received basal fertilizers consisting of 250 kg Urea/ha and 50 kg KCl/ha. Three pre-germinated seeds of maize, cultivar Yellow Srikandi were planted in each pot and thinned to one best plant after 1 week. The unused plants were returned and incorporated into the soil.

The experiment was conducted for 45 days. Water was supplied daily to each pot in order to keep the moisture content of the soil at the approximate field capacity. At harvest (45 days after planting), maize shoots were harvested from all pots at a height of 1 cm above the soil surface. Roots were separated manually from the soil by sieving and rinsing with water. The shoots and roots were then oven dried at 60^{o}C for 48 hours, weighed and ground to pass through a 1 mm sieve. P content of shoots and roots was analyzed using $HClO_4$ + HNO_3 extraction method. P uptake was calculated by multiplying P concentration and plant dry weight.

Soil indicators determined included: soil pH (pH H_2O and pH KCl) using a glass electrode method (pH mete), inorganic P was extracted using H_2SO_4 0.5 M, total P was measured as inorganic P but the soil was ignited at 550^{O} C; organic P was calculated by subtracting total P and organic P; available P was determined using Bray II method; exchangeable Al was extracted using 1N KCl, Al chelate, Al-oxs, and P adsorption were determined using Blackmore method. Statistical analysis was performed at significant levels of 5% and 1%. Differences between treatments were tested using Duncan multiple range test. Correlation and regression analyze were performed to judge relationships between measured parameters.

Table 1. Treatments of Glasshouse experiment.

Code	Treatments	Input (mg/ kg soil)		
		Humic Acid	**Fulvid Acid**	**P**
P0	Controk (no pruning)	0	0	0
KG1	5 t *Giricidia* pruning /ha	321.731	106.480	8.543
KG2	7.5 t *Giricidia* pruning /ha	482.60	159.720	12.815
KG3	10 t *Giricidia* pruning /ha	643.467	212.960	17.087
KG4	20 t *Giricidia* pruning /ha	1286.934	425.920	34.174
KG5	40 t *Giricidia* pruning /ha	2573.868	851.840	68.348
KG6	80 t *Giricidia* pruning /ha	5147.736	1703.680	136.696
KT1	5 t *Tithonia* pruning /ha.	614.081	141.903	10.210
KT2	7.5 t *Tithonia* pruning /ha	921.122	212.855	15.315
KT3	10 t *Tithonia* pruning /ha	1228.163	283.807	20.420
KT4	20 t *Tithonia* pruning /ha	2456.326	567.614	40.840
KT5	40 t *Tithonia* pruning /ha	4912.652	1135.228	81.680
KT6	80 t *Tithonia* pruning /ha	9825.304	2270.456	163.360

Results and Discussion

Soil Al and pH

Application of *Gliricidia* and *Tithonia* prunings significantly reduced Al_{exch} concentration from 11.73 meq/100g to 2.29 meq/100g (Table 2). The lowest concentration of Al_{exch} was observed for application of *Tithonia* pruning at a rate of 80 t/ha (KT6) from 11.73 meq/100g to 2.29 meq/100g or reduced by 80.48%. The sharp decrease of Al_{exch} concentration due to application of *Gliricidia* pruning occurred at rate of 40 t/ha and for *Tithonia* at a rate of 20 t/ha. No sharp increase was observed at a higher application rate. It was likely that application of *Tithonia* pruning resulted in lower concentration of Al_{exch} than that of *Gliricidia* pruning.

The low reduction of Al_{exch} concentration at application rate of more than 20 t/ha for *Tithonia* pruning and 40 t/ha for *Gliricidia* pruning might be related to transformation mineralized NH_4^+ to NO_3^-. This anion will bind Al^{3+} to form unstable complexes (Lindsay, 1979).

In agreement with Al_{exch} concentration reduction, application of *Gliricidia* and *Tithonia* prunings significantly reduced Al_o concentration and increased Al_p ($Al_{chelate}$) (Figure 1). Al_o concentration was reduced from 3.75% to 1,98% for *Gliricidia* treatment, and from 3.75% to 1.95% for *Tithonia* pruning treatment. The highest percentage of the Al_o reduction (22.35%) was observed for application of 20 t *Tithonia* pruning /ha, followed by application of *Gliricidia* pruning 40 t /ha (17.55%) (Figure 1). At higher rates of pruning application, the reduction of Al_o tended to decrease, i.e. 2.93% for *Tithonia* at a rate of 40 t/ha and 2.01% for 80 t/ha, and 1.98% for *Gliricidia* at a rate of 80 t/ha.

Table 2. Changes of Al_{exch} and soil pH due to application of *Gliricidia* and *Tithonia* prunings.

Treatments *)	Al_{exch} (meq/100 g)		Soil pH (H_2O)	
Control	11.73	m	4.40	a
KG1	9.09	l	4.84	b
KG2	8.93	k	4.97	d
KG3	7.55	h	5.15	e
KG4	5.55	f	5.41	g
KG5	3.47	d	5.57	i
KG6	3.12	c	5.88	k
KT1	8.81	j	4.92	c
KT2	8.61	i	4.98	d
KT3	6.87	g	5.26	f
KT4	3.94	e	5.53	h
KT5	2.66	b	5.79	i
KT6	2.29	a	5.99	j

*) see Table 1

Al_p concentration increased from 0.22% to 1.11% for *Gliricidia* pruning treatment and from 0.22% to 1.29% for *Tithonia* pruning treatment (Figure 1). Application of 20 t *Tithonia* pruning /ha resulted in 62.71% of $Al_{chelate}$ increase. Such an increase could only be reached by application of about 60 t *Gliricidia* pruning /ha as application of 40 kg/kg only increased $Al_{chelate}$ by 46.88%. Patterns of Al_p increase and Al_o decrease were very similar to Al_{exch} reduction pattern. This is in agreement with results of experiment 1 which indicated that *Tithonia* pruning was stronger than *Gliricidia* pruning reducing Al_{exch} and increasing $Al_{chelate}$. Supriyadi (2003) has reported that application of *Tithonia diversifolia* prunings on an Andisol of Tawangmangu significantly increased formation of $Al_{chelate}$ in the soil. Furthermore, application of *Gliricidia* prunings on the same soil type reduced Al_o concentration by 29.85% which led to the release of phosphate into soil solution (Minardi et al., 2007b).

Application of *Gliricidia* and *Tithonia* prunings significantly increased soil pH. The highest pH was due to application of 80 t *Tithonia* compos / ha (KT6).The pH has increased from 4.4 to 5.99 after 45 days (Table 2). As expected, pH increases due to application of *Tithonia* pruning were greater than those of *Gliricidia* pruning. This might be related to the higher contents humic and fulvic acids of *Tithonia* pruning than *Gliricidia* compos (Table 1).

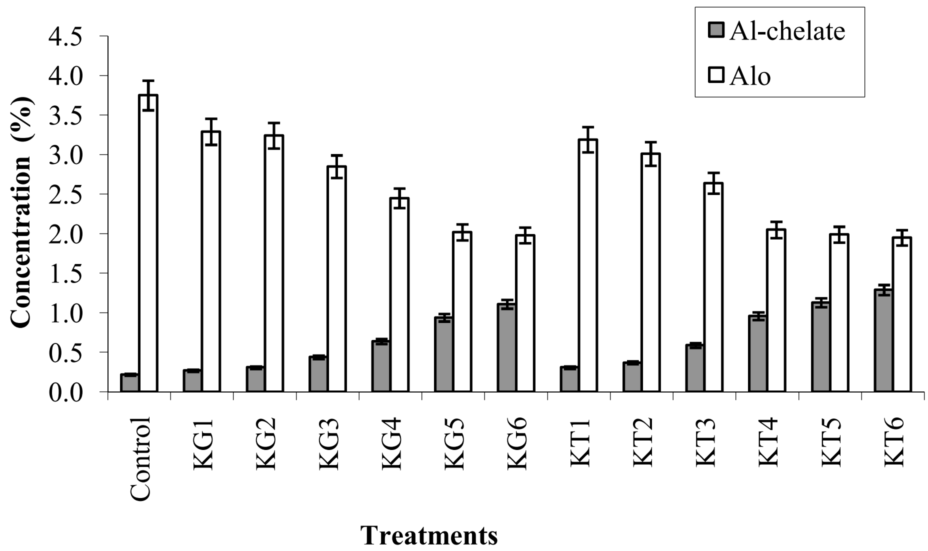

Figure 1. Effects of application of *Gliricidia* and *Tithonia* prunings on concentration of soil $Al_{chelate}$ and Al_o (KG: *Gliricidia* pruning; KT: *Tithonia* pruning: 1, 2, 3, 4, 5 and 6 are rates of 5, 7.5, 10, 20, 40 and 80 t/ha, respectively).

Based on the percentage of pH increase, application of 80 t *Tithonia*/ ha resulted in the higher percentage of pH increase (36.14%), compared to that of *Gliricidia* application at similar rate (33.64%). As discussed above, this indicated the stronger roles of humic and fulvic acids derived from *Tithonia* pruning than that of *Gliricidia* pruning in contributing additional free OH ion to soil solution (Mokolobate and Haynes (2002). The pH increase could also be due to the present of base cations that were released during decomposition of the prunings leading to the increase of OH ion concentration in soil solution (Hairiah et al., 2000).

Soil phosphorus

Application of 80 t *Tithonia* and *Gliricidia* prunings reduced P adsorption in the soil by 74.77% and 68.71%, respectively (Table 3). This resulted in significant increases of available P in the soil. In general, the percentage of soil available P increase due to application of *Tithonia* pruning was greater than that applied with *Gliricidia* pruning. This is, again, in agreement with pattern of soluble aluminium reduction in the soil (Table 2).

Reduction of Al_{exch} content due to chelate formation made by humic and humic acids has weakened Al reactivity to P which led to the decrease of P adsorption and accordingly available P increase. According to Weil and Magdoff (2004), organic acids (including humic and fulvic acids) that produced during decomposition of organic matter can reduce activity of aluminium through formation of organic-metal complexes which leads to pH increase, release of adsorbed P and increase of available P for plant uptake. Calculation of P balance showed that the amount of total P (soil available P, P taken up by maize, and release of P adsorbed) at harvest (45 days) was higher than that at planting time.

Table 3. Changes in Soil P status as affected by application of *Tithonia* and *Gliricidia* prunings.

Treatment *)	P adsorption (%)		Available P (mg/kg)	
Control	85.47	m	7.26	a
KG1	81.16l	l	7.69	b
KG2	76.69j	j	9.84	c
KG3	70.01	i	12.28	f
KG4	58.02	f	16.00	h
KG5	37.70	d	20.88	j
KG6	26.74	b	24.59	i
KT1	79.19	k	9.99	d
KT2	69.89	h	12.20	e
KT3	60.21	g	14.55	g
KT4	48.58	e	19.43	i
KT5	31.02	c	24.44	k
KT6	21.56	a	31.07	m

*) see Table 2

The higher additional available P than additional total P was caused by addition of P released from adsorption. The increase of available P due to application of the prunings has led to the increase of P recovery in maize, particularly at application of 10 t pruning/ha. The remaining available P in the soil (not taken up by plant) is thought to be in the form of P microbial biomass, or rebound by aluminium.

Growth of maize

Application of either *Gliricidia* pruning or *Tithonia* pruning significantly affected plant height, shoot dry weight and root dry weight (Figures 2 and 3). Shoot and root dry weights increased with increasing rate of pruning applied to the soil. The highest shoot and root dry weight was observed when the soil was applied with of 80 t pruning/ha (Figure 3). Application of 80t *Gliricidia* pruning/ha produced 78,95 g dry shoot and 10,81 g dry root, that of 80t *Tithonia* pruning/ha produced 92,17 g dry shoot and 12,19 g dry root (Figure 3).

Increasing shoot and root dry weight due to application of prunings led to increasing shoot: root ratio by 1.5-3.5 times compared to control treatment. This indicated that there was no growth inhibition for the maize. It is widely known that shoot: root ratio can be used an indicator of shoot-root functional relationships. A low shoot: root ratio indicates the present of root growth inhibitors that affecting shoots development.

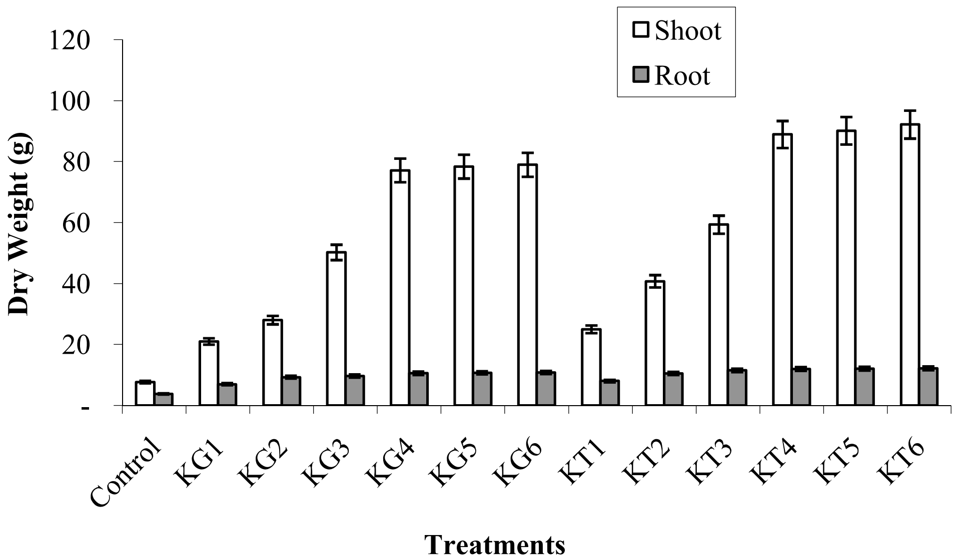

Figure 2. Effects of application of *Gliricidia* and *Tithonia* prunings on maize shoot and root dry weights (KG: *Gliricidia* pruning; KT: *Tithonia* pruning: 1, 2, 3, 4, 5 and 6 are rates of 5, 7.5, 10, 20, 40 and 80 t/ha, respectively).

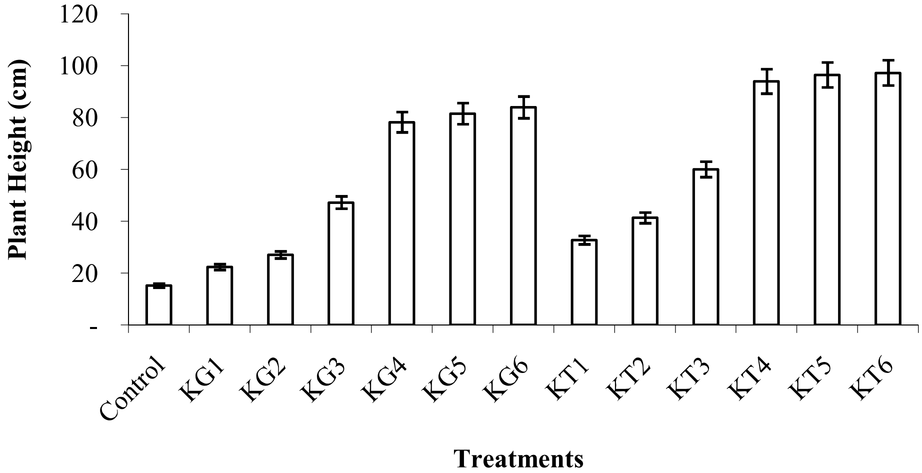

Figure 3. Effects of application of *Gliricidia* and *Tithonia* prunings on maize plant height (KG: *Gliricidia* pruning; KT: *Tithonia* pruning: 1, 2, 3, 4, 5 and 6 are rates of 5, 7.5, 10, 20, 40 and 80 t/ha, respectively).

Using a quadratic model of $Y = b_o + b_1X+b_2X^2$, where Y = yield of maize biomass (shoot + root), X = rate pruning application, b_1 and b_2 are regression coefficients, and b_o is a constant, to estimate rate of pruning application to yield a maximum maize, it was known that equation for the model is $Y = 3.28 + 0.93X – 0.009X^2$ for *Gliricidia* pruning, and $Y = 5.81 + 0.99X – 0.009X^2$ for *Tithonia* pruning (Figures 4 and 5). Based on the equations it can be estimated that an optimum rate of *Gliricidia* pruning was similar to that of *Tithonia* pruning, i.e. approximately 40t/ha.

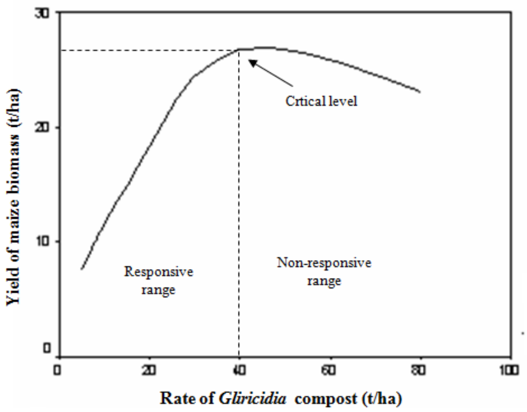

Figure 4. Optimum rate (dose) of *Gliricidia sepium* pruning

Application of 40 t *Gliricidia* pruning /ha yielded maize biomass of 25.86 t/ha, but application of 40 *Tithonia* pruning / ha yielded maize biomass of 31.13 t /ha. Application of either *Gliricidia* or *Tithonia* pruning at rates higher than 40t /ha will decrease biomass yield, for examples; application of 80 t *Gliricidia* pruning /ha will yield 19.77 t biomass / ha (24% decrease), and application of 80 t Tithonia pruning /ha will yield 27.65 t biomass/ha (11% decrease). The higher maximum yield obtained by *Tithonia* pruning than *Gliricidia* pruning was thought to be related to the difference contents of humic and fulvic acids of the prunings (Table 1) that resulted in differences in reduction of Al_{exch} and increase of available P.

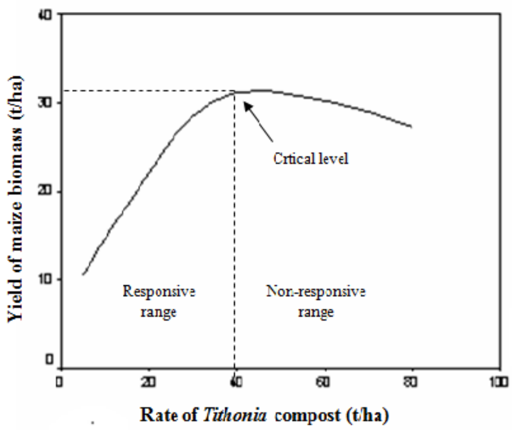

Figure 5. Optimum rate (dose) of *Tithonia diversifolia* pruning

P-uptake by maize

Application of *Gliricidia* and *Tithonia* prunings enhanced P uptake by maize with a maximum uptake of 45 mg P/kg soil for KT6 treatment (80 t *Tithonia* pruning/ha). In general, P uptake increased with increasing rate of pruning applied

(Figure 6). A better growth of maize grown on soil amended with *Tithonia* pruning compared to that of *Gliricidia* was in accordance with strong roles of *Tithonia* pruning in reducing aluminium solubility, increasing soil pH and improving P availability of the soil. Results of this study is in line with previous studies on the roles of *Tithonia* prunings in increasing P uptake in soils having high P adsorption (Jufri, 1999; Supriyadi, 2003), and roles of *Gliricidia* prunings in improving P availability in an Andisol (Minardi et al., 2007b).

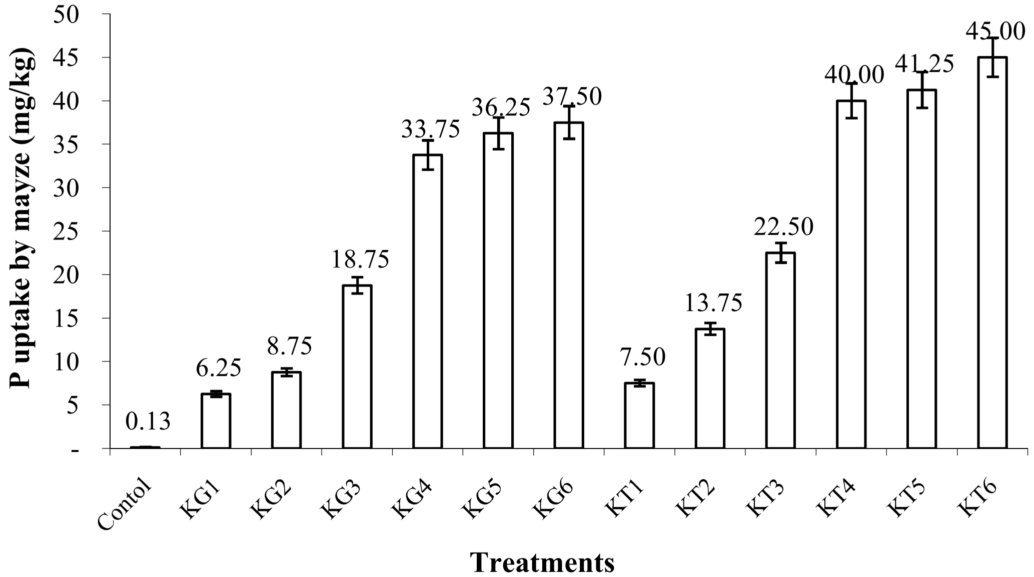

Figure 6. Effect of application of *Gliricidia* and *Tithonia* prunings on P-uptake by maize at 45 days (KG: *Gliricidia* pruning; KT: *Tithonia* pruning: 1, 2, 3, 4, 5 and 6 are rates of 5, 7.5, 10, 20, 40 and 80 t/ha, respectively).

Data presented in Table 4 show that the increase of shoot dry weight and P uptake by maize were strongly correlated with changes of soil chemical properties (P availability, pH (H_2O), Al_{exch} and Al_p).

Table 4. Coefficient of correlations (r) between changes in soil chemical properties, maize shoot dry weight and P uptake by maize.

Soil chemical properties	**Coefficient of correlation (r)**	
	Shoot dry weight	**P uptake**
Available P	0.91	0.94
pH (H_2O)	0.95	0.96
Al_{exch}	- 0.97	- 0.98
Al_p	0.93	0.96

Improvement of P availability has led to improvement of P uptake by maize. As discussed above, this is related to the decrease of Al_{exch} due to humic and fulvic acids present in the prunings of produced during their decomposition process. In addition, the increase of available P could also be mineralization of organic P formerly present in the prunings. This strongly indicated the beneficial effects of amendment on improving phosphorus availability and decreasing aluminium toxicity in an Ultisol, which in turn improving plant growth.

Conclusion

Application of *Gliricidia* and *Tithonia* prunings significantly increased soil pH, reduced Al_o concentration, increased Al_p content, increased P availability in an acid soil, and increased P taken up by maize grown for 45 days.

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References

Appelt, H., Coleman, N.T. and Pratt, P.F. 1975. Interaction between organic compounds, mineral and ions in volcanic ash derived soils. II. Effects of organic compounds on the adsorption of phosphate.

Soil Science Society of America Proceeding 39: 623-630.

Bates, T.R. and Lynch, J.P. 2001. Root hairs confer a competitive advantage under low phosphorus availability. *Plant and Soil* 236: 243-250.

Hairiah, K., Widianto., Utami, S.R., Suprayogo, D., Sunaryo., Sitompul, S.M., Lusiana, B., Mulia, R., van Noordwijk, M. dan Cadish, G. 2000. Pengelolaan Tanah Masam Secara Biologi: Refleksi Pengalaman dari Lampung Utara. ICRAF.

Hue, N.V., Craddock, G.R. and Adams, F. 1986. Effect of organic acids on aluminium toxicity in subsoil. *Soil Science Society of America Journal* 50: 28-34

Jufri, J. 1999. Peningkatan Ketersediaan P Oleh Beberapa Macam Bahan Organik Pada Ultisol. Tesis S2 PPS Universitas Brawijaya, Indonesia.

Lindsay, W. L. 1979. Chemical Equilibrium in Soils. John Wiley & Sons. New York.

Minardi, S., Suntoro, Syekhfani. dan Handayanto, E. 2007a. Peran asam humat dan fulvat dari bahan organik dalam pelepasan P terjerap pada Andisol. *Agrivita* 29: 15-22

Minardi, S., Suntoro, Syekhfani. dan Handayanto, E. 2007b. Penggunaan macam bahan organik dengan kandungan total asam humat dan fulvat berbeda dan pupuk P terhadap ketersediaan dan serapan P pada tanaman jagung manis. *Agrivita* 29:131 – 137

Mokolobate, M.S. and Haynes, R.J. 2002. Increases in pH and soluble salts influence the effect that additions of organic residues have on concentrations of exchangeable and soil solution aluminium. *European Journal of Soil Science* 53: 481-489.

Notohadiprawiro, T. 2006. Budidaya Organik: Suatu Sistem Pengusahaan Lahan Bagi Keberhasilan Program Transmigrasi Pola Pertanian Lahan Kering. Repro: Ilmu Tanah UGM-Yogjakarta. h: 1-10.

Prasetyo, B.H. dan Suriadikarta, D.A. 2006. Karakteristik, potensi, danteknologi pengelolaan tanah ultisol untuk pengembangan pertanian lahan kering di Indonesia. *Jurnal Litbang Pertanian* 25 (4): 39-46.

Radjagukguk, B. 1983. Masalah Pengapuran Tanah Mineral Masam di Indonesia.

Sri Adiningsih, J., Sudjadi, M. and Setyorini, D. 1988. Overcoming soil fertility constraints in acid upland soils for food crop based farming systems in Indonesia. *Indonesian Agricultural Research and Development Journal* 10: 49-58.

Stevenson, F.J. 1994. Humus Chemistry: Genesis, Composition and Reaction.

Supriyadi. 2003. Studi Penggunaan Biomasa *Tithonia diversifolia* dan *Tephrosia candida* Untuk Perbaikan P dan Hasil Jagung (*Zea mays* L) di Andisol. Disertasi PPS Universitas Brawijaya, Indonesia. 172 h.

Swift, M. J. and Sanchez, P.A. 1984. Biological management of tropical soil fertility for sustained productivity. *Nature and Resources* 20: 2-10.

Tan, K.H. 1998. Principles of Soil Chemistry. Marcel Dekker Inc., Madison, New York.

Wawan. 2002. Pengelolaan Subsoil Masam Untuk Peningkatan Produksi Tanaman Pangan. Makalah Falsafah Sains. PPS-IPB, Bogor.

Weil, R.R. and Magdof, F. 2004. Significance of soil organic matter to soil quality and health. In: Magdof, F. and Weil, R.R. (eds), Soil *Organic Matter in Sustainable Agriculture*. pp 1-36.

Yusuf, W.A., Jumberi, A., Haris, A. dan Simatupang, R.S. 2004. Pengaruh pemberian pupuk organik terhadap fitotoksitas aluminium pada tanah masam. *Jurnal Tanah Tropika* 18: 109-115.