Legumes tree hedgerows in cassava farming affecting soil productivity and cassava yield

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ABSTRACT

Integration of legume trees as hedgerows in cassava (*Manihot utilisima Crantz*) farming is one possibility to reduce the negative effect of cassava farming on soil productivity. The experiment was conducted in the Tamanbogo Experimental Farm in East Lampung from November 2006 to November 2008, located at 05^0 00' 20" S and 105^0 29' 23" E. The field experiment had three factors of legumes hedgerow, and three factors of P fertilizer rates that were arranged in a split plot experimental design. The results showed that the total biomass of legumes tree pruning in 2007 and 2008 were not affected by P fertilization on cassava but it was affected significantly by the variety of legumes tree planted as hedgerows. The rates of P fertilization on cassava did not effect significantly on soil chemical characteristic in 2007 but it's tend to increase in 2008. Flemingia congesta hedgerows gave a significant lower soil bulk density and highest total soil pores space in 2008. The highest yield of fresh cassava (19.98 t ha^{-1}) was gained on Flemingia congesta hedgerows. Increasing the rates of P fertilizer from 36 to 72 kg P_2O_5 ha^{-1} increased the yield of cassava significantly in 2008.

Keywords: *Manihot utilisima Crantz, Flemingia congesta, Glyricidia sepium, biomass*

INTRODUCTION

Increasing population densities are posing a serious threat to the natural resource base and agricultural production in Indonesia because farmers' major response to higher food demands has been either an increase in cultivated area. Continuous cropping of cassava as a regional relied crop in Lampung Province, Indonesia in monoculture systems has caused to soil degradation. Dung et al. (2002) reported that soil fertility will be affected negativelly after several years of planting cassava in monoculture systems. Karama (2000) found out that there are very low rates application of inorganic and organic fertilizers on cassava farming in Lampung Province.

The ultisols soil order in Lampung Province developed from acidic tuff sediment parent materials (Hidayat and Mulyani, 2002), the soil has a coarse texture and low fertility. The content of soil C-organic and P nutrients were low but the content of Fe and Al oxides were high (Soelaeman et al., 2003) and will binds P to unavailable for plant growth. In terms of Al toxicity, cassava was classified as a resistant plant because the critical levels of Al exchangeable saturation for cassava was about 80%, while the level of Al exchangeable saturation of ultisols soil in Indonesia are generally does not exceeds to 75% (Subandi et al., 1994). High decomposition rates of organic matter due to high air temperature in tropical region and the poor returning back of cassava biomass to the soil may be responsible on low organic C contents in the soil.

One possibility to reduce the negative effect of growing cassava in ultisols soil would be intercropping of leguminous trees as hedgerows as a source of soil organic matter. During the cropping phase the trees can be pruned and the pruning materials was used as mulch to improve organic matter status of the soil and to provide nutrients to the crop. Preston et al. (2000) stated that to maintain soil fertility is planting arable crops in association with forage legumes in alley cropping systems.

Flemingia congesta and *Glyricidia sepium* are leguminous trees that are produce large amount of biomass and growth well in ultisols soil in Lampung

Province, Indonesia. They are drought tolerant crops and can withstand repeated pruning. Binh et al. (1998) and Andersson (2002) suggested that *Flemingia congesta* improves soil fertility though return to the soil of organic matter from fallen dead leaves. Szott and Kass (1993) mentioned that adding pruned biomass alone in phosphorus deficient soil, cannot sustain productivity of continues alley cropping since phosphorus may become limited. Pruned biomass continually can not accumulate sufficient amount of nutrients to make a significant contribution to the nutrient supply for crop. Therefore, application of N, P and K fertilizers were needed to support plant growth and yield.

The trial was conducted to determine the effects of legumes trees hedgerow and the rates of P required improving soil productivity and yield of cassava in ultisols soil.

MATERIALS AND METHODS

Study Site

The experiment was carried out in the Tamanbogo Experimental Farm of The Indonesian Soil Research Institute (ISRI), from November 2006 to November 2008 in East Lampung, located at 05^0 00’ 20” S and 105^0 29’ 23” E. The site has 5% land slopes and elevation at 300 m above sea level.

The climate of the area was monsoon-tropical climate, with the wet season was between November to May (6 months) and the dry season was from July to October (4 months). The average air temperature was 29^oC ranging from 24 to 34^0C and an average monthly rainfall was 179.76 mm. The climate was classified to C2 type (Oldeman et al., 1979) with the water surplus of 719 mm year^{-1} occurred from November to April and the water deficit of 164 mm from June to September (Figure 1).

The soil is typical upland soil classified as ultisols (Typic Kanhapludults) with characteristics of low pH (acid), low P nutrient, and low soil organic matter. Due to the relatively high rainfall, the soil bases such as Ca, Mg, K and Na cations were released and quickly leaching from the soil, thereby the soil becomes acid (Subagyo et al., 2000). The content of N, K_2O, P_2O_5 nutrients and soil organic C contents were low (Soelaeman et al., 2003). High contents of Al oxide will retain P into the forms of unavailable nutrient for plants growth (Singh, et al., 2003), so that the plant deficiency of P in acid upland soil was the most factor for crop production. Other than nutrient deficiencies, the upland ultisols soil has high soil bulk density (BD), low total soil pores space, soil permeability and available water (Soelaeman et al., 2003).

Experimental Design, Treatments and Management

The trial was arranged as split plot experimental design with three replications using plot size of 10 m x 10 m. The trial investigated 3 kinds of crop management as the main plot, there were 1). Hedgerows of *Flemingia congesta*, 2). Hedgerows of *Glyricidia sepium*, and 3). Without hedgerows/control. The legumes tree as hedgerows were grown in wide rows of 400 cm x 30 cm. Cassava was planted in the interspace between the legumes tree rows with plant spacing of 100 cm x 50 cm, 1 stick/hole. The sub plot consists of 4 rates of P fertilization; there were a). 0 kg P_2O_5 ha^{-1} as the control, b). 36 kg P_2O_5 ha^{-1}, c) 54 kg P_2O_5 ha^{-1}, and d). 72 kg P_2O_5 ha^{-1}. The entire dose of P fertilizer was applied into the hole at planting time.

The seed of *Flemingia congesta* was planted in plastic polybag nursery in March 2006. The nursery was maintained properly until the seeds has 1 month old (20-25 cm in height). The young plants of *Flemingia congesta* and the sticks of *Glyricidia sepium* at a height of 30 cm were planted at the field in April 2006 with plant spacing of 400 cm x 30 cm (plant population was 8.325 plants ha^{-1}). The hedgerows of *Flemingia congesta* and *Glyricidia sepium* were fertilized once per season in May 2006 at the rates of 23 kg N ha^{-1}, (50 kg urea ha^{-1}), 36 kg P_2O_5 ha^{-1} (100 kg Super phosphate ha^{-1}) and 30 kg K_2O ha^{-1}(100 kg KCl ha^{-1}), respectively. Due to limitation of water in the dry season (June to September), the growth of legumes tree at the field were very heterogeneous.

The first pruning of the legumes tree hedgerow was conducted at the start of the rainy season (November 2006) where the legumes has 7 months old; unfortunately growth performance of legumes tree were very heterogeneous because it was planted in the dry season. In an effort to reduce variability of soil fertility in the plot, the pruned biomass and all above ground biomass of weeds were transported out from the experimental plot. The next prunings were planned to be done periodically at the height of 50 cm above the ground surface to prevent shading and to reduce nutrient competition with cassava. The hedge rows were pruned in the rainy season in interval time of 1 month, and in the dry season was in interval time of 2-3 months. The pruned materials were broadcasted onto the soil surface of plot as mulch.

The test crop of Cassava (*Manihot utilisima* Crantz.) used Kasesart variety that was planted in the interspace between the hedgerows at the start of the rainy season (November 2006). The plant distance was 100 cm x 50 cm (plant population was 11.675 plants ha^{-1}) and it was harvested in October 2007 (11 months old). The soil was cultivated by hoe to about 30 cm depth so that the biomass residues were incorporating to the soil. After the soil has been cultivated, cassava was planted in November 2007 with the same form and methodology applied in the first farming year in 2006. Cassava was harvested in October 2008 at 11 months old. All plots of cassava were fertilized at the rate of 69 kg N ha^{-1} (150 kg Urea ha^{-1} and 120 K_2O ha^{-1} (100 kg KCl ha^{-1}). Fertilizers application was conducted 2 times, that were one third

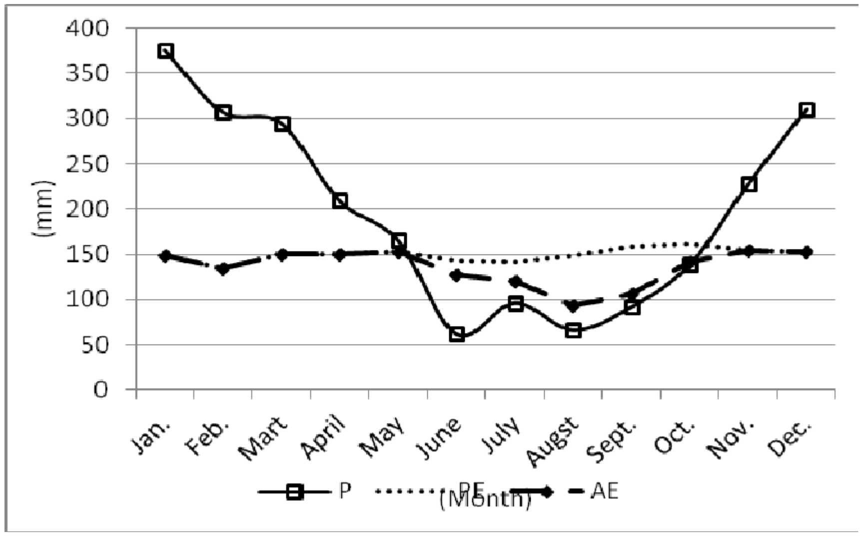

Figure 1. Monthly water balanced in Tamanbogo Experimental Farm (2001-2010)
Notes: P: precipitation, PE: potential evaporation, and AE: Actual evapotranspiration

parts of fertilizers applied into the hole at planting time and the remaining parts (two third parts) was applied when cassava was 1 month old.

Soil samples of each plot were collected before establishing the hedgerows and after harvesting the cassava crop in every farming year. The soil samples were randomly collected from five points of 0-30 cm soil depth and bulked into a composite soil sample. The composite soil samples were air dried, grounded and sieved with 2 mm mesh for chemical analysis. The undisturbed soil samples of each plot were collected for soil physical analysis in the laboratory. Soil pH was determined in free ion water and KCl 1 M solution in 1:5 (soil: solution ratio), soil organic carbon by Walkey and Black procedure, total N by Kjeldahl method, available P by Bray 1 procedure and CEC by leaching with neutral ammonium acetate solution (NH_4OAC, pH 7, 1N).

The data was analyzed using SAS Program v 9.3 for Windows. Duncan's Multiple Range Test (DMRT) was used to compare the effect of pruned biomass and P fertilization in improving soil productivity and yield of cassava.

RESULTS AND DISCUSSION

Hedgerows Growth and Biomass Production

Table 1 shows that in wide rows of 400 cm x 30 cm, the hedgerows of *Glyricidia sepium* grew faster in height compared to *Flemingia congesta*. The plant height and growth rate of *Glyricidia sepium* in 7 months old were 46.4% higher and 20, 43% faster compared to *Flemingia congesta*. The ddifferences of plant height and growth rate of the two legumes species was due to genetic differences in nature where the height of *Flemingia congesta* was shorter than *Glyricidia sepium*. However, the weight of *Flemingia congesta* biomass was 54.8% higher than *Glyricidia sepium*. This are represents the capability of *Flemingia congesta* to adapt in the dry season and on acidic soil in the first phase of the growth cycle.

One of the major benefits of hedgerows intercropping in cassava farming is the mulch provided by the hedgerow species in the form of prunings associated with crop. Table 2 shows that the total biomass of legumes tree hedgerows pruning in 2007 and 2008 were not affected by P fertilization on cassava but it was affected significantly by the variety of legumes tree planted.

Flemingia congesta was better in biomass production compared to the *Glyricidia sepium* both in 2007 as well as in 2008 (Table 2). Biomass production of *Flemingia congesta* was 36.9% and 37.12% higher than *Glyricidia sepium* at the end of 2007 and 2008 farming year, respectively. *Flemingia congesta* has a strong capability to coppice especially in the rainy season.

Effect of Pruned Biomass and P Fertilization on Soil Characteristics

An important benefit of intercropping of legumes tree as hedgerows in cassava farming was the addition of large amounts of organic materials from the legume prunings as mulch or green manure which can have favourable effects on soil productivity.

Soil Chemical Characteristics

The initial soil chemical properties at the beginning of the

Table 1. Plant height, growth rate and biomass yield of legume tree at 7 months old in Tamanbogo Experimental Farm, 2006

Leguminous Trees	Plant height (cm)	Growth rate (cm month^{-1})	Biomass Weight (t ha^{-1}) *
Flemingia congesta	56.3	9.3	0.51
Glyricidia sepium (bud)	82.4	11.2	0.36

* The pruned biomass was transported out from the plot

Table 2. Effect of P rates on cassava to the weight of fresh prune biomass hedgerows in Tamanbogo Experimental Farm

Year and rate of P on Cassava	Fresh Pruned Biomass Yields (t ha^{-1})		
	Flemingia congesta	***Glyricidia sepium***	**Mean**
2007			
0 kg P_2O_5 ha^{-1}	4.51a	3.33a	3.92a
36 kg P_2O_5 ha^{-1}	4.52a	3.31a	3.92a
54 kg P_2O_5 ha^{-1}	4.51a	3.33a	3.92a
72 kg P_2O_5 ha^{-1}	4.53a	3.25a	3.89a
Mean	4.52 A	3.30 B	3.91
2008			
0 kg P_2O_5 ha^{-1}	7.22 a	5.24 a	6.23a
36 kg P_2O_5 ha^{-1}	7.22 a	5.28 a	6.25a
54 kg P_2O_5 ha^{-1}	7.26 a	5.32 a	6.29a
72 kg P_2O_5 ha^{-1}	7.25 a	5.28 a	6.27a
Mean	7.24 A	5.28 B	6.26

Notes: Numbers followed by the same capital letter in the rows and the same small letter in the columns are not significantly different at 0.05 levels by DMRT

experiment at 0-30 cm soil depth revealed that the soil was sandy clay loam with soil N, P, K, C and cation exchangeable capacity (CEC) were low. Table 3 indicated that the rate of P fertilization on cassava did not affects significantly to that soil chemical characteristics in 2007, but the variety of hedgerows affected significantly ($P<0.0001$) compared to the control/without legume hedgerows.

Addition of *Flemingia congesta* and *Glyricidia sepium* pruning (4.52 t ha^{-1} and 3.30 t ha^{-1}) as mulch in Table 2 onto the soil surface has affected to some soil chemical characteristic compared to the control treatment at the end of the first farming year (2007). However, between *Glyricidia sepium* and *Flemingia congesta* hedgerows showed no significant differences in the soil chemical properties measured in 2007, except for the soil C content parameter ($P<0.0001$). The soil C content in *Flemingia congesta* hedgerows was significantly higher compared to *Glyricidia sepium* hedgerows due to the higher of pruned biomass returned back to the soil.

Table 3 shows that the soil chemical characteristics improved in 2008. It was affected by the variety of legume hedgerows and P fertilizers, except for the soil N content that was not significantly affected by P fertilization. The lack of effect of P fertilizer to soil N contents may be due to the fact that the residues of cassava biomass especially stem on soil surface was not completely decomposed. Application of P fertilizer in cassava farming tends to increase soil P and K in 2008. Kang *et al.* (1985), Lal (1989), Kang and Ghuman (1991) have demonstrated significant positive effects of alley cropping on soil fertility parameters such as organic C levels, N and extractable P levels over a range of climatic and soil conditions. The soil N contents in Flemingia congesta and Glyricidia sepium hedgerows were significantly higher compared to the control treatment in the last of the second farming year (2008).

There are interaction effects between legumes hedgerows species and P fertilization on soil C contents in 2008 (Table 4).

Increasing of P fertilizer rates from 0 to 72 kg P_2O_5 ha^{-1} in *Flemingia congesta,* and *Glyricidia sepium* hedgerows system as well as in cassava monoculture systems/without hedgerows increased soil organic C contents significantly. The soil organic contents in the rates of 54 kg P_2O_5 ha^{-1} is not significantly different

Table 3. Effect of pruned legumes hedgerows and P fertilization in cassava to soil chemical characteristics at Tamanbogo Experimental Farm in Lampung Province

Soil Chemical Parameters	2007					2008			
	N (%)	P (mg kg^{-1})	K (mg $100g^{-1}$)	C (%)	CEC (Cmol (+) kg^{-1}	N (%)	P(mg kg^{-1})	K (mg $100g^{-1}$)	CEC (Cmol (+) kg^{-1}
Flemingia	0.07 A	5.42 A	5.47 A	0.84 A	5.55 A	0.08 A	6.75 A	5.93 A	6.42 A
Glyricidia	0.06 A	5.41 A	5.44 A	0.77 B	4.94 A	0.08 B	6.07 B	5.58 B	4.90 B
Control	0.05 B	5.17 B	5.41 B	0.74 C	4.18 B	0.06 C	5.52 C	5.41 B	4.61 C
0 kg P_2O_5 ha^{-1}	0.6 a	5.33 a	5.43 a	0.78 a	4.42 a	0.7 a	5.76 b	5.46 b	5.05 b
36 kg P_2O_5 ha^{-1}	0.6 a	5.34 a	4.84 a	0.78 a	4.42 a	0.7 a	5.91 b	5.44 b	5.12 b
54 kg P_2O_5 ha^{-1}	0.5 a	5.33 a	5.45 a	0.78 a	4.59 a	0.7 a	6.22 ab	5.48 b	5.17 b
72 kg P_2O_5 ha^{-1}	0.6 a	5.34 a	5.47 a	0.79 a	3.50 a	0.7 a	6.57 a	6.18 a	5.91 a

Notes: Numbers followed by the same capital and small letter in the columns are not significantly different at 0.05 levels by DMRT.

Table 4. Interaction of pruned legume hedgerows and P fertilization on soil organic C in Tamanbogo Experimentral Farm, 2008

Sub Plot	Main Plot			
	Flemingia congesta **Hedgerows**	***Glyricidia sepium*** **Hedgerows**	**Without hedgerows**	**Mean**
0 kg P_2O_5 ha^{-1}	0.89 c A	0.75 c B	0.76 c B	0.80
36 kg P_2O_5 ha^{-1}	0.92 b A	0.78 b B	0.75 bc C	0.82
54 kg P_2O_5 ha^{-1}	0.95 a A	0.82 a B	0.77 ab C	0.85
72 kg P_2O_5 ha^{-1}	0.96 a A	0.85 a B	0.79 a C	0.87
Mean	0.93	0.80	0.77	

Notes: Numbers followed by the same small letter in the columns and with the same capital letter in the rows are not significantly different at 0.05 levels by DMRT.

compared to the soil organic content in 72 kg P_2O_5 ha^{-1}. The average soil organic contents in *Flemingia congesta* hedgerows systems was 16.25% higher than in *Glyricidia sepium* hedgerows systems and soil organic C contents in *Glyricidia sepium* systems was 14.29% higher than the treatment of without hedgerows systems/cassava monoculture.

Phosphorus fertilization at the rate of 36 to 72 kg P_2O_5 ha^{-1} in *Flemingia congesta* hedgerows gave higher soil organic C content compared to *Glyricidia sepium* and cassava monoculture systems/without hedgerows. However, the contents of soil organic C in the soil was lower with no application of P fertilization (0 kg P_2O_5 ha^{-1}). The soil organic C content in *Flemingia congesta* hedgerow systems was larger than the system with *Glyricidia sepium* hedgerows. Meanwhile, the soil organic contents in *Glyricidia sepium* hedgerows systems were not significantly different compared to cassava monoculture systems.

The interaction between legumes tree hedgerows and P fertilization on soil organic C may be attributed to the returning back of pruned legumes and cassava biomass to the soil. The highest yield of cassava was achieved in *Flemingia congesta* hedgerows with application of 36-72 kg P_2O_5 ha^{-1}. *Flemingia congesta* hedgerows accompanied with 72 kg P_2O_5 ha^{-1} fertilization gave the highest C contents in the soil.

Soil Physical Characteristics

Table 5 shows that application of pruned legumes as mulch (3.91 t ha^{-1}) did not affects soil bulk density (BD) in 2007, but after 6.26 t ha^{-1} of pruned legumes and cassava residues (ranging from 8.82 to 9.79 t ha^{-1}) have been incorporated to the soil, the types of legumes affected soil BD and total soil pores space independently at the end of 2008. No significant interaction effect between applications of pruned legume and P fertilization on soil BD and total soil pores space.

The pruned biomass produced by each variety of legumes did not affect soil BD in 2007, but it’s showed significant effects to the total soil pores space. *Flemingia*

Table 5. Effect of pruned legumes and P fertilization of cassava on soil physical properties in Tamanbogo Experimental Farm

Pruned legumes and P Fertilization	Soil Physical Parameters			
	Bulk Density (g cc^{-1})		Total Soil Pores (% vol.)	
	2007	2008	2007	2008
Legumes:				
Flemingia congesta hedgerows	1.46 A	1.43 B	45.37 A	44.88 A
Glyricidia sepium hedgerows	1.47 A	1.46 A	43.03 B	41.78 B
Without hedgerows	1.48 A	1.47 A	41.58 C	41.22 C
P Fertilization:				
0 kg P_2O_5 ha^{-1}	1.47 a	1.45 a	43.10 a	43.17 a
36 kg P_2O_5 ha^{-1}	1.47 a	1.45 a	43.44 a	43.20 a
54 kg P_2O_5 ha^{-1}	1.47 a	1.45 a	43.38 a	43.28 a
72 kg P_2O_5 ha^{-1}	1.46 a	1.45 a	43.39 a	43.32 a

Notes: Numbers followed by the same small letter and with the same capital letter in the columns are not significantly different at 0.05 levels by DMRT.

Table 6. Effects of pruned legumes hedgerow and P fertilization on cassava yield in Tamanbogo Station Farm

Year and P rates	Cassava Yield (t ha^{-1})			
	Flemingia congesta	***Glyricidia sepium***	**Without Hedgerows**	**Mean**
2007				
0 kg P_2O_5 ha^{-1}	5.13	5.23	4.85	5.07 c
36 kg P_2O_5 ha^{-1}	15.81	16.28	16.18	16.09 b
54 kg P_2O_5 ha^{-1}	17.94	17.22	18.18	17.78 ab
72 kg P_2O_5 ha^{-1}	19.25	19.58	19.93	19.59 a
Mean	14.53 a	14.58 a	14.78 a	
2008				
0 kg P_2O_5 ha^{-1}	6.14	5.30	3.95	5.13 D
36 kg P_2O_5 ha^{-1}	23.01	21.11	18.81	20.98 C
54 kg P_2O_5 ha^{-1}	24.93	22.45	19.00	22.13 B
72 kg P_2O_5 ha^{-1}	25.84	23.14	20.82	23.27 A
Mean	19.98 a	18.00 b	15.64 c	

Notes: Numbers with the same small letter and with the same capital letter in the columns are not significantly different at 0.05 levels by DMRT.

congesta hedgerows gave significant lower soil BD and highest total soil pores space in 2008. Soil BD was affected by the contents of soil organic C, soil texture and soil management. The higher the organic C contents in the soil, the lower the soil BD. Agus et al. (2006) sugested that soil BD has close relationship with root penetration into the soil, soil drainage and soil aeration, and the others soil characteristics. Min et al. (2003); Werner (1997) and Islam and Weil (2000) mentions that soil bulk density is inversely related to total soil porosity, which provides a measure of the porous space left in the soil for air and water movement. Lower bulk density implies greater pore space and improved aeration, and developing a suitable environment for biological activity and plant growth. Reicosky (2005) suggested that soil aggregation and stability of soil structure increases with increasing of soil organic C, in turn it was increases the infiltration rate and the available water holding capacity.

The phosphorus fertilization did not affect soil BD significantly in 2007 and 2008. Sultani et al. (2007) has found out that phosphorus fertilization did not show any significant effects on various soil physical properties. Phosphorus fertilization on cassava does not affect the amount of biomass produced by the legume hedgerows.

Effect of Pruned Biomass and P Fertilization on Cassava Yield

Table 6 shows that application of biomass from pruned legume hedgerows in cassava farming systems in 2007 did not increase the yield of cassava significantly compared to the control treatment (without hedgerows), however, the yield of cassava increased significantly in 2008. The highest yield of fresh cassava (19.98 t ha^{-1}) gained in *Flemingia congesta* hedgerows; it was attributed to the general improvement of soil quality as a result of highest biomass/mulch application to the soil.

Application of phosphorus fertilizers on cassava resulted significant (P<0.05) increased of cassava yield in both years. Raising the rate of P from 36 to 72 kg P_2O_5 ha^{-1} in 2008 increased the yield of cassava significantly from 20.98 t ha^{-1} to 23.27 t ha^{-1}. Szott and Kass (1993) mention that adding pruned biomass alone in phosphorus deficient soils cannot sustain productivity of continuous alley cropping since phosphorus may become limited. Cassava yield under legume hedgerows intercropping could improve if the most limiting nutrients especially P was added as inorganic fertilizer supplement.

CONCLUSIONS AND SUGGESTION

The hedgerow of Flemingia congesta on cassava farming was more resistant to drought and provides more pruned biomass because the plant has a strong capability to coppice in the rainy season. Flemingia congesta hedgerows produced more pruned biomass which improves the chemical and physical properties of the soil better than Glyricidia sepium hedgerows. However, there was an interaction between the kinds of legume that is planted with a rate of P fertilizer. The use of Flemingia congesta as hedgerows on cassava farming associated with P fertilizer at 36-72 kg P_2O_5 ha^{-1} gave the best soil C content and fresh cassava yield.

Pruning biomass weight of *Flemingia congesta* and *Glyricidia sepium* in this study was categorized low (3.30-7.24 t ha^{-1}). In order to produce more pruning biomass to improve land productivity faster, tree spacing within the rows should be as close as possible. Closer spacing within the row also allows for improved distribution of nutrients to a greater proportion of the intercrop/cassava.

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