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IMPACT OF *BRACHIARIA*, ARBUSCULAR MYCORRHIZA, AND POTASSIUM ENRICHED RICE STRAW COMPOST ON ALUMINUM, POTASSIUM AND STABILITY OF ACID SOIL AGGREGATES

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ABSTRACT

Acid soil is commonly grown with cassava, which in general, tolerate low soil fertility and aluminum (Al) toxicity. However, without any improvement efforts such soil will become worse. Intercropping cassava with *Brachiaria decumbens* (BD) which adapts to acid soil and tolerates low fertility soils as well as application of arbuscular mycorrhiza (AM) and organic matters are among the important efforts to rehabilitate this soil. The experiment was conducted to examine the impact of BD, AM, and potassium (K) enriched rice straw compost on exchangeable Al, available K, and stability of soil aggregates. Experiment was arranged in a completely randomized design with three factors and three replications. The first factor was BD as cassava inter-cropping, the second factor was AM, and the third factor was 2 t ha^{-1} rice straw compost enriched with 0 kg, 50 kg, 100 kg, and 200 kg KCl ha^{-1}. Brick pots (1 m length x 1 m width x 0.45 m depth) filled with Kanhapludult soil was used for growing cassava in which row of BD was planted at 60 cm from cassava stem. K-enriched rice straw compost and AM (10 g per stem) were applied around cassava stem at 2 and 12 days after planting, respectively. BD was cut every 30 days and the cutting was returned to the soil. Soil exchangeable Al was analyzed at 0, 3, 6 and 9 months after planting (MAP), while Al and K contents as well as aggregate stability were measured at 6 MAP. The results showed that planting BD decreased 33% exchangeable Al, which means that the root exudates of this grass was effective in detoxifying Al^{3+}. Treatment of BD and/or in combination with AM was effective in preserving K added to the soil, increasing total polysaccharides, and improving soil aggregate stability. This indicated that planting BD and applying AM and K-enriched rice straw compost improved acid soil fertility, and therefore can be recommended in cassava cultivation.

[***Keywords***: Acid soil, *Brachiaria decumbens*, arbuscular mycorrhiza, composts, aluminum, potassium]

INTRODUCTION

Cations interact each other in plant root zone. Exchangeable Al, Ca and Mg in root environment of low CEC soil (acid soils) reduce effectiveness of plant K sorption because these cations inhibit K^+ to place ion exchange complexes. Consequently, K^+ added to the soil through fertilizer exists much more in soil solution and is easier to lose through leaching (Tisdale *et al.* 1990). This increases the needs of K fertilizer for optimum crop growth in acid soil (Howeler 2002).

Cassava due to its tolerance to acid and poor soils, is mostly cultivated under low inputs. This practice can cause soil degradation because the harvested cassava roots take the essential nutrients, especially K out from the farm in high amount (Suyamto and Howeler 2001; Nakviroj *et al.* 2005). To maintain the quality of acid soil, cultivation of cassava farming should be improved.

Acid soil quality could be maintained and improved by application of organic matter. Root exudates could be utilized as a source of *in situ* organic matter (Violante and Gianfreda 2000). *Brachiaria decumbens* (BD) or signal grass, a tropical forage grass, adapts to acid soil and tolerates low fertility soils. Its root exudates, malic acid and citric acid (low molecular organic acids) are able to detoxify Al^{3+} (Wenzl *et al.* 2003; Gaume *et al.* 2004; Wenzl *et al.* 2006; Hafif *et al.* 2011).

BD as a monocotyledon plant absorbs more K (mono-valence) than the higher valence cations from the soil (Havlin *et al.* 1999). The grass is known as K harvesting plant and can potentially preserve K from leaching. Arbuscular mycorrhiza (AM) is effective in improving plant root system and increasing plant nutrient uptake, especially in low fertility soils. Its hyphae and glomalin (glycoprotein) secreted by hyphae are considered as primary soil aggregators (Howeler 2002; Rillig 2004; Borie *et al.* 2008).

Applying enough K is needed because the acid soil has low K content. Adding K to soil through K enriched rice straw compost is expected to increase K uptake by plant and reduce K loss by leaching.

The study aimed to examine the impact of BD root exudates, AM fungi and rice straw compost enriched with K on exchangeable Al, K availability and aggregate stability of acid soil planted to cassava.

MATERIALS AND METHODS

Site and Description

The experiment was conducted on Kanhapludult at Tegineneng Experimental Station of Lampung Assessment Institute for Agricultural Technology (AIAT) in April 2009 to May 2010. Mean air temperature in the research area was 27°C and mean annual rainfall was 1,700 mm, distributed from November to June with July to October almost completely dry. The characteristics of the Kanhapludult (silty clay loam) were 350 g kg^{-1} clay, 480 g kg^{-1} silt, 170 g kg^{-1} sand, pH 4.8 at a soil/water ratio of 1:1, 14 g kg^{-1} organic C, 1.1 g kg^{-1} total N, 13 mg kg^{-1} Bray I-extracted P, 60 mg kg^{-1} 25% HCl-extracted K, 2.84 cmol kg^{-1} 1 N NH_4-acetate extracted Ca, 1.51 cmol kg^{-1} 1 N NH_4-acetate extracted Mg, 0.11 cmol kg^{-1} 1 N NH_4-acetate extracted K, 6.65 cmol kg^{-1} 1 N NH_4-acetate extracted CEC, 750 g kg^{-1} base saturation, and 0.13 cmol kg^{-1} KCl-extracted Al.

Stolons of BD were originated from the grass nursery of Indonesian Research Institute for Animal Production, Bogor, West Java. AM used in the study was originated from the Laboratory of Forestry and Environmental Biotechnology, Center for Biotechnology Research, IPB, Bogor. The AM inoculants contained *Glomus manihotis*, *Glomus etunicatum*, *Giganspora* sp. and *Acaulospora* sp. Each 10 g of AM inocula contain about 100 spores. The inocula were applied 10 days after fertilization around the cassava stems as much as 5-10 g per plant.

Rice straw was composted at the research location. Each 2 t of fresh rice straw were enriched with KCl fertilizer at the rates of 0, 50, 100 and 200 kg. To accelerate the straw decompositions, three microbial decomposers originated from the Indonesian Biotechnology Research Institute for Estate Crops, Bogor, i.e. *Trichoderma harzianum*, *T. pseudokoningii* and *Aspergilus* sp. were added to the K enriched K rice straw. Chemical analysis of non-K enriched compost is shown in Table 1.

Experimental Design

The experiment was arranged in completely randomized design (CRD) with three factors and three replications. The first factor was BD, i.e. without (B0) and cassava intercropping with BD (B1); the second factor was AM, i.e. without (M0) and with AM inoculation (M1); and the third factor was K enriched rice straw compost, i.e. application of 2 t compost ha^{-1} or 200 g per cassava stem enriched with 0 kg (K0), 50 kg (K50), 100 kg (K100), and 200 kg (K200) KCl ha^{-1}, respectively.

The treatment was carried out in artificial pots (1 m length x 1 m width x 0.45 m depth) to which the Kanhapludult of 0-20 cm top-soil and 20-40 cm subsoil passing 0.5 mm sieve was filled. The inside of the pot was coated with black plastic.

Cassava stem (20 cm long) of UJ-5 variety was vertically planted at 30 cm distance from one edge of the pot and 50 cm from other left and right edges of the pot, then five stolons of 5-7 buds of BD were planted at the distance of 20 cm from the cassava stem (Fig. 1). Cassava of UJ-5 variety was chosen because it has high cyanic acid content and recommended for industrial raw material by the Indonesian Legume and Tuber Crops Research Institute, the

Table 1. Chemical properties of non-enriched K-rice straw compost used in the study.

Compost properties	Value
pH (H_2O)	8.70
Organic-C (%)	18.44
Nitrogen (%)	1.76
C/N	10.48
P_2O_5 (%)	0.19
K_2O (%)	1.00
Humic acid (%)	1.03
Fulvic acid (%)	0.21

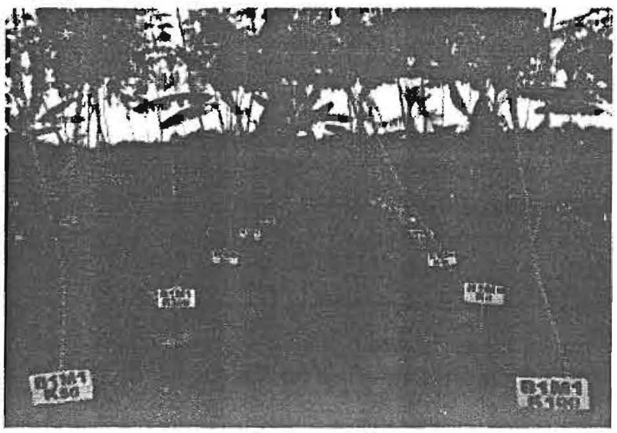

Fig. 1. Performance of experimental pots conducted in Kanhapludult of Tegineneng Experimental Station, Lampung, April 2009-May 2010.

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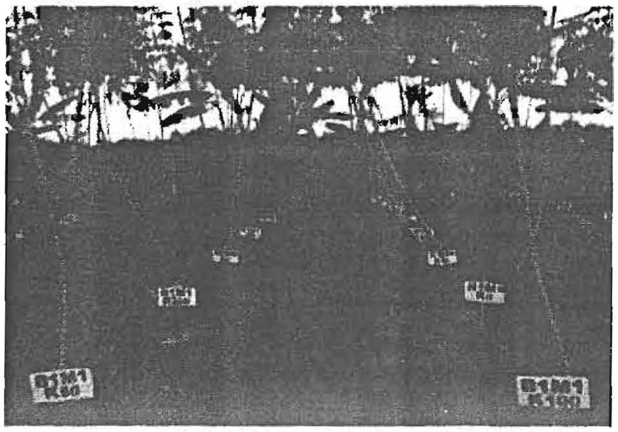

Fig. 1. Performance of experimental pots conducted in Kanhapludult of Tegineneng Experimental Station, Lampung, April 2009-May 2010.

Indonesian Agency for Agricultural Research and Development (IAARD).

K-enriched rice straw compost and base fertilizers consisted of 200 kg urea and 150 kg SP-36 ha^{-1} were applied at 2 days after planting, while the AM (10 g per cassava stem) was applied at 10 days after fertilizing. BD was cut every 30 days and the cuttings were returned to the soil around the cassava stem at pots of the treatment.

Soil and BD Tissue Sampling

Soil samples were taken for exchangeable Al analysis at 0, 3, 6 and 9 months after planting (MAP) using soil auger at 0-20 cm depth at different corners of the pots, i.e (1) 10-15 cm from the BD hedgerow; (2) 25-30 cm from BD chump and the cassava stem (the middle between cassava stem and BD); (3) 20-25 cm from cassava stem at pots without BD treatment (B0); and (4) control (soil samples taken in one corner of the pot of B0M0K0 treatment that was not influenced by the growth of cassava roots). BD leaves were sampled from all BD treated pots at 6 MAP for analyses of Al and K contents. Soil samples for available K analysis were taken at 30 cm from cassava stem at 6 MAP from all pots.

Undisturbed soil clods from all pots were sampled carefully at 0-5 cm depth by a field knife at distance of 30 cm from cassava stem and used for aggregate stability analysis. The samples were put in closed plastic glasses, placed in a cartoon box and brought to the laboratory.

Soil and Plant Tissue Analysis

Exchangeable Al was analyzed with unbuffered KCl 1N method, available K with Bray extract method, total K and Al in BD leaf tissues with dry ash method, and stability of soil aggregates, i.e. macroaggregate 1 (2-5 mm), small macroaggregate (1-2 mm), mesoaggregate (0.25-1 mm), and microaggregate (0.053-0.25 mm) with wet sieving method (Kemper and Rosenau 1986). Total polysaccharides (TPS) and dilute acid-extracted polysaccharides (DAP) or polysaccharides other than cellulose in each aggregate were determined with Lowe method (Martins *et al.* 2009).

Data Analysis

Analysis of variance was performed using SAS General Linear Model Procedure (SAS Institute 1997). Comparison of means was done using least significant difference test at 1% and 5% significant levels. The mean significant difference at 10% level was also justified.

RESULTS AND DISCUSSION

Soil Exchangeable Al

Exchangeable Al of the soil in BD root zone at 6 MAP was 0.14 cmol kg^{-1} or 41% lower than that of the control (0.24 cmol kg^{-1}) (Fig. 2). It appears that soil exchangeable Al was not only affected by BD root exudates and BD leaf cuttings, but also by cassava root exudates. At 6 MAP, Al concentration was 0.35 cmol kg^{-1} which was 42% higher than that of the initial concentration. The exchangeable Al of topsoil affected by cassava root exudates only (0.22 cmol kg^{-1}) was 10% lesser than that of the control.

Concentrations of exchangeable Al of the soil at 6 MAP tended to increase in all treatments, assumed as a result of the relatively high rainfall. While from the time of planting until 3 MAP, watering plants was assisted by artesian well water. Relatively high rainfall might intensify mineral weathering by hydrolysis which increases soil exchangeable Al.

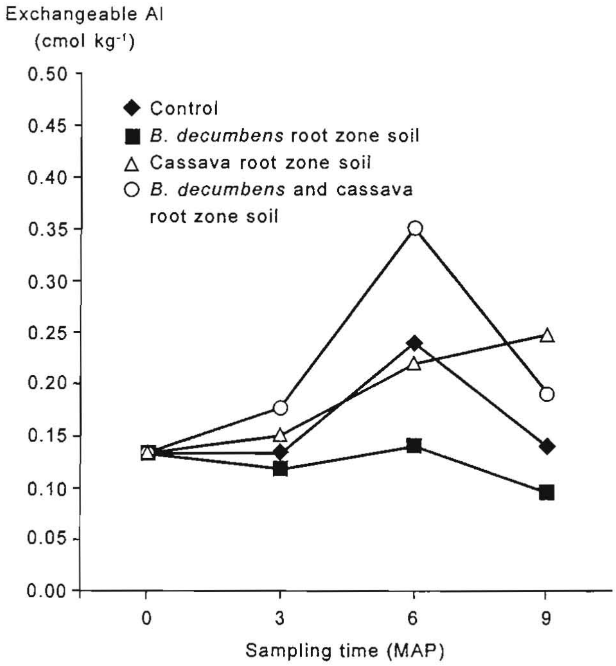

Fig. 2. Exchangeable Al of soil in *Brachiaria decumbens* root zone, cassava root zone, and soil affected by *B. decumbens* and cassava root zone and the control at 0, 3, 6 and 9 months after planting (MAP), Kanhapludult of Tegineneng, Lampung, April 2009-May 2010.

Exchangeable Al of soil of all pots at 9 MAP was mostly lower than that measured at 6 MAP, except the exchangeable Al of soil affected by cassava root exudates. The exchangeable Al of soil in this zone (0.25 cmol kg^{-1}) was 73% higher than that of the control (0.14 cmol kg^{-1}). The exchangeable Al of soil treated by both BD and cassava root exudates and also by BD leaf cuttings returned to soil decreased from 0.35 cmol kg^{-1} at 6 MAP to 0.19 cmol kg^{-1} at 9 MAP. Meanwhile, exchangeable Al of soil affected by BD root exudates (0.10 cmol kg^{-1}) was 33% lower than that of the control (0.14 cmol kg^{-1}).

The decrease in exchangeable Al of soil in BD root zone at 6 and 9 MAP seems to be caused by chelation of Al by malic, citric and oxalic acids of the BD root exudates. As reported by Hafif *et al.* (2011), roots of BD release low molecular weight organic acids such as malic, citric and oxalic acids to chelate Al^{3+}. Chelating Al from soil solution induced partial desorption of Al from the colloid surface (ion exchange complex) and decreased the exchangeable Al. In addition, BD absorbed Al and accumulated it in leaf tissues. Result of tissue analysis showed that BD leaves contained 67-287 mg Al kg^{-1}. Returning BD leaf cuttings to the soil around cassava stem increased exchangeable Al of that soil at 6 MAP. At 9 MAP, however, exchangeable Al of that soil decreased drastically. At this time most of BD leaf cuttings have already decomposed and presumably produced organic acids (humic and fulvic acids). These organic acids then chelated Al which decreased exchangeable Al of the soil. Increasing exchangeable Al of the soil in cassava root zone was assumed to be the effect of cyanic acid released by cassava roots. The cyanic acid accelerated mineral weathering (Frey *et al.* 2010) and presumably increased exchangeable Al.

Available K

The concentrations of available K in the soil receiving K-enriched rice straw compost, in treatments of B1M0 (58-150 mg kg^{-1}) and B1M1 (55-123 mg kg^{-1}) were higher than that in the B0M0 treatment (46-58 mg kg^{-1}). This means that application of K enriched rice straw compost was not effective without BD and AM treatment (Fig. 3).

The BD root exudates effectively increased soil organic C (Gale *et al.* 2000). The grass was also able to absorb more monovalent cations such as K than the cations with higher valence (Havlin *et al.* 1999). Therefore, it could be used to preserve soil K from leaching. At 6 months of the experiment, returning BD leaves to the soil around cassava stem as much as 7.8 kg $hill^{-1}$ or equivalent to 3.5 kg dry weight, containing 62 g K_2O kg^{-1} on the dry weight basis, effectively maintained and increased available K in the soil (Fig. 3). This means that total K returned to the soil within 6 months was approximately 22 g per cassava stem.

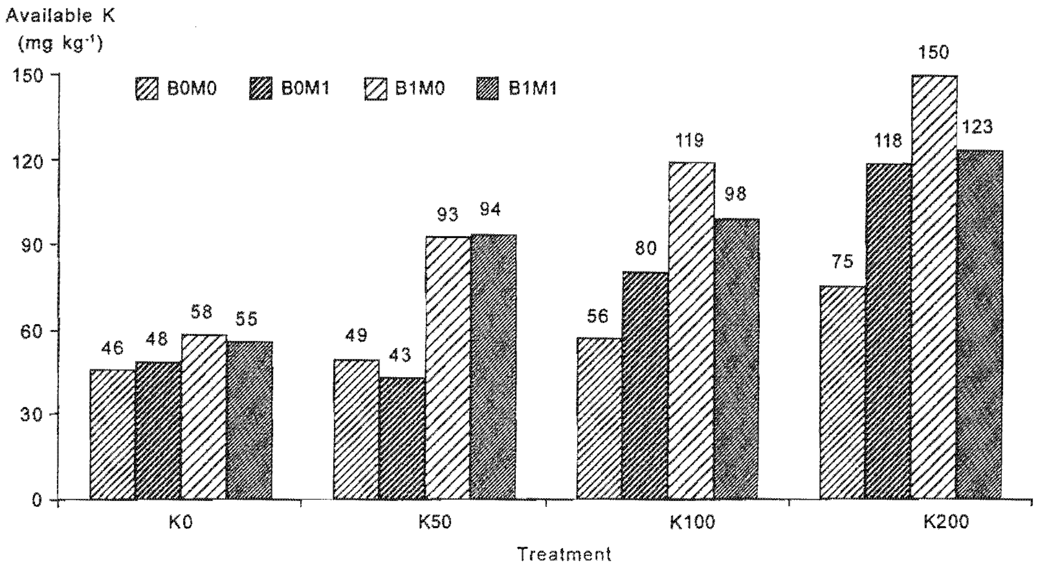

Fig. 3. Available K of acid soil treated with K-enriched rice straw compost (K), *Brachiaria decumbens* (BD), and arbuscular mycorrhiza (AM) at 6 months after treatment, Kanhapludult of Lampung, 2010. B0 = without BD, B1 = with BD, M0 = without AM, M1 = with AM.

Correlation of Al Accumulation in BD Leaf Tissue and Available K in Topsoil

Al content in BD leaf tissues was negatively correlated with available K in the soil (Fig. 4). The reason for this phenomenon is that the monocotyledon species tend to absorb more monovalent cations such as K^+ than divalent or higher valence cations due to low root cation exchange capacity (10-30 cmol kg^{-1}) (Havlin *et al.* 1999).

Soil Aggregate Stability

Although there was a great variety of methods to assess soil aggregate stability, the ratio or the difference in the fragment sizes before and after application of mechanical energy is generally used. Analysis of variance indicated that the stability of soil aggregates with various sizes was not significantly affected by BD, AM, and rice straw compost application. Yet the interaction of BD and AM affected significantly the stability of large macroaggregate, mesoaggregate, and microaggregate. The microaggregate and mesoaggregate stability under the interaction of BD and AM (B1M1) and BD (B1M0) were higher than those under AM (B0M1) and control (B0M0). The macroaggregate stability was less affected by B1M1 than B0M0, B1M0, and B0M1 (Fig. 5A).

The plant roots can promote soil aggregation by releasing organic compounds (root exudates) that can directly stabilize soil particles or by favoring microbial activity that in turn will affect soil aggregation (Tisdall and Oades 1982). As organic compound decomposition proceeds, stability of the macroaggregates declines. The root exudates create zones of failure in the macroaggregate. When the aggregates contact with water rapidly, the macroaggregate will be slaking and then release microaggregate (Angers and Caron 1998; Gale *et al.* 2000). It was the reasons that the mesoaggregate and the microaggregate were more stable under the effect of BD root exudates.

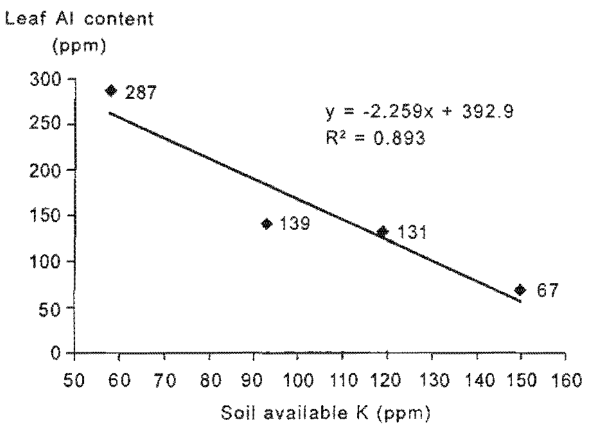

Fig. 4. Correlation between Al content in *Brachiaria decumbens* leaves and available K in soil, Kanhapludult of Lampung, 2010.

The large macroaggregates (2-5 mm) under AM treatment (B0M1) were more stable than that under other treatments. It caused by extraradical-hyphae and hydrophobic proteinaceous substance (glomalin) of AM which is able to bind soil particles and microaggregates to construct macroaggregate (Rillig 2004; Bedini *et al.* 2009). Meanwhile, stability of the large macroaggregates under B1K100 and B1K200 was not significantly different from that of B0K0 and B0K50. Utilizing rice straw compost enriched with 100 and 200 kg KCl ha^{-1} reduced the effect of BD root exudates on fragmenting macroaggregates. K ion in complexes with humic and fulvic acids derived from compost (Hayes and Bolt 1990) was able to coat the macroaggregate to protect the macroaggregate from root exudate penetration or reduce fragmentation energy of root exudates.

Polysaccharides as Aggregation Agent

Polysaccharides have a transient effect functioning as bridges to bind soil particles or sometimes acting as glue for maintaining soil particles together (Borie *et al.* 2008). Under BD treatment (B1M0) both total polysaccharids (TPS) within mesoaggregates (5.00 g kg^{-1}) and dilute acid-extracted polysaccharides (DAP), i.e. polysaccharides other than cellulose within macroaggregates (4.06 g kg^{-1}) were lower than those under AM treatment (B0M1). The contrast result was found in microaggregates. Compared with the aggregates under BD (B1M0), macroaggregates and mesoaggregates of the soil under AM treatment (B0M1) contained higher DAP and higher TPS, respectively, whereas microaggregates contained lower TPS. The BD and AM treatment interaction (B1M1) increased TPS in mesoaggregates and microaggregates and in entire of aggregates significantly (Table 2).

The high TPS content in microaggregates was caused by fragmenting of macroaggregates to microaggregates by BD root exudates, especially in B1M1 and B1M0 treatments. Gale *et al.* (2000) found that the organic C like polysaccharide gel (*mucigel*) excreted by plant roots was more than 60% associated with macroaggregates at the beginning. Fragmenting of macroaggregates to microaggregates increased

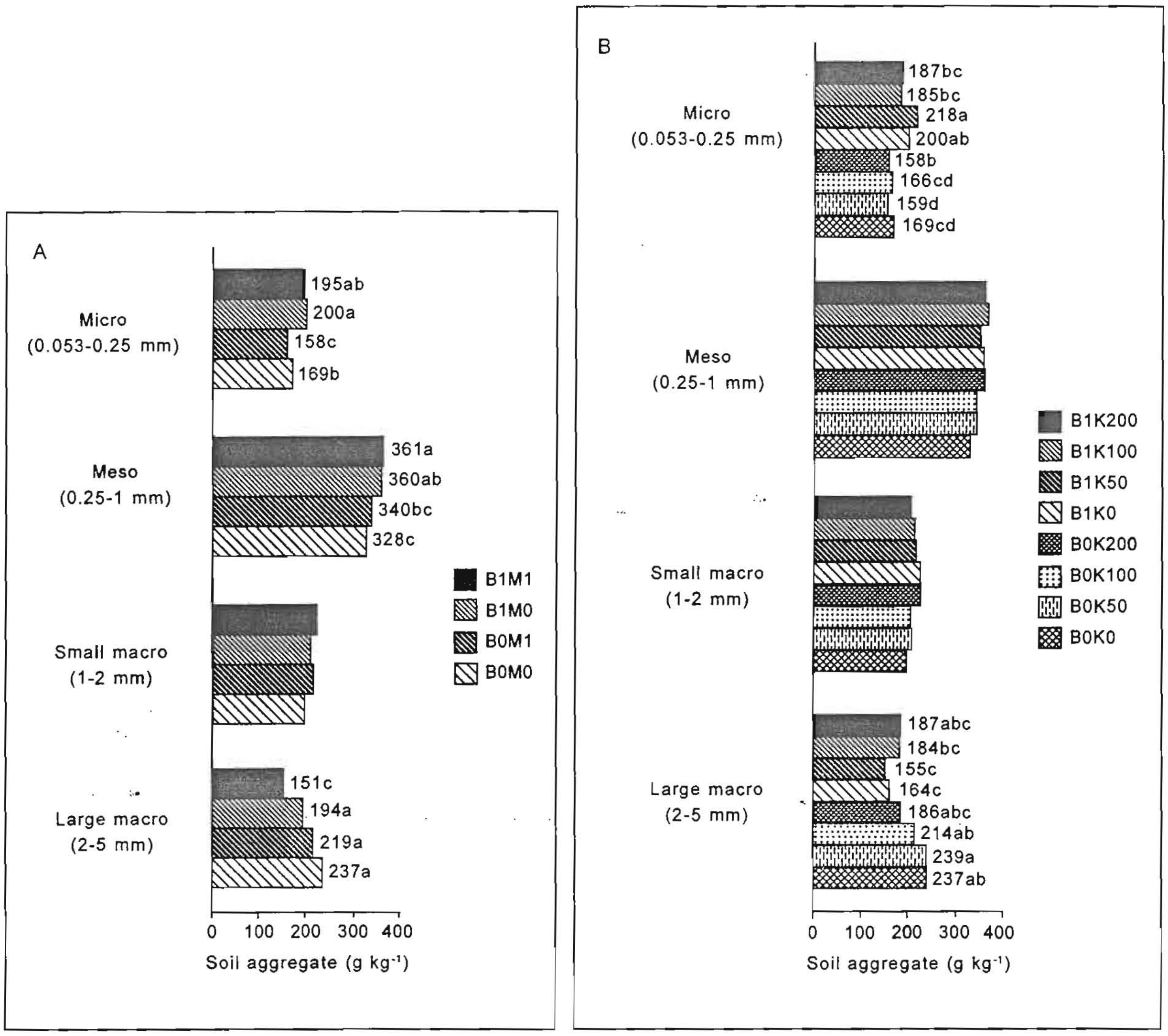

Fig. 5. Interaction effect of (A) *Brachiaria decumbens* (BD) and arbuscular mycorrhiza (AM), and (B) BD and K enriched rice straw compost on stability of macroagregate (2-5 mm, 1-2 mm), mesoagregate (0.25- 1 mm) and microagregate (0.053-0.25 mm) of Kanhapludult of Lampung, 2010. Values followed by the same letter are not significantly different (at $P < 0.05$) according to the Student LSD test.

Table 2. Total polysaccharides (TPS) and dilute acid-extracted polysaccharides (DAP) in macroaggregates, mesoaggregates and microaggregates, and total polysaccharides in all of soil aggregates as the effect of *Brachiaria decumbens* (BD) and arbuscular mycorrhiza (AM) treatment, Kanhapludult of Lampung, 2010.

Treatment	Macroaggregate (>1 mm)		Mesoaggregate (0.25-1 mm)		Microaggregate (0.053-0.25 mm)		Total polysacharide in soil aggregates	
	TPS ($g\ kg^{-1}$)	DAP ($g\ kg^{-1}$)	TPS ($g\ kg^{-1}$)	DAP ($g\ kg^{-1}$)	TPS ($g\ kg^{-1}$)	DAP ($g\ kg^{-1}$)	TPS ($g\ kg^{-1}$)	DAP ($g\ kg^{-1}$)
B0M0	4.93	4.78a	5.00c	4.76	5.38b	4.68	15.30b	14.21
B0M1	6.37	4.75a	6.13b	4.31	4.73b	4.68	17.23b	13.73
B1M0	4.70	4.06b	5.00c	4.34	5.88ab	5.41	15.56b	13.80
B1M1	5.28	4.77a	8.06a	5.71	8.94a	5.70	22.26a	16.17
LSD 0.05		0.38	0.78		3.21		3.07	

B0 = without BD, B1 = with BD, M0 = without AM, M1 = with AM

Values followed by the same letter are not significantly different (at $P < 0.05$) according to the Student LSD test.

organic C in microaggregates and decreased it in macroaggregates. While high TPS content in meso-aggregates as an effect of AM treatment (B0M1 and B1M1) was assumed as the contribution of chitin, β-(1=4) acetylglucosaminosan substance excreted by AM extraradical hyphae reach with carbohydrate (Bedini *et al.* 2009) and glycoprotein (glomalin) produced by hyphae (Wang dan Qiu 2006).

In the entire soil aggregates, the highest TPS was found under B1M1 treatment. It means that BD root exudates and AM are potential to enrich soil polysaccharides either as the aggregation agent or as sources of microorganism substrates. Gaume *et al.* (2004) reported that high BD adaptation to poor soil such as acid soil was contribution of AM association with BD roots.

CONCLUSION

Intercropping *Brachiaria decumbens* with cassava in acid soil effectively detoxified Al^{3+} as indicated by reduced exchangeable Al of the soil as much as 33%. Incorporation of *B. decumbens* organic matters into the soil and application of arbuscular mycorrhiza and K-enriched rice straw compost improved mesoagregate and microaggregate stability and increased total polysaccharides in the soil aggregates. The study indicates that planting *B. decumbens* as an intercropping plant with cassava, applying AM and K-enriched straw compost are able to improve acid soil fertility.

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