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Effects of Four Soil Conservation Methods on Soil Aggregate Stability

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ABSTRACT

In order to reduce soil erosion on sloping lands, empty fruit bunches (EFB), Ecomat, oil palm frond heaps, or silt pit have been used by major oil palm plantations. Studies have shown that at 0-15 cm soil depth, organic matter content in EFB is highest among the four treatments. Besides, EFB had the highest humic acid content compared to the others, about two times higher than control. Our analysis showed that aggregate stability of EFB was the highest among four treatments at 54.88%, followed by Ecomat (47.7%), silt pit (44.76%) and finally, control (42.12%). We observed that organic matter content inversely correlated with Fe ($p < 0.05$) and Al ($p < 0.05$) oxides. Finally, yield of humic acids correlated with soil pH ($p < 0.05$), aggregate stability ($p < 0.01$) and aggregate size distribution ($p < 0.01$). Among the four treatments, application of EFB as a mulching material commonly practised in oil palm estates was found to be the best practice on sloping lands due to its high organic matter and humic substances content that retain soil particles by improving soil aggregate stability and aggregation.

Keywords: Oil palm fronds, empty fruit bunches, Ecomat, silt pit, humic and fulvic acid

INTRODUCTION

The oil palm is a major agricultural crop that requires extensive land for cultivation. The crop occupies over four million hectares of Malaysia's land area. Moreover, the oil palm cultivation is expanding rapidly every year due to a high demand for palm oil in the market. This has caused new oil palm plantations to move into hilly and steep land areas due to limited fertile, lowland areas. Little or no canopy cover can cause large losses to soil, nutrients and organic matter on sloping lands (Ghulam *et al.* 1997). Furthermore, without proper conservation methods to retain topsoil which is susceptible to soil erosion, reduction on soil productivity will occur (Morgan 2005). In order to reduce soil erosion on sloping lands, empty fruit bunches (EFB), Ecomat, oil palm frond heaps, or silt pit have been used by major oil palm plantations. Ecomat is a biodegradable mat. It is made of natural

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oil palm fibres with no chemicals added (Khalid and Tarmizi 2008). As Ecomat is light and easy to handle, it is usually used as mulching material to prevent erosion on hill slopes. Ecomat also enhances roots growth resulting in increased vegetative growth of oil palms (Khalid and Tarmizi 2008). The benefits of using EFB as a mulching material in oil palm plantation include improved water holding capacity, soil aeration, soil pH, nutrient status, cation exchange capacity, and as well as reduced leaching and soil loss (Khalid and Tarmizi 2008). Oil palm fronds, usually stacked across the slope as mulching material to reduce soil erosion, have a significant effect on soil pH and nutrients. According to Khalid and Tarmizi (1999), pruned fronds release Ca and Mg to the soil where Ca and Mg are essential nutrients for oil palm growth development. Besides the use of EFB, palm fronds and Ecomat, silt pits, which are long and wide trenches, are dug on to terraces to prevent soil erosion as well. Silt pits retain water, leading to significantly higher soil moisture content in comparison to no conservation practices.

The most important soil property in influencing aggregate stability is soil organic matter which acts as a binding agent that binds mineral particles into stable aggregates (Tisdall and Oades 1982). Soil organic matter is known to correlate with aggregate stability due to the binding action and other microbial by-products (Haynes *et al.* 1997; Hermawan and Bomke 1997; Shepherd *et al*. 2001). There is also a relationship between soil organic carbon and aggregation. Since the interactions of organic matter with metallic cations and clay particles play a crucial part in soil aggregate stability, the loss of organic matter is closely related to decreasing soil aggregate stability (Oades 1988). Humic acids can improve the macrostructural stability of soils by forming a hydrophobic coating around the aggregates (Mbagwu and Piccolo 1989). Besides that, humic substances form an organo-mineral complex with the soil inorganic component and act as a base of the soil aggregates (Cornejo and Hermosin 1996). Piccolo *et al.* (1997a) suggest that humic substances can be used as soil conditioners as the humic substances can improve aggregate stability significantly as well as it can reduce the disaggregating effects of cyclic wetting and drying. Finally, Al and Fe oxides are believed to be the most efficient cations in linking organic matter and clay materials and thus reducing soil erosion effectively (Theng and Scharpenseel 1975; Theng 1976).

Humic substances are important in soils due to their microbial recalcitrant property which leads to the existence of a stable organic carbon reservoir (Piccolo 1996). Humic substances are differentiated by solubility in acidic and alkaline solutions. Humic acids are soluble in alkaline solutions, but precipitate in acidic solutions. Fulvic acids are soluble in both acidic and alkaline solutions. Fulvic acids have lower molecular weights and higher oxidation states than humic acids (Stevenson 1982). Humic acids are heterogeneous components, consisting of hydrophilic acidic functional group (made up of carboxylic and phenolic groups) and the hydrophilic groups (made up of aliphatic and aromatic carbon groups) (Stevenson 1994). Hence, hydrophilic groups in humic acids can increase water retention capacity in soils (Stevenson 1982).

Little is known about the amount of soil organic constituents in these four types of soil conservation methods in order to determine which method is best to practise in oil palm estates. Hence, the objective of this study was to determine the relative differences in organic constituents and aggregate stability and factors affecting these two soil parameters between the four soil conservation methods.

MATERIALS AND METHODS

Field Experiment

The experiment was conducted at Balau Estate, managed by Boustead Plantation at Semenyih, Selangor (02º55’57”N 101º52’56”E), with a slope of 6º. This area has 10-year-old oil palm trees planted with 8 × 8 m spacing. The soil type is Typic Paleudult (Renggam Series) which consists of 37% clay and 56% sand (sandy clay texture, USDA Taxonomy classification). The study site has an average pH of 4.79, cation exchange capacity of 7.81 $cmol_c\ kg^{-1}$, organic carbon of 2.2% and bulk density of 1.43 $Mg\ m^{-3}$ (Moradi *et al.* 2012).

The experimental design was a split-split plot design with 3 replications, treatment (main plot), soil depth (sub plot) and time (sub-sub plot). Thus, total experimental units consisted of 24 plots (4 treatments × 3 replications × 2 soil depths). Each plot had four palm trees. Four treatments were randomly arranged in each block. The treatments were control (pruned oil palm fronds), EFB, Ecomat and silt pit. Application rate of each treatment is shown in Table 1. Duration of the experiment was from January 2009 to December 2009. Mulching materials took about 9 months to decompose and thus data was collected every 3 months starting from June, September and finally December 2009. The chemical characteristics of EFB, Ecomat and palm frond are shown in Table 2.

TABLE 1
The four different treatment applications used in this study

Treatment	Application
Control	Oil palm frond heaps after pruning (* approx. 4.28 $kg\ m^{-2}\ yr^{-1}$ dry matter)
EFB	1000 $kg\ plot^{-1}\ year^{-1}$ arrange d in a single layer (* approx. 11.93 $kg\ m^{-2}\ yr^{-1}$ dry matter)
Ecomat	4 Ecomat carpets, each 1 × 2 m and 0.02 m thick arranged in a single layer (* approx. 3.23 $kg\ m^{-2}\ yr^{-1}$ dry matter)
Silt pit	1 m wide, 4 m long, 0.5 m deep

*Data obtained from Moraidi *et al*. (2012)

Measurement of Organic Matter

The method of Walkley and Black (1934) was used to determine soil organic carbon. The percentage of organic matter was obtained by multiplying the percentage of organic carbon by a factor of 1.724 (Nelson and Sommers 1982).

TABLE 2
Physico-chemical properties of EFB, Ecomat and palm frond

	C/N*	P, %*	K, %*	Ca, %*	Mg, %*	Water content, w/w, %*
EFB	56.15	0.05	1.89	0.20	0.12	64.17
Ecomat	82.09	0.03	1.13	0.17	0.05	12.58
Palm frond	41.38	0.05	1.51	0.64	0.07	65.57

* Data obtained from Moraidi et al . (2012)

Measurement of Al and Fe oxides

Al and Fe oxides were extracted using dithionite-citrate (DC) method (Soil Conservation Service 1972). A 0.5 g of air-dried soil was weighed into a 50 mL centrifuge tube. Before the sample was shaken on a mechanical shaker overnight, 25 mL of 0.68 M sodium citrate and 0.4 g sodium dithionite were added into the centrifuge tube. Subsequently, the sample was centrifuged at 10,000 rpm for 20 minutes and filtered to remove suspended material in the extract. Concentrations of Al and Fe were measured using Perkin Elmer 5100 atomic absorption spectrophotometry (AAS). Conversion factor was applied to obtain the percentage of Al and Fe oxides as below:

$$\text{Al oxide (\%)} = 1.89 \times \text{Al (\%)}$$
$$\text{Fe oxide (\%)} = 1.43 \times \text{Fe (\%)}$$

Measurement of Humic Substances

Extraction, fractionation and purification of humic substances were determined by the method of Norhayati and Verloo (1984). For extraction of humic substances, 20 g of air-dried soil were weighed into a 250 mL centrifuge bottle. The sample was shaken with 200 mL of 0.2 N sodium hydroxide for 16 hours. Nylon wool was used to remove suspended material and centrifuged at 2600 rpm for 25 minutes. The supernatant was decanted and shaken overnight with 5 g of anhydrous sodium sulphate before centrifugation. Secondly, for fractionation of humic substances, the supernatant was filtered and acidified to pH 1 with concentrated sulphuric acid. After overnight equilibration for 12 hours, the humic acids precipitated out while fulvic acid remained in acid solution. To separate humic acids from fulvic acids, the mixture was centrifuged at 7000 rpm for 15 minutes and the acid solution was decanted off. Finally, fulvic acids were purified in cellulose tubing by dialysis for 1 week with daily change of distilled water whereas humic acids were further purified with hydrochloric and hydrofluoric acid mixture by shaking for 48 hours. The humic and fulvic acids were then oven dried at 40°C for 1-2 weeks. The content of humic and fulvic acids were expressed as mg kg^{-1}.

Measurement of Soil pH in Water

The soil pH was measured in the ratio of soil to water 1: 2.5.

Measurement of Aggregate Size Distribution and Aggregate Stability

Nested sieves method was used to determine aggregate size distribution (Kemper and Rosenau 1986). Aggregate size distribution was expressed as the mean weight diameter in mm. Aggregate stability (AS) was determined by the wet-sieving method (Kemper and Rosenau 1986). Aggregate stability was expressed as the percentage of aggregates larger than 0.25 mm.

Statistical Analysis

All soil properties were analysed using ANOVA (analysis of variances) to determine significant differences as well as the correlation coefficients. Significant differences were analysed using LSD test at 5% significant level. The analyses were carried out using Statistical Analysis System (SAS) version 9.1 (SAS Inst. 2004).

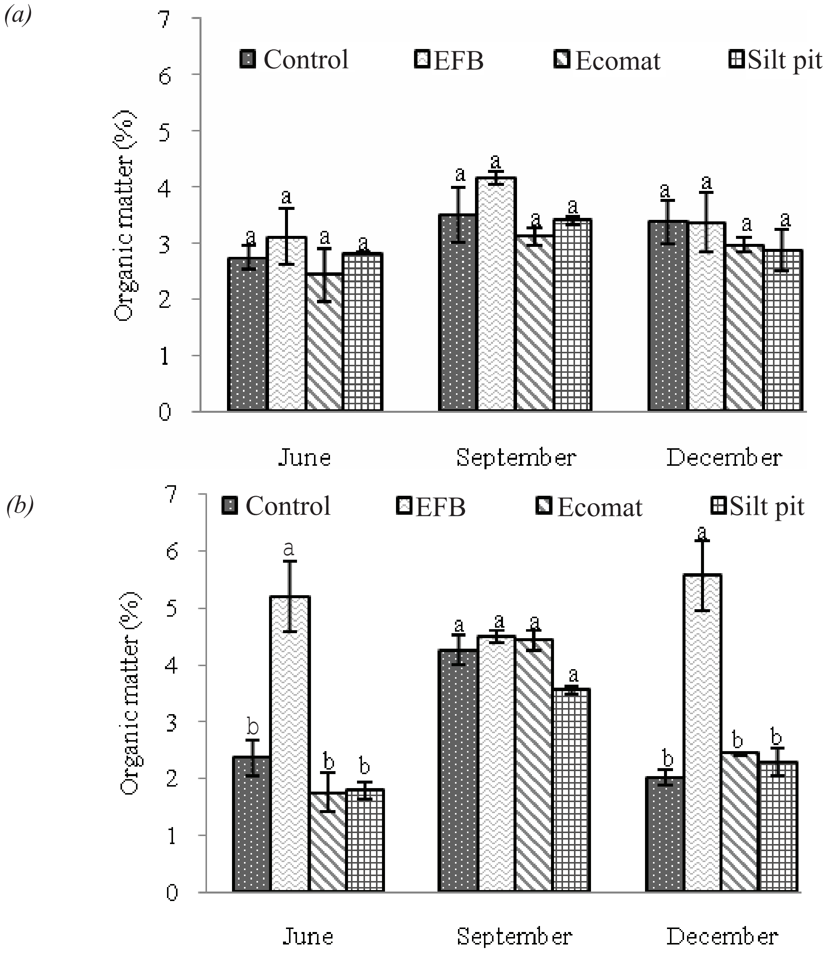
RESULTS AND DISCUSSION

Organic Constituents

ANOVA showed a significant interaction between treatment × time × soil depth ($p < 0.05$) for soil organic matter. Between the two soil depths, only 0-15 cm soil depth in June and December samplings had significant differences ($p < 0.01$) (*Fig. 1a*) whereas there was no significant difference at 15-30 cm soil depth (*Fig. 1b*). At 0-15 cm soil depth, organic matter content in EFB was the highest among the others. However, no significant difference was observed at 15-30 cm soil depth due to organic matter being frequently decomposed and concentrated in the top layer of soil. A significant increase in organic C, total N and available P were observed in EFB treatment at 0-15 cm soil depth (Moradi *et al*. 2012). Studies have shown that high organic matter content in EFB improves chemical and physical properties of soils (Khalid and Tarmizi 2008). Recent studies indicate that EFB is better than Ecomat in improving soil chemical and physical properties (Teh *et al.* 2011). In addition, EFB had the highest amount of dry matter addition compared to Ecomat and palm fronds; thus the amount of nutrients released were in proportion to the amount of dry matter added (Table 1).

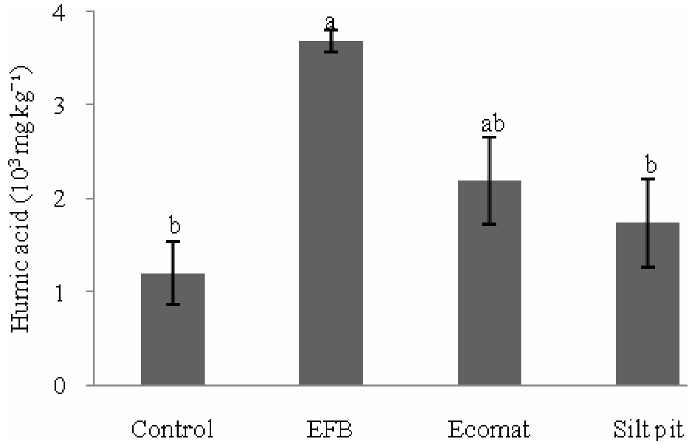
ANOVA showed significant difference between treatments for humic acids content ($p < 0.05$) (*Fig. 2*). No significant interaction effects were detected in content of humic acids. EFB had the highest humic acid content compared to the others, about two times higher than control. Furthermore, only the interaction effect of treatment × time on fulvic acids content was significant ($p < 0.05$) (*Fig. 3*). In the June sampling, fulvic acids content in EFB and silt pit were the highest, 2980 mg kg^{-1} and 2960 mg kg^{-1}, respectively. However, in the September sampling, there was no significant difference between the treatments. Finally, in the December sampling, the silt pit had the highest fulvic acids content, which was 2420 mg kg^{-1}. The study is also in line with the findings of Soong (1980) and Tajuddin (1992) who also reported that fulvic acids are greater than humic acids in most Malaysian mineral soils. In this study, control, Ecomat and the silt pit had higher fulvic acids than humic acids. However, in the EFB treatment, humic acids content was higher than the fulvic acids content. This suggests that EFB as a mulching material has a slower rate of humification. As a consequence, losses of organic constituents are slower compared to the others treatments. Furthermore, organic matter released was the highest in the EFB treatment, thus the humic acid content would also be high in the EFB treatment.

ANOVA showed significant interaction only for the effect of treatment × time on Fe oxides ($p < 0.05$) (*Fig. 4*). In the June sampling, Fe oxides in control was the highest, at 3.03%. Lowest Fe oxides were observed in EFB and Ecomat treatments at 2.11% and 1.65%, respectively. In September and December samplings, there were no significant differences between treatments. ANOVA showed significant



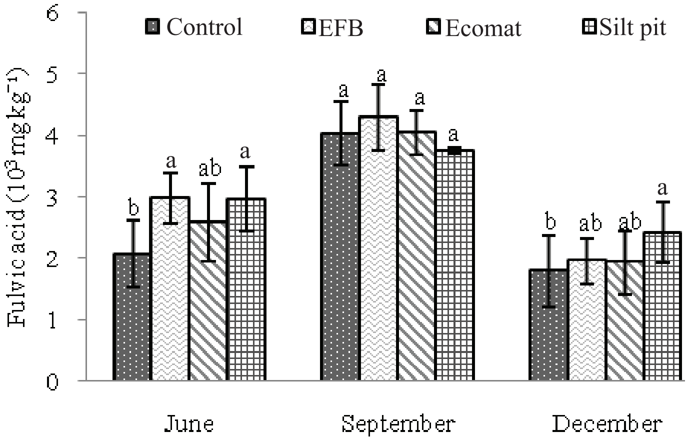
For a given month, means with the same letter are not significantly different at 5% level according to LSD test. (LSD = 1.15%)

Fig. 1: Organic matter content at (a) 0-15 cm and (b) 15-30 cm soil depth.



Means with the same letter are not significantly different at 5% level according to LSD test. (LSD = 1520 mg kg^{-1})

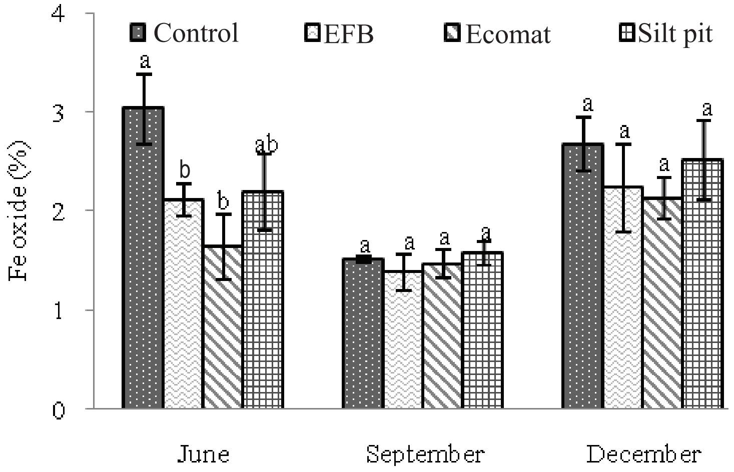
Fig. 2: Humic acids averaged across soil depths and time.



For a given month, means with the same letter are not significantly different at 5% level according to LSD test. (LSD = 300 mg kg^{-1})

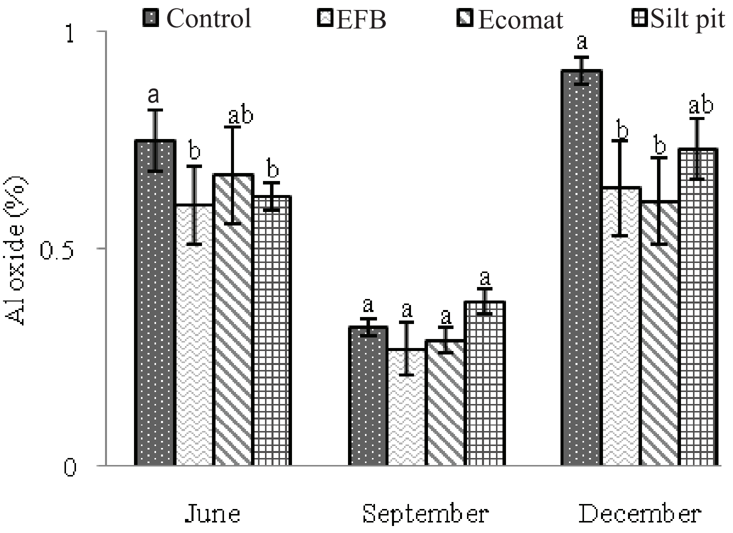
Fig. 3: Fulvic acids averaged across soil depths.

interaction effect of treatment × time on Al oxides ($p < 0.05$) (*Fig. 5*). In June sampling, Al oxides in control was the highest at 0.75%. In September sampling, there was no significant difference between treatments. Finally, in December sampling, control still ranked the highest in Al oxides, which was 0.91%. There was significant difference between treatments in soil pH as shown in ANOVA ($p < 0.01$) (*Fig. 6*). EFB was found to have the highest soil pH compared to others, which was pH 6.12. The results are consistent with the findings of Zaharah and Lim (2000) and Lim and Zaharah (2002) where EFB increased the soil pH as well as organic matter content in soil. It is also known that during EFB decomposition period, release of K is much quicker than N and P (Moraidi *et al.* 2012) (Table 2). This basic cation caused the soil pH to increase gradually.



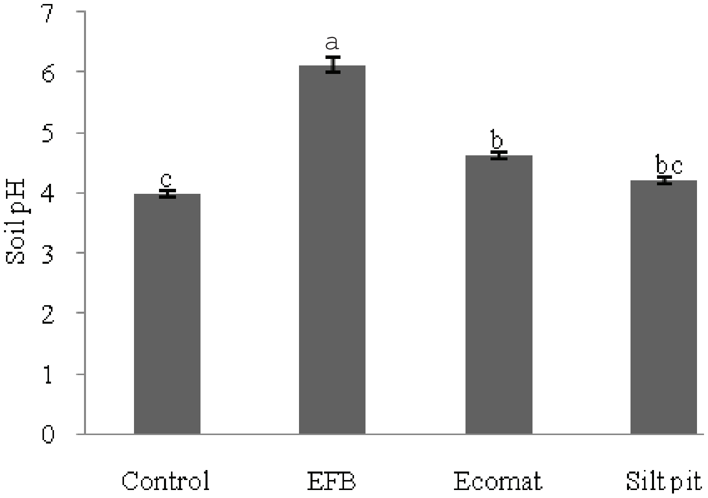
For a given month, means with the same letter are not significantly different at 5% level according to LSD test. (LSD = 0.84%)

Fig. 4: Fe oxides averaged across soil depths.



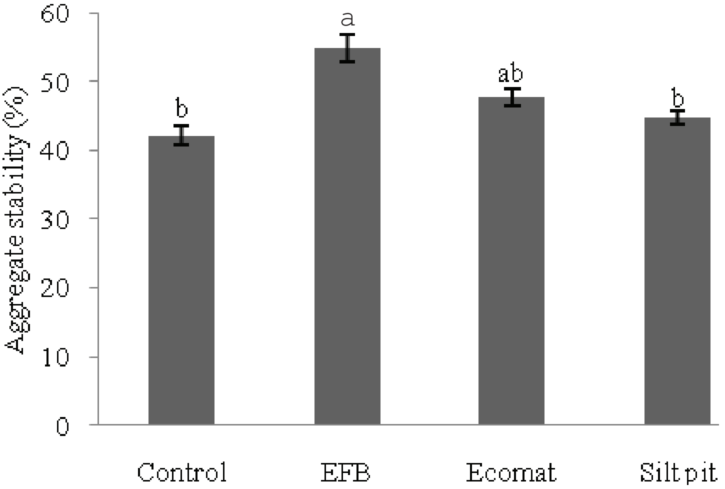
For a given month, means with the same letter are not significantly different at 5% level according to LSD test. (LSD = 0.23%)

Fig. 5: Al oxides averaged across soil depths.



Means with the same letter are not significantly different at 5% level according to LSD test. (LSD = 0.51)

Fig. 6: Soil pH averaged across soil depth and time.

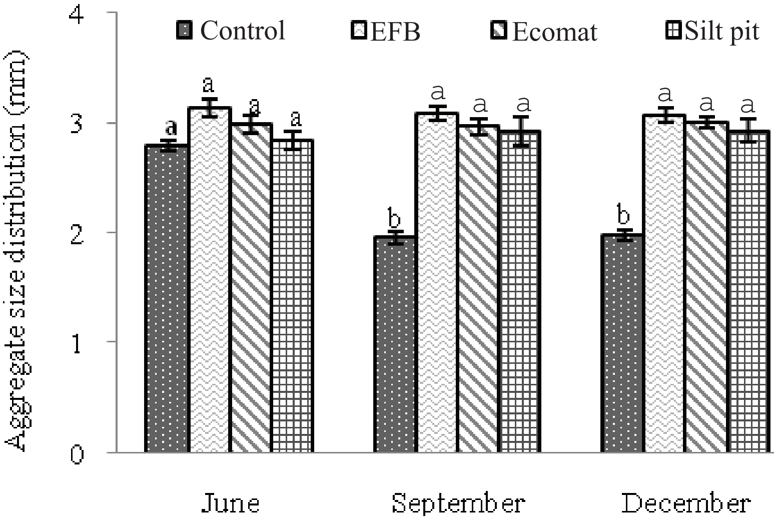


Means with the same letter are not significantly different at 5% level according to LSD test. (LSD = 8.71%)

Fig. 7: Aggregate stability averaged across soil depth and time.

Soil Aggregate Stability and Aggregate Size Distribution

ANOVA showed treatments to be significantly different in aggregate stability ($p < 0.05$) (*Fig. 7*). Aggregate stability of EFB was the highest among four treatments, at 54.88%, followed by Ecomat (47.7%), silt pit (44.76%) and finally, control (42.12%). In aggregate size distribution, ANOVA showed significant interaction effect of treatment × time ($p < 0.05$) (*Fig. 8*). There were significant differences in September and December samplings. Both samplings indicated that aggregate size distribution of EFB, Ecomat and silt pit were equally higher than control. Not much change was observed on aggregate size distribution during the six-month study period in EFB, Ecomat and silt pit. This might be due to the need for a longer



For a given month, means with the same letter are not significantly different at 5% level according to LSD test. (LSD = 0.23 mm)

Fig. 8: Aggregate size distribution averaged across soil depths.

duration for organic constituents of mulching materials to affect soil aggregate stability and aggregation. Moradi *et al.* (2012) observed no change in the first year of EFB treatment in soil N. However in the second year of experiment, a significant increase in soil N was observed in EFB treatment. It can be concluded that mulching materials such as EFB require at least 12 months of decomposition in order to improve soil chemical and physical properties.

Iron (*Fig. 4*) and Al oxides (*Fig. 5*) were low in September in comparison with June and December samplings. In contrast, organic matter (*Fig. 1*) and fulvic acids content (*Fig. 3*) were high in September sampling. Mulching materials, in particular EFB and Ecomat were estimated to fully decompose after 9 months of application resulting in high amounts of organic matter content in the September sampling (Teh *et al.* 2010).

Correlation Between Soil Properties

We observed that organic matter correlated inversely with Fe ($p < 0.05$) and Al ($p < 0.05$) oxides (Table 3). This suggests that organic matter is highly correlated with metal-binding agents. Soil pH in tropical soils, in particular in Malaysian soils, is usually low; for example, Fe exists as soluble form at soil pH lower than 3.5 and Al at pH lower than 5.2. However, due to the application of mulching material such as EFB, soil pH and humic substances may have increased, leading to Al and Fe chelation to humic substances. Therefore, the effectiveness of Al and Fe oxides acting as cementing agents to prevent soil erosion and retain soil particles in this case is not as promising as the effectiveness of organic matter or humic substances. Moreover, both EFB and Ecomat are not good sources for Al and Fe.

TABLE 3
Correlation coefficient (r) between soil properties (n = 12) at 0-15 cm soil depth

	HA	FA	OM	Al	Fe	AS	AGG
FA	0.19						
OM	0.14	0.48					
Al	-0.15	-0.56	-0.65**				
Fe	-0.25	-0.55	-0.6**	0.83*			
AS	0.82*	0.19	0.13	-0.04	-0.13		
AGG	0.74*	0.11	-0.03	-0.02	-0.26	0.75*	
pH	0.88**	0.75	0.68	0.07	-0.1	0.93**	0.85**

* indicates $p < 0.01$ and ** indicates $p < 0.05$.
HA: Humic acids (mg kg^{-1}); FA: Fulvic acids (mg kg^{-1}); OM: Organic matter content (%); Al: Al oxides (%); Fe: Fe oxides (%); AS: Aggregate stability (%) and AGG: Aggregate size distribution (mm).

Results show that humic acids correlated with soil pH ($p < 0.05$), aggregate stability ($p < 0.01$) and aggregate size distribution ($p < 0.01$) (Table 3). Humic substances persist in soil as they can form stable and strong coordinate bonds between organic ligands on the humic substances and metals in soil (Syuntaro *et al.* 2006). Piccolo *et al*. (1997b) stated that a reduction in soil loss of 36% and improvement in water retention capacity were observed by adding humic substances from oxidised coal into two soils with severe structural problems. According to Soong (1980), humic acids were found to be important in soil aggregation and the size of the aggregates in the soils when small amounts of humic acids were added to clay-sand mixtures. Humic acids are believed to be responsible for soil aggregation properties rather than organic matter content due to their microbial recalcitrant property (Piccolo 1996). Aggregate stability and aggregation is closely dependant on humic acids for retaining soil particles between the four different soil conservation methods.

CONCLUSION

Humic acids correlated with soil aggregation, aggregate stability and pH instead of Al and Fe oxides, fulvic acids and organic matter content. Among the four treatments, application of EFB as a mulching material commonly practised in oil palm estates was the best practice for sloping lands due to its high amount of organic matter and humic acids which assist in retaining soil particles by improving soil aggregate stability and aggregation.

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