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Fresh Organic Matter Application to Improve Aggregate Stability of Ultisols under Wet Tropical Region

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ABSTRACT

Ultisol as a marginal soil has become 'a hope' by farmers in Indonesia due to land use change, lately. However, the soil is susceptible to degradation since it has low soil aggregate stability (SAS) as affected by low soil organic matter (SOM) content. A pot trial about application of fresh organic matter (FOM) was aimed to improve SAS of Ultisols under wet tropical rainforest. Three types of FOM (*Tithonia diversifolia*, *Chromolaena odorata*, and *Gliricidia sepium*) at different size (8, 6, 4, 2, and 0.5 cm) were applied for 1% (20 g 2 kg^{-1} soil), then mixed and incubated for three months. The experimental units were allocated in a completely randomized design at a glass-house. The results showed that FOM generally increased SOM content, percent aggregation, as well as SAS of the Ultisol. Among the organic matter (OM) sources, tithonia gave the highest SOM content after a 3-month incubation. Within the types of OM source, the smallest OM size applied showed the highest SOM content. *Tithonia* at 0.5 cm in size gave the highest SOM (3.47%) of the Ultisol and SAS increased by 68% compared to the initial soil. Overall, there was a positive correlation (R^2 = 0.43) between SOM content and aggregate stability index, but no correlation (R^2=0.04) between SOM content and percent aggregation of the Ultisols.

Keywords: Fresh organic matter, soil aggregate stability, Ultisols, wet tropical area

INTRODUCTION

Aggregate stability of soils in wet tropical regions seem to be a key factor to determine soil degradation, especially in the sloping areas such as in West Sumatra. High annual rainfall, up to 6500 mm (Rasyidin 1994), combined with wavy and hilly topography in the region has caused the soils become very susceptable to degradation mainly through erosion process. This is primarily found under annual cropping systems, in which farmers during preparing seed bed, tend to cultivate the soils intensively that causing the SOM was oxidized. SOM is considered as the best soil binding agent (Albiach *et al*. 2001) to stabilize soil aggregates (Tisdall and Oades 1982; Zhang *et al*. 2012). Therefore, soils under minimum tillage had the highest water stable aggregates and potential to sequester C and N compared to soils under ridge tillage and conventional tillage in agricultural soils (Kasper *et al*. 2009).

Soil OM depletion by cultivation can be explained through either better environment provided for degrading microbes or more OM exposed to the microbes after cultivation. It was reported that about 19% of the organic carbon (OC) decreased in Ferrosol soil (= Oxisols) as forest was changed into grassland ecosystems for almost 100 years (Yulnafatmawita *et al*. 2003). In Alfisols, SOM depleted by 15% and 35%, consecutively, as land use changed from bush land into conservation and conventional farming system (Yulnafatmawita 2004). Decreasing SOM content by 97% on the top 10 cm compared to the native field was also reported by (Sa *et al*. 2001) in Oxisols under conventional tillage. The impact was much worse in marginal soil such as Ultisols. As reported by Yulnafatmawita (2006), that land use change from forest to annual cropping ecosystem had decreased SOM content of Ultisols Limau Manis by 42% (from 9.86% to 5.75%) and by 55% (from 9.86% to 4.42%) at 0-10 cm depth and by 45% (from 3.79% to 2.09%) and 18% (from 3.79 % to 3.10%) at depth 10-20 cm depth as forested ecosystem was changed into perennnial and annual crops, respectively, for about 15 years after land clearance.

Ultisol is one of acid soil being widely distributed in Indonesia. In West Sumatra it reaches 353,900 ha (Hakim 2006). This type of soil is found under old, wavy to hilly landscape, from 25 m – 350 m above sea level. The soil texture belongs to clay

class which is accumulated on B2t horizon (Tan 2008).

Ultisol in West Sumatra has generally low SOM content, even though OM production is quite high in this wet tropical area. As reported by Yulnafatmawita *et al.* (2008; 2011) the OM content of Ultisol Limau Manis ranged from 1% to 3 %. Therefore, OM should be added to this soil regularly to improve soil aggregate stability and to keep it out of erosion process and to anticipate soil degradation. Wei *et al.* (2006) found that land management practices, such as residue management could enhance soil aggregation. Furthermore Wuddivira and Camps-Roach (2007) reported that soil becomes more stable as it has more SOM content, especially for soil containing small amount of clay. Application of several sources of OM at field site could improve physical properties of Ultisols after 3 months and especially soil aggregate stability up to 43.5% (from 39.9 to 57.3) and SOM content up to 98% (from 3.02 to 5.98%) (Yulnafatmawita *et al*. 2008). Zhang *et al*. (2012) explained that soil organic carbon did not directly influence aggregate stability, but through the effects of carbon and nitrogen content of microbial biomass, as found under black soil in Northeast China.

There are many types of OM that can be utilized to improve soil physical properties, such as manure, waste product of agriculture for example straw of rice and imperata (Yulnafatmawita *et al*. 2008), compost (Annabi *et al.* 2007), but application of fresh OM that can be produced *in situ* will give double profits. It is not only able to degrade fast and then contributes to SOM content, but it is also able to reduce production cost. Low or no production cost can be due to the fact that farmers do not need to pay for collecting and transporting the OM from the origin to the field site. This second earning is seemed to be very important for farmers in developing countries, since they do not have enough capital in cultivating their land.

Among the FOMs growing well in this research area were *Tithonia diversifolia*, *Chromolaena odorata*, and *Gliricidia sepium.* Tithonia (*Tithonia diversifolia*) or known as Mexican sunflower belongs to family *Asteraceae*. Hakim and Agustian (2003) suggested to use Tithonia as *in situ* OM production since it has dense canopy, deep root, and can be trimmed periodically for farming land. Then, chromolaena (*C. odorata*) which is widely distributed in Indonesia also belongs to family *Asteraceae*. It can be found either under agricultural or non-agricultural land. Therefore, it is suitable to use as OM source for soils. Gliricidia *(G. sepium)* is another source OM that can be used as soil OM source. It is in form of tree crop. Therefore, besides as a soil ameliorant, it can also function as a fence for the farming land.

Stabile soil aggregates has been determined to be linearly correlated to SOM content (Tisdall and Oades 1982) and SOM has been approved to be higher by application of OM to soil (Yulnafatmawita *et al.* 2008). Therefore, regular application of OM to Ultisol under wet tropical rainforest is seemed to be a must. Fresh OM application has been discussed to give double profits. However, the best source and the size of FOM to be applied that could increase SOM content as well as SAS of Ultisol under wet tropical rainforest regions were still to be studied further.

MATERIALS AND METHODS

Study Site

This research was in form of pot trial which was conducted from 2008 untill 2009 in a Glasshouse, Agriculture Faculty Andalas University Padang, Indonesia. Ultisols having sub group typic kandiudult (Fitrisia 2004) was sampled from Limau Manis, lower footslope of Mount Gadut, Pauh District, Padang city.

Research Design

This research consisted of two factors with four replications. The first factor was types of fresh organic matter (FOM) which consisted of *T. diversifolia*, *C. odorata*, and *G. sepium*. The second factor was the cutting size which were 8, 6, 4, 2, and 0.5 cm. There were totally sixty experimental units which were allocated under a completely randomized design (CRD).

Application of FOM and Parameters

The OM was applied in fresh form for 1% (20 g 2 kg^{-1} soil) based on dry matter weight. The OM was evenly mixed with soil, then the mixture were watered, and kept moist (around field capacity) for a three-month incubation. Soil physical properties were analyzed before and after treatments. Some parameters initially determined were soil texture using sieve and pipet method, soil aggregation percentage and aggregate stability using dry and wet sieving, BD and total pore using gravimetric method, permeability using permeameter based on Darcy's law, and pore size distribution using pressure plate apparatus (Soil Research Institute 2006), organic carbon using Walkley and Black method (Soil Research Insitute 2009). After incubation, there were only three parameters determined, those were

SOM content, percent aggregation, and aggregate stability index of the soil as the same methods as initial ones.

Data Analysis

The data from the three parameters were statistically analyzed using F-test. If the value of F-calculated > F-table, the test was continued using least significant different (LSD) at 5% level of significance.

RESULTS AND DISCUSSION

Initial Soil Physical Properties

Some physical properties of Ultisol from wet tropical area especially in Limau , West Sumatera, are presented in Tabel 1. It shows that the soil had clay in texture with approximately 68% of particles < 2 um. It indicates that the soil had been advancedly weathered. It is found to be true since the sampling site is located under wet tropical rainforest, receiving up to 6500 mm rainfall annually (Rasyidin 1994) and mean annual temperature > 18°C. As stated by Tan (2008) that Ultisols in West Sumatra was dominated by clay particles (particles < 2 µm) which was approximately 78.1% in cultivated (Ap) horizon.

High clay content of the Ultisol has caused the soil permeability to be low, since fine particles will stay close together producing small pores among them. The clay particles will also retain water more stronger than silt or sand size particles, due to its wider specific surface area. Therefore, the water cannot move faster, in other words, the soil permeability was considered low (0.37 cm h^{-1}).

Tabel 1. Initial soil physical properties of Ultisol Limau Manis.

Parameter	Value	Criteria*
Soil texture		
Sand (%)	20.21	
Silt (%)	12.18	
Clay (%)	67.61	
Hydrolic conductivity (cm h^{-1})	0.37	Slow
Bulk density (g cm^{-3})	1.03	Med
Total pores (%)	60.76	Med
Aerated pore (%)	5.72	Low
Slowly drained pore (%)	12.58	Med
Available water pore (%)	11.32	Med
Soil organic matter (%)	1.23	Very Low
Aggregate stability index	46.75	Less Stable
Soil aggregation (%)	40.08	

*Soil Research Institute (2006).

Fine particles dominated by this Ultisol also affected the soil BD. The value of the soil BD was considered as medium for plant growth (Soil Research Institute 2006). This was found to be true since the amount of clay particles in a mass unit was more, so the percentage of space among the particles would be higher than that of sand particles. The same tendency for the BD was also found by Yasin *et al.* (2007) in Ultisol Dharmasraya, West Sumatra. The BD of the soil belonged to medium criteria (0.87 g cm^{-3} in forest and 1.15 g cm^{-3} after forest conversion to dry land farming system). The same criteria was also reported by Yulnafatmawita *et al.* (2011), BD of Ultisol from Tanjung Pati Lima Puluh Kota Regency in West Sumatra was 0.81 g cm^{-3} and 0.88 g cm^{-3} for 0-10 cm and 10-20 cm depth, respectively. Since the BD is inversely related to percentage of soil pore, the total pore of this Ultisol was also considered medium (± 60.76%).

Pore size distribution of this Ultisol was found to be unbalanced. Large sized pores or macropores filled by air was considered low (5.72%). This might be due to the soil has high clay with low SOM content. As found in Table 1 that percentage of slowly drained pores as well as available water pores was approximately doubled the aerated pores. Therefore, this soil had initially aeration problem, because the soil retained more water. As explained by Yulnafatmawita *et al.* (2011) that clayey soils having low SOM was found to have more micropores and less macropores, therefore, it hold more water and less air.

Soil OM content in this research was grouped into very low (Soil Research Insitute 2006). This was probably due the climate under wet tropical rainforest having high annual rainfall and temperature which had caused intensive OM oxidation. Therefore, the OM content of the soil could not be accumulated, even though the OM production was quite high all year long. Low SOM content was also found in Ultisol Dharmasraya (Yasin *et al*. 2010), Lubuk Minturun and Lima Puluh Kota (Yulnafatmawita *et al*. 2011) other regions in West Sumatra.

High clay content combined with low SOM had caused the binding agent of the soil aggregates was dominated by clay. Clay is known to produce less stable soil aggregates, especially when the soil is promptly wetting. As it is wetted, clay will adsorb water, and the aggregate bonding becomes loose, then the aggregates becomes degraded, and finally dispersed if the water is continuously added. Therefore, this Ultisol had less stable aggregates.

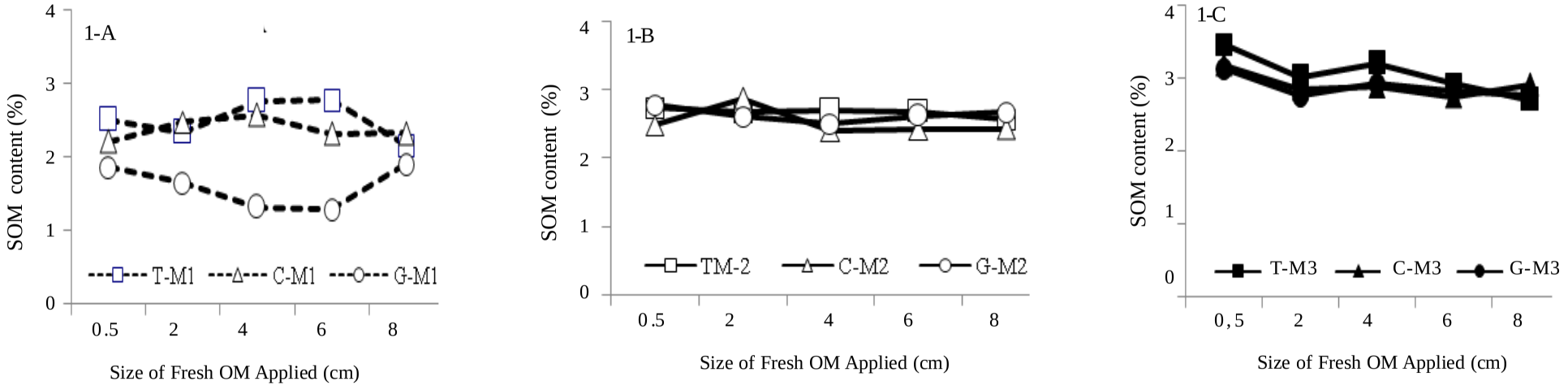

Figure 1. Soil organic matter (SOM) content of Ultisol after being incubated by three types of FOM at different size for 1 (1-A), 2 (1-B), and 3 (1-C) months. I-A, standar error (SE) = 0.32, I-B, SE = 0.27, and I-C, SE = 0.25. T = *T. diversifolia*, C = *C. odorata*, and G = *G. sepium*. M1 = 1 month, M2 = 2 month, and M3 = 3 month

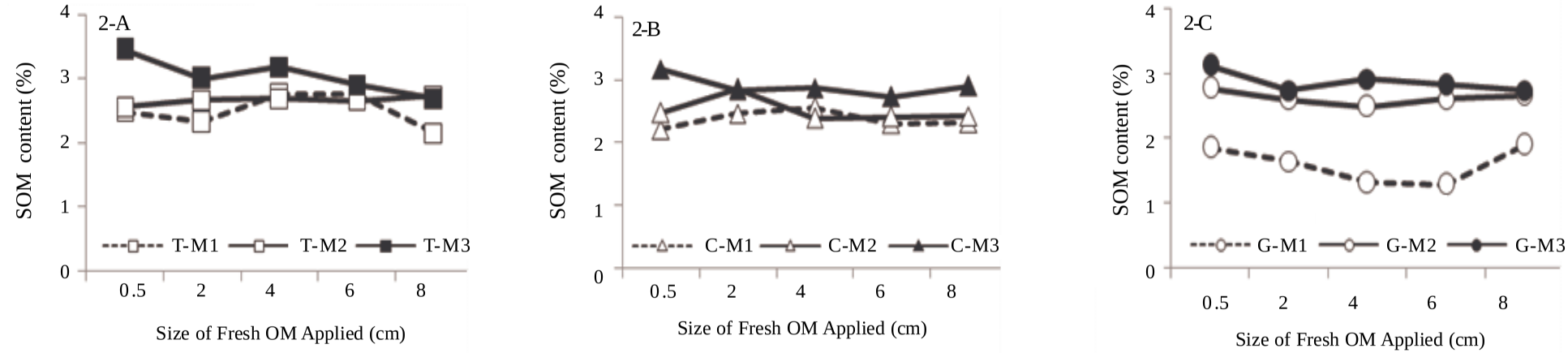

Figure 2. Soil organic matter (SOM) content of Ultisol after being incubated by *T. diversifolia* (2-A), *C. odorata* (2-B, and *G. sepium* (2-C) at different size for 3 months. 2-A, standar error (SE) = 0.25, 2-B, SE = 0.29, and 2-C, SE = 0.31. T = *T. diversifolia*, C = *C. odorata*, and G = *G. sepium*. M1 = 1 month, M2 = 2 month, and M3 = 3 month.

Tabel 2. SOM content of Ultisol Limau Manis after 1st, 2nd, 3rd month of FOM application .

FOM source	Month of incubation		
	First	Second	Third
C. odorata	2.38 a	2.52 a	2.94 a
G sepium	1.60 b	2.64 a	2.88 a
T diversifolia	2.50 a	2.67 a	3.06 a
	P < 0.00	P > 0.10	P > 0.10
Fom size (cm)			
0.5	2.19 a	2.67 a	3.26 a
2.0	2.15 a	2.72 a	2.87 b
4.0	2.21 a	2.54 a	3.00 ab
6.0	2.12 a	2.57 a	2.83 b
8.0	2.13 a	2.56 a	2.84 b
	P > 0.10	P > 0.10	P < 0.05

Note: Data followed by the same letter are not significantly different based on LSD at 5% level.

SOM Content

In general, there was a tendency of increasing SOM content of Ultisol by time (up to 3 months) after three types of FOM at all cutting size were incubated (Figure 1 and 2). It was found to be true, that SOM increased after more FOM is was degraded. Additionally, microbial activity in degrading OM became more intensive by time, since they utilized the energy resulted from the decomposition for proliferation. The degraded parts of the materials contributed to SOM.

Among the FOM applied, Gliricidia contributed the lowest (P < 0.00) SOM content of Ultisol at the first month of incubation (Tabel 2). This could be understood that Gliricidia had heavier and stronger leaves, therefore, the decomposing microbials needed more energy and time to attack. This was proved by much fresh materials found in the soil, especially after one month application. Additionally, Gliricidia had less moisture content than the other two materials. Therefore, it took a longer time by microbes to decompose. Besides that, Gliricidia contained 10.9-18.4% lignin (Putra 2006) and bactericida oil in the tree bark (Reddy and Jose 2010) that could resist microbial activity in decomposing OM. However, after three months of incubation, the contribution to SOM was not significantly different from titonia and chromolaena. It means that Gliricidia needed more time to be attacked for the first time, after that it was easily degraded. Therefore, it is not suggested to apply Gliricidia to Ultisol if the time before planting is limited or < 2 months.

Among the types of OM source, Tithonia seemed to contribute higher OM content than the others to Ultisols (Figure 1). This was clearly seen after a three-month incubation, even though it was not significantly different from the others. Higher OM content of Ultisol treated by Tithonia was probably due to higher decomposition rate of Tithonia, therefore more OM contributed to the soil. This was found to be true since the Tithonia had softer tissue and higher moisture content (watery) and also contained high nutrients, such as 3.5% N, 0.38% P, and 4.1% K (Jama *et al*. 2000), therefore it could be degraded by microorganisms faster than the others. Degraded materials of the Tithonia contributed to SOM, and functioned to link particles in creating and stabilizing soil aggregates.

After two months, the amount of SOM was not significantly different from that after three months of incubation (Figure 2C). It seemed that the softer part of the Gliricidia materials had been degraded for the first two months during incubation. Hartemink and O'Sullivan (2001) found that *G. sepium* contained about 25.2 g N kg^{-1} DM, 149.8 g lignin kg^{-1} DM, and 26.2 g polyphenol kg^{-1} DM. Pandey and Rai (2007), on the other hand, reported that Gliricidia leaves, under humid climate of South Andaman, India, could release N maximum at 15 days after application, the rate was relatively the same between incorporated and surface application of the leaves. However, the degradation rate increased after the leaves were attacked.

Besides the source, the size of FOM applied also significantly affected SOM content. After incubation for three months, higher SOM content of Ultisol tended to increase by reducing the size of the fresh OM applied. This was due to the microbial effectiveness in decomposing the OM applied. As the size of the OM became smaller, the easier was the microbes to attack the OM. This was caused by the fact that the decomposing microbes did not have to spend their energy in cutting the large size OM into the smaller one. In other words, the

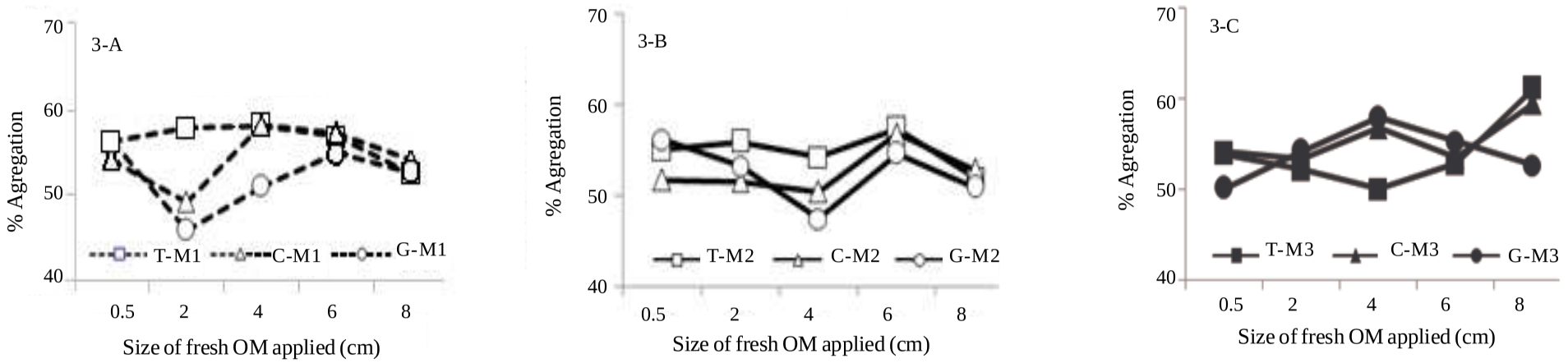

Figure 3. Percent aggregation of Ultisol after being incubated by three types of FOM at different size for 1 (3-A), 2 (3-B), and 3 (3-C) months. 3-A, standar error (SE) = 4.43, 3-B, SE = 4.32, and 3-C, SE = 4.87. T = *T. diversifolia*, C = *C. odorata*, and G = *G. sepium*. M1 = 1 month, M2 = 2 month, and M3 = 3 month.

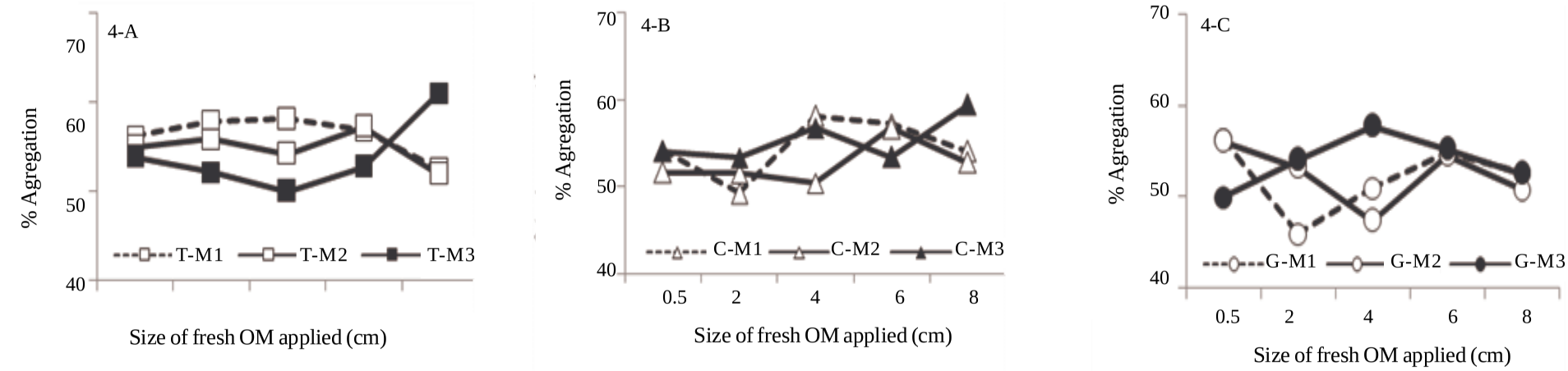

Figure 4. Percent aggregation of Ultisol after being incubated by *T. diversifolia* (4-A), *C. odorata* (4-B, and *G. sepium* (4-C) at different size for 3 months. 4-A, standar error (SE) = 2.27, 4-B, SE = 3.49, and 4-C, SE = 3.62. T = *T. diversifolia*, C = *C. odorata*, and G = *G. sepium*. M1 = 1 month, M2 = 2 month, and M3 = 3 month.

microbes could directly oxidize the OM and produced simple OM compounds that contributed to SOM. However, the tendency was not yet found after one or two months of incubation. It means that, size of FOM between 2-8 cm did not affect the contribution to SOM, while 0.5 cm size significantly affected after 3 months of incubation.

Compared to the original one, SOM content of Ultisol Limau Manis increased by 134-150% after three months of FOM application, without any significant difference among the types of the FOM source. Among the size, SOM content of Ultisol was significantly higher ($P < 0.05$) under 0.5 cm size of FOM applied than the others.

Aggregation Percentage

Aggregation percentage of Ultisols was significantly affected by types of FOM source ($P < 0.05$) at the first month after incubation as well as by the size of FOM applied ($P < 0.10$) after the first and the second month after incubation (Tabel 3). Gliricidia contributed to the lowest and Tithonia contributed to the highest soil aggregation percentage to Ultisol Limau Manis under laboratory condition. This was correlated to the SOM status (Tabel 2) of the soil at the first month after incubation. Then, FOM applied at size 6 cm in length showed the highest soil aggregate percentage at the first and the second month after incubation. However, there was no significant difference either among the types or among the sizes of the FOM applied after three months. This could be influenced by the effectiveness of microbial in creating aggregates > 2 mm under disturbed soil samples which might be limited. As reported by Zhang *et al.* (2012) microbial biomass and easily extractable glomalin-related soil proteins were found in macroaggregates.

Based on Figure 3 and 4, there was not a clear pattern of soil aggregation process after application and incubation of different types and sizes of FOM for three months at Ultisol Limau Manis under laboratorium condition. Furthermore, there was not a tendency of increasing aggregation process of Ultisol by time from one to three months after incubation of FOM. As shown in Tabel 3, the average aggregation percentage of the soil stayed the same for the first, the second, and the third month of FOM application. It seemed that the amount of SOM did not reach the marginal amount to create aggregates > 2 mm.

The pattern of soil aggregation percentage of Ultisol after application of FOM for three months did not follow the pattern of OM content of the soil. It means that content of SOM did not correlate ($R^2 = 0.04$) to the process of aggregation in Ultisol for 3 months incubation as described in Figure 7a. This could be due to less time to bind particles even though the OM content of the soil tended to increase by time. In other words the microbes decomposing FOM was still active in degrading the OM. It means that after three months of FOM application, there was still not enough time to bind larger aggregates (> 2 um in size). It could be concluded that it needed more than 3 months after FOM application to increase aggregation process or to produce aggregates > 2 um. If it was compared to the original soil sample, soil aggregation percentage increased by approximately 36% in average, it did not change each month.

Muneer and Oades (1989) reported that soil particles of a red-brown earth on the surface were up to 80% bound into aggregates > 2,000 µm after addition of glucose and Ca compounds. The aggregates resulted were resistant against dispersion with $Na_4P_2O_7$ but not with HCI (0.02 *M* and 0.1 *M*)

Tabel 3. Aggregation percentage of Ultisol Limau Manis after 1st, 2nd, 3rd month of FOM application.

FOM Source	Month of incubation		
	One	Two	Three
C. odorata	54.57 ab	52.62 a	55.41 a
G. sepium	52.16 b	52.44 a	53.96 a
T. diversifolia	57.52 a	55.74 a	52.18 a
	P < 0.05	P > 0.10	P > 0.10
FOM Size (cm)			
0.5	55.57 ab	54.25 ab	52.66 a
2.0	50.98 b	53.55 ab	53.21 b
4.0	55.75 ab	50.65 b	54.85 ab
6.0	56.33 a	56.21 a	53.81 b
8.0	55.14 ab	53.35 ab	54.72 b
	P > 0.10	P < 0.10	P > 0.10

Note: Data followed by the same letter are not significantly different based on LSD at 5% level.

Tabel 4. Aggregate stability index of Ultisol Limau Manis after 1st, 2nd, 3rd month of FOM application.

FOM Source	Month of incubation		
	One	Two	Three
C. odorata	0.57 a	0.57 a	0.66 a
G. sepium	0.50 c	0.57 a	0.68 a
T. diversifolia	0.54 b	0.55 a	0.68 a
	P < 0.00	P > 0.10	P > 0.10
FOM Size (cm)			
0.5	0.56 a	0.57 a	0.72 a
2.0	0.54 a	0.56 a	0.67 a
4.0	0.53 a	0.59 a	0.67 a
6.0	0.54 a	0.55 a	0.67 a
8.0	0.53 a	0.55 a	0.66 a
	P > 0.10	P > 0.10	P > 0.10

Note: Data followed by the same letter are not significantly different based on LSD at 5% level.

addition. At this condition, Ca functioned as a bridge between polycarboxylic macromolecules (humic acids) and clays. Slurry application was able to enhance macro-aggregate formation. Types of slurry gave different effect on aggregate formation. The amount of aggregates > 2,000 μm increased in the order of the plots treated with digested slurry > aerated slurry > untreated slurry > compost = chemical fertilizers. This seemed to be due to high content of fine (< 53 μm) fraction in the digested slurry which played important role in binding the small aggregates into the larger ones (Seiichi *et al*. 2005).

Aggregate Stability Index

Based on Table 4, there was a different effect of types and sizes of FOM applied on aggregate stability of Ultisol after the first month of incubation. Aggregate stability index was significantly highest (P < 0.00) under chromolaena application. However, the effect was not significantly different at the second and the third month of incubation. The size of the FOM did not significantly affect the aggregate stability index of Ultisol after the first, second, and third month of application. It means that the size of FOM applied from 0.5 to 8 cm in length did not significantly affect the affectivity of the OM source on stabilization process of aggregates for three months of incubation. Different effect of FOM types on the first month could be due to the instability of the degradation within one month. It was proved that after the second and the third month of incubation the effect was not significant.

Not significant effect of types and sizes of FOM on aggregate stability index was probably due to the fact that less time was available to create association between soil and OM. Additionally, the composition of the all types of the FOM used were not so different, since all were grouped as green manure. One of the requirements for a plant to be a green manure crop is that the crops have to contain high nutrient content, especially N and low lignin content causing them easier to degrade and contribute to stabilize soil aggregates.

However, there was a tendency of increasing aggregate stability index by time of incubation from the first to the third month (Figure 5 and 6). This did not follow the aggregate percentage (Figure 3 and 4). The aggregation process resulted in size larger than 2 μm did not significantly happened, but the SOM was positively correlated (R^2 = 0.43) as presented in Figure 7. The increase in SOM content improved aggregate stability index of Ultisol after a 3-month incubation. This could be supported by the amount of SOM which increased by time until three months after incubation. The more OM content in the soil means the more binding agent is provided to stabilize soil aggregates. As reported by Albiach *et al*. (2001) that total OM of a soil could be used as a predictor for the aggregate stability. Therefore, soils being covered by vegetation, such as under forest and shrub as reported by An *et al*. (2010) had higher soil aggregate stability, because vegetation contributed OM to the soils.

Even though the percent aggregation could not improve by increasing SOM (as explained before), but aggregate stability increased by time. It means that by three months after incubation, SOM stabilized small aggregates (< 2 um), rather than creating larger aggregates. Haynes and Swift (1990) reported that the formation of stable aggregates was correlated to the pool of OC in this case was carbohydrate

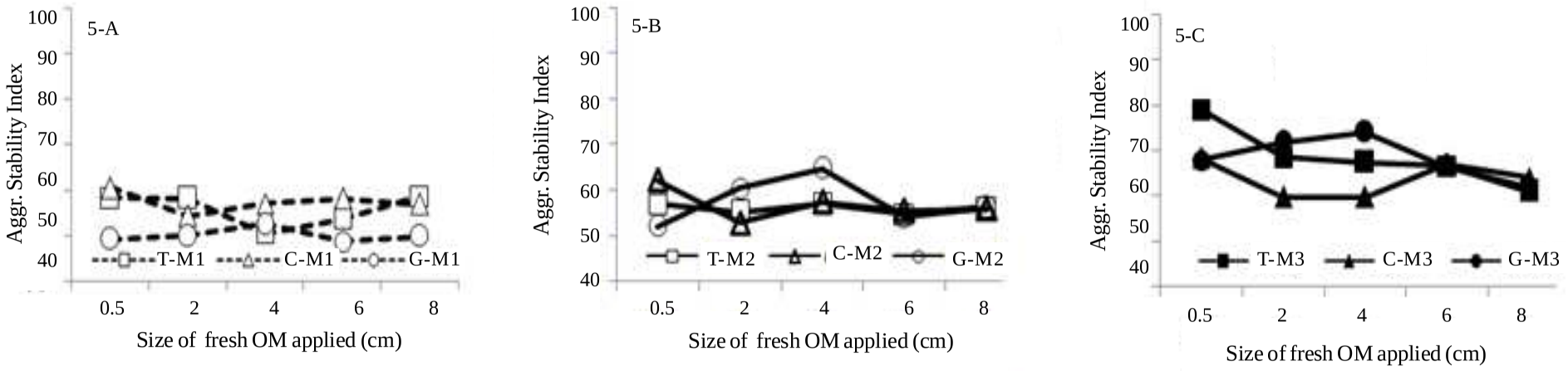

Figure 5. Aggregate stability index of Ultisol after being incubated by three types of FOM at different size for 1 (5-A), 2 (5-B), and 3 (5-C) month. 5-A, standar error (SE) = 2.94, 5-B, SE = 5.08, and 5-C, SE = 5.09. T = *T. diversifolia*, C = *C. odorata*, and G = *G. sepium*. M1 = 1 month, M2 = 2 month, and M3 = 3 month.

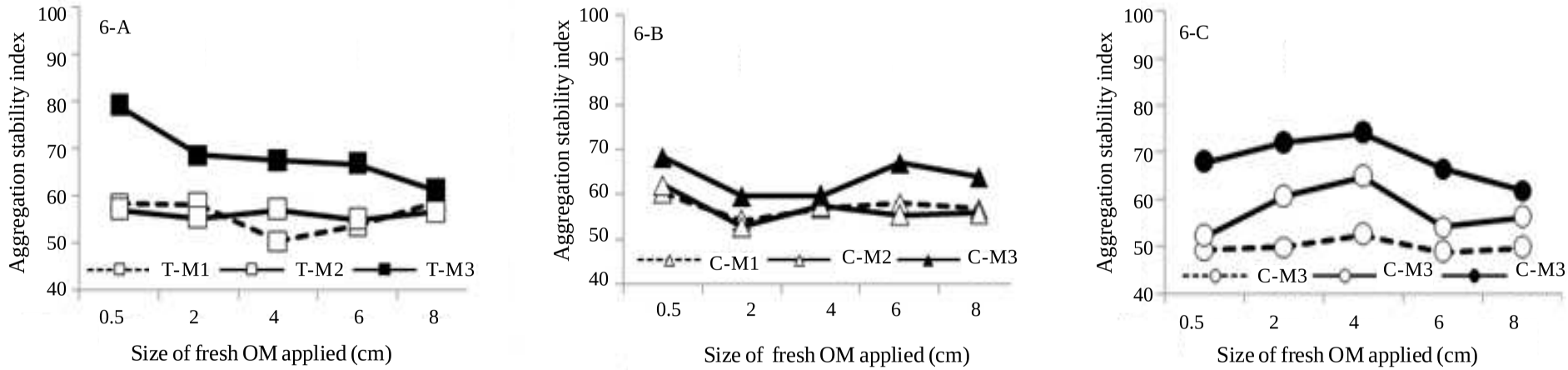

Figure 6. Aggregate stability index of Ultisol after being incubated by *T. diversifolia* (6-A), *C. odorata* (6-B), and *G. sepium* (6-C) at different size for 3 months. 6-A, standar error (SE) = 3.05, 6-B, SE = 2.42, and 6-C, SE = 4.65. T = *T. diversifolia*, C = *C. odorata*, and G = *G. sepium*. M1 = 1 month, M2 = 2 month, and M3 = 3 month.

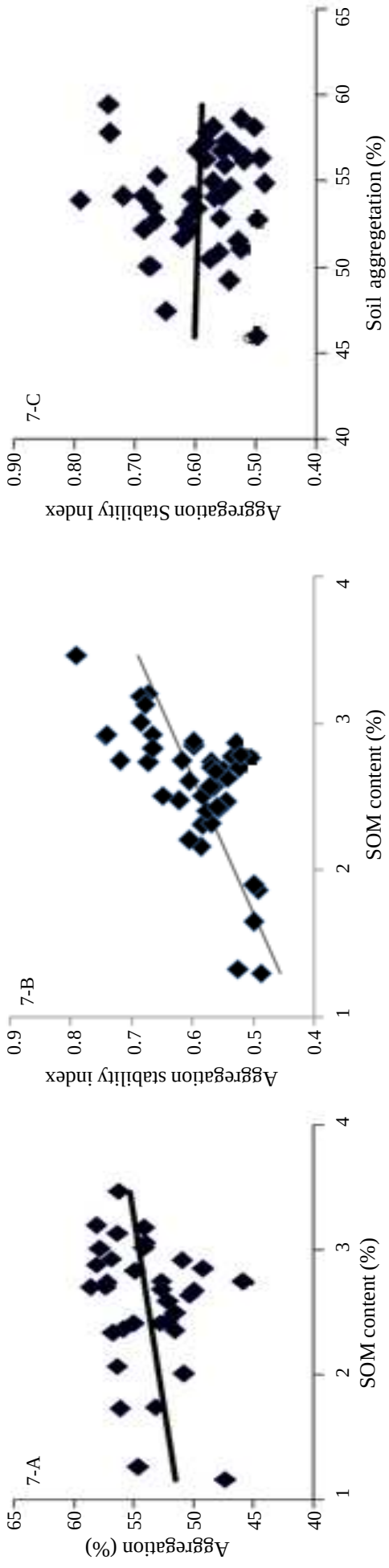

Figure 7. Relationship between SOM content and soil aggregation (7-A; y = 1.39x + 50.46, R^2 = 0.05), between SOM content and aggregate stability index (7-B; y = 0.11x + 0.32, R^2 = 0.42) as well as between soil aggregation and aggregate stability index (7-C; y = -0.001x + 0.02, R^2 = 0.002).

which could be extracted in hot water. Annabi *et al* (2007) stated that OM (either mature or immature compost) controled aggregate stability in loam soils. Stable aggregates were resulted from diffusion of organic substances as binding agent into aggregates causing inter-particular cohesion of the aggregates increased.

Among the OM types, Tithonia tended to give higher aggregate stability index especially at 0.5 cm size for three months after FOM application on Ultisol. This was caused by higher SOM available after 3 months of incubation (as presented in Table 2). Soil OM is known as one of the best binding agents which is functioned to stabilize soil aggregates. Figure 6 also shows that there was a tendency of decreasing aggregate stability index of Ultisol Limau Manis (especially for soil applied with Tithonia and Gliricidia) as FOM size increased from 0.5 to 8 cm. This could be true since the SOM stabilized the aggregates, so increase of SOM content in a soil could increase the soil aggregate stability.

Overall, FOM application increased the aggregate stability of Ultisol by 15%, 19%, and 21% for the first, second, and third month after incubation, respectively compared to the initial soil properties. Soil aggregate stability improved by 45% as Tithonia and Gliricidia applied and 41% as chromolaena applied on Ultisol. Tithonia at 0.5 cm size seemed to have the highest (69%) improvement of aggregate stability of Ultisol after three months of incubation compared to the original soil sample. This was correlated to the SOM content of the soil (Table 2). As found by Caravaca *et al*. (2002) that aggregate stability of rhizosphere from plant species containing higher OC content was on average higher than that of non-rhizosphere aggregates. Then, Filho *et al.* (2002) reported that aggregation process at 0-20 cm layer of red latosol (Typic Haplorthox) in Brazil was related to high OC content under no-tillage than conventional tillage system.

CONCLUSIONS

Based on laboratory analyses of Ultisol Limau Manis after being incubated with 3 different types and 5 different sizes of FOM, it can be concluded that FOM application (either different types or sizes) increased SOC content, aggregate percentage, and aggregate stability index after three months of incubation compared to the original properties of the soil. Gliricidia application contributed significantly low SOM content and SAS of Ultisol for a one-month incubation but there was not a significant effect among the FOM types (*T.*

diversivolia, C. odorata, and *G. sepium*) after 3 months. The smallest size (0.5 cm in length) of FOM applied contributed the highest SOC content of Ultisols after 3 months. Soil organic matter contents were positively correlated to the soil aggregate stability index of Ultisol ($R^2 = 0.43$), but not to soil aggregation percentage. No correlation was also found between percent of soil aggregation and aggregate stability index.

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