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Influence of Soil Organic Matter on Aggregation of Soils in Peninsular Malaysia

N.K. SOONG

The influence of soil organic matter on percentage aggregation (0.25) and mean weight diameter of Peninsular Malaysian soils was studied. The results showed that decomposed organic matter had pronounced influence on percentage aggregation (0.25) and mean weight diameter while the undecomposed forms, such as, particulate matter, had little influence. Aggregate analysis carried out after complete oxidation of the organic matter in the twelve soils with H_2O_2 showed that almost all the water-stable aggregates larger than 0.25 mm were broken down into micro-aggregates and/or primary soil particles.

Of the four types of organic substances, viz., *particulate matter, soil polysaccharides, humic acid and fulvic acid investigated, only humic acid and fulvic acid were found to be important for soil aggregation. Statistical analyses showed that humic acid and fulvic acid had significant positive correlations with percentage aggregation (0.25) and mean weight diameter. When small amounts ($<$ 0.2% weight/weight) of purified humic acid and fulvic acid were added to clay–sand mixtures, rapid aggregation of the clay particles took place.*

When organic matter was added to soil, structural improvement was obtained in most cases. The soil had better tilth, became more crumby and the aggregates were more resistant to water dispersion[1]. Because of these obvious effects, much work has been done to identify the actual organic polymers that cause soil aggregation[2-8]. Some investigators attributed the beneficial effects of soil organic matter on aggregate formation to certain polysaccharides formed during the decomposition of organic residues by microbiological activity[9-14]. Other aggregating agents that were found to be of importance were the high molecular weight humic substances,[15-18] modified lignins, proteins, oils, fats and waxes[19,20].

It is important to know the actual organic substances that are involved in soil aggregation because this could indicate the mechanisms by which water-stable aggregates are formed. The information would also serve to indicate the manner in which soil can be manipulated so that its structure can be improved or sustained. If soils in Peninsular Malaysia are to be exploited efficiently it is essential to preserve or enhance their structure. This can be achieved only when the mechanisms and factors governing soil aggregation are known. For this reason, the influence of organic matter on soil aggregation of some soils in Peninsular Malaysia was investigated.

MATERIALS AND METHODS

Materials

Twelve contrasting soils, the Kuantan, Prang, Durian, Batu Anam, Segamat, Selangor, Senai, Rasak, Langkawi,

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Rengam,Tampoi and Lanchang series were selected for this study. Details of the twelve soils are given in *Table 1.* Bulk samples were collected from the *Ah* and *B* horizons of the soils. For the purpose of this study, *Ah* horizon was designated as topsoil and *B* horizon as subsoil. All samples were collected from rubber plantations with similar agro-management practices.

For aggregate analysis, the soils were passed through a 8 mm sieve and then air dried. For mechanical and chemical analyses, the soils were dried at 56°C and passed through a 2 mm roller sieve.

Three basic techniques were adopted in this study. They are:

- Analytical techniques in which physical and chemical data of total soil were correlated with selected parameters of soil aggregation.
- Extraction techniques in which changes in soil aggregation were determined following extraction of the aggregates with different solvents.
- Addition techniques in which selected aggregating agents were added to clay-sand mixtures and their direct effects on soil aggregation were determined.

TABLE 1. ORIGIN AND CLASSIFICATION OF THE TWELVE SOILS

Soil series	Soil order	Parent material	Location of sampling site	Soil horizon (cm) Ah	B
Kuantan	Oxisol	Basalt	Near Bukit Groh, Agricultural Station, Pahang	0–15	15–46
Prang	Oxisol	Red shale	Prang Besar Estate, Selangor	0–13	13–30
Segamat	Oxisol	Andesite	Muar River Estate, Johore	0–8	8–22
Langkawi	Oxisol	Limestone	Sengat Estate, Perak	6–25	25–66
Tampoi	Oxisol	Older alluvium	Sungai Tiram Estate, Johore	0–13	13–61
Durian	Ultisol	Siliceous shale	Near Department of Agriculture, Ayer Itam, Johore	0–8	8–38
Senai	Ultisol	Gabbro	Linden Estate, Johore	0–3	3–30
Rasak	Ultisol	Shale	Kamuning Estate, Perak	0–8	8–38
Rengam	Ultisol	Granite	RRIM Experiment Station, Selangor	0–5	5–25
Lanchang	Ultisol	Granodiorite	Amber Estate, Johore	0–15	15–71
Batu Anam	Inceptisol	Shale	Near Department of Agriculture, Ayer Itam, Johore	0–15	15–46
Selangor	Inceptisol	Marine alluvium	Gedong Estate, Perak	0–8	8–36

Soils were classified according to the Seventh Approximation, United States Department of Agriculture (Chan 1975).

Methods

Aggregate analysis. Aggregate analysis was by the wet-sieving technique of Yoder[21] using apparatus modified by Low[22]. For each determination 50 g of air-dried soil was used. Ten determinations were carried out for each soil sample. The aggregation data were expressed as percentage aggregation (0.25) and mean weight diameter. Percentage aggregation (0.25) is the percentage weight of water-stable soil aggregates in a given weight of soil that is larger than 0.25 millimetres. Mean weight diameter is a value (millimetres) representing the weighted average of the total range of water-stable aggregates of different sizes[23].

Soil analyses. The soil samples were analysed for pH, mechanical composition, organic carbon, humic acid, fulvic acid, polysaccharide and particulate matter. Soil pH was measured with a Dynacap pH meter on a suspension of soil in water (2:5) standardised with pH buffers 3.97 and 7.17. Mechanical composition was determined by the pipette method described by Piper[24]. Organic carbon was determined by the widely used wet combustion method of Walkley and Black[24]. Humic acid, fulvic acid and polysaccharides were extracted from the soil samples by 0.5*N* NaOH. The method of Lynch *et al.*[25] was used to isolate and purify the humic substances from the alkaline extracts and the method described by Rennie *et al.*[26] was used for polysaccharides. Particulate organic matter, the unhumified or partially humified organic residue in soil, was separated from the test soils by the flotation method of Coughlan *et al.*[27]

Peroxidation of soil aggregates. Fifty grammes of 8 mm sieved soil (air-dried) was treated with 50 ml of 20% volume AR H_2O_2. When the organic matter was completely oxidised the soil sample was wet sieved. For the blanks, water was used instead of H_2O_2.

Periodate oxidation of soil aggregates. This technique was used to study the influence of soil polysaccharides on aggregation. A volume of 450 ml of 0.01 *M* $NaIO_4$ solution was added to 50 g of air-dried soil. The oxidation was allowed to proceed in the dark for 24 h, after which the sodium periodate solution was sucked out and 450 ml borate buffer (pH 10) added. After 2 h, the buffer was removed and the soil wet-sieved. For the blanks, water and 0.01 *M* NaCe were used instead of 0.01*M* $NaIO_4$.

Addition of humic acid and fulvic acid to clay-sand mixtures. Extraction techniques were not suitable for studying the effects of humic acid and fulvic acid on soil aggregation because all the known reagents that can extract these two organic substances efficiently also remove other organic and inorganic substances which may themselves be important aggregating agents. For this reason, the addition technique was used. Humic acid and fulvic acid extracted from soil were added to 1:1 clay-sand mixtures at the rate of 0%, 0.5%, 1.0%, 1.5% and 2.0%. The clay was commercial grade kaolin and the sand (0.2 – 0.02 mm diameter) was obtained by direct sieving. The mixtures were allowed to air-dry. The extent of micro-aggregate formation in the mixtures was then determined by the sedimentation method, described by Martin and Waksman[28].

RESULTS

Physical and Chemical Properties of Soils

Mechanical composition. There were considerable variations in mechanical composition among the twelve soils *(Table 2)*. The content of coarse sand varied from 0.5 percent by weight in Selangor series to 42% in Tampoi series. Fine sand ranged from about 5% in Kuantan, Batu Anam and Senai series to 22% in Tampoi series. The content of silt was less than 10% in Rengam and Tampoi series but more than 38% in Durian series. Clay content ranged from about 30% in Tampoi series to 60% in Kuantan, Batu Anam, and Senai series. In most of the soils, there was more clay in the subsoil than topsoil, the difference between the two horizons ranged from 4% to 13%.

Chemical properties and organic substances in soils. All the soils were acid in reaction, as indicated by their low pH values in water *(Table 3)*. Except for Selangor and Langkawi series, the pH values of all the soils varied within a narrow range of 4.2 to 4.6. The extreme acidity of Selangor series soil, particularly in the subsoil horizon, is a normal characteristic of this soil because of its inherent 'acid-sulphate' nature. The comparatively high pH value found in Langkawi series soil is due to its limestone origin.

The content of organic carbon in the topsoil ranged from 0.66% by weight in

TABLE 2. MECHANICAL COMPOSITION OF SOILS

Soil series	Soil horizons	Mechanical composition (%) Coarse sand	Fine sand	Silt	Clay
Kuantan	Topsoil	8.6	5.3	17.2	59.0
	Subsoil	7.2	4.3	13.5	76.6
Prang	Topsoil	6.8	10.0	23.8	58.1
	Subsoil	8.7	15.8	19.9	50.0
Segamat	Topsoil	3.6	8.2	29.3	57.7
	Subsoil	2.6	11.2	29.4	54.7
Langkawi	Topsoil	24.2	16.0	15.3	45.3
	Subsoil	23.4	14.2	6.9	56.3
Tampoi	Topsoil	42.1	22.5	9.5	28.0
	Subsoil	40.7	20.5	4.3	32.4
Durian	Topsoil	11.9	13.1	38.1	37.1
	Subsoil	9.1	9.8	31.7	50.4
Senai	Topsoil	7.7	5.0	28.8	58.7
	Subsoil	8.2	5.0	24.2	64.3
Rasak	Topsoil	5.2	19.6	20.4	52.2
	Subsoil	5.3	19.5	23.6	49.8
Rengam	Topsoil	36.3	11.8	8.7	44.4
	Subsoil	34.3	9.6	8.8	48.9
Lanchang	Topsoil	22.4	14.9	10.3	53.0
	Subsoil	19.6	11.7	5.8	62.7
Batu Anam	Topsoil	1.1	6.7	36.9	53.1
	Subsoil	0.8	5.4	34.5	60.4
Selangor	Topsoil	0.5	12.4	36.5	50.6
	Subsoil	0.5	4.6	33.5	61.6

Rasak series to 2.44% in Kuantan series *(Table 3)*. In the subsoil, it ranged from 0.39% in Durian series to 1.27% in Selangor series. In each soil, the content of organic carbon in the topsoil was about two to three times higher than that in the subsoil.

The amount of particulate organic matter combined with soil aggregates was found to be very low in all the soils, particularly in the subsoil horizon. The range of values in the topsoil was from 0.01% in Langkawi series to 0.24% in Tampoi series but in the subsoil, the values ranged from 0.01% to 0.05%.

The organic matter in most of the soils contained appreciable amounts of polysaccharides that were soluble in 0.5*N* NaOH. The highest content was found in Senai series and the lowest in Tampoi series; in the latter, polysaccharides were not detected in the subsoil. From the values obtained, it was calculated that 10% – 90% of the organic carbon in the soils occurred as polysaccharides. This is contrary to the results of other investigators. Using a more refined technique of purification, Swincer *et al.*[29] found that the proportion of organic carbon present as polysaccharides in most soils varied only from 5% to 25%. Some of the high

TABLE 3. CHEMICAL PROPERTIES AND ORGANIC SUBSTANCES IN SOILS

Soil series	Soil horizon	pH	Organic C (%)	Particulate matter (%)	Polysaccharides (%)	Humic acid (mg/100 g soil)	Fulvic acid (mg/100 g soil)
Kuantan	Topsoil	4.6	2.44	0.05	1.16	464	2 565
	Subsoil	4.2	1.01	0.02	0.53	62	1 611
Prang	Topsoil	4.4	1.39	0.02	0.56	152	1 789
	Subsoil	4.4	0.91	0.02	0.28	60	1 431
Segamat	Topsoil	4.5	1.61	0.09	1.23	150	1 740
	Subsoil	4.6	0.66	0.02	0.80	13	925
Langkawi	Topsoil	5.9	1.05	0.01	1.42	68	1 106
	Subsoil	5.8	0.55	0.02	1.15	555	922
Tampoi	Topsoil	4.6	1.44	0.24	0.16	421	1 204
	Subsoil	4.4	0.47	0.01	0	72	495
Durian	Topsoil	4.6	1.42	0.18	0.74	523	1 143
	Subsoil	4.5	0.39	0.02	0.64	65	600
Senai	Topsoil	4.3	1.88	0.17	1.70	298	2 507
	Subsoil	4.4	0.95	0.05	0.59	55	1 244
Rasak	Topsoil	4.2	0.66	0.11	1.09	70	1 149
	Subsoil	4.2	0.48	0.04	0.93	36	915
Rengam	Topsoil	4.4	1.99	0.07	0.84	972	1 510
	Subsoil	4.2	0.82	0.05	0.63	247	438
Lanchang	Topsoil	4.4	1.17	0.10	0.93	203	1 401
	Subsoil	4.2	0.51	0.04	0.74	42	795
Batu Anam	Topsoil	4.5	1.47	0.18	0.71	488	1 604
	Subsoil	4.4	0.45	0.02	0.31	70	720
Selangor	Topsoil	3.9	1.84	0.17	0.94	1 002	1 670
	Subsoil	3.6	1.27	0.05	0.31	737	1 830

values obtained here indicated that the polysaccharides contained other organic materials which were also solubilised by NaOH during the extraction process. These materials were humic acid, fulvic acid and humins which were not completely removed during isolation of the polysaccharides[8]. For this reason, the amount of polysaccharides, humic acid and fulvic acid added up to more than the total organic matter for some soils *(Table 3)*.

The differences in humic acid content among soils and soil horizons within each soil series were large. In the topsoil, humic acid content ranged from 68 mg per 100 g soil in Langkawi series to 1002 mg in Selangor series. In the subsoil, the highest humic acid content was also observed in Selangor series (737 mg per 100 g), but the lowest in Segamat series (13 mg per 100 g).

The content of fulvic acid was consistently very much higher than that of humic acid in all the soils. This was true for both soil horizons. This suggests that most of the organic matter in the selected soils had already undergone a high degree of humification[30]. The range of values in the topsoil was from 1106 mg per 100 g in Tampoi series to 2565 mg per 100 mg in Kuantan series and in the subsoil, the values ranged from 434 mg per 100 g in Kuantan series to 1830 per 100 g in Selangor series.

Aggregation of Soils

Percentage aggregation (0.25). Percentage aggregation (0.25) varied significantly among the twelve soils at each soil depth *(Table 4)*. In the topsoil, Kuantan series soil was the most highly aggregated, with 88%, by weight, of its primary particles being formed into water-stable aggregates

TABLE 4. PERCENTAGE AGGREGATION (0.25) AND MEAN WEIGHT DIAMETER OF THE SOILS

Soil series	Percentage aggregation (0.25)		Mean weight diameter (mm)	
	Topsoil	Subsoil	Topsoil	Subsoil
Kuantan	88.0	71.8	3.51	1.09
Prang	86.6	80.0	2.59	1.76
Segamat	84.6	66.8	2.53	0.90
Langkawi	69.1	45.6	2.24	0.56
Tampoi	65.7	35.1	1.85	0.59
Durian	86.2	53.4	3.46	1.51
Senai	79.5	61.8	2.55	1.04
Rasak	73.2	55.1	1.93	0.72
Rengam	65.6	53.1	2.65	1.41
Lanchang	53.2	37.4	1.55	0.42
Batu Anam	84.7	51.2	3.65	1.06
Selangor	79.5	80.6	3.21	3.22

S.E. of mean among soil series	± 1.29	± 0.063
L.S.D. (PC 0.05)	3.60	0.170
S.E. of mean among soil depth	± 0.53	± 0.026
L.S.D. (PC 0.05)	1.50	0.070

larger than 0.25 millimetres. Other soils which had percentage aggregation (0.25) values greater than 80% were Prang, Durian, Batu Anam, and Segamat series. Senai and Selangor series soils, although pedologically different from each other[20], had the same percentage aggregation (0.25) value of 79.5%. The rest of the soils were found to be less well aggregated with percentage (0.25) values ranging from 73.2% to 53.2%, the lowest value was found in Lanchang series soil.

Generally, the subsoil horizon had significantly lower percentage aggregation (0.25) than the topsoil. An exception to this trend was found in Selangor series soil. The magnitude of the difference in percentage aggregation (0.25) between the two soil horizons depended on the type of soil. It was very large in the case of Durian and Batu Anam series and only marginal in Prang and Selangor series. Considering the subsoil horizon alone, Selangor series soil was the most highly aggregated and Tampoi series soil, the least. The other ten soils had percentage aggregation (0.25) values ranging from 80.0% to 37.4%. As in the case of topsoil, the difference in percentage aggregation (0.25) in subsoil was found to be significant among the soils.

Mean weight diameter. Mean weight diameters were significantly different among the twelve soils *(Table 4)*. In the topsoil, Batu Anam series soil had the largest mean weight diameter and Lanchang series, the smallest. Soils with mean weight diameters larger than 3 mm were Batu Anam, Kuantan, Durian and Selangor, those with mean weight diameters of 2 – 3 mm were Rengam, Prang, Segamat, Senai and Langkawi series, the rest of the soils had mean weight diameters of 1 – 2 millimetres.

Mean weight diameter in the subsoil was generally smaller than in the topsoil. The only exception to this trend was Selangor series soil which had almost similar values in both horizons.

Influence of Organic Matter on Soil Aggregation

Statistical analysis. The influence of organic carbon and organic substances on percentage aggregation (0.25) and mean weight diameter was first examined by simple and multiple regression analyses. In simple regression analysis, both percentage aggregation (0.25) and mean weight diameter were found to be positively correlated with percentage organic carbon and the relationships were highly significant *(Table 5)*. This indicates that soil organic matter enhanced the amount and size of water-stable aggregates. Significant relationships of aggregation were also established with humic acid and fulvic acid contents. The amount of particulate matter in the soil had little influence on percentage aggregation (0.25) but had a significant relationship with mean weight diameter. Soil polysaccharides did not seem to have any influence on the two soil parameters.

In multiple regression analysis, a combination of the four organic substances, *viz.* particulate matter, polysaccharides, humic acid and fulvic acid, accounted for about 59% of the variations in percentage aggregation (0.25) *(Table 6)*. Fulvic acid was the most important in accounting for these variations and polysaccharides, the least. Humic acid was ranked second in importance. The same four organic substances accounted for 71% of the variations in mean weight diameter and the two main substances that contributed to this successful variance removal were humic acid and fulvic acid. Particulate

TABLE 5. SIMPLE REGRESSION EQUATIONS OF PERCENTAGE AGGREGATION (0.25) AND MEAN WEIGHT DIAMETER ON ORGANIC SUBSTANCES

Organic substances	Percentage aggregation (0.25) (Y_1) Regression equation	r	Mean weight diameter (Y_2) Regression equation	r
Percentage organic carbon (X_1)	$Y_1 = 44.32 + 19.87\ X_1$	0.694***	$Y_2 = 0.260 + 1.482\ X_1$	0.817***
Percentage particulate matter (X_2)	$Y_1 = 60.86 + 77.86\ X_2$	0.323^{NS}	$Y_2 = 1.318 + 8.197\ X_2$	0.537***
Percentage polysaccharides (X_3)	$Y_1 = 56.15 + 0.013\ X_3$	0.334^{NS}	$Y_2 = 1.537 + 0.0005\ X_3$	0.193^{NS}
Humic acid (mg/100 g) (X_4)	$Y_1 = 60.659 + 0.022\ X_4$	0.406*	$Y_2 = 1.253 + 0.003\ X_4$	0.725***
Fulvic acid (mg/100 g) (X_5)	$Y_1 = 37.614 + 0.022\ X_5$	0.764	$Y_2 = 1.70 + 0.013\ X_5$	0.687***

NS = not significant
* $P < 0.1$
** $P < 0.01$
*** $P < 0.001$

TABLE 6. PARTIAL REGRESSION COEFFICIENTS OF PERCENTAGE AGGREGATION (0.25) AND MEAN WEIGHT DIAMETER ON ORGANIC SUBSTANCES

Aggregation parameter	Percentage particulate matter (X_2)	Percentage polysaccharides (X_3)	Humic acid (X_4)	Fulvic acid (X_5)	Intercept	R_2
Percentage aggregation (0.25) (Y_1)	11.442^{NS}	0.0003^{NS}	0.004^{NS}	0.021***	37.417	0.592
Mean weight diameter (Y_2)	2.304^{NS}	-0.00003^{NS}	0.002**	0.0008*	0.290	0.712

NS = not significant
*$P < 0.1$
** $P < 0.01$
*** $P < 0.001$

matter and polysaccharides were of less importance.

Peroxidation of soil aggregates. The influence of soil organic matter on aggregation was also determined by observing the changes in percentage aggregation (0.25) and mean weight diameter after the soil sample had been treated with 20% volume AR H_2O_2. For the control, water was used instead of H_2O_2. The results are shown in *Table 7.*

Subjecting the soil aggregates to water treatment and gentle heating reduced both percentage aggregation (0.25) and mean weight diameter. The amount of reduction varied with the type of soil. Aggregates from Kuantan, Prang, Durian, Segamat, Senai, Rasak and Langkawi series soils suffered less destruction than those from Batu Anam, Rengam, Tampoi and Lanchang series. For Batu Anam series soil, treatment of the aggregates with water and gentle heating had a very destructive effect. Almost all the aggregates larger than 0.25 mm were completely destroyed.

It was noted that aggregates from the subsoil horizon suffered greater breakdown than those from the topsoil. The only exception was observed in Selangor series soil, the subsoil aggregates were less severely broken down by water and heat treatment.

When organic matter in all the soils was removed or destroyed by complete oxidation with H_2O_2, practically all the water-stable aggregates > 0.25 mm were broken down into micro-aggregates and/or the various mechanical fractions. As shown in *Table 7*, percentage aggregation (0.25) was reduced to less than 1% by weight for most of the soils. Mean weight diameters were decreased to less than 0.12 mm in most soils, the range being 0.05 mm to 0.11 millimetres. Aggregates from both topsoil and subsoil were broken down to a similar extent by the peroxidation treatment.

Periodate oxidation of soil aggregates. Dilute solutions of sodium periodate oxidise soil polysaccharides at room temperature and the oxidised polysaccharides become unstable under alkaline conditions. This means that when soil aggregates are first treated with sodium periodate and then with an alkaline buffer at pH 10, they should break down into micro-aggregates and/or mechanical fractions if polysaccharides are the main aggregating agent. This extraction technique was adopted for investigating the role of polysaccharides as an aggregating agent in the twelve soils. The results are shown in *Table 8*.

When compared with the blank (water treatment), almost all the soils suffered some reduction in percentage aggregation (0.25) after oxidation of the polysaccharide by 0.01*M* sodium periodate, the effect being better exhibited in the subsoil than the topsoil. However, there was generally less than 10% difference in the values of percentage aggregation (0.25) between water treatment and periodate oxidation. In most of the soils, particularly in the topsoil horizon, the reduction in stability of their aggregates could be attributed to the dispersive effect of the sodium ions present in the periodate, rather than the removal of polysaccharides. This was because treatment with 0.01 *M* NaCl also reduced percentage aggregation (0.25); the magnitude of the reduction being very similar to that produced by sodium periodate.

Sodium periodate treatment had also very minor effects on the size distribution of the soil aggregates. There was a slight decrease in mean weight diameter values for most of the soils when sodium periodate treatment was compared with the blank, but this could be attributed to dispersion by sodium ions, as in the case of percentage aggregation (0.25).

Addition of Humic Acid and Fulvic Acid to Clay-sand Mixture

The effects of humic acid and fulvic acid on aggregation of kaolinitic clay are shown in *Figure 1*. The results showed that even in the absence of humic acid and fulvic acid some aggregation did

TABLE 7. EFFECT OF OXIDATION OF ORGANIC MATTER BY HYDROGEN PEROXIDE ON PERCENTAGE AGGREGATION (0.25) AND MEAN WEIGHT DIAMETER

Soil series	Soil horizon	Percentage aggregation (0.25)[a]		Mean weight diameter[a] (mm)	
		Water	H_2O_2	Water	H_2O_2
Kuantan	Topsoil	37.9	0.4	1.76	0.06
	Subsoil	30.1	0.3	0.71	0.05
Prang	Topsoil	37.2	4.6	1.72	0.10
	Subsoil	30.8	5.7	0.83	0.11
Segamat	Topsoil	36.9	0.4	1.71	0.05
	Subsoil	22.1	0.3	0.41	0.05
Langkawi	Topsoil	57.6	2.4	1.28	0.08
	Subsoil	26.7	2.2	0.28	0.07
Tampoi	Topsoil	21.4	2.3	0.91	0.11
	Subsoil	8.8	1.5	0.24	0.08
Durian	Topsoil	39.7	0.9	1.00	0.06
	Subsoil	15.1	0.2	1.29	0.05
Senai	Topsoil	31.1	2.1	0.56	0.06
	Subsoil	19.5	0.4	0.42	0.06
Rasak	Topsoil	39.7	1.1	0.72	0.06
	Subsoil	34.8	0.3	0.37	0.05
Rengam	Topsoil	16.2	0.8	0.90	0.08
	Subsoil	3.8	0.2	0.16	0.06
Lanchang	Topsoil	22.6	3.2	0.44	0.09
	Subsoil	4.3	1.9	0.10	0.07
Batu Anam	Topsoil	7.6	0.1	0.20	0.05
	Subsoil	1.5	0.2	0.07	0.05
Selangor	Topsoil	36.6	0.1	2.21	0.05
	Subsoil	45.2	0.5	2.25	0.05

[a]Mean of three readings

take place in the clay-sand mixture. This was due mainly to cohesion of the orientated clay particles themselves. The amount of clay involved in this form of aggregation was about 14% of the total clay content in the mixture.

Both humic acid and fulvic acid were found to promote the formation of micro-aggregates in the clay-sand mixture. Humic acid, at 0.5% by weight, increased the amount of aggregated clay from 14.2% to 40% of the total clay content. The influence of fulvic acid was even more pronounced. At 0.5% level, it increased the amount of aggregated clay to 57.5%. Therefore, both humic acid and fulvic acid had strong aggregating effects on clay even at very low levels of application.

When the content of humic acid was increased to 1.0%, the weight of aggregated clay was doubled to 81.6%. Further increase of humic acid to 1.5% and 2.0% by weight, promoted almost complete aggregation of the clay particles (91.4% and 94.1% respectively). With

TABLE 8. EFFECT OF SODIUM PERIODATE TREATMENT ON PERCENTAGE AGGREGATION (0.25) AND MEAN WEIGHT DIAMETER

Soil series	Soil horizon	Percentage Aggregation (0.25)[a]			Mean weight diameter[a] (mm)		
		Water[b]	NaCl	$NaIO_4$	Water[b]	NaCl	$NaIO_4$
Kuantan	Topsoil	75.5	74.9	80.3	1.66	1.87	1.85
	Subsoil	64.2	67.7	56.7	0.68	0.64	0.53
Prang	Topsoil	77.8	77.4	77.0	1.51	1.59	1.35
	Subsoil	77.3	74.1	73.0	1.56	1.18	1.25
Segamat	Topsoil	67.6	64.0	60.7	1.25	1.15	1.11
	Subsoil	54.0	47.6	48.3	0.46	0.40	0.39
Langkawi	Topsoil	47.0	46.9	47.0	0.63	0.69	0.68
	Subsoil	30.1	22.0	22.3	0.25	0.22	0.20
Tampoi	Topsoil	61.9	62.0	62.0	1.14	1.35	1.01
	Subsoil	48.2	35.8	35.9	0.41	0.37	0.31
Durian	Topsoil	62.5	57.0	57.7	1.42	1.16	1.23
	Subsoil	13.2	12.1	10.6	0.26	0.21	0.17
Senai	Topsoil	71.7	71.8	71.4	1.46	1.39	1.35
	Subsoil	46.0	36.2	32.8	0.49	0.38	0.38
Rasak	Topsoil	42.7	48.2	43.2	0.72	0.85	0.77
	Subsoil	38.4	36.9	36.9	0.26	0.32	0.25
Rengam	Topsoil	62.2	59.4	56.8	1.35	1.20	1.12
	Subsoil	22.5	21.9	17.9	0.27	0.33	0.23
Lanchang	Topsoil	51.4	49.7	49.4	0.95	0.84	0.92
	Subsoil	29.6	26.9	21.8	0.25	0.20	0.19
Batu Anam	Topsoil	32.2	30.9	29.4	0.52	0.46	0.37
	Subsoil	5.4	5.4	5.4	0.11	0.11	0.08
Selangor	Topsoil	63.9	63.3	64.3	1.37	1.33	1.37
	Subsoil	75.9	74.6	74.5	1.87	1.82	1.72

[a]Mean of three readings

[b]The blank was slightly different from that of the peroxidation experiment because no heating was involved.

fulvic acid, the maximum effect on aggregation of clay particles was at 1.0%. Further increases in its content did not improve aggregation.

DISCUSSION

The importance of decomposed organic matter in the aggregation of soils in Peninsular Malaysia has been demonstrated in this study. Aggregate analysis carried out after complete oxidation of the organic matter in all the twelve soils with H_2O_2 showed that almost all the water-stable aggregates > 0.25 mm were broken down into micro-aggregates and/or primary soil particles. Even soils with high contents of clay and sesquioxides, such as Kuantan, Prang, Segamat, Senai and Langkawi series[31], were highly sensitive to peroxidation treatment. This suggests that the formation of macro-aggregates (> 0.25 mm) in Peninsular Malaysian soils is dependent more on organic matter than on clay and sesquioxides. Recent studies by Soong[31] substantiate this observation. Peroxidation caused the destruction of the organic molecules as well as the clay-

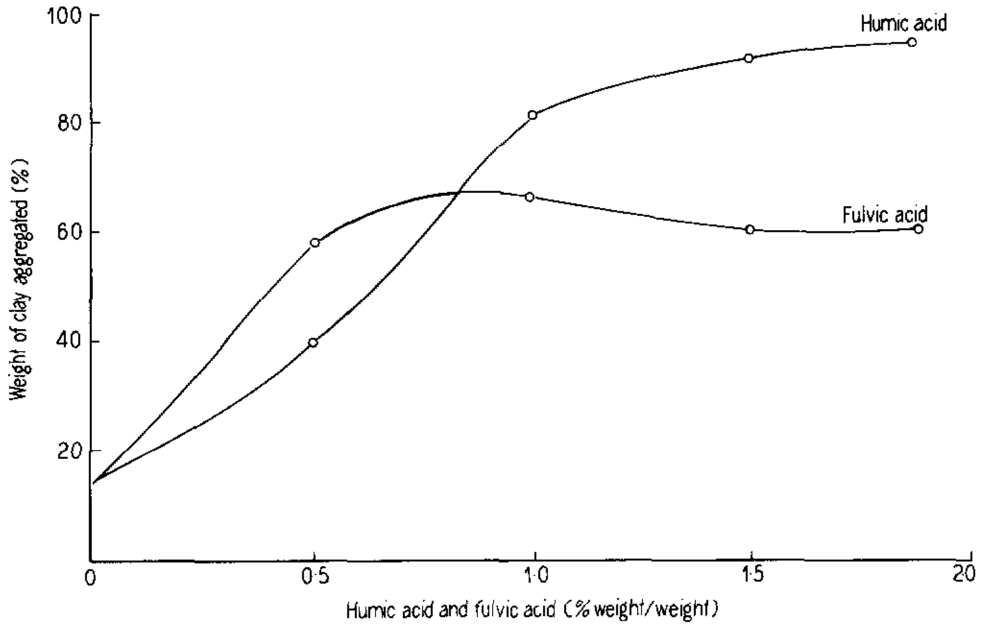

Figure 1. Effect of humic and fulvic acids on aggregation of clay in 1:1 clay-sand mixture.

humus and sesquioxides – humus complexes in the soil aggregates, leading to their breakdown.

Statistical analyses also substantiated the important role of decomposed organic matter in the aggregation of Peninsular Malaysian soils. Organic carbon content was significantly correlated with percentage aggregation (0.25) and mean weight diameter, the relationships being positive. The results indicated that decomposed organic matter enhanced aggregation and the size of the aggregates in the soils. This effect was very well exhibited by the striking difference in percentage aggregation (0.25) and mean weight diameter between the topsoil and subsoil horizons within each soil series. The topsoil horizon which contained more organic matter had significantly higher percentage aggregation (0.25) and larger mean weight diameter than the subsoil.

It has been established that the bulk of soil organic matter is made up of polysaccharides, humic acid and fulvic acid[30]. Therefore, it is necessary to investigate the relative importance of these organic substances in causing soil aggregation. Both simple and multiple regression analyses showed that polysaccharides extracted by 0.5 *N* NaOH had very little influence on percentage aggregation (0.25) and mean weight diameter. This was also confirmed by the results obtained from periodate oxidation of the soil aggregates in which minor and inconsistent reduction in percentage aggregation (0.25) and mean weight diameter were observed following periodate treatment. On the other hand, humic acid and fulvic acid had significant relationships with the two soils used to assess soil structure.

However, fulvic acid should have a more important role than humic acid in the aggregation of the rest soils because it occurred in far greater amount than the latter. The abundance of fulvic acid in Peninsular Malaysian soils has been confirmed by Zainab[32] who found that 75% – 90% of the organic carbon were in the form of fulvic acid. Both simple and multiple regression analyses also showed that fulvic acid had significant influence on percentage aggregation (0.25) and mean weight diameter.

Humic acid was superior to fulvic acid for improving aggregating. This was demonstrated in the 'addition' experiment. When humic acid and fulvic acid were added to kaolinitic clay, the former produced more micro-aggregates than fulvic acid, at the three levels of application *(Figure 1)*. This finding confirmed the results of earlier workers (e.g. Swaby[15]) who found that humic acid and its salts were more effective as aggregating agents than fulvic acid.

For humic acid and fulvic acid to be effective aggregating agents, they need to be adsorbed onto clay surfaces. The adsorption mechanisms of humic acid and fulvic acid onto clay surfaces are as follows. Under normal circumstances, both humic acid and fulvic acid, being organic anions, are repelled from the surfaces of negatively charged clay particles. However, when aluminium or iron is present on the clay surfaces, as in the case of Peninsular Malaysian soils[33, 34] the adsorption of these organic anions is possible. Greenland[35] has discussed the various ways in which humic acid and fulvic acid are adsorbed onto clay surfaces through the influence of aluminium and iron hydroxides on the clay surfaces. Firstly, the organic anions are adsorbed to the positive sites on aluminium and iron hydroxides by simple coulombic attraction. Secondly, humic acid and fulvic acid can be bonded to aluminium and iron hydroxides through 'ligand exchange' reactions or specific adsorption. In this type of adsorption, the organic anion penetrates the co-ordination shell of an iron or aluminium atom in the surface of the hydroxide. The anion is thus incorporated with the surface hydroxyl layer. Another way by which humic substances can be attached to clay surfaces is through precipitation by iron and aluminium hydroxides followed by dehydration[36]. In this way, the humus sesquioxide complexes are fixed as a film on the clay by the irreversible process of dehydration and not by chemical linkage. All the three mechanisms by which humic acid and fulvic acid gain access to clay surfaces probably occur in the soils of Peninsular Malaysia. This is because the chemical and mineralogical make-up of the soils favour these mechanisms. Most of the soils are acid in reaction and their exchange complexes (mainly kaolinitic clay) are dominated by aluminium ions[33]. Both amorphous and crystalline iron oxides also occur in these soils, their contents range from less than 1% to about 20%. These iron oxides occur as crusts on the planar surfaces of kaolinite[35]. Harradine and Jenny[37] observed greater adsorption of humic substances in soils that have aluminium ions dominating the exchange complex, and under acid conditions, Evans and Russell[38] showed that aluminium and iron hydroxides have strong affinity for humic substances.

CONCLUSION

Soil organic matter has been found to be important for soil aggregation. It enhances the amount of water-stable aggregates and the average size of the aggregates (mean weight diameter). The organic substances which are responsible for binding soil particles into aggregates are humic and fulvic acids. The latter is more important because of its abundance in Peninsular Malaysian soils. Particulate organic matter and polysaccharides seem to have very little influence on soil aggregation.

The results obtained from this study have some practical significance. Since soil organic matter influences soil aggregation significantly it can therefore be used to improve or preserve structure in a soil so that its productivity can be enhanced or sustained. This can be achieved mainly by implementing appropriate cropping systems and cover management. However, if quicker results are required soil conditioners can be used with equal effectiveness for improving soil structure, but at very much higher costs.

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Rubber Research Institute of Malaysia
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