The Stability of Individual Macroaggregate Size Fractions of Ultisol and Oxisol Soils

C. B. S. Teh[1]

ABSTRACT

Aggregate stability is an important soil property because it dictates how strongly a soil can resist water erosion. The objectives in this study were: (1) to compare the stability of six soil aggregate size fractions, primarily to determine if aggregate stability varies with aggregate size, and (2) to determine with which aggregate size fraction the stability of most soils would be different from one another. Eight soils classified as Ultisols and Oxisols and from varying land uses, of different textures and overall acceptable aggregate stability were sampled and each separated into six aggregate size fractions of: 5-8, 3-5, 2-3, 1-2, 0.5-1, and 0.25-0.5 mm. Aggregate stability of whole soils and of individual aggregate size fractions were determined through wet-sieving, using nested sieves. It was shown that: (1) the kind of relationship between soil aggregate stability and aggregate size depended on both factors of soil type and individual aggregate size; (2) the stability of any two soil aggregate size fractions would become progressively less linearly related as the differences in aggregate size became more pronounced; (3) for the same soil, the stability of the large aggregate size fractions of > 0.5 mm were significantly different from that of the small aggregate size fractions of 0.25-0.5 mm; and (4) the differences in aggregate stability among whole soils were due more to the differences in the stability of the soil aggregate sizes larger than 3 mm. The study revealed that for Ultisol and Oxisol soils, it was not necessary to measure the stability of individual aggregate size fractions. Instead, the stability of a single aggregate size fraction could be used to represent the macroaggregate stability of whole soils.

Keywords: Aggregate breakdown, Nested sieves, Wet-sieving.

INTRODUCTION

The physical and chemical properties of soil individual aggregate size fractions are often different one from the other. The contents of clay, organic matter, and exchangeable cations for example, often differ in one aggregate size fraction than those in another (Garey, 1954; Cambardella and Elliot, 1993; Cruvinel *et al.*, 1993). Consequently, these physical and chemical properties differing, may cause soil aggregates of different sizes be of differing stabilities as well. If the stability measured only on whole (non-fractionated) soil, one can lose a substantially great deal of information concerning the stability of individual aggregate size fractions. Low (1954), for example, discovered through his studies that the percentage of water-stable aggregates in the category of 0.25-1 mm size group decreased, whilst the fraction of water-stable aggregates in the greater than 3 mm category increased. He remarked that if he had weighed the amount of water-stable aggregates above the aggregate size of 0.25 mm only, he would have concluded that aggregate stability had not changed.

The difference in stability between various aggregate sizes is due to several factors. The stability of microaggregates is insensitive to

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[1] Department of Land Management, Faculty of Agriculture, Malaysia Serdang University, Putra Malaysia. e-mail: cbsteh@yahoo.com

changes in either soil organic matter content or soil management practices (Tisdall and Oades, 1982; Zhang and Horn, 2001). Microaggregates are very stable because they are built-up of persistent aromatic humic material associated with amorphous Fe and Al compounds. The stability of macroaggregates, on the other hand, varies with the changes in organic matter content or in management practices (Chenu *et al.*, 2000; Boix-Fayos *et al.*, 2001; Six *et al.*, 2004; Nozellemeyer *et al.*, 2008). This is because macroaggregates are stabilized by such transient or temporary binding agents as roots, hyphae, and microbial- as well as plant-derived polysaccharides. Although organic matter decreases with decreasing aggregate size (Elliott, 1986; Gupta and Germida, 1988; Cambardella and Elliott, 1993; Puget *et al.*, 1995; Zhang and Horn, 2001), the organic matter in the smaller aggregate size fractions is older, more stable, and more highly processed than the organic matter in the larger aggregates (Parton *et al.*, 1983; Paul, 1984; Elliott, 1986; Gupta and Germida, 1988). Also, Monreal *et al.* (1995) found that the macroaggregate stability is correlated with many types of such organic matter structures as lignin dimers, alkylaromatics, lipids, sterols, organic carbon and nitrogen. The microaggregate stability, however, failed to be correlated with any of the organic matter structures. They concluded that soil organic matter and its entities may be less important than the inorganic components in stabilizing microaggregates. Moreover, cohesion between clay particles, mediated by humic substances linked to polyvalent cations, may play a more important role in microaggregate stability (Krishna Murthi *et al.*, 1977; Monreal *et al.*, 1995). Principal component analysis, a multivariate statistical method, revealed that the microaggregate stability of seven Italian soils of different pedogenesity origin was mainly related to soil mineralogy with the organic carbon; on the other hand, exerting little effect (Nwadialo and Mbagwu, 1991).

Unfortunately, few studies on the stability differences in among different soil aggregate sizes are done for tropical soils. Consequently, the main objectives of this study were: (1) to compare the stability of six aggregate size fractions among each other, primarily to determine if aggregate stability varies with aggregate size, and (2) to determine with which aggregate size fraction of soil the stability of most soils would be different one from the other.

MATERIALS AND METHODS

Soils were sampled from eight experimental sites in Serdang (2° 59' 59" N, 101° 42' 45" E), Malaysia. These experimental sites are 30 m above sea level, with a relief of either flat or gently undulating. Mean annual temperature and total precipitation in the sites' area are 27°C and 2500 mm, respectively. The land use in these sites are: oil palm, coffee, tea, vegetables, pines, rubber, grassland, and fallow (six months). Apart from fertilizer application rates being different, the soils in these sites are managed in the same manner, *viz.* the soils are untilled, and no mulching materials or irrigation applied. The eight picked up soils were classified as Ultisols and Oxisols (Soil Survey Staff, 2006) and were selected primarily to provide samples with different textures, overall aggregate stability, and different land uses (Table 1).

Ten soil samples were randomly collected from each site and from a soil depth of 0-150 mm. Soil samples were collected from locations at least 20-30 m apart from each other. It should be noted that the ten samples collected from each site were not mixed and made into bulks, but separately stored and then analysed. Thus, a total of 80 soil samples were collected, and then air-dried for a duration of one week (mean room temperature of 25°C and mean relative humidity of 80%). All analyses on the 80 samples were done in triplicates. Particle size analysis was carried out through pipette method (Gee and Bauder, 1986).

Table 1. Characteristics of the soils investigated. Values are means related to ten samples with standard deviations given in brackets.

Soil	Taxonomy	Land use/ Crop	Particle size distribution (%)			MWD (mm)
			Clay < 2 μm	Silt 2-50 μm	Sand > 50 μm	
A	Typic Hapludox	Oil palm	18.74 (10.66)	45.29 (21.83)	35.97 (15.25)	0.95 (0.62)
B	Typic Hapludox	Coffee	63.53 (14.75)	9.96 (6.77)	26.50 (8.06)	2.28 (0.19)
C	Typic Paleudult	Fallow	56.15 (8.44)	14.06 (3.89)	29.79 (4.79)	2.35 (0.20)
D	Typic Paleudult	Tea	45.36 (7.21)	16.69 (0.62)	37.95 (7.03)	3.38 (0.20)
E	Typic Paleudult	Vegetables	57.35 (1.58)	6.71 (0.53)	35.94 (1.58)	2.24 (0.46)
F	Xanthic Hapludox	Pines	37.19 (3.57)	19.68 (0.91)	43.13 (3.24)	1.47 (0.30)
G	Xanthic Hapludox	Rubber	29.12 (5.59)	25.93 (6.16)	44.95 (10.70)	1.64 (0.73)
H	Typic Paleudult	Grassland	46.07 (2.96)	18.57 (1.69)	35.36 (4.42)	2.19 (0.41)

Aggregate stability was assessed through wet-sieving method using a series of nested sieves following the method by de Boodt *et al.* (1961), and Kemper and Chepil (1965). Hundred g samples of uncrushed soil aggregates (0.25–8.0 mm) were wet-sieved using a nest of six sieves with aperture sizes of: 5-8, 3-5, 2-3, 1-2, 0.5-1, and 0.25-0.5 mm. Wet-sieving was performed for 30 minutes, at 40 rpm, through a vertical distance of 40 mm. following wet-sieving, aggregates retained on each sieve were separately collected, oven-dried, and weighted. Aggregate stability of whole soils was expressed as the index Mean Weight Diameter (MWD):

$$MWD = \sum_{i=1}^{n} W_i \bar{x}_i$$

where, $\bar{x}_i$ is the mean diameter of aggregate size fraction i ($i = 1$ to n), and W_i is the proportion of aggregate size fraction i to the total sample weight.

The stability of the six aggregate size fractions (3-5, 2-3, 1-2, 0.5-1, and 0.25-0.5 mm) was each determined by wet-sieving of 100 g of uncrushed aggregates using the wet-sieving method as described earlier. The stability of the individual aggregate size

fraction was expressed as the percentage of water-stable aggregates of size fraction i (AS_i):

$$AS_i = \frac{(W_{ai} - Y_i) - s_i}{W_{ai} - s_i} \times 100\%$$

where, s_i is the correctional weight for sand particles larger than sieve size i.

The experimental design for determining the effects of soil type and aggregate size on aggregate stability was a three-factor partial nested (hierarchical) design (Winer, 1971). The three factors were: (1) soil type; 8 levels, (2) soil sample; 10 levels; nested within soil type, and (3) aggregate size; 6 levels. Factors 1 and 3 were fixed effects, while factor 2 being a random effect. Data was transformed by squaring, before analysis of variance (ANOVA), as the original data had violated the ANOVA assumptions of homogeneity of variance and sphericity. Statistical analysis was performed through SPSS ver. 12 (SPSS Inc., Chicago). Note that factor 1 was given the term "soil type" which should not be interpreted as meaning a rigorous delineation between soils based on any taxonomic classification scheme. The factor "soil type" referred to the eight individual

soils employed in the study, which, as noted earlier, differed one from the other in terms of texture, aggregate stability, as well as land use.

RESULTS AND DISCUSSION

Results obtained through ANOVA revealed that the effects of soil type and aggregate size on aggregate stability were both highly significant (Table 2). The significant effect of soil type was expected as soils in this study were selected partly for their differences in texture and overall aggregate stability (Table 1). Nevertheless, the significant effect of aggregate size revealed that the stability among the six aggregate sizes was significantly different. But most importantly, there was a highly significant interaction observed among the soil type and aggregate size factors.

There was no clear evidence that, with decrease in aggregate size, aggregate stability would either always increase or decrease (Table 3). For soils C and D, aggregate stability decreased with decreasing aggregate size, while for soils A and F, the trend was the opposite namely, aggregate stability increased with decreasing aggregate size. There was a less clear trend observed for other soils. These observations confirm the ANOVA results that these trends were dependent upon both soil type and aggregate size.

The effects of the interaction between soil type and aggregate size on aggregate stability was significant because aggregate stability is a complex result of the interactions among many soil constituents, namely organic matter, clay fraction, as well

as exchangeable cations (Six *et al.*, 2004; Noellemeyer *et al.*, 2008). The beneficial effect of organic matter is dependent on its soillevel of content, type, and its components (polysaccharides, humic acids and fulvic acids), as well as its position (location) within the aggregates (Greenland, 1981). Even within the same soil, the composition of aggregates has often been observed to vary from one size fraction to another. With increase in aggregate size, the level of organic matter and clay content would increase and decrease, respectively (Garey, 1954; Dexter, 1988; Mendonça *et al.*, 1991; Cambardella and Elliott, 1993; Cruvinel *et al.*, 1993). Moreover, organic matter in larger aggregates is usually younger, less resistant and less processed than in smaller aggregates (Parton *et al.*, 1983; Paul, 1984; Elliott, 1986; Gupta and Germida, 1988). The distribution of exchangeable cations was also found to be non-uniform within different size aggregates (Cruvinel *et al.*, 1993); compared to smaller aggregates, the larger ones contained a higher concentration of K while lower Ca concentrations.

Table 4 clearly demonstrates that the stability trend between any two aggregate size fractions would become progressively less linearly related as the differences in aggregate size became larger. For example, the correlation coefficient (r) involving the stability of 5-8 mm fraction dropped from 0.93 (with 3-5 mm) to 0.06 (with 0.25-0.5 mm). A similar trend was observed for all other pairs of aggregate size fractions. However, the 0.25-0.5 mm fraction behaved distinctively from other size fractions. Its stability in general correlated the lowest with all the other aggregate size fractions.

Table 2: ANOVA of a three-factor partial nested design.

Source of variation	*df*	*MS*	*F*
Soil type (S)	7	85140811.0	27.63**
Sample within soil type (SwS)	72	3081794.5	
Aggregate size (A)	5	15912266.0	39.58**
A x S	35	7739467.2	19.25**
SwS x A	360	402073.9	

* $P< 0.05$; ** $P <0.01$.

Table 3. Mean stability of the six aggregate size fractions. Values are means for ten samples with standard deviations given in brackets.

Soil	Aggregate size fractions (mm)					
	5-8	3-5	2-3	1-2	0.5-1	0.3-0.5
A	22.37	22.96	33.91	31.10	38.10	35.01
	(20.15)	(20.77)	(9.93)	(15.63)	(12.09)	(9.81)
B	51.30	62.78	57.71	68.67	67.16	52.89
	(12.20)	(8.75)	(6.12)	(2.79)	(5.85)	(9.35)
C	72.70	75.66	65.79	71.96	62.64	45.95
	(10.27)	(7.99)	(6.37)	(4.77)	(2.98)	(5.71)
D	77.17	72.94	60.16	58.48	48.78	29.50
	(10.31)	(9.85)	(6.17)	(5.80)	(6.92)	(15.17)
E	57.44	45.38	40.58	44.53	49.27	41.78
	(14.66)	(9.99)	(4.91)	(4.96)	(4.27)	(6.76)
F	22.01	31.26	39.29	44.39	50.74	43.15
	(12.73)	(11.75)	(5.12)	(4.61)	(3.81)	(7.57)
G	32.12	38.58	39.91	38.28	41.41	36.98
	(24.00)	(15.45)	(8.82)	(9.85)	(6.80)	(12.44)
H	53.35	52.24	47.13	48.94	50.10	41.65
	(14.70)	(10.90)	(4.31)	(5.05)	(2.76)	(5.76)

Paired sample t-test showed that the stabilities of the five largest aggregate size fractions (> 0.5 mm) were significantly different from the stability of the smallest aggregate size fractions 0.25-0.5 mm (Table 4). The stabilities of the five largest aggregate fractions, however, were not significantly different one from the other. The distinctiveness of 0.25-0.5 mm aggregate size fraction might be explained by this size fraction standing in the intermediate or transitory stage between macro- and microaggregate stabilities (Tisdall and Oades, 1982). Aggregates of 0.25-0.5 mm are more close to the size of 0.25 mm which is the size generally taken as the boundary separating the characteristics of macro- and microaggregates (Tisdall and Oades, 1982). Such a boundary exists because microaggregates are distinctively different from macroaggregates. As mentioned earlier, cementing agents that operate in aggregates larger than 0.25 mm (macroaggregates) are different from those operating in aggregates smaller than 0.25 mm (microaggregates). While microaggregates are stabilised by persistent humic materials and amorphous Fe and as well by Al compounds, macroaggregates are stabilised by such transient binding agents as

Table 4. Correlation coefficient between the stabilities of any two aggregate size fractions. Values given in brackets are the t values of the paired sample t-test.

Aggregate size (mm)	5-8	3-5	2-3	1-2	0.5-1
3-5	0.93**				
	(1.55)				
2-3	0.83**	0.96**			
	(0.28)	(1.90)			
1-2	0.70**	0.86**	0.92**		
	(1.12)	(0.44)	(0.40)		
0.5-1	0.46**	0.64**	0.72**	0.89**	
	(1.00)	(0.42)	(0.30)	(0.27)	
0.3-0.5	0.06	0.21	0.28*	0.41**	0.66**
	(2.57*)	(3.75**)	(4.43**)	(5.94**)	(9.83**)

* $P < 0.05$; ** $P < 0.01$.

roots and fungal hyphae (Tisdall and Oades, 1982). Whereas microaggregate stability is insensitive to changes in soil organic matter and soil management practices, the stability of macroaggregates is susceptible to such factors. Being in this intermediate stage between macro- and microaggregates may explain why the 0.25-0.5 mm fraction is of a different stability as compared with the other (and larger) aggregate size fractions investigated in this study. In addition, the similarities between cementing agents responsible for macroaggregate stability may explain why the stability between the larger aggregates (> 0.5 mm) was different one from the other, but to an insignificant level.

Kemper and Rosenau (1986) indicated that single aggregate size fraction and multiple aggregate size fractions are equally well correlated with such field phenomena as soil fertility. They further suggest that the aggregate size fraction of 1-2 mm is an adequate representation of whole soil stability. In other words, instead of an assessment of the stabilities of several aggregate size fractions, the evaluated stability of aggregate size fraction 1-2 mm should suffice to represent the whole soil stability. The results of the present study are in agreement with the above suggestion, as the stability of the 1-2 mm fraction was shown to be different, but not at significant level from the stabilities of the other aggregate size fractions. Nonetheless, this study also revealed that the 0.25-0.5 mm aggregate size fraction presented a significantly different stability from the larger aggregates. Thus, the stability of the

0.25-0.5 mm fraction might be a better representation of microaggregate stability.

Coefficient of variation (c.v.) was employed to compare the variations of mean aggregate stabilities among the six aggregate size fractions (Table5). Variability decreased with decreasing aggregate size. For instance, variability was the highest in the 5-8 mm aggregate size fraction, followed by the 3-5 mm size fraction. The four lowest aggregate size fractions (2-3, 1-2, 0.5-1, and 0.25-0.5 mm) possessed the least variabilities, with their variabilities almost equal to each other. Variability decreasing with decrease in aggregate size would mean that the stability differences among whole soils are due more to differences in the stability of the larger aggregates (> 3 mm) rather than the smaller ones (< 3 mm).

The trend that the stability between soils would be more dissimilar in the larger aggregate size fractions was probably because the stabilising effects of organic matter on larger aggregates are more varied than their effects on smaller aggregates (Zhang and Horn, 2001). The soils selected in this study were characterized by different land uses. The larger aggregates were probably stabilized by organic matter still characteristic of The larger aggregates were probably stabilized by organic matter still characteristic of the plant type, whereas the smaller aggregates were stabilised by more decomposed and undistinguishable forms of organic matter (Tisdall and Oades, 1982). Organic matter in the larger aggregates is usually younger, more liable, and less processed than in smaller aggregates. Organic matter in the larger aggregates would then exist in more diverse forms than in smaller aggregates

Table 5. Descriptive statistics of the stability of the six aggregate size fractions.

Aggregate size (mm)	Mean	Standard error of mean	Standard deviation	Coefficient of variation (c.v.)
5-8	48.56	2.79	24.94	0.51
3-5	50.22	2.43	21.71	0.43
2-3	48.06	1.42	12.73	0.26
1-2	50.79	1.73	15.44	0.30
0.5-1	51.03	1.23	11.00	0.22
0.3-0.5	40.87	1.27	11.36	0.28

where the organic matter is more intensely decomposed into further similar and stable forms of humus.

CONCLUSIONS

It was finally indicated in this study that for Ultisols and Oxisols, it was unnecessary to measure the stability of individual aggregate size fractions. Instead, the stability of a single aggregate size fraction (*e.g.*, 1-2 mm) could be used to represent the macroaggregate stability of soils. Nonetheless, the stability of 0.25-0.5 mm aggregate size fraction was found to be distinctly different from the stability of the larger aggregate sizes. The stability of 0.25-0.5 mm aggregate size fraction was probably more representative of microaggregate stability.

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س. ب. س. ته

چکیده

استحکام کلوخه یکی از خواص مهم خاک است زیرا مقاومت خاک در برابر فرسایش آبی را تعیین می‌کند. اهداف این مطالعه عبارت بودند از: ۱) مقایسه استحکام شش اندازه کلوخه با یکدیگر به منظور تعیین تاثیر اندازه کلوخه بر استحکام آن و ۲) تعین کلاس اندازه کلوخه‌ای که می‌تواند در مقایسه با دیگر کلاسهای پایداری اکثر خاکها را مشخص نماید. از شش خاک رده بندی شده به عنوان خاک‌های آلتیسول و آکسیسول از کاربری‌های متفاوت و بافت و استحکام کلوخه متفاوت نمونه‌برداری شد و خاک‌ها به شش گروه اندازه کلوخه ۸-۵، ۵-۳، ۳-۲، ۱-۰/۵ و ۰/۵-۰/۲۵ تقسیم شدند. استحکام کلوخه کل خاک‌ها و هر اندازه کلوخه به وسیله غربال کردن در حالت تر در غربال‌های تودرتو تعیین گردید. این مطالعه نشان داد که: ۱) رابطه بین استحکام کلوخه و اندازه آن هم به نوع خاک و هم به اندازه کلوخه بستگی دارد. ۲) با افزایش تفاوت اندازه کلوخه، رابطه بین استحکام هر دو اندازه کلوخه بیشتر از حالت خطی خارج می‌شود. ۳) در هر خاک، استحکام کلوخه‌های درشت (mm۰/۵<) به طور معناداری با استحکام کلوخه‌های ریز (mm ۰/۲۵-۰/۵) متفاوت بود و ۴) تفاوت در استحکام کلوخه بین انواع کل خاک بیشتر به تفاوت استحکام کلوخه‌های درشت‌تر از ۳ میلی‌متر مربوط بود. این مطالعه نشان داد که برای خاک‌های آلتیسول و آکسیسول نیازی به اندازه‌گیری استحکام اندازه‌های مختلف کلوخه به‌طور جداگانه نیست. در عوض، می‌توان از استحکام یک اندازه کلوخه به عنوان معرف استحکام کلوخه‌های درشت خاک بهره برد.