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THE UNDERLYING FRAMEWORK OF AGGREGATE STABILITY MEASUREMENTS

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ABSTRACT

Factor analysis was used to differentiate between efficient and inefficient aggregate stability indices, and to determine which of these indices can satisfactorily represent aggregate stability. Aggregate stability of 80 soil samples (Ultisols and Oxisols) were measured using six indices. 1) percentage of water-stable aggregates > 0.3 mm (WSA > 0.3), 2) average percentage of water-stable aggregates of all aggregate size fractions (AIA), 3) water-dispersible clay (WDC), 4) water-dispersible clay plus silt (WDCS), 5) mean weight diameter after wet-sieving (MWD_W), and 6) clay ratio (CR). Factor analysis showed that no matter how different the indices are from each other, or which aspects of aggregate stability the indices measure, all aggregate stability indices would ultimately relate back to two main aspects of aggregate stability, aggregate breakdown resistance and dispersion. Depending on how strongly an index relates back to these two main aspects, the efficiency of the indices were ranked as: WSA > 0.3 = WDCS > AIA > MWD_W > WDC > CR. The best index to measure aggregate breakdown resistance was WSA > 0.3, while WDCS measured dispersibility the best. Thus, to measure aggregate stability efficiently only WSA > 0.3 and WDCS are needed. The six indices measured aggregate breakdown resistance more than dispersion. This is because aggregate breakdown resistance is a broader aspect of aggregate stability than dispersion.

INTRODUCTION

Aggregate stability is a measure of the aggregates' ability to resist disruptive forces (Hillel, 1982). Behind this simple meaning, however, hides the complexity of aggregate stability behaviour. Part of its complexity stems from the fact that aggregate stability cannot be measured directly; neither can it be measured adequately. Moreover, being influenced by many and interacting factors, aggregate stability has many aspects to it that could be used to measure its property. Current ways to measure aggregate stability include the use of indices. But aggregate stability indices are inadequate measure or representation of aggregate stability because each type of index covers only a limited range of aggregate stability aspects. In other words, no single index is suitable for all circumstances (Payne, 1988).

Because of this, some researchers (Bryan, 1971; Cattell, 1965; Epstein, 1983; Sharma and Aggarwal, 1984) recommend the use of many indices or types of measurement to measure a single property that is itself a composite of many characteristics or attributes. In this way, more aspects of aggregate stability will be covered, thereby giving a more holistic evaluation of aggregate stability.

Thus the objective of this study was determine the interrelationships and relative efficiencies among several aggregates stability indices; that is to analyze the underlying structure or framework of aggregate stability measurement. By doing this, it was hoped not only to discern between efficient and inefficient indices, but also to determine the number of indices (and which indices) that can give an adequate representation of aggregate stability.

MATERIALS AND METHODS

Eight areas were sampled in *Universiti Pertanian Malaysia*. The areas were under oil palm, coffee, tea, rubber, pine, fallow, vegetables, and grassland. From each area, ten soil samples were sampled randomly from a depth of 0-15 cm. The eighty soil samples (Ultisols and Oxisols) were air-dried. Particle size distribution was analyzed by the pipette method, and the percentages of primary particles were used to calculate the clay ratio (CR) index (Bouyoucos, 1935). Five other indices were used to measure aggregate stability, average water-stable aggregates of all aggregate size fractions (AIA), water-stable aggregates > 0.3 mm (WSA > 0.3), mean weight diameter after wet-sieving (MWD_W), water-dispersible clay (WDC), and water-dispersible clay plus silt (WDCS). Before any aggregate stability tests, all soil samples were pre-wetted by incubation under room temperature and at approximately 98% relative humidity for 24 hours.

Wet-sieving

Wet-sieving was similar to the method by de Boodt *et al.* (1961), and Kemper and Chepil (1965). Samples were wet-sieved using a nest of sieves with openings of 8.0, 4.76, 2.83, 2.0, 1.0, 0.5 and 0.3 mm. Wet-sieving was for 30 minutes, at 40 rpm, and through a vertical distance of 4.0 cm. After wet-sieving, sand content was determined for sand correction. From wet-sieving, three aggregate stability indices were calculated: AIA, WSA > 0.3, and MWD_W.

Water-dispersible clay (WDC), and water-dispersible clay plus silt (WDCS)

Five grams of soil (< 2 mm) were added to 50 ml distilled water (ratio of soil to water was 1:10), and shaken end-over-end for 30 minutes at 40 rpm. The contents were then poured into a 1-litre measuring cylinder, the volume made up to one liter, and the solution gently stroked up down to distribute the contents. The clay and silt particles were siphoned at 10 cm depth using a 25 ml pipette at the appropriate settling time (according to Stoke's Law). WDC was expressed as the percentage of dispersed clay to the total amount of clay (obtained from mechanical analysis); and WDCS as the percentage of dispersed clay and silt to the total amount of clay and silt (obtained from mechanical analysis).

Statistical analysis

To identify and summarize the relationship patterns among the six indices, a multivariate statistical method called *factor analysis* was used. Before indices were factor analyzed, they were checked for violations of normality. Only the CR index had severely violated normality (skewness=2.71; kurtosis=7.79), and was transformed by: ln (CRx100). All indices were standardized to have zero means and variance of one (standardized variables were prefixed with the letter *z*). The whole data set was then tested if it was appropriate for factor analysis by using Bartlett's test of sphericity, and Kaiser-Meyer-Olkin measure of sampling adequacy (KMO). Factors were extracted by Principal factor method; the number of factors selected based upon Cattell's Scree test; and the rotation of factors was by the oblique rotation of Direct Oblimin. All factor analysis computations were done using SPSS for Windows[1] release 6.0.

RESULTS AND DISCUSSION

Table 1 shows the correlation coefficients between all pairs of aggregate stability indices. WSA > 0.3 correlated the highest with all other indices. Its correlation with MWD_W was strong (r = 0.80**) but even stronger with AIA (r = 0.87**). Comparing with MWD_W, AIA has stronger correlations with all other indices.

Table 1. Correlation matrix between all pairs of aggregate stability indices

	AIA	MWD_W	WSA>0.3	WDC	WDCS	*T*CR
AIA	—					
MWD_W	.77**	—				
WSA > 0.3	.87**	.80**	—			
WDC	-.45**	.26*	-.47**	—		
WDCS	-.63**	-.41**	-.69**	.77**	—	
*t*CR	-.63**	-.61**	-.76**	.37**	.53**	—
*p<0.05	**p<0.01	prefix *t* – denotes transformed variable				

The appropriateness of data was tested and found to be suitable for factor analysis because: 1) Bartlett's test of sphericity was convincingly rejected (389.99; p < .0000), and 2) KMO sampling adequacy was measured at 0.81 (1.00 being the highest). Moreover, factor analysis produced a low anti-image covariance matrix, and reproduced the correlation matrix (Table 1) accurately with 0.0% residuals of absolute values above 0.05. Using Cattell's Scree Test, two common factors were selected. Table 2 shows the unrotated and rotated factor matrix.

Table 2 shows that the six aggregate stability indices, though different from one another, were related to one another in two common factors. This means the various aspects of aggregate stability the six indices measure are ultimately related to two larger aspects of aggregate stability as represented by the two common factors.

To identify the first and second common factors, it is crucial to consider the remark by Emerson (1954) and Emerson and Greenland (1990). They noted that aggregate breakdown encompasses only two main phenomena: slaking and dispersion. Slaking is the breakdown of aggregates due to explosion of entrapped air within the aggregates whereas dispersion is the discharge of primary particles from the aggregates. Slaking is usually measured using the wet-sieving method.

From the factor structure in Table 2b, the first common factor correlated strongly with the first three indices: AIA, MWD_W, and WSA > 0.3. These three indices are so-called "wet-sieving indices" because they are derived from the results of wet-sieving process. They tend to measure the aggregates' ability to retain their sizes during the disruptive effects of water. On the other hand, the second common factor correlated more strongly with indices that are derived from the dispersibility of primary particles. These indices were WDC and WDCS.

[1] SPSS is registered trademark of SPSS Inc., and Windows is a trademark of Microsoft Corporation.

Table 2. Correlation of factors with indices, where: (a) unrotated factor structure, and (b) rotated factor structure

Indices (a)	Factor 1	Factor 2	Variance explained by factors
zWSA >0. 3	.96	.19	.97
zAIA	.88	.17	.80
zWDCS	-.82	.54	.97
zMWD,	.77	.41	.76
ziCR	-.73	-.14	.55
zWDC	-.60	.51	.62
Variance explained by indices	.643	.134	.777

Indices (b)	Factor 1	Factor 2
zWSA >0.3	.98	-.63
zAIA	.89	-.57
zMWDw	.86	-.34
ziCR	-.74	.48
zWDCS	-.61	.98
zkVDC	-.42	.79

Relationship between the two common factors:

	Factor 1	Factor 2
Factor 1	1.00	
Factor 2	-.55	1.00

Therefore, applying the remark by Emerson (1954) and Emerson and Greenland (1990), the first common factor can be interpreted as slaking and the second common factor as dispensability. However, that the first common factor represents slaking, though correct, is imprecise. Slaking is only one way larger aggregates could breakdown into smaller pieces. Other physical disruptions such as by water agitation during wet-sieving or by the falling impacts of raindrops can also cause aggregate breakdown. Therefore, it would more precise to interpret the first common factor as representing a larger or more generic aspect than slaking. Thus, the first common factor was interpreted as representing the *aggregate breakdown resistance* whilst the second common factor as the *dispersion* aspect.

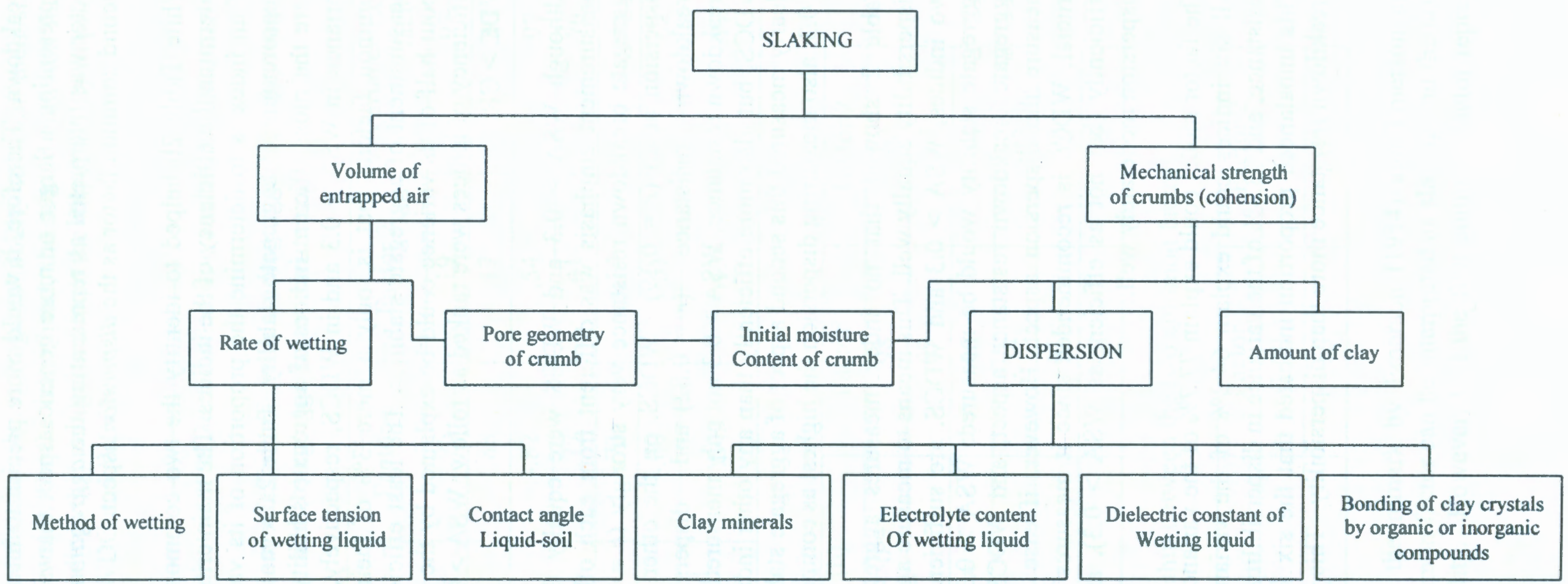
While Table 2b helped to identify the two common factors, Table 2a was used to determine the efficiency of the indices. The main criterion to determine the efficiency of an index is to determine the proportion of its variance that was involved in the measurement of aggregate stability. Table 2a revealed that WSA > 0.3 and WDCS were the most efficient indices of aggregate stability. This was because 97% of the variance in WSA > 0.3 and in WDCS, respectively, could be explained by the two common factors; that is, only a mere 3% of their variance was involved in the measurement of aggregate stability. The least efficient index was CR because only about half of its variance could be explained by the two common factors. Thus, the efficiency of indices were ranked as follow: WSA > 0.3 = WDCS > AIA > MWD_W > WDC > CR.

Although WSA > 0.3 and WDCS were equally the most efficient indices, their measurement emphasis was different from each other. WSA > 0.3 measured the aggregate breakdown resistance very strongly (r = 0.96) but almost not measuring dispersion at all (r = 0.19). WDCS, on the other hand, measured both aggregate breakdown resistance (r = 0.82) and dispersion (r = 0.54). For aggregate breakdown resistance, WSA > 0.3 not only measured this aspect more efficiently than WDCS, but also more efficiently than any other indices. But for dispersion, WDCS clearly measured this second aspect of aggregate stability more efficiently than WSA > 0.3; also measuring dispersion the highest as compared to other indices.

Table 2 showed that no index measures aggregate breakdown resistance and dispersibility equally well. This means to measure aggregate stability efficiently, only two indices, WSA > 0.3 and WDCS, are sufficient. In this way, both aspects of aggregate stability would be measured: WSA > 0.3 stressing very strongly on the aggregate breakdown resistance aspect, and WDCS index is needed to include or measure the dispersion aspect. However, if ease and speed of measurement are crucial, WDCS is recommended since it measures aggregate breakdown resistance efficiently (but not as efficient as WSA > 0.3), and at the same time measuring dispersion moderately well.

The factor model could explain 77.7% of the variance in all the six indices (Table 2). All six indices could explain 64.3% of the variance in the aggregate breakdown resistance, and 13.4% of the variance in dispersibility was explained by all six indices. This unbalanced proportion indicated that the six indices measured the aggregates' breakdown resistance more than dispersibility. This was true for every index.

Figure 1: Important factors of slaking and dispersion (after Emerson, 1954)



This unequal emphasis in measurement is because slaking is a broader aspect than dispersion, being influenced by more factors, and that dispersion is a subset of slaking (Figure 1). Although the chart in Figure 1 by Emerson (1954) involves slaking, not the more generic aspect of aggregate breakdown resistance as used in this study, this chart is still applicable to explain the relationship between dispersion and aggregate breakdown resistance since the latter aspect encompasses the more specific slaking phenomenon.

From Figure 1, the factors important to dispersion such as the characteristics of the liquid and the type of clay minerals were similar in all soils used in this study. Although the soils were not analyzed for their clay mineral types, it is unlikely that these soils (Ultisols and Oxisols) would have such differing clay mineral types to affect dispersibility differently. The only factor affecting dispersibility differently among the soils is the amount (and type) of organic and inorganic compounds. Slaking, on the other hand, is influenced by the same factors affecting dispersion and by other factors unique only to slaking. In other words, slaking is influenced by more extensive factors than dispersion, which is why slaking (hence, aggregate breakdown resistance) tends to be measured more by the aggregate stability indices as compared to dispersion.

CONCLUSIONS

Factor analysis showed that no matter how different the indices are from each other, or which aspects of aggregate stability the indices measure, all aggregate stability indices would ultimately relate back to two main aspects of aggregate stability: aggregate breakdown resistant and dispersion. Depending on how well an index relates back to either or both of these two main aspects, the efficiency of the indices were ranked as follow: WSA > 0.3 = WDCS > AIA > MWD_W > WDC > CR. The index WSA > 0.3 was the best index to measure aggregate breakdown resistance, while WDCS measured dispersibility the best. Factor analysis also showed that WSA > 0.3 and WDCS were sufficient to measure aggregate stability efficiently.

Factor analysis revealed that aggregate stability indices tend to measure aggregate breakdown resistance more than dispersion. This is because aggregate breakdown resistance is a broader aspect than dispersion, being influenced by more factors than dispersion, and that dispersion is a subset of aggregate breakdown resistance. Aggregate resistance and dispersion correlated moderately with each other at –0.55.

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