



UNIVERSITI PUTRA MALAYSIA

**SOIL AGGREGATE STABILITY: ITS EVALUATION AND
RELATION TO ORGANIC MATTER CONSTITUENTS AND
OTHER SOIL PROPERTIES**

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SOIL AGGREGATE STABILITY: ITS EVALUATION AND
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OTHER SOIL PROPERTIES

By

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*Dedicated to:
God,
my parents,
Bonnie,
and Grey*



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LIST OF ABBREVIATIONS

AIA	average intact aggregates
C-P-OM	clay-polyvalent cation-organic matter
c.v.	covariation
CEC	cation exchange capacity
CR	clay ratio
EI	erosion index
FA	fulvic acid
FA COOH	carboxyl functional groups in fulvic acid
FA OH	phenolic-hydroxyl functional groups in fulvic acid
HA	humic acid
HA COOH	carboxyl functional groups in humic acid
HA OH	phenolic-hydroxyl functional groups in humic acid
KMO	Kaiser-Meyer-Olkin sampling adequacy test
LOI	loss-on-ignition
MWD _w	mean weight diameter after wet-sieving
polysac.	polysaccharides
PRESS	prediction error sum of squares
SSE	sum square of error
TP	turbidity percentage
WDC	water-dispersible clay
WDCS	water-dispersible clay plus silt
WSA >0.3	water-stable aggregates larger than 0.3 mm
WSA >0.5	water-stable aggregates larger than 0.5 mm



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Faculty: Agriculture

The purpose of this study were: 1) to compare the aggregate stability of individual aggregate size fractions, 2) to determine the interrelationship and efficiency of several aggregate stability indices, and 3) to determine the relationship and importance of organic matter and other soil constituents on aggregate stability.

To compare the aggregate stability of individual aggregate size fractions, a mathematical model was developed to estimate the breakdown of individual aggregate size fractions in the wet-sieving (using nested sieves) method. This model was validated and calibrated by comparing the estimation values to the actual aggregate breakdown values by paired sample t-test, linear regression and prediction



error sum of squares. The average percentage of stable aggregates for all aggregate size fractions were represented in an index called average intact aggregates (AIA).

Factor analysis was used to determine the interrelationship and efficiency of several aggregate stability indices. Aggregate stability of eight soil samples were measured with eight indices: percentage of water-stable aggregates >0.3 mm (WSA >0.3) and >0.5 mm (WSA >0.5), AIA, water-dispersible clay (WDC), water-dispersible clay and silt (WDCS), mean weight diameter after wet-sieving (MWD_w), turbidity percentage (TP), and clay ratio (CR).

To determine the relationship between aggregate stability and soil constituents, whole soils as well as individual aggregate size fractions were analyzed. For analysis of whole soils, nine soil samples were analyzed for organic matter and its constituents, texture, free iron oxides, aggregation, bulk density, cation exchange capacity and exchangeable cations. Aggregate stability of whole soils were measured with the same eight indices used in the factor analysis study. For analysis of individual aggregate size fractions, four soils were selected. Each soil was separated into six aggregate size fractions: 1000-2000 μm , 500-1000 μm , 250-500 μm , 150-250 μm , 53-150 μm , and <53 μm . Each aggregate size fraction was analyzed as done in the analysis of whole soils. However, additional analysis included free aluminum oxides and the carboxyl (COOH) and phenolic hydroxyl (OH) functional groups in humic acid (HA) and fulvic acid (FA). Aggregate stability was measured using WDCS, WDC and TP indices.

The mathematical model to estimate the aggregate breakdown was very accurate. Because of this model, aggregate stability of individual aggregate size fractions could be determined and compared with each other. Within a soil, there were three aggregate size groups of insignificantly different stabilities: 1) 2.0-8.0

mm. 2) 0.5-2.0 mm, and 3) 0.3-0.5 mm. Also, the differences in aggregate stability among soils were largely due to the differences in stability of the larger aggregate size fractions of 2.0-8.0 mm.

Factor analysis showed that all aggregate stability indices are related to two main aspects of aggregate stability: aggregate breakdown resistance and dispersion. Depending on how well an index relates back to these two aspects, the efficiency of the indices were: (WSA >0.3) = (WSA >0.5) = WDCS > AIA > MWD_w > WDC > CR. The TP index was unreliable because it is unsuitable to make turbidimetric comparisons among different soils types. To measure aggregate stability efficiently on the whole, only two indices are sufficient: WSA >0.3 (or WSA >0.5) and WDCS.

For analysis of whole soils, soil constituents associating significantly to aggregate stability were fine sand, very fine sand, fulvic acid and K cation. Finer sand particles may be vital because the formation of stable aggregates needs a certain ratio between clay and finer sand particles. The insignificant correlations of other organic matter fractions to aggregate stability were probably due to the low variability of the constituents among the soils. For analysis of individual aggregate size fractions, dispersibility as measured by WDCS would increase with increasing amounts of silt, HA COOH and FA OH, but with decreasing amounts of free Fe oxides and fine sand. The order of relative importance were: silt > free Fe oxides > fine sand > FA OH > HA COOH. The adverse effect of the functional groups in HA and FA on aggregate stability is probably because HA and FA are negatively charged; thus repel and disrupt interparticle bonds between clay particles.

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**KESTABILAN AGREGAT TANAH: PENILAIAN DAN
PERHUBUNGANNYA DENGAN KONSTITUEN-KONSTITUEN BAHAN
ORGANIK DAN LAIN-LAIN SIFAT TANAH**

OLEH

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September 1996

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Tujuan kajian ini adalah untuk: 1) membandingkan kestabilan agregat tiap-tiap kumpulan saiz agregat, 2) menentukan saling perhubungan dan kecekapan beberapa indeks kestabilan agregat, dan 3) menentukan perhubungan dan kepentingan bahan organik dan lain-lain konstituen tanah kepada kestabilan agregat.

Untuk membandingkan kestabilan agregat tiap-tiap kumpulan saiz agregat, satu model matematik telah dibentuk untuk menaksir pemecahan tiap-tiap kumpulan saiz agregat dalam kaedah ayakan basah (cara ayak bertingkat). Model ini telah diuji dan dikalibrasi dengan membandingkan nilai-nilai taksiran dengan nilai-nilai pemecahan agregat sebenar dengan menggunakan ujian sampel t, regresi linear dan jangkakan jumlah ralat ganda dua. Purata peratusan agregat stabil bagi kesemua

kumpulan saiz agregat diwakili oleh suatu indeks bernama purata agregat tidak pecah (AIA).

Analisis faktor telah digunakan untuk menentukan saling perhubungan dan kecekapan beberapa indeks kestabilan agregat. Kestabilan agregat lapan sampel tanah diukur dengan lapan indeks: peratusan agregat stabil air >0.3 mm (WSA >0.3) dan >0.5 mm (WSA >0.5), AIA, pemeroian lempung oleh air (WDC), pemeroian lempung dan kelodak oleh air (WDCS), purata berat diameter selepas ayakan basah (MWD_w), peratusan kekerohan (TP), dan nisbah lempung (CR).

Untuk menentukan perhubungan antara kestabilan agregat dan konstituen-konstituen tanah, keseluruhan tanah dan kumpulan-kumpulan saiz agregat telah dianalisis. Untuk penganalisan keseluruhan tanah, sembilan sampel tanah dianalisis untuk bahan organik dan konstituennya, tekstur, ferum oksida bebas, pengagregatan, ketumpatan pukal, keupayan penukaran kation dan kation tukarganti. Kestabilan agregat keseluruhan tanah telah diukur dengan lapan indeks yang sama seperti yang digunakan dalam kajian analisis faktor. Untuk penganalisan kumpulan saiz agregat, empat tanah telah dipilih. Setiap tanah dibahagikan kepada enam kumpulan saiz agregat: 1000-2000 μm , 500-1000 μm , 250-500 μm , 150-250 μm , 53-150 μm , dan <53 μm . Setiap kumpulan saiz agregat dianalisis seperti mana yang telah dilakukan untuk analisis keseluruhan tanah. Walau bagaimanapun, tambahan analisis termasuk aluminium oksida bebas dan kumpulan berfungsi karbosilik (COOH) dan hidroksil fenolik (OH) dalam asid humik (HA) dan asid fulvik (FA). Kestabilan agregat diukur dengan WDCS, WDC dan TP.

Model matematik untuk menaksir pemecahan agregat amat tepat. Oleh kerana model ini, kestabilan agregat setiap kumpulan saiz agregat dapat ditentukan dan dibandingkan antara satu sama lain. Dalam suatu tanah terdapat tiga kumpulan saiz

agregat yang mempunyai perbezaan kestabilan yang tidak bermakna: 1) 2.0-8.0 mm, 2) 0.5-2.0 mm, dan 3) 0.3-0.5 mm. Lagi pun, perbezaan kestabilan agregat antara tanah kebanyakan disebabkan oleh perbezaan kestabilan kumpulan-kumpulan saiz agregat yang lebih besar iaitu 2.0-8.0 mm.

Analisis faktor menunjukkan bahawa kesemua indeks kestabilan agregat berhubung kait kepada dua aspek utama kestabilan agregat: ketahanan pecahan agregat dan pemeroian. Bergantung kepada betapa kuatnya sesuatu indeks berhubungkait dengan dua aspek tersebut, kecekapan indeks-indeks adalah: $(WSA > 0.3) = (WSA > 0.5) = WDCS > AIA > MWD_w > WDC > CR$. Indeks TP tidak cekap kerana perbandingan kekerohan antara jenis-jenis tanah berlainan adalah tidak sesuai. Untuk mengukur kestabilan agregat pada keseluruhannya dengan cekap, hanya dua indeks sudah memadai: $WSA > 0.3$ (atau $WSA > 0.5$) dan WDCS.

Untuk analisis keseluruhan tanah, konstituen-konstituen tanah yang berkorelat dengan bermakna dengan kestabilan agregat adalah pasir halus, pasir sangat halus, asid fulvik dan kation K. Kumin-kumin pasir yang halus mungkin penting kerana pembentukkan agregat stabil memerlukan nisbah antara lempung dan kumin pasir halus yang tertentu. Korelasi-korelasi yang tidak bermakna antara lain-lain komponen bahan organik dengan kestabilan agregat mungkin disebabkan oleh kebanyakan tanah mempunyai amaun komponen bahan organik tersebut yang hampir sama. Untuk analisis setiap kumpulan saiz agregat, pemeroian seperti yang diukur dengan WDCS akan meningkat dengan meningkatnya amaun kelodak, HA COOH, FA OH, tetapi pemeroian akan meningkat dengan berkurangnya amaun ferum oksida bebas dan pasir halus. Aturan kepentingan konstituen-konstituen tanah adalah: kelodak > ferum oksida bebas > pasir halus > FA OH > HA COOH. Kesan negatif kumpulan-kumpulan berfungsi dalam HA dan FA kepada kestabilan agregat mungkin kerana HA dan FA bercas negatif, lalu menolak dan memecah ikatan antara partikel lempung.

CHAPTER I

INTRODUCTION

Whenever water is supplied from rainfall or irrigation, it is important that the soil absorbs this water. Otherwise water is wasted and erosion happens. How well a soil absorbs water depends strongly on the characteristics and stability of its aggregates. Especially when the soil is initially very dry, the aggregates must be able to sustain their structure under rainfall. To lose their structure means the dispersed clay particles would clog up the pores and form crusts at the soil surface. These crusts would impede infiltration of water into the soil and promote erosion especially through surface run-off. However, this does not mean that stronger aggregates are always favourable. Aggregates must be weak enough so that plant roots could burrow into the soil, but yet strong enough to resist structural breakdown when subjected to mechanical stress (Emerson and Greenland, 1990).

Aggregate stability is the ability of aggregates to resist disruptive forces (Hillel, 1980), and as noted above, it is a very important soil physical property affecting not only erosion but many other soil properties as well. This is why aggregate stability is studied extensively even as early as 1920s. In the study of aggregate stability, however, researchers often encounter diverse problems like trying to explain the poor performance of certain types of organic matter, or to explain the inconsistent effects of certain soil factors on aggregate stability. But from the review of literature, it seems that all of these problems can be summarized into three statements: 1) it is difficult to measure aggregate stability, 2) it is difficult to detect causality and to determine the relative importance of several aggregate stability



factors, and 3) it is difficult to deal with the diverse nature of the soil constituents that affect aggregate stability. Although most researchers are aware of these three problems, it is quite surprising that none of them has ever explicitly discussed these three problems together in their study of aggregate stability.

It is difficult to measure aggregate stability either directly or adequately because aggregate stability is influenced by many and interacting factors. Aggregate stability has many aspects to it that could be used by the indices to measure its property. Indices, however, are inadequate measure or representation of aggregate stability because each index covers only a limited range of aggregate stability aspects. In other words, no single index is suitable for all circumstances (Payne, 1988).

This is why some researchers recommend the use of several indices simultaneously so that each index measures an aspect (or aspects) of aggregate stability not measured by the other indices. In this way, more aspects will be covered, thereby evaluating aggregate stability more completely. Although using several indices simultaneously is better than using only one index, this raises two more problems: *Of the many indices that are available today, how many and which indices should one use? Even if one uses several indices, how would one know if these indices had thoroughly measured aggregate stability or not?*

The first and most important step in solving these two problems is unwittingly solved by Emerson (1954) and Emerson and Greenland (1990). According to these researchers, aggregate stability encompasses only two main aspects: slaking and dispersion. This means all aggregate stability indices, no matter how different they are from each other, or how differently they measure aggregate



stability, are ultimately related to these two main aspects of aggregate stability. This "linking back" is crucial because in the second step, a multivariate statistical method called factor analysis can be used to measure how strongly an index relates back to either or both slaking and dispersion. Hence, an index's efficiency in measuring aggregate stability can be gauged accurately. Factor analysis is a powerful technique because it identifies, summarizes and analyses the patterns of relationship among several aggregate stability indices. In this way, factor analysis can help, not only to measure the efficiency of an index, but also to determine the minimum number of indices and which indices that can effectively measure aggregate stability.

Another related problem in the study of aggregate stability is the difficulty in detecting causality and in determining the relative importance of aggregate stability factors. It is difficult to verify whether the statistically significant relationship between a soil factor and aggregate stability is due to causality or merely an association. Causality is different from associations because causality is an effect of a factor on aggregate stability, whilst association is merely how one factor changes when the level of aggregate stability changes. Causality can only be inferred from controlled experiments. However, controlled experiments have a major disadvantage: they can overestimate the effect of a factor because other important factors of aggregate stability are controlled. But correlational studies (for measuring associations) may measure the effect of a factor more realistically because all factors are considered simultaneously.

It is a common misconception to believe that high correlations between aggregate stability and its factors are necessary before these factors are considered important enough. Several statisticians (Abelson, 1985; Cattell, 1965; Epstein, 1983) have shown that for a property like aggregate stability, low or moderate correlations,

not high correlations are expected because aggregate stability is a result of the continuous effects of several soil factors.

The study of aggregate stability is also complicated due to the diverse nature of soil constituents. Because of their diverse nature, relationship between aggregate stability and its factors have been inconsistent. A good example is the dual behaviour of organic matter. Although organic matter and its fractions usually stabilize aggregates, they can also cause clay dispersion (Emerson, 1983; Oades, 1984).

Today it is insufficient to merely relate the characteristics of soil improvements with how much one puts organic matter into the soil. Several researchers have shown that total organic matter can deviate more often than like in its influence over soil properties. Manures and sludges are two such examples that continue to frustrate plans to form a simple conclusion on organic matter behaviour (Avnimelech and Cohen, 1988).

With this growing awareness, researchers now shift their attention to the effects of the organic matter constituents, namely humic acid, fulvic acid and polysaccharides on aggregate stability. But by going into this detail, researchers now face a myriad of new problems instead. Because the chemical structures of humic acid and fulvic acid are still uncertain, it is difficult to explain why in temperate mineral soils humic acids are better than fulvic acids in improving aggregate stability, and why the opposite is true in tropical mineral soils; or in equal amounts, which is better in increasing aggregate stability. Cheshire et al. (1983) went as far as to say that all soils are stabilized by polysaccharides. This may be true, but local researchers Soong (1980) and Tajuddin (1992) discovered that polysaccharides may not be as important as compared to other soil constituents because the amount of

polysaccharides in the soils that they studied did not correlate significantly to aggregation or aggregate stability.

Researchers have also begun to search extensively for chemical characteristics that they believe control the behaviour of organic matter constituents. Most researchers now believe that functional groups such as carboxylic acids and phenolic-OH groups in humic acids and fulvic acids are the major performers in affecting aggregation and aggregate stability.

Other soil constituents like iron and aluminum oxides, particle size distribution, and cations are also studied extensively because organic matter constituents, though extremely important to aggregate stability, rarely operate alone. The aggregate model C-P-OM (clay-polyvalent cations-organic matter), for example, shows that organic matter needs both clay and cations to form and stabilize aggregates. Nevertheless, an often neglected area of study is to determine how the aggregate sizes affect aggregate stability. Most researchers measure aggregate stability of whole soils, then attempt to determine how aggregate stability relates to the constituents or properties of whole soils. Aggregate stability of individual aggregate size fractions, especially aggregates smaller than 250 μm , are often neglected. The size of the aggregates should not be neglected because the chemical and physical properties of aggregates vary with their sizes, and are different from whole soils. Why this is so is related to the aggregation process. For all soils, there exists some sort of aggregate hierarchy, where larger aggregates are assemblages of smaller aggregates or particles. And because of this aggregate hierarchy, certain aggregate size fractions have their own distinct physical and chemical properties. For example, the distribution of some soil constituents especially organic matter decreases in amount with decreasing aggregate size (Elliott, 1986). Moreover, aggregate stability of aggregate size fractions may be different from one another

because the mechanism of aggregate stability varies with the aggregate sizes. Tisdall and Oades (1982), for example, proposed three different types of cementing agents operating at different aggregate sizes.

Therefore, the general objective of this study is to critically evaluate aggregate stability, and to determine the relationship between aggregate stability and the soil constituents and the aggregate sizes. The specific objectives are:

- a) To develop a mathematical model to estimate the aggregate breakdown of individual aggregate size fractions in the wet-sieving method using *nested sieves*, so that the aggregate stability of individual aggregate size fractions can be compared with each other.
- b) To discern between efficient and inefficient aggregate stability indices, and to determine the minimum number of indices and which indices that can efficiently measure or represent aggregate stability. This is to be done using a multivariate statistical method called factor analysis.
- c) To determine the relationship and relative importance of organic matter constituents and other soil properties on aggregate stability.

For the first objective, a mathematical model needs to be developed because to separately wet-sieve each aggregate size fraction is too tedious and time-consuming. To compare the aggregate stability of individual aggregate size fractions with one another, the best method is the wet-sieving method because several aggregate sizes can be used. Other methods like raindrop shatter test or water dispersibility tests do not allow a wide range of aggregate sizes to be tested. Wet-sieving using nested sieves, however, do not measure the aggregate stability of

individual aggregate size fractions, only the aggregate stability of whole soils. Therefore, a model is needed to estimate very accurately the aggregate stability of individual aggregate size fractions when all aggregate size fractions are wet-sieved simultaneously in the nested sieves.

CHAPTER II

LITERATURE REVIEW

Measurement of aggregate stability

The study of aggregate stability is in a way quite ironic: to understand the meaning of aggregate stability is very simple, but yet to explain its behaviour can be difficult. Although there are many definitions to aggregate stability, ranging from broad to specific definitions, aggregate stability is simply the measure of the aggregates' ability to resist disruptive forces (Hillel, 1982). Therefore, aggregates of one soil that resist stronger than aggregates of another soil has the higher or better aggregate stability. This is essentially what aggregate stability means. However, to explain why one soil has higher aggregate stability than another may not be as easy. This is because aggregate stability is influenced by many factors (Elliott, 1986; Krishna Murthi et al., 1977; Little, 1989); one of them being organic matter and its constituents such as humic acid, fulvic acid and polysaccharides. Particle size distribution is also just as important; so are iron and aluminum oxides, and the cations in the soil. Not only are there many factors that affect aggregate stability, but these factors can interact with one another as well. Consequently, whenever the relationship between aggregate stability and the soil properties is discussed, one usually jumps ahead to immediately review the individual effects of these factors. But to do this, misses a subtle but important issue; that is, the measurement of aggregate stability.

