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Modelling The Dynamics of Soil Aggregate Breakdown And Distribution of Ruptured Aggregates

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Abstract. The wet-sieving method using nested sieves is a common way to measure aggregate stability, but this method can only be used to measure the stability of whole soils, not the stability of individual aggregate size fractions. The main objective of this study was to estimate the amount of aggregate breakdown in the individual aggregate size fractions in the routine wet-sieving method. Three assumptions were used. Firstly, aggregates were assumed to breakdown into several aggregate size fractions simultaneously; secondly, ruptured aggregates of the same size fraction are assumed to have equal weights, provided they are from the same origin (that is, they are pieces of the same larger aggregate size fraction); and lastly, it was assumed that aggregates of the same size fraction would breakdown equally in percentage. The amount of aggregate breakdown and its distribution in the various sieves were described in a series of equations. By using the three assumptions, these equations could then be solved. The model was tested on several soil types of various texture and land use. For each soil, each of the six aggregate size fractions (5-8, 3-5, 2-3, 1-2, 0.5-1 and 0.3-0.5 mm) was wet-sieved separately to determine the actual breakdown and distribution of aggregates in the various sieves. The model's mean estimation error was 1.33 g (6.65%), and it showed no bias in estimating the weight of intact aggregates.

Keywords. *aggregate breakdown, wet sieving, aggregate stability, model, aggregate size distribution, soil structure*

Introduction

Wet-sieving using nested sieves (Yoder, 1936; Kemper and Chepil, 1965) is a common method to measure aggregate stability of *whole soils*. However, to determine the stability of *individual aggregate size fractions* means each aggregate size fraction has to be wet-sieved separately. In practice, however, separate wet-sievings are too tedious and time-consuming. To overcome these problems, Christopher *et al.* (1998) developed a simple model to estimate the amount of breakdown of individual aggregate size fractions in the routine wet-sieving method. By estimating the amount of aggregate breakdown of individual size fractions, the stability of these individual aggregate size fractions could then be calculated. Christopher *et al.* (1998) however found that their model tended to overestimate the amount of aggregate breakdown and this problem was corrected by calibrating the model's estimates through a simple linear regression. Consequently, the objectives of this study was to improve the work of Christopher *et al.* (1998) by developing an improved and mechanistic model to estimate the amount of breakdown and distribution of aggregates after wet-sieving.

Materials and Methods

Figure. 1 illustrates the breakdown and movement of aggregates in a nest of three sieves during wet-sieving, where i denotes the sieve number (i = 1 to n) where sieve 1 is the sieve with the largest aperture size, followed by sieve 2, and so on. Note that the sieve n (last sieve) refers to the container that holds the water and the nest of sieves.

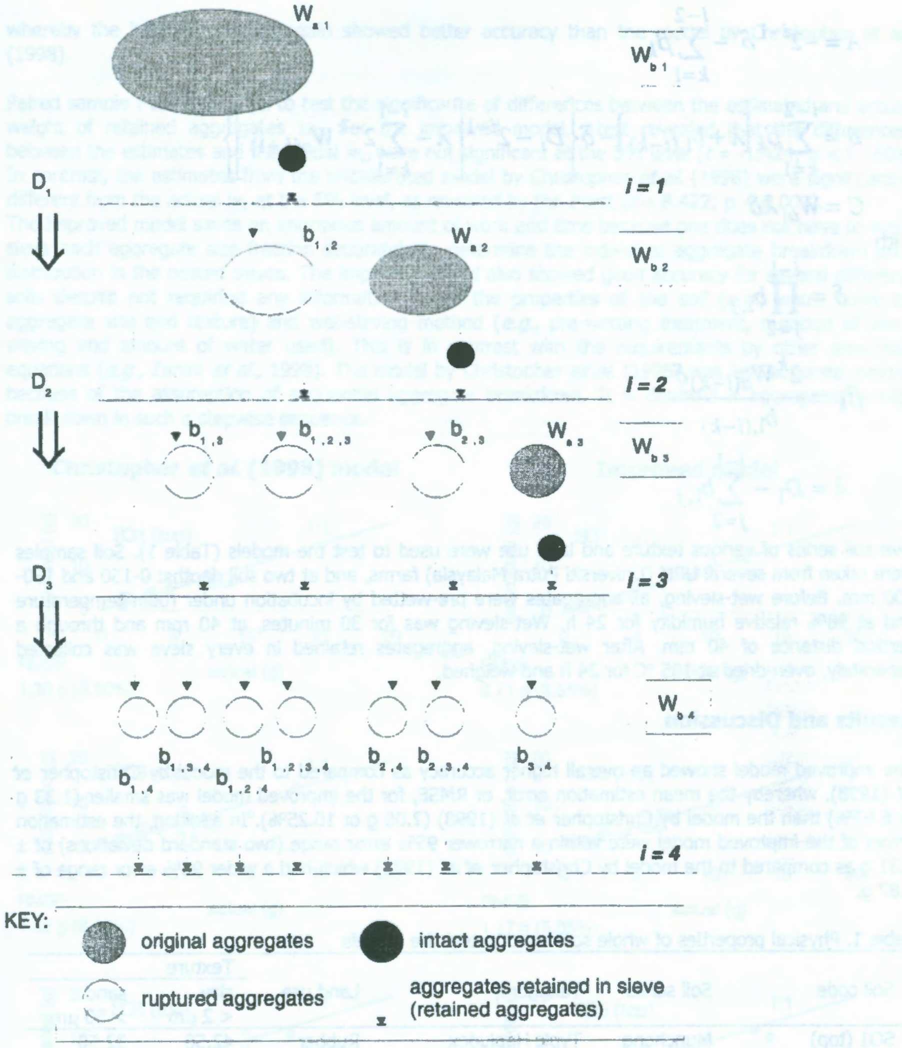

Figure 1. Simultaneous breakdown and movement of aggregates in a nest of three sieves in the wet-sieving method

Three assumptions were used. Firstly, aggregates were assumed to breakdown into several aggregate size fractions simultaneously; secondly, ruptured aggregates of the same size fraction are assumed to have equal weights, provided they are from the same origin (that is, they are pieces of the same larger aggregate size fraction); and lastly, it was assumed that aggregates of the same size fraction would breakdown equally in percentage. The amount of aggregate breakdown and its distribution in the various sieves were described in a series of equations. By using the three assumptions, these equations could then be solved. Consequently, it can be shown that the general equation to determine the weight of the ruptured aggregates ($b_{1,i} \geq 0$) for any number of sieves is calculated by

$$b_{1,i} = \frac{-B - \sqrt{B^2 - 4AC}}{2A} \tag{1}$$

where

$$A = -2^{i-1}\delta - \sum_{k=1}^{i-2}\beta_k$$

$$B = \sum_{k=1}^{i-2}\beta_k\left[\lambda + b_{1,(i-k)}\right] - \delta\left\{D_i - 2^{i-1}\left[\lambda - \sum_{k=1}^{i-1}2^{-k}W_{a(k+1)}\right]\right\}$$

$$C = W_{ai}\lambda\delta$$

with

$$\delta = \prod_{j=2}^{i-1} b_{1,j}$$

$$\beta_k = \frac{2^k W_{a(i-k)}\delta}{b_{1,(i-k)}}$$

$$\lambda = D_1 - \sum_{j=2}^{i-1} b_{1,j}$$

Five soil series of various texture and land use were used to test the models (Table 1). Soil samples were taken from several UPM (Universiti Putra Malaysia) farms, and at two soil depths: 0-150 and 150-300 mm. Before wet-sieving, all aggregates were pre-wetted by incubation under room temperature and at 98% relative humidity for 24 h. Wet-sieving was for 30 minutes, at 40 rpm and through a vertical distance of 40 mm. After wet-sieving, aggregates retained in every sieve was collected separately, oven-dried at 105 °C for 24 h and weighed.

Results and Discussion

The improved model showed an overall higher accuracy as compared to the model by Christopher *et al.* (1998), whereby the mean estimation error, or RMSE, for the improved model was smaller (1.33 g or 6.65%) than the model by Christopher *et al.* (1998) (2.05 g or 10.25%). In addition, the estimation errors of the improved model were within a narrower 95% error range (two standard deviations) of ± 2.31 g as compared to the model by Christopher *et al.* (1998) which had a wider 95% error range of ± 2.87 g.

Table 1. Physical properties of whole soils used to test the models

Soil code	Soil series	Taxonomy	Land use	Texture	
				clay < 2 μm	sand > 50 μm
SO1 (top)	Munchong	Typic Hapludox	Rubber	42.58	32.50
SO1 (sub)	Munchong	Typic Hapludox	Rubber	51.57	25.99
SO2 (top)	Munchong	Typic Hapludox	Oil palm	56.48	32.20
SO2 (sub)	Munchong	Typic Hapludox	Oil palm	63.30	26.70
SO3 (top)	Melaka	Xanthic Hapludox	Pine	28.80	47.70
SO3 (sub)	Melaka	Xanthic Hapludox	Pine	39.40	35.53
SO4 (top)	Prang	Typic Hapludox	Bare	62.92	18.67
SO4 (sub)	Prang	Typic Hapludox	Bare	51.75	22.31
SO5 (top)	Bungor	Typic Paleudult	Grassland	22.75	69.79
SO5 (sub)	Bungor	Typic Paleudult	Grassland	23.63	67.55
SO6 (top)	Serdang	Typic Paleudult	Vegetable	34.08	54.11
SO6 (sub)	Serdang	Typic Paleudult	Vegetable	32.13	53.69

Figure. 2 shows the comparisons between the estimated and actual weight of retained aggregates for each soil (top soil 0-150 mm depth). Both models showed an overall good agreement between the estimates and actual weights; however, of the two models, the improved model consistently had the lower mean estimation error (except for the SO2 soil). This could also be seen by the tighter clustering of points along the 1:1 line of agreement for all soils by the improved model. Similar results like those shown in Figure. 2 were also obtained for the sub-soils 150-300 mm depth (figure not shown), whereby the improved model again showed better accuracy than the model by Christopher *et al.* (1998).

Paired sample *t*-test was used to test the significance of differences between the estimated and actual weight of retained aggregates $w_{i,j}$. For the improved model, *t*-test revealed that the differences between the estimates and the actual $w_{i,j}$ were not significant at the 5% level (t = -1.424; $p < 0.160$). In contrast, the estimates from the uncalibrated model by Christopher *et al.* (1998) were significantly different from the actual $w_{i,j}$ at the 5% level, as revealed by the *t*-test (t = 8.422; $p < 0.001$).
The improved model saves an enormous amount of work and time because one does not have to wet-sieve each aggregate size fraction separately to determine the individual aggregate breakdown and distribution in the nested sieves. The improved model also showed good accuracy for several different soils despite not requiring any information about the properties of the soil (*e.g.*, water content, aggregate size and texture) and wet-sieving method (*e.g.*, pre-wetting treatment, duration of wet-sieving and amount of water used). This is in contrast with the requirements by other empirical equations (*e.g.*, Zanini *et al.*, 1998). The model by Christopher *et al.* (1998) was less accurate mainly because of the assumption of sequential aggregate breakdown. It is doubtful if aggregates would break down in such a stepwise sequence.

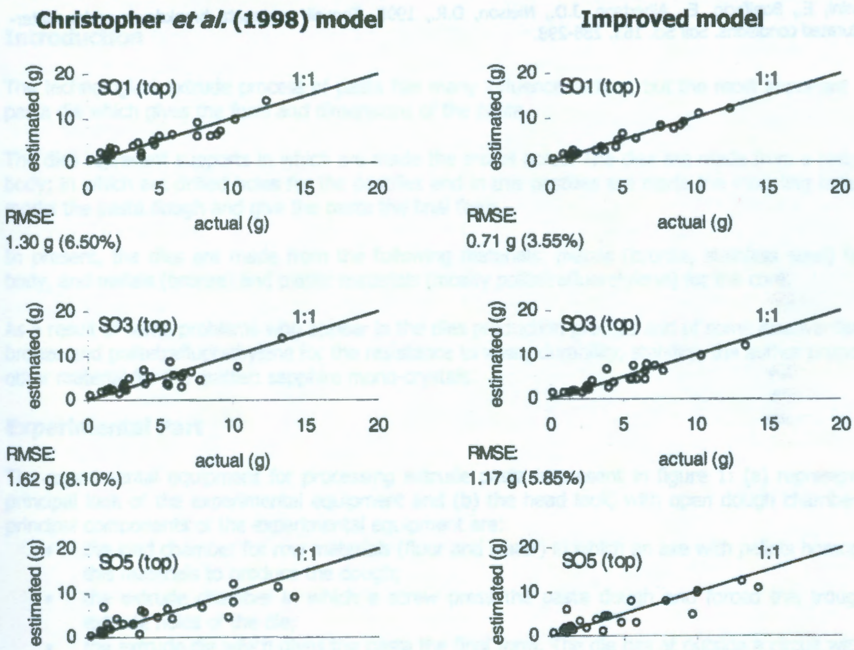

Figure 2. Comparisons between the estimated and actual weight of retained aggregates $w_{i,...,j}$ for selected soil types (0-150 mm soil depth). Graphs in the left and right columns are the performance of the Christopher *et al.* (1998) model and the improved model, respectively.

Conclusion

This study successfully improved the model by Christopher *et al.* (1998) by using the assumption of simultaneous aggregate breakdown rather than the assumption of a sequential aggregate breakdown. Tested on several soil types, the improved model showed better accuracy than the model by Christopher *et al.* (1998), where the mean estimation errors were 1.33 g (6.65%) and 2.05 g (10.25%), respectively. The improved model also showed no bias in estimation, in contrast to the model by Christopher *et al.* (1998) which tended to underestimate the weight of intact aggregates.

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