TITLE : Depth Profiles of Soil Stability for Selected Soils from Mozambique
AUTHOR : S.M. Cousen and P.J. Farres
PUBLISHER: Portsmouth Polytechnic, Portsmouth
YEAR : 1984

DEPTH PROFILES OF SOIL STABILITY FOR SELECTED SOILS FROM MOZAMBIQUE.

Stella M Cousen and Paul J Farres.

Research Assistant & Senior Lecturer
Department of Geography
Lion Terrace
Portsmouth Polytechnic
PORTSMOUTH
HANTS
PO48QT

1. INTRODUCTION:

Soil erosion defined as the removal of surface material by wind or water is considered a major problem in many areas of the world. The resistance of the soil system to erosion can ultimately result in the success or failure of a population as it is this phenomenon that can govern the potential quality of the land. Where soils are easily dispersed or compacted by rains and or high winds agricultural practices may be severely limited by the loss of top soil or a reduction in quality it becomes desirable to develop some kind of index that will enable the assessment of the potential erodibility, or resistance, of the soil system to erosion. This will assist in the planning of land management regimes in the hope of developing more enlightened soil conservation programmes in the future.

The aspect of soil erosion dealt with here is that of raindrop impact, studied in some detail by Ellison (1944) and Ekern (1950). The stability of compound particles (soil aggregates) against the stress of raindrop impact is a very important aspect of soil structure (Grieve 1979, Smith & Cernuda 1950). It has long been accepted that aggregation is an important factor in agriculture as it governs the quality of the soil for plant growth and nutrition (Toogood 1978). The amount of soil removed from any system depends to a large extent on the ability of the individual aggregates to resist the disruptive forces of raindrop impacts (Bruce-Okine & Lal 1975). Detachment of soil particles from the soil mass in this way may be considered as the first stage in the erosion process, therefore it is desirable to be able to predict how a soil may react to the disruptive influence of rain falling upon its surface.

Many attempts have been made in the past to define potential erodibility of soils in terms of their physical and chemical properties. The most imfamous of these are probably those that employ the 'Universal Soil Loss' equation used in conjuction with the soil erodibility factor K (Mitchell & Bubenzer 1982). The relationships are purely statistical, based often on ill defined correlation type analysis (Farres 1984). They constitute what may be termed 'black-box' models and pay little or no attention to the actual processes and mechanisms of erosion that may be operative. Detailed laboratory or field studies into the processes of erosion are numerous (Kirkby & Morgan 1982) many of which lay great emphasis on the disaggregation of soil peds, the transportation of smaller particles by rainsplash and the resulting surface sealing with the formation of dense surface layers or crusts.

The implications of soil crusts to the subsequent behaviour of the soil system are manifold. Primarily the instantaneous infiltration rate and final infiltration capacity of the soil is drastically reduced (Farrell & Larson 1972) which may then cause surface runoff and much increased erosion. In addition the land capability may also be affected by the dense surface layers hindering seedling germination and emergence and the disruption of tillage practices (Hanks 1960).

Research by Europeans in this field is now generally based on the opinion that soil aggregate stability indicies produced using single drop rainfall simultion techniques are perhaps the most appropriate as these alone come closest to mimicking real world processes (Bergsma & Valenzuela 1981, De Meester & Jungerius 1978, Imeson & Jungerius 1976). It is on this basis that the following report considers the structural stability of soil aggregates from different horizons from a series of iron rich soils from Mocambique.

II. EXPERIMENTAL METHOD:

Many methods exist for aggregate stability assessment. Within this report the single drop test initiated by Mc Calla (1944), developed by Low (1954) and modified by Farres & Cousen (1984) is used. Essentially all these methods involve generating water drops from some form of pendant drop former. These drops are then allowed to fall some distance on to a soil aggregate. The number of drops, or time required for the aggregate to be reduced in size enough to pass through an aperture of known dimensions is then measured. This measurement is used to obtain the stability of the aggregate to drop impact.

II.1 THE DESIGN AND OPERATION OF THE SINGLE DROP SIMULATOR:

The design of the apparatus is reported in detail by Farres & Cousen (1984). The design takes into account, and minimizes the variations in results that have formerly been controlled for inadiquately. Particular attention has been paid to . . .

(1) Chemistry of drop forming solution

(2) Variations in drop sizes and intensity of application

(3) Definitions of breakdown

(4) Variations in fall height

The characteristics of previous single drop rainfall simulators and stability measurements are given in table 1. The apparatus used for this study are shown in figure 1.

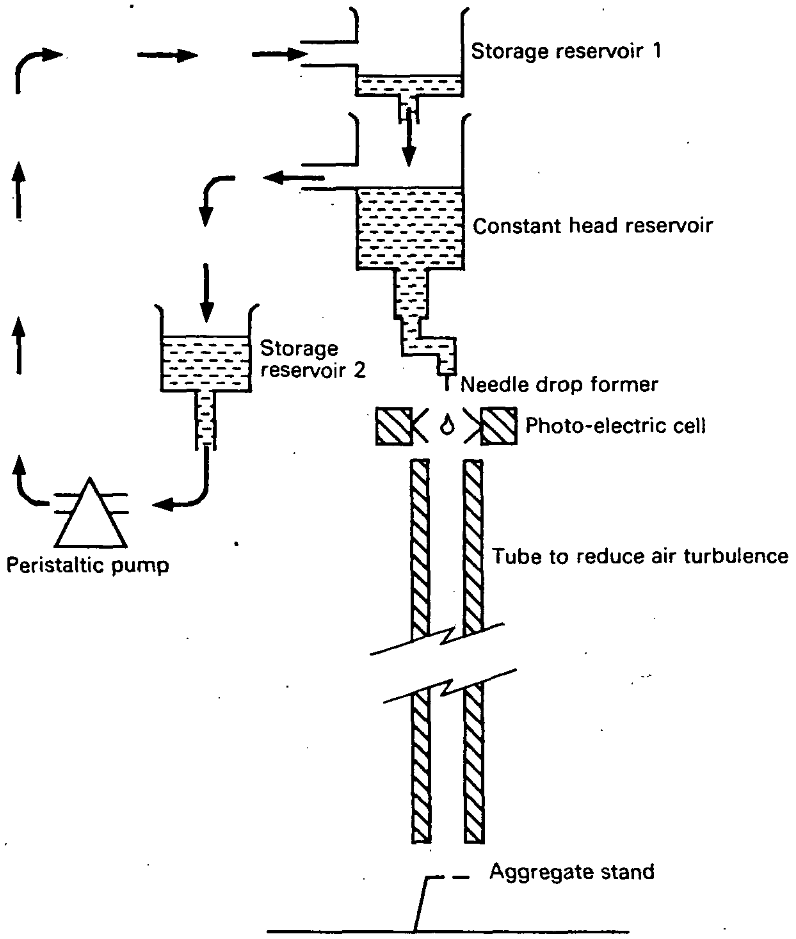


Figure 1: Single drop rainfall simulator for soil aggregate stability assessment.

TABLE 1 Summary of characteristics of previous research using single drop rainfall simulation for soil aggregate stability assessment.

NAME	DATE	AGGREGATE SIZE	DEFINITION OF BREAKDOWN	DROP SIZE DIAMETER	DROP FALL HEIGHT
IMESON and JUNGERIUS	1976	4-5 mm diameter	3 mm	0.1 g 5.75 mm	1 m
McCALLA	1944	0.15 g	1 mm	4.7 mm	30 cm
LOW	1954	4-5 mm	3 mm	5.75 mm	1 m
BERGSMA and VALENZUELA	1981	4-5 mm	3 mm	5.5 mm	1 m
GRIEVE	1979	4-5 mm	3 mm	0.1 g 5.75 mm	1 m
DE MEESTER and JUNGERIUS	1978	4-5 mm	3 mm	0.1 g 5.75 mm	1 m
GHADRI and PAYNE	1977	6-8 mm	2 mm	2.8-6.7 mm	0.5-6 m
BRUCE-OKINE and LAL	1975	3.45-1.25 g	2 mm	0.157 g 6.7 mm	1 m
COUSEN and FARRES	1983	4-6 mm	3 mm	2.9 mm	0.25-1m

The apparatus has a recirculating water supply which allows the control of the chemistry of the liquid forming the drops. Deionized water buffered to the pH of water in equilibrium with the atmosphere i.e. pH 5.6, is used. The liquid supply system is so designed to give a constant head of solution above the drop former. A hypodermic needle gauge 23, with an internal diameter of 0.33 mm is used as the drop former. Because of the high tolerence in manufacture of such needles they give repeatable results. The effect of this configuration of needle, head, and lead in tubes gives drops of 2.9 mm (equivalent spherical diameter) being produced at a rate of 120 drops per minute. In addition the apparatus used here has a photo-electric cell mounted just below the drop forming nozzle; this is connected to a timer-scaler allowing exact counts of the number of drops to pass the cell during any time period to be made.

The drops fall a distance of 2 m through a tube 10 cm in diameter; the tube has the affect of minimizing air turbulence around the path of the falling drops and therefore the wandering of the drops away from the target aggregate, a problem frequently encountered when using alternative apparatus. A fall height of 2 m is used as it is the greatest height normally expected within soil laboratories and can thus be readily repeated by other workers. It is also known that the greater the fall height the greater the consistancy of results (Farres & Cousen 1984).

Soil aggregates are held in a specifically designed aggregate stand Figure 2. Aggregates with mean diameter 5 mm are used and the size

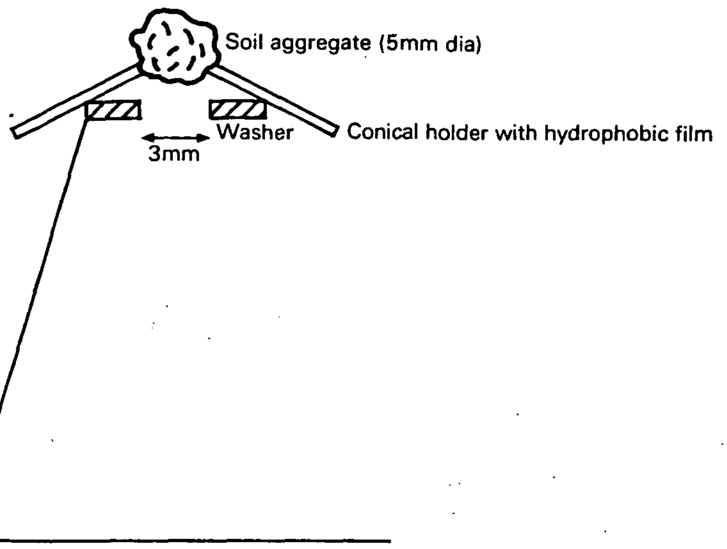


Figure 2: Soil aggregate stand and holder.

of aperture through which they are to pass for breakdown to be considered to have taken place is 3 mm (see section **III. 2** for details). The whole apparatus is sited in the soils laboratory at Portsmouth Polytechnic in a room with an air temperature within the range 17-20° C.

At the start of an experimental run the reservoirs are filled and the pump switched on to allow the liquid to circulate, more liquid is then added to the reservoirs until the system is free of air and has sufficient storage to give a constant head in the reservoir above the drop former. The needle drop former is then 'milked' with the aid of a larger bore needle and syringe encouraging the free formation of drops. The intensity tested using the photo-electric cells and timer-scaler is monitored at this point for consistency. When the rate has reached the equilibrium intensity of 120 ∓ 10 drops minute experimentation can begin. The full apparatus is shown in plate 1.

II.2 PRE-TREATMENT AND BREAKDOWN DEFINITION:

The soil samples from each horizon are gently crumbled by hand and allowed to break into their natural structural units. They are then air dried at 20 C in this condition for two weeks. Once the bulk sample is air dry and easy to handle it is hand shaken through a nest of sieves separating the aggregates into three size fractions:- >6 mm, 4-6 mm, <4 mm. This particular series of experiments only uses the aggregates in the range 4-6 mm generally the largest fraction. Well formed crumbs from this size fraction are selected, oven dried and weighed. The amount of moisture required to give these aggregates 25% moisture content by weight is then calculated. Moisture is gently, and slowly added by micro-syringe working to an accuracy of ∓ 2 ml (plate 2). The aggregates are then allowed to equilibriate for twenty-four hours in an atmosphere of totally dry air.

The aggregate stand is dried and one of the pre-treated aggregates is placed in the conical holder (plate 3). Stand and aggregate are moved under the falling drops produced by the simulator as described in the previous section. As soon as the first drop strikes the aggregate the timer-scaler and separate stop watch timer are started. As the aggregate is hit by the drops it may start to crumble, as soon as its size is re-

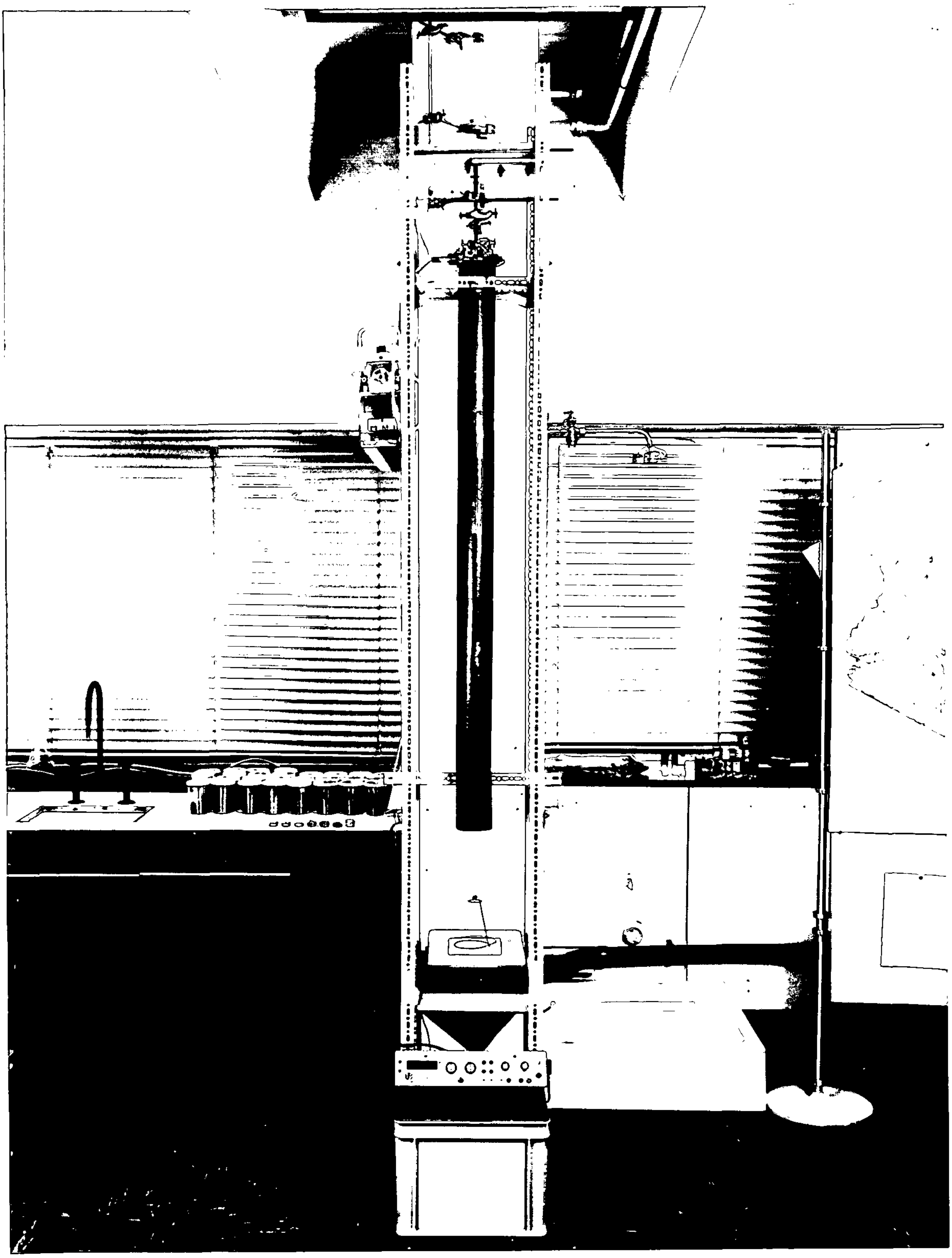


PLATE 1

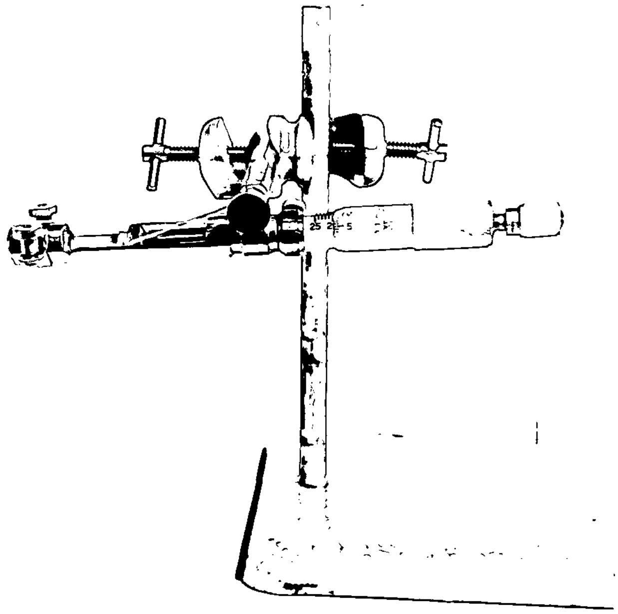
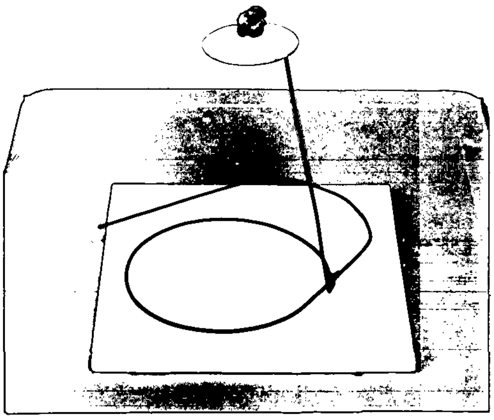


PLATE 2

PLATE 3



duced enough for it to pass through the 3 mm washer below the holder the aggregate is deemed to have broken down. The time and number of drops for this to have happened are recorded. Aggregates that resist bombardment by drops for 240 seconds are here regarded to be rain stable.

III. DATA ANALYSIS:

The objective of the analysis is to provide an index of the structural stability of aggregates to raindrop impact for each horizon within a number of different soil types. A sample of aggregates from each horizon is used, the following data is available. . .

(a) Weight of aggregate (W)

(b) Time to breakdown (T)

(c) Number of impacts to breakdown (I)

Time to breakdown is considered the best relative measure of stability for each individual aggregate for the reasons developed in Farres & Cousen (1984). Any aggregate not breaking down before some critical time (T_{crit}) is said to be 'rain stable'. The critical time in this set of experiments was defined as 240 seconds.

The pattern of stability of the aggregates, within any one horizon and between soil profiles can be shown by the distributions of either;

(i) Time to breakdown (T_{ijk})

(ii) Time to breakdown controlled for initial weight (T^{w}_{ijk}) gs where i = soil code

j = horizon code

k = aggregate code

w = weight code

Data for these two parameters are either skewed or bimodal as a result of their being a finite limit to the possible values they can take. This means that using average measures for T_{ij} or T^{w}_{ijk} does not truely reflect the distribution, and are therefore inappropriate as indices of stability for the whole sample derived from any one horizon.

To obviate this problem a distribution free index has to be formulated for each sample, in this way direct comparisons between horizons and soils will be possible. One traditional method would be to express each aggregates stability as a standardized z score, summing these scores and index for the whole sample is obtained (equation 1).

$$I_{ij} = \sum_{k=1}^{n} \left(\frac{(T_{ijk} - \bar{T}_{ij})}{\sigma_{ij}} \right) \quad \ldots\ldots\ldots\ldots (1)$$

where $\bar{T}_{ij}$ = mean of sample

σ_{ij} = standard deviation

Although such an approach does give a comparable index it has the disadvantage of not having an upper finite limit, and its interpretation has little meaning in terms of process.

If for each value of T_{ijk} is divided through by T_{crit} the values become standardized between 0 and 1. This new parameter can now be accumulated across the whole sample for any one horizon (equation 2).

$$I_{ij}=\left(\frac{\sum_{k=1}^{n}\left(T_{ijk}/T_{crit}\right)}{n}\right).100 \quad \ldots\ldots\ldots(2)$$

where n = sample size

The index may now be defined as:- Percentage structural stability.

A value for I_{ij} of 100 implies total structural stability, as I_{ij} tends to 0 so the horizon structural instability. The structural stability of the horizons within each soil is shown in Figure 3.

From figure 3 it may be seen that a number of distinct aggregate stability profiles exist. At one end of the spectrum stability declines with depth, at the other stability increases with depth. In terms of the potential of the soils to crusting and splash erosion they may defined as being stable, metastable or unstable depending on the form of their stability profiles (Figure 4).

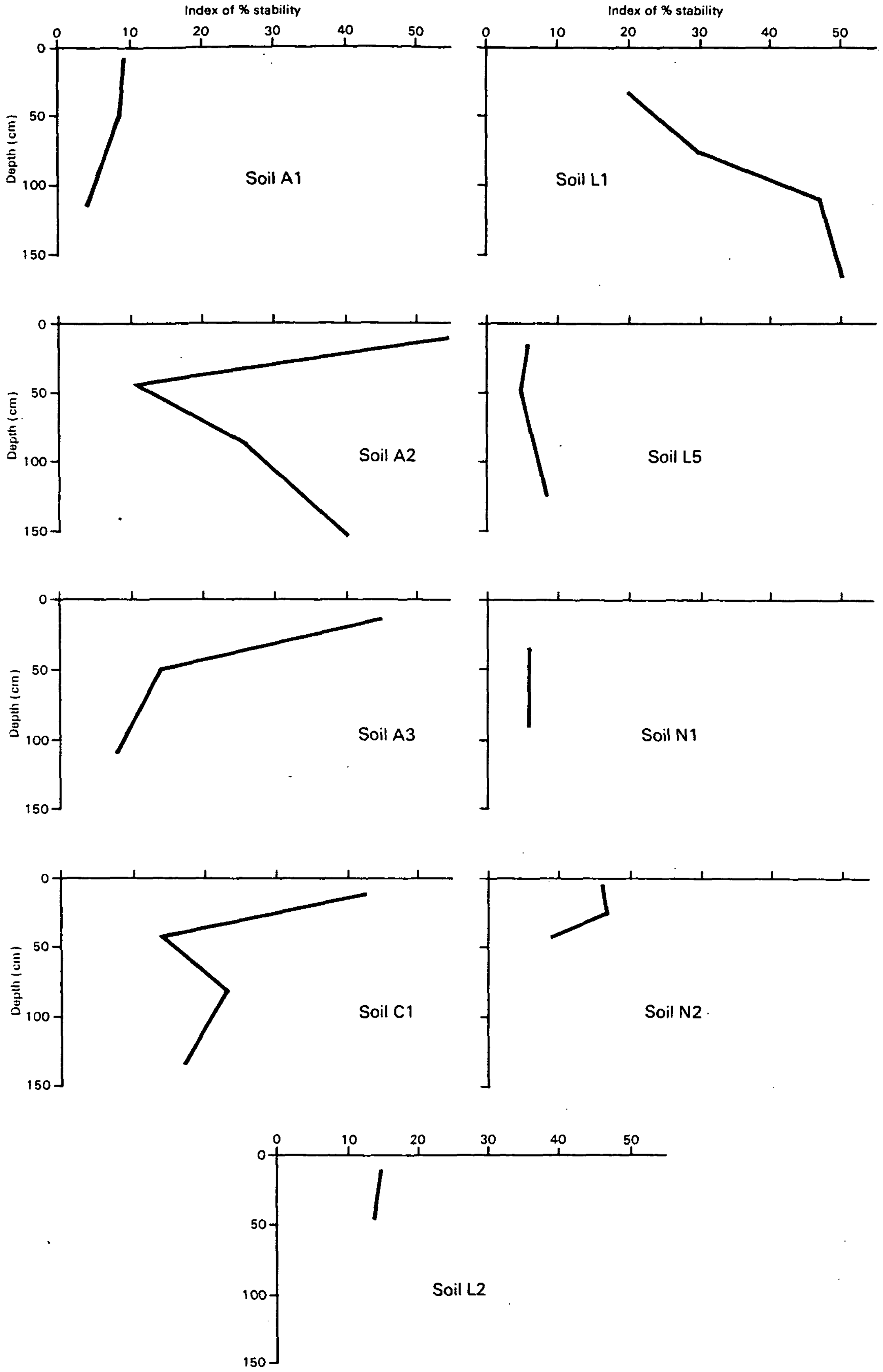


Figure 3: Vertical profiles of aggregate stability index for nine soils.

Conclusions so far are based solely upon the form of the profiles rather than the values of the index. From the point of view of erodibility assessment a more interesting consideration is the variation in the relative ranks of the soils (based on their index measures) with changes in depth, figure 5.

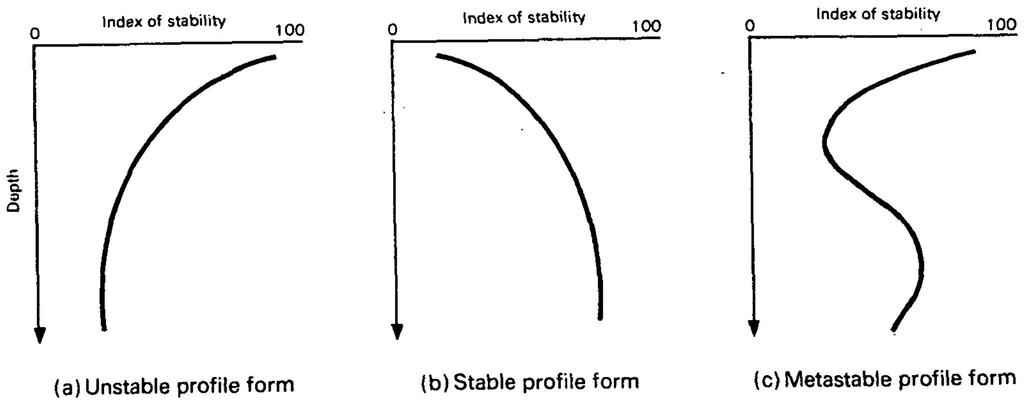


Figure 4: Schematic representation of eqilibrium status of soil profiles.

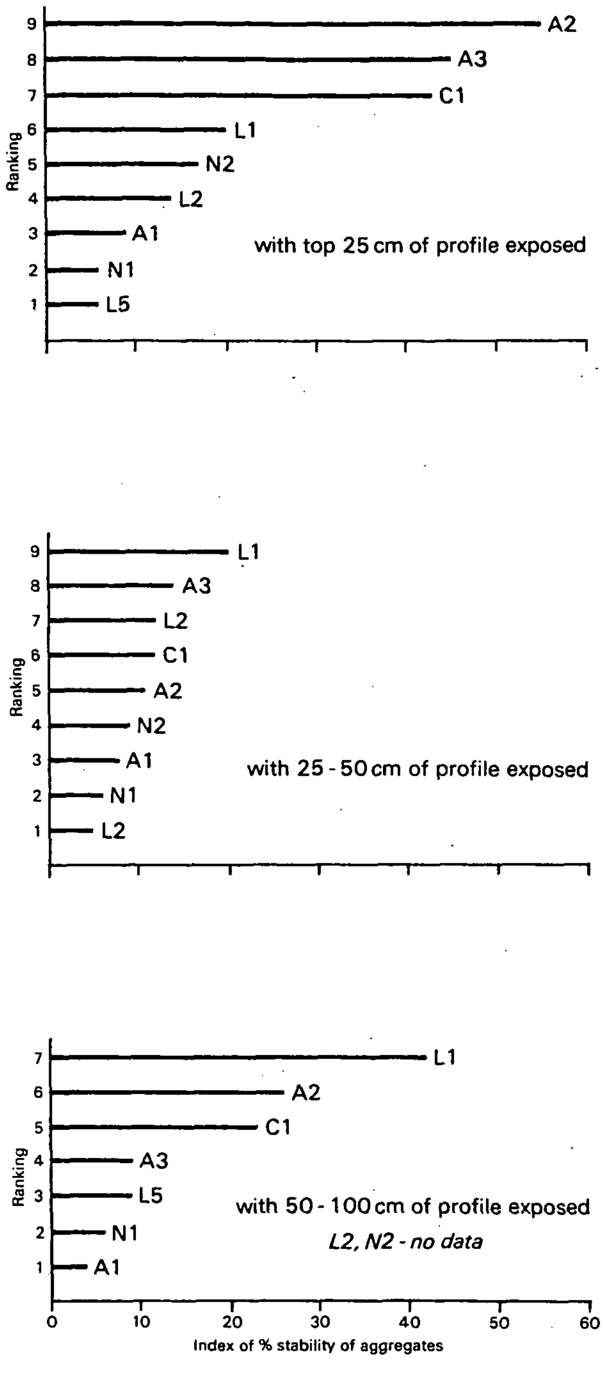


Figure 5: Relative stability between soils for changes in depth.

ACKNOWLEDGEMENTS:

We would like to thank Dr Sombroek and his collegues at the International soil Museum, Wageningen, Holland, and particularly Sief Kauffman for making the soil material available. Thanks also to the technical staff in the Department of Geography, Portsmouth Polytechnic for their help in the production of this report.

References

Bergsma, E. and Valenzuela, C.R. 1981. 'Drop testing aggregate, stability of some soils near Merida, Spain', Earth Surface Processes, 6, 309-318.

Bruce-Okine, E. and Lal, E. 1975. 'Soil erodibility as determined by raindrop technique', Soil Science, 119(2), 149-157.

De Meester, T. and Jungerius, P.D. 1978. 'The relationship between stability and micromorphological properties of soils in the Hornos area, Southern Spain', Earth Surface Processes, 3, 379-381.

Ekern, P.C. 1950. 'Raindrop impact as the force initiating soil erosion Proc. Soil. Sci. Soc. of Amer. 15, 7-10.

Ellison, W.D. 1944. 'Studies of raindrop erosion', Agricultural Engineering, 25, 131-136.

Farrell, D.A. and Larson, W.E. 1970. 'Dynamics of the soil water system during a rainstorm', Soil Science, 113(2), 88-95.

Farres, P.J. 1980. 'Some observations on the stability of soil aggregates to raindrop impact', Catena, 7(2/3), 223-231.

Farres, P.J. and Cousen, S.M. 1984. 'An improved method of aggregate stability measurement', (forthcoming).

Grieve, I.C. 1979. 'Soil aggregate stability tests for the geomorphologist', B.G.R.G. Technical Bulletin, 25.

Hanks, R.J. 1960. 'Soil crusting and seedling emergence', Proc. 7th International Congress of Soil Science, 340-346.

Imeson, A.C. and Jungerius, P.D. 1976. 'Aggregate stability and colluviation in the Luxembourg Ardennes; an experimental and micromorphological study', Earth Surface Processes, 1, 259-271.

Kirkby, M.J. and Morgan, R.P.C. 1980. 'Soil Erosion', Wiley, Chichester

Low, A.J. 1954. 'The study of soil structure in the field and the laboratory', Journal of Soil Science, 5(1), 57-78.

Mitchell, J.k. and Bubenzer, G.D. 1980. 'Soil loss estimation', in 'Soil Erosion', pages 17-62, Kirkby and Morgan (eds) Wiley, Chichester

McCalla, T.M. 1944. 'Water drop method of determining stability of soil structure', Soil Science, 58, 117-121.

Smith, R.M. and Cernuda, C.F. 1950. 'Some applications of water drop stability testing to tropical soils of Puerto Rico', Soil Science, 71, 337-345.

Toogood, J.A. 1978. 'Relation of aggregate stability to properties of Alberta soils', in 'Modification of Soil Structure', Emerson and Greenland (eds) Wiley, Chichester.