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ERODIBILITY OF NEW ZEALAND SOILS

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ABSTRACT

The relevance of the concept of soil erodibility to potential land use planning and to sediment yield production is discussed. It is emphasized that erodibility must be considered in the context of a particular erosion type. A method of direct laboratory measurement of erodibility in the context of rainfall and overland flow erosion is reported, with preliminary results for samples of three South Island yellow-grey earths. These results are compared with those obtained by estimates based on easily measured soil properties.

INTRODUCTION

Approximately 30% of the land area of New Zealand has been subjected to reconnaissance land inventory survey for the preparation of land capability plans; 9% of that part of the total land area used for agricultural purposes has been included in detailed conservation farm plans (Dick, 1968). An important part of land capability classification is the recognition of limitations to land use caused by erodibility, wetness, soil limitations within the rooting zone, and climate (SCRCC, 1969). Both the past situation and future susceptibility to the particular limitation (or combination of limitations) are assessed and, as they may be either permanent or removeable, their permanence is taken into account when deciding capability.

When taking this process the further steps of estimating potential land use and assigning a 'recommended land use', the advantages of being able to assess accurately the effects of changes in land management, for the large variety of soils and topographic and climatic situations encountered, will readily be seen.

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Another aspect of present and future soil erosion is the estimation of sediment yields from catchments. Accelerated soil erosion consequent upon past and continuing changes in land use will continue to be an important problem in New Zealand in the foreseeable future.

This paper discusses one aspect of prediction of the consequences of changes in land use – the concept of erodibility of soils.

SOIL ERODIBILITY

Erodibility, a property of a particular soil, is one factor influencing soil erosion. Baver (1940) stated that erosion depended on climatic, topographic, vegetal, soil and 'human' factors; he did not attempt to show an explicit relationship, nor did he rule out the possibility of the various factors being interdependent. The various soil loss prediction equations, notably the 'universal' soil loss equation for rainfall-induced soil loss on cropping lands (USDA, 1961), represent attempts to produce an explicit (but empirical) relationship between erosion and defined forms of factors such as those listed by Baver. Erodibility, for instance, has a specific definition in the 'universal' soil loss equation; it is the rate of erosion, for specified rainfall conditions, of soil which has been in continuous fallow for two years, tilled up and down on a 9%, 22 m long slope. (The manner and frequency of cultivation are also specified, see USDA, 1965.)

When not specifically defined in such a manner, erodibility is usually taken to mean that property of a soil which makes its susceptibility to erosion different from another soil, when the two soils are in situations which make all other influences on erosion (climatic, topographic, vegetal and 'human') the same.

If the concept of erodibility is to be of real use there are two closely related problems to be solved:

(1) The measurement of erodibility, independently of other factors influencing erosion.

(2) The recombination of measured values of erodibility with other factors influencing erosion to predict erosion in the field.

The 'universal' soil loss equation represents the best-known attempt to solve these problems, and the difficulties and possibilities associated with the use of it or a similar approach in New Zealand need further investigation. Only the measurement of erodibility will be further considered here.

MEASUREMENT OF ERODIBILITY

Any attempt to solve the first problem, above, soon makes clear that erodibility cannot be considered to be truly independent of other factors. Progress can be made by specifying a particular type of erosion, and this will often involve limiting the other factors in some way. Consideration of wind erosion, for example, will assign most importance to wind forces in the climatic factor and allow an 'erodibility to wind' to be determined (USDA, 1968). Erosion in gullies involves a particular topographic situation and results in an erodibility (Selby, 1970) which will be quite different from the erodibility to wind. The investigations described below consider erodibility in the context of rainfall and overland flow erosion on sloping land. They follow the pattern of a study reported by Bryan (1968a) on the erodibility of soils in Derbyshire, England.

Three methods of assigning values to erodibility have been used:

1. *Direct field measurement.*

By direct measurement of soil loss from field plots under natural or simulated rainfall, under controlled conditions which determine other factors, soils can be ranked by choosing reference values of particular forms of the other factors. This is the method used to provide 'bench-mark' values of erodibility for use with the 'universal' soil loss equation (Olson and Wischmeier, 1963).

2. *Direct laboratory measurement.*

This again involves direct measurement of soil loss, under simulated rainfall and from samples of soil which have ranged from a few hundred cubic centimetres to a few cubic metres. Soil samples may be either disturbed or undisturbed (Bryan, 1968a; Khatri Chhetri, 1971).

3. *Correlation with indicative soil properties.*

Where certain combinations of soil properties have been shown (by comparison with the first or second methods, above) to be indicators of erodibility, they have been used to estimate the erodibility of other soils for which no direct measurements have been made (Bryan, 1968b; Wischmeier and Mannering, 1969).

Workers in the United States Department of Agriculture have also estimated values of erodibility by "considering a soil's characteristics and tempering the estimate of its erodibility against the established values" (USDA, 1965). This amounts to a subjective ranking based on the experience of numerous method-1 trials.

All three methods have recently been reviewed, taking into consideration their relevance to New Zealand's requirements and resources, and laboratory equipment and test procedures have been developed which allow the second and third methods to be used (Khatri Chhetri, 1971).

THE PRESENT STUDY

Direct laboratory measurement of erodibility was chosen as the most appropriate method to study. Direct field measurement has been shown in the United States to be expensive and to require long periods to obtain results. Outdoor rainfall simulators reduce the time taken to collect results, but are themselves expensive and only one suitable type is at present operating in New Zealand (at Moutere experimental basin, run by the Ministry of Works). Correlation with indicative soil properties is not independent of the other two methods unless results from work outside New Zealand are found to be applicable. Bryan (1968b) has shown that erodibility indices are often unreliable. However, the relative cheapness and ease with which they allow estimates of erodibility to be made make the method highly desirable, and it was included in the present study.

Direct laboratory measurement allows control of the magnitudes of relevant variables and replication of tests. A standard procedure was adopted so that different soils could be ranked in order of their susceptibility to the treatment given. It differs from the procedure of Bryan (1968a) in having a soil bin of 27 times the surface area of his sample pan (to reduce border effects), a different method of rainfall simulation, and in details of the test procedure.

Laboratory Equipment

Rainfall simulation for laboratory studies has been extensively reviewed (e.g. Meyer, 1965; Hall, 1970). A dripping type which had a drop-size distribution (median size 4 mm) and storm kinetic energy similar to natural rainfall was constructed (Fig. 1). The spatial uniformity achieved is indicated by a statistical uniformity coefficient (1 — standard deviation / mean) of 70% at 76 mm/h intensity. Intensities during tests on the Waipara, Takahe and Timaru soil samples were 76, 55 and 64 mm/h respectively, giving rainfall erosion index (EI) values (Wischmeier, 1959) of 72, 41 and 57. (The value in J m^{-1} h^{-1}; they are 42, 24, and 33 in the foot-ton-second system, in which natural erosive storms usually have values in the range 1 to 100.)

The tilting soil bin, also shown in Fig. 1, has dimensions of 2.74 m × 0.91 m × 0.30 m (0.76 m^3). It has a roughened floor covered with 50 mm depth of fine gravel and sand, and free drainage could occur from the lower end.

Soil Samples

Three yellow-grey earths of loessial origin were chosen for these initial tests. They are identified as Waipara, Timaru and Takahe samples, but it is not suggested that they are necessarily representative of these soil sets.

Approximately 3 m^3 of each soil was collected from sites of similar topography, aspect and vegetal cover (pasture) a few days after a rain and before the setting in of winter, 1970. After removing vegetal surface material, soil was taken from the top

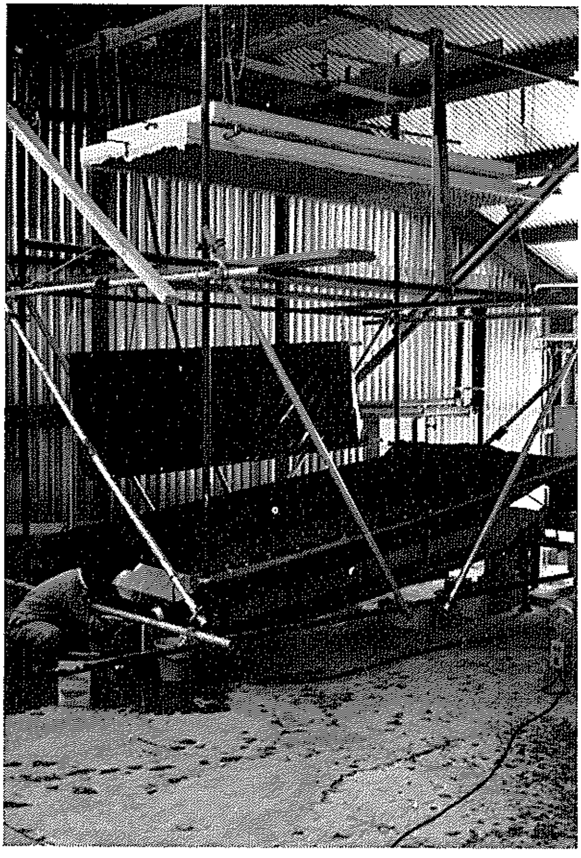

FIG. 1 — The rainfall simulator and soil bin.

0.5 m, air-dried and passed through an 8 mm sieve. The soil was thoroughly mixed and placed in the soil bin in a standard fashion with no compaction. Bryan (1968a) discusses the merits and disadvantages of using the soil in this sieved, disturbed condition, making the important point that it is necessary to ensure the exclusion of factors other than the soil factor.

Test Procedure

With the soil surface initially parallel to the top of the bin, and the bin on a 16% slope (9°), three 30-minute applications of high-intensity rainfall were made, separated by intervals of 30 and 15 minutes (dry, wet and saturated soil conditions). Water, and soil washed off, were continuously collected (replacing containers each 5 minutes) and the soil splashed from the soil surface to a surrounding apron was collected (by washing down) after each 30-minute run. The pattern of erosion was recorded photographically during the 2¼-hour test.

Results of Direct Soil Loss Measurement

Splash and wash-off erosion and total soil loss are summarized in Fig. 2a. Because exactly identical storms were not applied to the samples (an acknowledged deficiency of this preliminary study) it is necessary to compare total soil loss compensated in some way for the different treatments. The most satisfactory way is believed to be on the basis of Wischmeier's (1959) erosion index (EI), a storm energy-intensity interaction term shown to be highly correlated with soil loss from fallow plots. Fig. 2b gives this compensated comparison of total soil loss; the results from the first 30-minute period of rainfall have been used, implying that these are the erodibility figures applicable when the soil is initially air-dry.

Results from Indicative Soil Properties

The original soil samples, washed-off and splashed fractions and soil remaining in the soil bin after tests were subjected to numerous laboratory tests, with emphasis on those related to stability of aggregates in the presence of water. Some of the properties measured were: particle size distribution, density, dispersion, cohesion (plasticity index), water-stable size distribution and water-stability of aggregates (using a Yoder-type test), organic matter content and pH. Profile descriptions were also obtained for each collection site.

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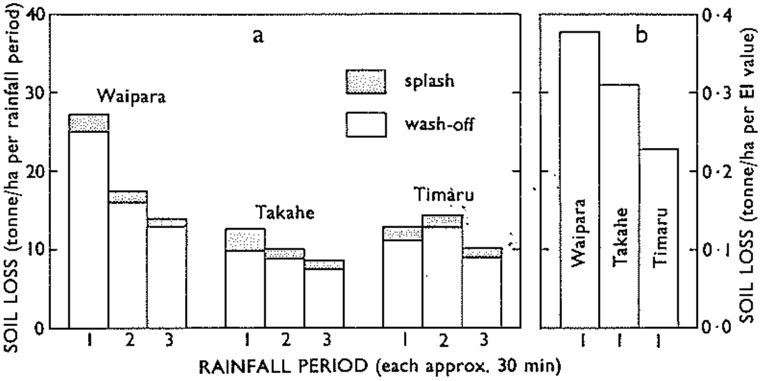

FIG. 2 — Total soil loss for three soil samples: (a) as measured from the 0.76 m^3 soil bin; (b) results for first periods after compensation for varying storm erosion indices.

Combinations of properties previously suggested as indices of erodibility were compared with the direct measurements. Many of them did suggest that the Waipara sample should be more erodible than the Takahe and Timaru samples (as it was) but did not distinguish clearly between these two.

A method recently suggested (Wischmeier and Mannering, 1969) is to establish a correlation between erodibility and quite a large number of variables which are interaction terms, including soil physical properties and profile characteristics. From a statistical study of 55 U.S. Corn Belt soils, from sandy loams to a silty clay, these authors presented an empirical equation to calculate the erodibility factor of the 'universal' soil loss equation. It contains 24 'independent' variables, which are specific combinations of profile and physical properties which analysis had shown to be significant. The success of the equation was demonstrated by the values it predicted for erodibility of 11 bench-mark soils whose erodibility had been previously established by other means.

Although there are formidable assumptions involved in applying this equation directly to the properties measured in this study, the results are interesting. Erodibility values of 0.38, 0.12, and 0.05 tonnes per hectare per EI value are obtained for the Waipara, Takahe and Timaru samples respectively. These are in the same order as the direct measurement, although the absolute values would not be expected to be the same. (The result for Waipara, cf. Fig. 2b, is almost certainly coincidental.)

DISCUSSION

The simulated rainfall used in this study had a continuous spectrum of drop sizes, larger on the whole than corresponding natural rainfall, but of lower terminal velocity, so that the kinetic energy was comparable (74% of 76 mm/h natural rainfall).

The pretreatment and placing of soil in the soil bin did not attempt to reproduce field conditions, but to provide a replicable, standardized procedure which removed all factors other than the soil factor.

Rilling patterns formed on the soil surface soon after runoff began, and the pattern of erosion was similar to sheet and rill erosion on sloping, fallow fields.

The Waipara soil sample was found to be most susceptible to the treatment given, followed by the Takahe and Timaru samples. It is not suggested that the absolute values of soil loss measured from the plots can be applied to field situations, nor even that the order determined should be reflected in the field behaviour of these soil sets. Further work is required before the relationship of the laboratory rankings and absolute values to field erodibilities can be established.

The Waipara sample had the lowest fraction of water-stable aggregates greater than 2 mm (9%) and the highest fraction of water-stable aggregates less than 0.25 mm (70%). It also had the highest 'suspension percentage' (Middleton, 1930), 19.5%, and 'dispersion ratio' (Middleton, 1930), 37%. These and other factors (Khatri Chhetri, 1971) combined to show that the Waipara was the most unstable of the three samples, slaking or dispersing quickly, reaching a relatively low infiltration rate more quickly than the other two, and ensuring that more soil would be lost by wash-off.

Splash erosion (which was much less than wash-off erosion; see Fig. 2a) was highest for the Takahe sample, in spite of this test being at the lowest rainfall intensity. This sample had clearly the highest sand content, 65% (0.2 to 2 mm), while the Timaru and Waipara samples were similar at 40% and 45% sand respectively. Splash erosion decreased with time, as would be expected from the surface sealing which took place during runs and the lower availability of loose material in the surface layers as time passed.

The results of testing various indices of erodibility have been presented in detail (Khatri Chhetri, 1971) but it seems unlikely (Bryan, 1968b) that any one property, or combination of a few, could be a universal indicator of erodibility (even in the restricted sense considered here).

Wischmeier and Mannering's (1969) equation for erodibility is an interesting and worthwhile approach, although the three samples with which it has been compared in this study do not constitute a test of its applicability. As all the properties required are easily measured in the laboratory or assessed from a profile description, such an equation would be a most useful and inexpensive method of estimating erodibility.

CONCLUSIONS

Erodibility of soils needs to be considered in the context of the erosion type to which the erodibility applies. In New Zealand, it is an aspect of potential land use classification and of prediction of sediment yield from catchments, which deserves further attention.

A preliminary study of direct laboratory measurement of erodibility, in the context of rainfall and overland flow erosion, has been carried out and shows sufficient promise to warrant further work.

A relatively quick and inexpensive method of estimating erodibility from soil physical properties and profile characteristics is available. The extent of its applicability in New Zealand, and any possible modifications, need to be determined.

ACKNOWLEDGMENTS

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