

# THE DETERMINATION OF SOME SOIL ERODIBILITY FACTORS USING A RAINFALL SIMULATOR

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### Abstract

A method for simulating rain storms at the rate of 63 mm of precipitation per hour for an hour, using a rotating boom rainfall simulator, is described. The soils subjected to this treatment ranged from a weak structureless sand to a well structured clay and included Cartref, Longlands, Kroonstad, Hutton, Bonheim and Fernwood soil forms. The measured erodibilities for the less structured soils showed a close correlation with those determined by the nomograph method developed in the United States of America. The results obtained for the structured Bonheim soil showed little correlation between the factor predicted by the nomograph and that determined by actual measurements in the trials.

### Introduction

There is a great need to measure specific soil and water losses which occur from sugarcane fields throughout the life cycle of the crop, in order to improve constantly the recommendations for soil protection and water conservation. It is estimated that approximately 35 000 ha, or 10% of the area under sugarcane in South Africa, is replanted each year. It is the area being replanted that is most vulnerable to heavy rain storms and, as the major portion of this area is prepared for replanting using traditional ploughing and discing methods, the bare tilled fallow was chosen as the standard condition of the land in this investigation.

Runoff plots are now in operation at five sites as reported by Platford<sup>2</sup> to measure soil erodibility under natural rainfall conditions. Because of the great variability of natural rain storms, both spatially and temporally, these runoff plot experiments are a longterm project. To try to achieve some idea of comparative soil erodibility values in a shorter period it was decided to use a rainfall simulator on eight different sites. Five of the sites were on Experiment Station field stations and three on property belonging to Tongaat Sugar Company Limited, Natal Estates Limited and the farm Aveton belonging to Mr. V. R. Rodgers. The tests were carried out by applying 63 mm of water in an hour on two occasions 24 hours apart. In this way a large number of tests could be conducted over a relatively short period. Most of the work was carried out on land prepared for replanting, generally having been ploughed with one or two subsequent discing operations. Because more appropriate sites were not available on one occasion, a field that had been burnt before harvest was used and on another occasion trash was used to cover 90% of the surface of a ploughed field.

### Materials and Methods

The rainfall simulator was built from a design by Swanson<sup>1</sup>. The same type of equipment has been used extensively in the United States of America to assess soil and water losses from land under different agricultural crops and also to evaluate the suitability of different cover materials used to protect steep roadside cuttings.

#### The machine

The machine, shown in Figure 1, consists of a box frame mounted on a two-wheel trailer chassis, with a vertical centre spindle which can be lowered to the horizontal position for

transporting the machine from site to site. A removable head which can rotate is fitted with ten short extensions set 36° apart. A six metre long galvanised boom is attached to each extension by a snap lock irrigation coupling. Cross stay wires and support wires above the boom provide the necessary stability. To set each boom in its correct horizontal position adjustments are made to the support wires and cross stay wires. Vee jet nozzles

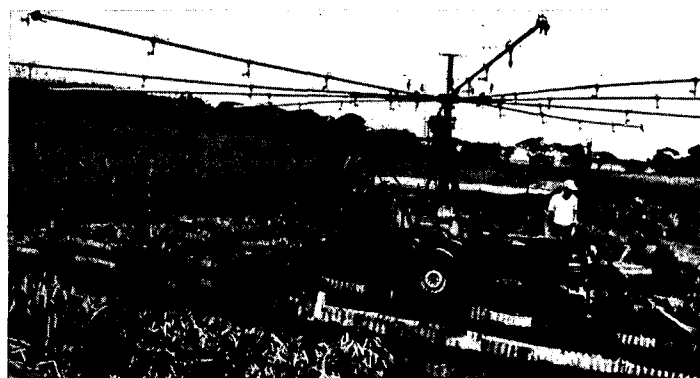
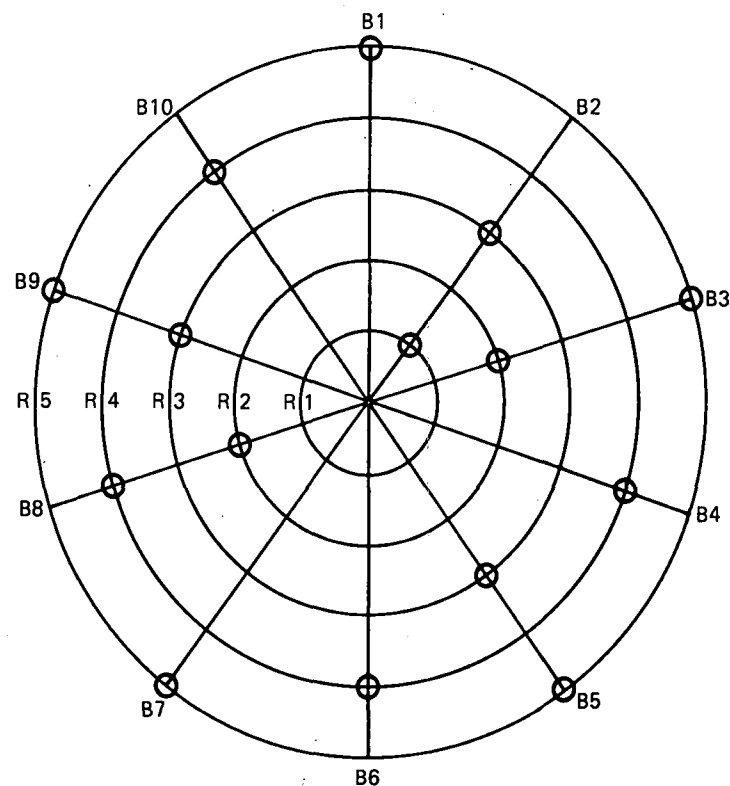


FIGURE 1 The rainfall simulator set up on a 5% slope of Central Field Station, where the soil is a Hutton/Clansthal, recent sand. The two bare fallow plots are in the foreground.

- |                 |         |      |                |
|-----------------|---------|------|----------------|
| B = BOOMS       | 1 to 10 | R5 = | 5 Nozzles open |
| R = RINGS       | 1 to 5  | R4 = | 4 Nozzles open |
| O = OPEN NOZZLE |         | R3 = | 3 Nozzles open |
|                 |         | R2 = | 2 Nozzles open |
|                 |         | R1 = | 1 Nozzle open  |



Application rate 63,5 mm/hr

FIGURE 2 Rainfall simulator nozzle patterns.

are fitted to the underside of the boom as shown in Figure 2. These nozzles spray a flat fan of water at right angles to the direction of rotation.

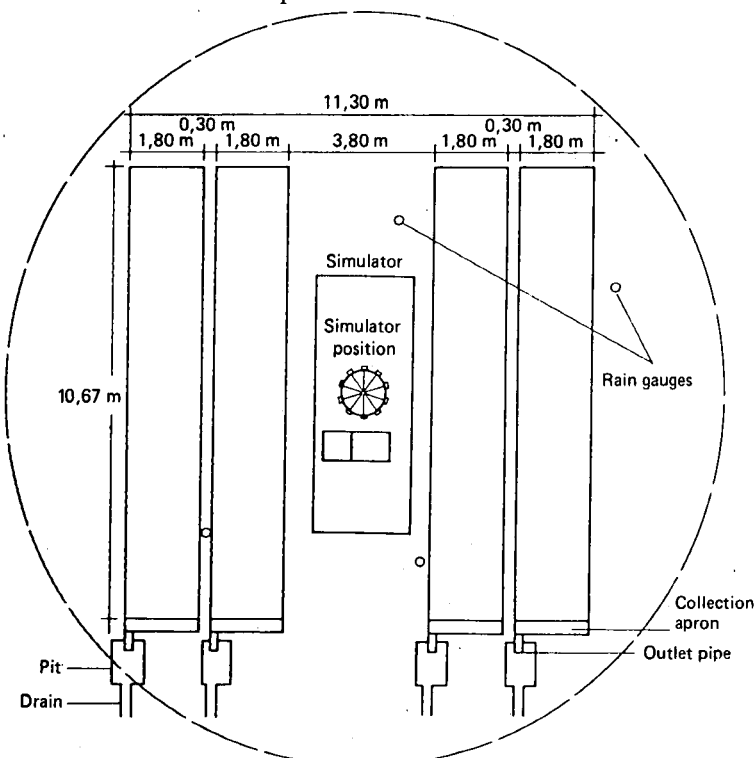
The head and booms are rotated by a hydraulic motor driven by a small petrol engine. A two-way control valve attached to the oil reservoir allows rotation to be reversed. The booms normally rotate five or six times per minute. Water is supplied to the head through a sealed centre spindle. A Saunders pressure control valve maintains a constant pressure of 42 kPa at the nozzles and total water applied is measured through a flowmeter. A gauge on top of the head monitors the nozzle pressure.

A jack at each corner of the machine allows the machine to be set up, with the booms horizontal, on sloping ground. The level is checked by using a metre long builder's level.

**Plot layout**

After the sites had been selected they were brought to a tilth required for a seedbed. The practices used varied from site to site because of the large range of soil types encountered. Land preparation ranged from one disc harrowing on the Fernwood soil, to a ploughing, a disc harrowing and rotavating on the Bonheim soil. Every effort was made to use the same operations as would normally be used for the particular soil type under practical farming conditions.

Four plots, each 1,8 metres wide by 10,67 metres long were laid out with the long axis up and down the slope as shown in Figure 3. Each plot was sealed against unwanted soil and water from neighbouring areas by overlapping one metre lengths of corrugated galvanised steel sheets, which protruded 20 mm above the soil surface. At the bottom of the plot a steel base board was hammered into the ground until it was exactly horizontal with the top of the board 20 mm below soil level. The combined collection apron, cover and delivery chute was then clipped over the base board, care being taken to maintain the level of the board. A shield protruded slightly over the sampling box to prevent any direct spray from the nozzles from entering the box. The box was sealed by compacting soil all around it to ensure that only soil and water from the plot could enter and be sampled.



**FIGURE 3** Plot layout for rainfall simulator tests.

**Pre-test sampling**

A neutron probe was used to determine the bulk density and moisture content of the soil at each site. To calibrate the probe it was lowered into an access tube set in the soil and readings were taken at 150 mm, 300 mm, 450 mm, 600 mm and 700 mm depths. An auger hole was then bored next to the aluminium access tube and soil samples were taken at the same depths for the laboratory determination of moisture content.

In order to check the distribution pattern of water from the simulator 76 glass jars were placed on the test area together with four rain gauges placed in random positions. The machine was then run for forty minutes and an example of the volumes collected is shown in Figure 4.

Average volume per jar ( $\bar{X}$ ) = 169 ml

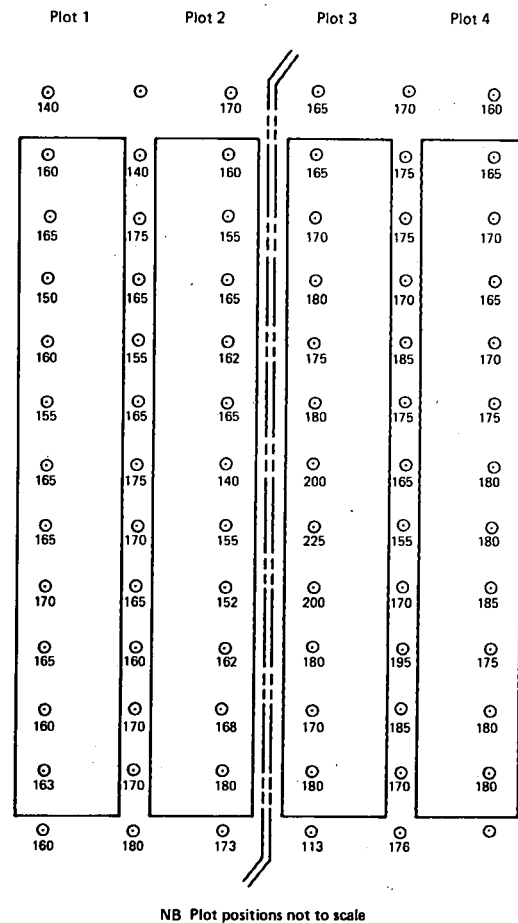
Mean deviation (md) = 10 ml

Coefficient of uniformity (Cu) =  $100 - \left( \frac{10 \times 100}{169} \right) = 94\%$

Rain gauge readings : 41 mm, 39 mm, 35 mm, 39 mm

Average = 38,5 mm

Before the first test run at each site, a pit was dug to determine the soil form and series from the diagnostic horizons and to take samples for particle size analysis (Table 1 and Figure 5). Neutron probe readings were taken before each test run on each plot and also at the end of the one hour application. Samples of soil from the surface stratum were taken to determine bulk density and moisture content before each test run.



**FIGURE 4** The volume of water collected in each of the bottles is shown during a 40 minute application through the rainfall simulator to calculate the co-efficient of uniformity.

TABLE 1  
Site details and properties of soils tested with the rainfall simulator

Site	Slope	Soil						
		Form	Series	Depth	Particle size distribution			Organic Matter
					Clay	Silt + V.F. Sand	Sand	
%	cm	<0,002 mm	0,002-0,1 mm	0,1-2 mm	%			
Rogers Averton Est. . . . .	9,0	Cartref	Cartref	60	11	19	70	1,0
SASA Chakaskraal . . . . .	7,0	Longlands	Waldene	40	21	48	31	1,5
SASA La Mercy . . . . .	3,5	Kroonstad	Kroonstad	30	7	12	81	0,5
SASA C.F.S. . . . .	12,0	Hutton	Clansthal	>200	8	11	81	0,5
SASA C.F.S. . . . .	3,5	Hutton	Clansthal	>200	10	10	80	0,7
SASA C.F.S. . . . .	4,0	Hutton	Clansthal	>200	10	10	80	0,7
Tonga Sugar 'Buffelsdale' . . . . .	7,5	Bonheim	Bonheim	40	43	45	12	3,0
The Natal Estates 'Cornubia' . . . . .	3,0	Fernwood	Fernwood	>200				0,5

#### Test procedure

Water was supplied either from a tanker or from an irrigation line. After the engine was started the control valve was closed and the booms rotated. Starting time and initial flow meter readings were recorded. The time taken for runoff from the plots to commence was noted. Runoff and sediment samples were collected in 500 ml glass bottles. One sample was taken every minute for the first five minutes. The bottles were held under the outlet from the apron and either the effluent was collected for 30 seconds or the time taken to fill each bottle was recorded if this was less than 30 seconds. After five minutes had elapsed, runoff samples were taken at two minute intervals for a further ten minutes and then every five minutes for the balance of the test run of 60 minutes. The test was repeated 24 hours later, this being the so called wet run.

After each artificial storm all the samples were sent to the laboratory for analysis.

#### Sediment analysis

Each sealed glass bottle containing the runoff and sediment was weighed before adding hydrochloric acid to hasten precipitation. After the bottle had stood overnight the clear water was siphoned off leaving the sediment and a small quantity of water. The bottle was then placed in an oven to evaporate the remaining water. When the bottle had cooled it was weighed before washing out the soil, drying and taking the tare weight of the bottle. Using the time recorded to take the sample a rate of soil loss and rate of water runoff was calculated. Progressive totals were calculated to find the total mass of soil and water lost during the hour's run.

Surface bulk density and moisture content values were determined using gravimetric methods.

#### Results and Discussion

In the temperate to sub-tropical climates of the United States of America soil erodibility values (K) have been determined empirically from a very large data bank established from runoff plots under natural rainfall.

The results show that particle size distribution is most closely associated with soil erodibility<sup>3</sup>. A first approximation of K can be obtained from data for the percentage of silt plus very fine sand, the percentage of sand and the percentage of organic matter. This value can be made more accurate by taking soil structure and permeability into account.

For the tests carried out in this project the tons of soil lost per hectare, incorporating an adjustment to a standard slope of nine percent, were calculated. Using the amount of energy that had been applied in the form of simulated rain, a K-value (tons soil loss per unit of energy) was calculated. This value was compared with the predicted value from the nomograph.

A summary of soil and water losses and K values is given in Table 2.

The greatest soil loss, 30 ton/ha, was recorded for the Cartref series soil. On average 87% of the 63 mm of water applied was lost as runoff. This occurred because the soil profile was quickly saturated. Despite saturation a final infiltration rate of 9 mm/h was measured, suggesting that seepage was occurring. The nomograph value for this soil was 0,18 while the measured value was 0,39.

The Waldene series soil lost 24 tons of soil per hectare on a 7% slope. Eighty-two percent of the water was lost as runoff because this soil is shallow and because the surface tends to seal. Although the soil was saturated after the wet run a final infiltration rate of 11 mm/h was measured. After adjustment for slope the measured K value (0,33) was fairly close to the nomograph value (0,42).

The Kroonstad series soil on a 3,5% slope lost only 1,5 tons/ha and 37% of the water was lost as runoff. After the wet run the final infiltration rate was 30 mm/h. Both the measured value of K (0,08) and the nomograph value (0,12) indicate that this soil is only slightly erodible.

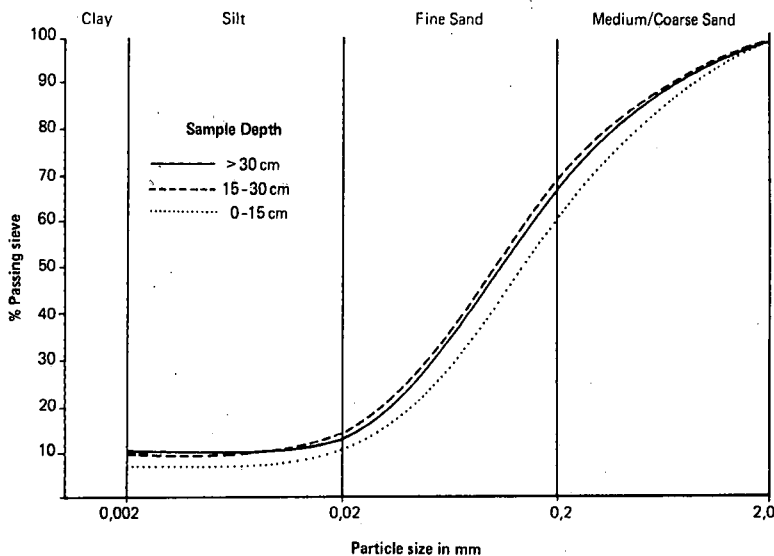
Two tests were conducted on Clansthal series soils (Figure 5). In the first test on a 12% slope there was a loss of 3,5 tons/ha, which was more than twice as much as the 1,5 tons/ha that was lost from a 3,5% slope in the second test. The runoff from the steeper plot averaged 47% of the water applied, while from the flatter plot the average was 31%. The final infiltration rates of 35 mm/h and 44 mm/h for the steeper and flatter plots respectively indicate that the depth of these soils is sufficient to allow them to accept large amounts of water. Where the slope was 12% the measured and predicted values of K were both 0,06, indicating high resistance to erosion. Where the slope was 3,5%, the value of K was 0,02 and the predicted value was 0,06.

Two further tests were carried out on the Clansthal soil. In one instance the crop had been burnt before harvesting and unburnt tops and remaining pieces of stalk covered 5% of the soil surface. In the second instance a bare fallow was prepared for planting and then trash was imported to cover 90% of

**TABLE 2**  
Summary of measured soil and water losses from eight test sites

Soil series	Slope %	Storm 1 and 2 mm/h	Treatment	Soil losses t/ha	Average runoff %	Final infiltration rate mm/hr	Nomograph K	Measured K
Cartref . . . . .	9,0	63	Bare ploughed fallow	30,0	87	9	0,18	0,39
Waldene . . . . .	7,0	63	Bare ploughed fallow	24,0	82	11	0,42	0,33
Kroonstad . . . . .	3,5	63	Bare ploughed fallow	1,5	37	30	0,12	0,08
Clansthal . . . . .	12,0	63	Bare ploughed fallow	3,5	47	35	0,06	0,06
Clansthal . . . . .	3,5	63	Bare ploughed fallow	1,5	31	44	0,06	0,02
Clansthal . . . . .	4,0		Burnt	—	—	63	—	—
			Trashed	—	—	63	—	—
Bonheim . . . . .	7,5		Bare ploughed fallow	1,0	40	9	0,32*	0,01
Fernwood . . . . .	3,0		Bare ploughed fallow	—	—	63	—	—

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**FIGURE 5** Grading analysis for a typical red recent sand soil found along the coastal belt of the sugarcane growing area in Natal.

the soil surface. Two runs with applications of 63 mm/ha each were carried out, but neither produced any runoff.

The strongly structured Bonheim soil lost only 1,0 tons/ha although 40% of the applied water ran off the plots. The final infiltration rate was only 9 mm/h, showing that at the end of the hour's application most of the cracks and crevices had closed due to soil swelling, resulting in much runoff during the later stages of the test. The predicted K value (0,32) was very different from that measured in the field (0,01).

A final test was carried out on a grey recent sand (Fernwood series). The site had a 3,0% slope and was a bare, ploughed fallow. No runoff was produced.

**Conclusions**

There was a fairly good correlation between predicted and measured values of erodibility for soils of the Waldene, Kroonstad and Clansthal series. Although the tests simulated a storm of only moderate intensity, the bare fallow Cartref and Waldene soils lost large amounts of soil and water. The high losses that were expected from the sandy Kroonstad and Clansthal soils did not materialise. Undisturbed plots and those with a 90% trash blanket were able to absorb all the water applied without any runoff occurring. The amounts of low soil and water lost from the Bonheim soil were unaccountably much lower than indicated by the nomograph.

The use of the simulator to compare different soils showed that useful results could be achieved quickly. Because no runoff occurred from some of the plots future work should include heavier and longer applications of simulated rain. It might be profitable to analyse the samples of run-off in the laboratory for dissolved and adsorbed chemicals.

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