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Tests on a Small Rainfall Simulator for Evaluating Soil Erodibility[1]

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ABSTRAK

Beberapa tanah bukit, in situ *diperlakukan dengan hujan tiruan jangka pendek untuk menentukan kaedah yang sesuai bagi penilaian erodibiliti tanah di Malaysia. Alat hujan tiruan menghasilkan sejumlah 18mm hujan dalam tiga minit dan titis-titis hujan menimpa ke atas 0.0625m² permukaan petak ujian pada kecerunan 20% dari ketinggian purata 0.4m. Hasil daripada kedua-dua jenis tanah permukaan dan tanah bawah menunjukkan variasi pada kehilangan tanah di antara petak-petak adalah lebih kecil berbanding dengan variasi bagi simulasi yang berturut-turut pada petak tetap. Kehilangan tanah purata bagi tanah-tanah yang diuji ialah di antara 5.42g hingga 12.66g setiap petak. Kehilangan tanah didapati tidak begitu peka terhadap perubahan kecil pada kandungan air asal petak ujian dalam lingkungan muatan medan. Kaedah hujan tiruan ini kelihatan berupaya membezakan gerak balas di antara tanah-tanah dan dengan itu sesuai untuk kajian erodibiliti tanah bukit di Malaysia.*

ABSTRACT

A selected number of upland soils were subjected, in situ, *to simulated rain of short duration in order to establish a methodology for evaluating erodibility of Malaysian soils. The rainfall simulator produces an 18mm shower in three minutes from an average height of 0.4m, falling onto a 0.0625m² test plot area at 20% slope. Results from both the surface and sub-surface horizons show less variability in the soil loss between plots than between successive runs on the same plot. Mean soil loss ranged between 5.42g and 12.66g per plot. Soil loss was found to be not very sensitive to small variations in antecedent soil moisture around the field capacity value. The method appears capable of discriminating responses between soils and is thus, suited to the study of erodibility of upland soils in Malaysia.*

INTRODUCTION

The inherent susceptibility of a given soil to water erosion is quantitatively expressed by its erodibility, namely, the K-factor of the universal soil loss equation (USLE) (Wischmeier and Smith, 1960) which represents the integrated effect of particle detachability, transportability and infiltration characteristics. El-Swaify and Dangler (1977) categorized three approaches to determining soil erodibility, i.e., actual measurements of soil loss form standard bare plot (Wischmeier 1976), measurements under simulated rainfall and, finally, estimations using predictive equations or nomographs. The first two approaches, particularly the actual measurements from bare plots, are costly and time consuming. In the third approach, however, the predictive equations or nomographs based on them have to be first derived from experimental data obtained by either one of the first two approaches.

Quantitative and qualitative assessments of

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soil erosion by water in Malaysia are well-documented (Douglas, 1968; Wan Sulaiman *et al.,* 1981). Yet very little is known about the erodibility of the soils inspite of its importance in conservation planning, the main reason being the excessive cost and effort in obtaining this parameter. An early attempt was made by Wong (1974) who, basing on field observations, classified soils with clay contents exceeding 27% and sand contents less than 45% as 'less erodible' and soils with more than 45% sand and less than 27% clay as 'more erodible'. Static laboratory rainfall simulators have also been used to compare erodibilities of several soils under disturbed conditions (Maene *et al.,* 1975; Abdul Rashid, 1975). Erodibility factors of two soils, the Durian series (an Orthoxic tropudult) and Padang Besar series (a Petroferric tropudult) have been measured using unit plots and reported to be 0.08 and 0.02 respectively (Soil Science Department, 1979 and 1980). The present study is part of a systematic effort in evaluating erodibility of Malaysian soils. A selected number of upland soils were subjected, *in situ,* to short duration simulated rain from a small portable rainfall simulator. The objective was to evaluate their response and reproducibility in the soil loss and runoff collected so as to establish a methodology for using the simulator on Malaysian Soils.

MATERIALS AND METHODS

The Rainfall Simulator

There are many rainfall simulators of varying sizes, complexity and cost depending on their purpose. Some are the static laboratory type designed for studying mechanisms while others are portable, intended for field use. Among the latter category is a small unit that can easily be carried around and operated in a very short time (Kamphorst, 1987). It produces an 18 mm rainshower in three minutes, thus giving an intensity equivalent to 36 cm/h. The raindrops fall from an average height of 0.4m, onto a 0.0625 m^2 surface area of the test plot having a 20% slope. Details of the design, operational procedure and field plot preparation are fully described by Kamphorst (1987).

Assessing Intra- and Inter-plot Variations

Four soil series common to the upland areas were selected for the test. The soils were Munchong (Tropeptic Haplorthox), Serdang, Bungor and Padang Besar (all Typic Paleudult). For Bungor series soil, two sites were chosen, one at the UPM Serdang Farm (designated Bungor UPM) and the other at the Puchong Farm (designated Bungor Puchong). Simulation runs were made on both the surface (0-15 cm) as well as sub-surface (15-30 cm) horizons. For each soil, eight plots (replications) were selected on sites under similar vegetation or landuse. Each of the first four plots was subjected to four successive simulated rainstorms at three–minute intervals, giving sufficient time to collect the erosion sample and reset the simulator. The remaining four plots were subjected to single rainstorms only. Erosion samples were taken back to the laboratory where the amounts of runoff and sediment were determined by weighing and drying.

As part of the standard procedure, all the simulation runs were made at a time when the soils were at or very near field capacity, with the exception of the consecutive runs on the same plot. A simple rule of thumb is that, the soil would be at field capacity one day after a moderate rainfall or two days after a prolonged downpour. But if there was no rain or very little of it for several days, the current water content was determined by gravimetric sampling and with previously measured values of field capacity (volumetric water content at 10 kPa), the amount needed to bring the top 5 cm of the test area to field capacity was computed and then added to plot.

Effect of Antecedent Water Content

Additional runs were conducted on the surface horizons of Munchong and Bungor Puchong soils at two moisture conditions, namely, wetter than field capacity (wet run) and drier than field capacity (dry run). For the wet case, measurements were made on the day following a heavy overnight storm and for the dry case, after 5 consecutive days without rain. No pre-wetting was done in either case.

RESULTS AND DISCUSSION

Variations between Consecutive Runs and between Plots

Variations in soil loss and runoff between replicates (plots) and between consecutive runs on the same plot are illustrated by results for the surface horizons of four soils (*Figs. 1* and *2*). The soil losses recorded, mostly less than 10g and none exceeding 20 g were comparable to the riverine soils and fine loess in the Netherlands (Kamphorst, 1987) but much lower than the aeolean soils and the coarser loesses. Successive runs on the same plot yielded a decreasing trend in the soil loss. For instance, a loss of between 8.6 g and 10.8 g for the first run on the Serdang series soil fell to 2.4-4.6 g on the fourth run. In the case of runoff, a slight increasing trend was seen with the successive runs. The observed trends were also true for the other cases tested with some showing more pronounced effects than others. Consequently, the sediment concentration (soil loss/runoff volume) decreased with successive runs.

The variation in soil loss with successive runs could be attributed partly to the difference in antecedent soil moisture, whereby, the soil that was at field capacity prior to the first run became wetter with each succeeding run. However, it is unlikely that increasing antecedent soil moisture would cause a reduction in the soil loss. Dangler and El-Swaify (1976) reported lower soil loss from drier soils than from wetter ones where simulated rain was applied to a much bigger area and for a longer duration. A more probable cause is redeposition of the eroded material. After the first run the original smooth surface became rough with interspersed cavities and mini-rills created by the raindrop impact and channel flow. During subsequent runs these cavities and mini-rills provided sites for redeposition of eroded material from upslope. On the other hand, the increasing trend in the runoff volume is to be expected due to a reduction in the infiltration rate with increasing soil saturation. Partial suface sealing by fine particles resulting from splash could also contribute further to the decrease in the rate of infiltration. Indeed, *fig. 2* shows that for Padang Besar, Bungor and Serdang, runoff on consecutive runs could be as much as the applied shower (1125 ml falling on 0.0625 m^2) and this could be explained only by the infinite impedance of the surface seal. That such a condition (when infiltration rate essentially became zero) was achieved in a very short time would have a profound effect on the surface runoff from large exposed soil surfaces.

Table 1 gives a comparison between the means of first simulation runs from four replicates and the average of the means of the four successive runs within each plot together with their respective coefficients of variation (CV). The mean soil loss for first runs only was greater than that for the successive runs in every case with the exception of Serdang subsurface soil, where, both were virtually identical. The difference is a necessary consequence of the decreasing trend seen with successive runs on the same plot.

The strengh of a particular method depends very much on its reproducibility. The coefficients of variation in the soil loss for first runs only seem generally smaller than those for averages of successive runs. The larger CV in the latter could be due to the uneven soil surface and material redeposition mentioned earlier. The range of 6% to 24% for first runs only can be considered acceptable for erosion measurements. In the casse of runoff, the coefficients of variation for single runs are slightly larger than for averages of consecutive runs and in overall terms, runoff data appear more reproducible than the soil loss figures. However, considering that soil loss is more important than runoff in erodibility determination, measurements of single runs only offer a better alternative for assessing relative erodibilities. For greater confidence, the number of replicates could be increased to between 6 and 8. Notwithstanding these, special attentian must be given to the selection of plot sites, avoiding obvious dissimilarities. The influence of local heterogeneities which are usually masked in large plots like the unit erosion plot, can appear in their entirety with the current method. In the present study there

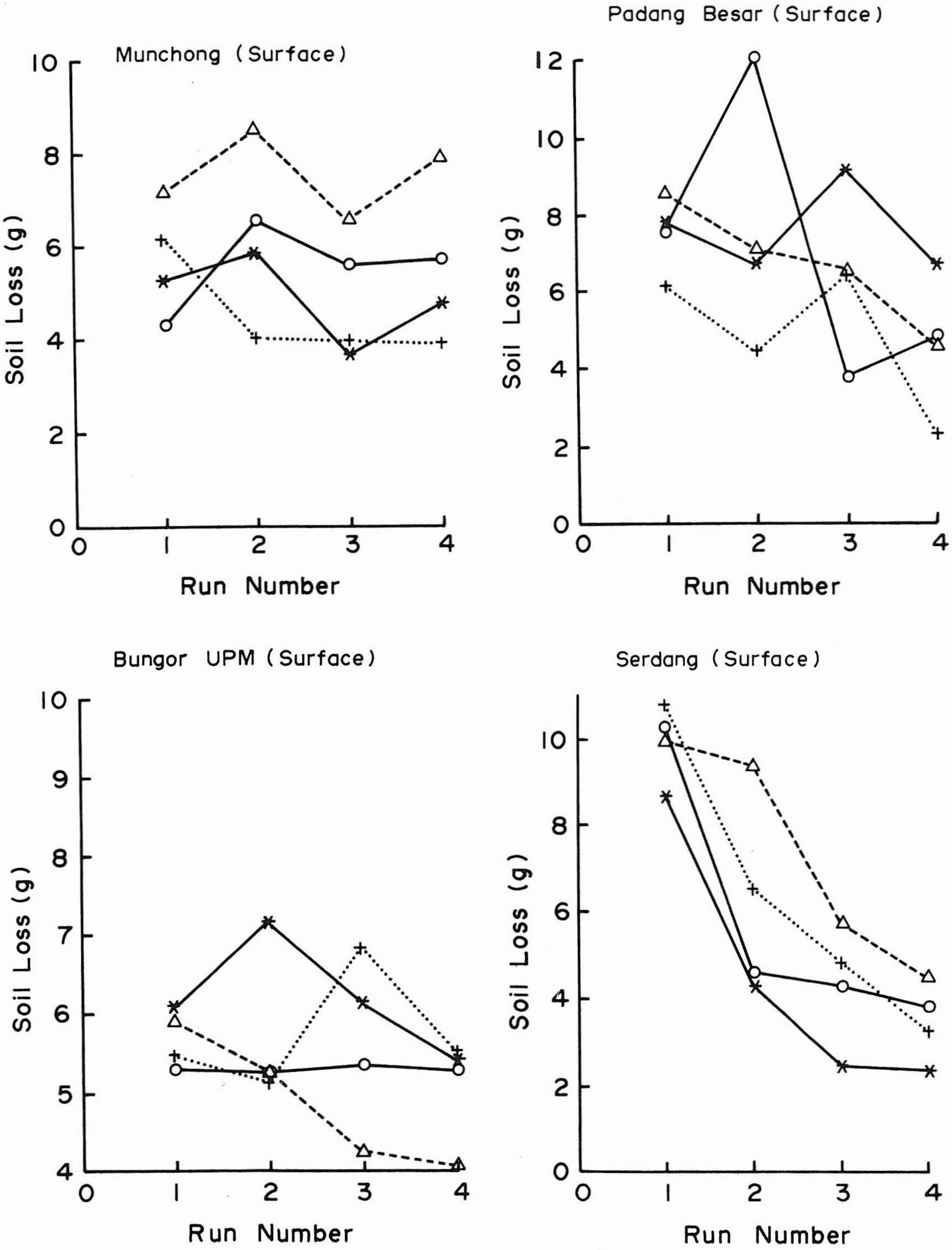

Fig. 1: Soil losses from rainfall simulator test plots of four soils. Points connected by a line represent soil losses from consecutive runs on one plot.

were several instances when measurements (plots) had to be discarded because runoff differed from those of other replicates by more than 100%. The cause was traced to differences

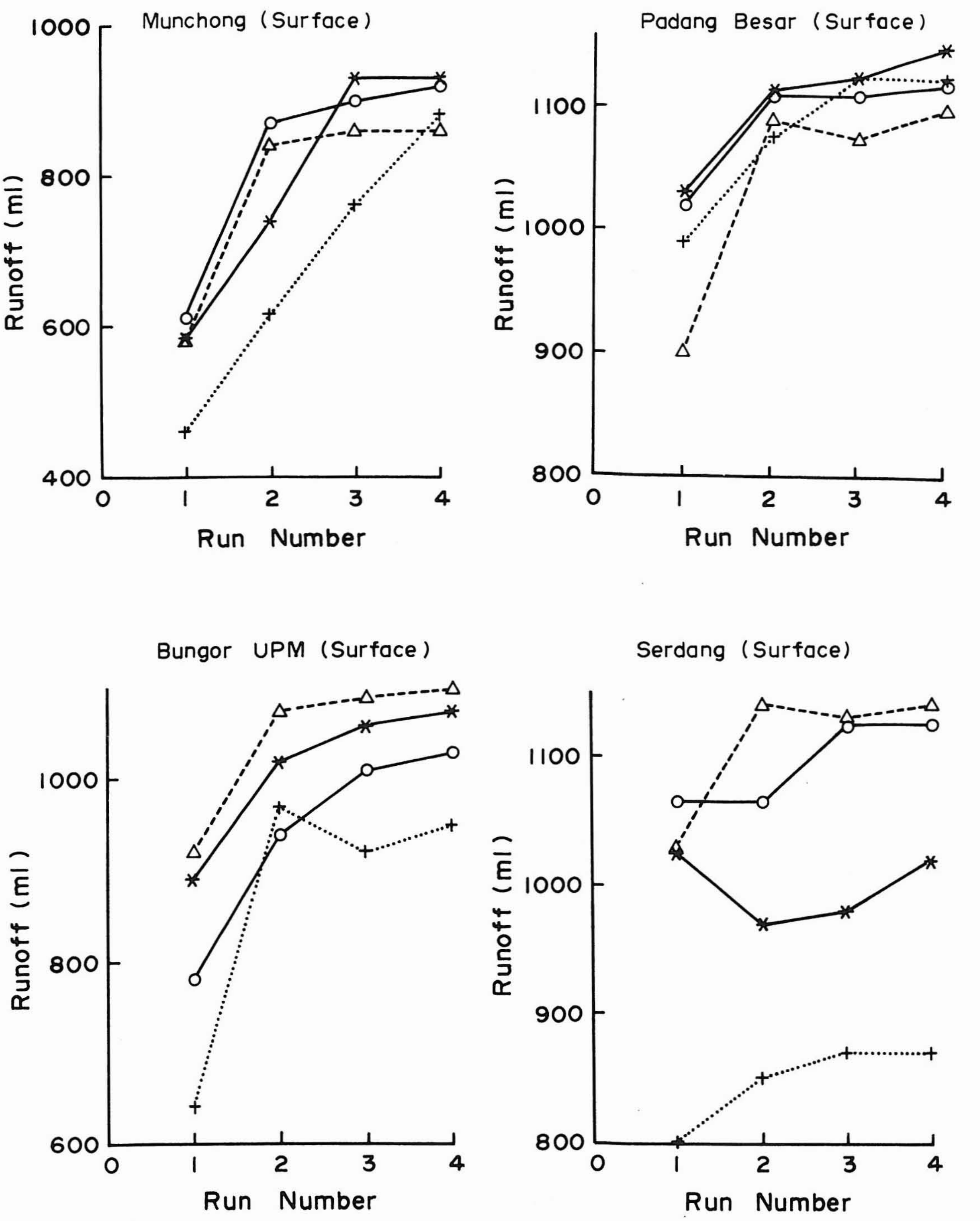

Fig. 2: Runoff from rainfall simulator test plots of four soils. Points connected by a line represent runoff from consecutive runs on one plot.

in texture, colour (related to organic matter content) and abundance of roots.

Table 2 presents the means and coefficients of variation based on eight replicates of single runs only. The coefficients of variations are observed to be of the same magnitude and perhaps slightly smaller than for the case of four replicates only. The

TABLE 1
Comparison of plot replications and means of successive runs

Soil Series	First run only		Avg. of 4 successive runs	
	Mean soil loss (g) or runoff (ml)	CV (%)	Mean soil loss (g) or runoff (ml)	CV (%)
		SOIL LOSS		
Munchong (s)	5.71	21.5	5.60	23.9
Munchong (ss)	8.28	9.7	7.14	17.3
Bungor UPM(s)	5.68	6.2	5.52	10.1
Bungor UPM (ss)	6.08	22.7	4.28	19.5
Bungor Puchong (s)	14.08	17.3	13.00	34.3
Bungor Puchong (ss)	8.20	15.0	6.69	22.6
Serdang (s)	9.87	9.2	5.95	20.5
Serdang (ss)	5.43	17.9	5.48	27.4
Padang Besar (s)	7.53	13.4	6.53	18.7
Padang Besar(ss)	7.62	19.8	6.81	51.2
		RUNOFF		
Munchong (s)	558	12.0	771	13.5
Munchong (ss)	884	7.1	984	8.3
Bungor UPM (s)	808	15.7	970	7.9
Bungor UPM (ss)	828	18.9	972	9.0
Bungor Puchong (s)	1052	3.3	1090	4.0
Bungor Puchong (ss)	856	24.5	981	16.7
Serdang (s)	980	12.4	1090	11.8
Serdang (ss)	785	15.5	944	8.6
Padang Besar (s)	985	6.0	1080	2.7
Padang Besar (ss)	939	11.1	1037	5.7

s= surface horizon; ss= subsurface horizon
CV= coefficient of variation

discriminating power of the method can be assessed from results of the Duncan's multiple range test. There were significant differences in the response of the soils, both in terms of soil loss and runoff. Soil loss of 5.50 g from Bungor UPM, for instance, was found to be significantly different (p=0.05) from a loss of 7.40 g from Padang Besar soil. It is interesting to note that for the riverine soils and fine loess in the Netherlands (Kamphorst, 1987) losses of 4.1g and 8.3g were found not to differ significantly from each other suggesting greater variability in their measurements. The latter were also based on eight measurements but made on unploughed fallow plots during the wettest season in the cultivation cycle. In the present study, the sites chosen were all under permanent crops ranging from pasture to bananas and, thus, had experienced less disturbance. Significant differences are also observed between surface and subsurface horizons of Munchong, Bungor Puchong and Serdang soils. Another important feature is the large difference between soil loss occurring on the same soil series (Bungor series) but at two different localities (both incidently were under pasture). From the above observations the method appears to be sensitive to the intrinsic soil properties and hence well-suited to upland soils of Malaysia. Report on the relationship between soil loss measured with the same rainfall simulator and several soil properties is under preparation.

TABLE 2
Soil loss and runoff from different soils for 8 replications

	Soil loss		Runoff	
Soil Series	Mean (g)	CV (%)	Mean (ml)	CV (%)
Munchong (s)	5.95 de	18.9	639 d	19.0
Munchong (ss)	8.23 c	7.9	828 bc	12.6
Bungor UPM(s)	5.50 e	7.5	758 cd	17.2
Bungor UPM (ss)	5.94 de	18.4	822 bc	10.5
Bungor Puchong (s)	12.66 a	23.4	989 a	11.3
Bungor Puchong (ss)	8.52 bc	12.6	864 abc	18.4
Serdang (s)	9.95 ab	14.4	975 a	6.8
Serdang (ss)	5.42 e	14.9	812 c	13.1
Padang Besar (s)	7.39 cd	14.9	957 ab	4.7
Padang Besar(ss)	7.40 cd	16.8	885 abc	12.3

s = surface horizon; ss = subsurface horizon;
CV = coefficient of variation;
Values within a column having a letter in common do not differ significantly at the 5% probability level according to Duncan's multiple range test.

TABLE 3
Mean erosion losses from Muchong and Bungor Puchong soils for different antecedent moisture conditions

Munchong			Bungor Puchong		
Antecedent moisture (v/v)	Soil loss (g)	Runoff (ml)	Antecedent moisture(v/v)	Soil loss (g)	Runoff (ml)
0.37	5.71 a	660 a	0.41	16.74 a	1070 a
0.32	5.95 a	639 a	0.29	12.66 b	989 b
0.29	5.52 a	546 a	0.22	10.77 b	770 c

Values within a column having a letter in common do not differ significantly at the 5% probability level according to Duncan's multiple range test.

Effect of Antecedent Moisure

Soil loss and runoff collected for Munchong and Bungor Puchong surface soils at different antecedent soil moisture contents are presented in Table 3. For Munchong soil, there was no significant difference in the results at the three antecedent moisture conditions tested. The result is consistent with the soil loss pattern shown in *Fig. 1.* In the case of Bungor Puchong, soil loss for the 'wet run' was significantly higher than either the 'field capacity run' or 'dry run'. The soil loss from the dry run was lower than from the field capacity run by 1.89g, being just smaller than the critical range of 1.90g for significant difference according to Duncan's multiple range test. It is not the intention of this study to explain the difference in response between the two soils but it is worth noting that the Bungor series is an ultisol of moderate to good drainage while Munchong is an oxisol having a higher infiltrability, better drainage and presumably higher structural stability. What is more relevant is that while acknowledging the importance of antecedent moisture in the process of soil erosion, the rainfall simulator measurements do not appear to be very sensitive to small variations in antecedent soil moisture around the field cspacity value. Large differences, however, can occur if the initial soil condition is too wet or too dry.

Limitations fo the Rainfall Simulator

There are several features of the rainfall simulator that need to be reemphasized. Firstly, the average height of fall is 0.4m only, too small to allow the raindrops to attain terminal velocity. Secondly, the plot size is very small, being only 0.0625 m^2. Finally, to offset these small dimensions, a very high intensity shower (18 mm in three minutes, equivalent to 36 cm h^{-1}) is used so as to produce measurable erosion losses within a short duration that can also be discriminated from one soil to another. The soil loss recorded during the test runs varies from 5.42 g to 12.66 g. If expressed in terms of per hectare per annum, the loss will be enormous. In the light of these, the simulator cannot be used to obtain absolute values of erodibility. Rather, it was designed with the specific purpose of evaluating relative erodibility among soils, hence the fixed slope and procedures of plot preparation. Nevertheless, it might be feasible to obtain indirectly the absolute erodibility, if soil loss with the simulator can be calibrated against known K values. This implies that simulation runs must first be made on soils whose K values are already known.

CONCLUSION

The rainfall simulator described by Kamphorst (1987), by virtue of its small size, was designed for use on soils where spatial variations in properties have been reduced through previous cultivation. However, with judicious site selection the method can be equally effective on the less disturbed upland soils in Malaysia. Its small size makes it possible to assess differences in erodibility with different landuse even on a small scale.

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