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Field measurement of splash erosion

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ABSTRACT Although detachment of soil particles by raindrop impact is the first and fundamental phase of sediment production on hillslopes, no satisfactory method has been developed for measuring splash erosion in the field. Various techniques of field measurement are reviewed and the results of a field study of splash erosion are presented for sandy loam and clay soils under bare soil and cereal crop conditions in mid Bedfordshire, England. A comparison of the results with those from field and laboratory experiments of other researchers shows that, where splash erosion is a simple response to rainfall energy, field conditions can be adequately simulated in the laboratory. Where surface crusting, frost action or a plant cover interact with the splash process, data from laboratory investigations have limited validity in the field. With slight modifications to the design, the field splash cup provides a suitable method of field measurement.

<u>Les mesures de l'érosion par le splash sur le terrain</u>

RESUME Quoique le détachement des parcelles du sol par l'impact des gouttes de pluie soit la première phase fondamentale de la production de sédiment sur les versants des collines, aucune méthode satisfaisante n'avait pu être developpée pour mesurer l'érosion par le splash sur le terrain. Des techniques diverses de mesures sur le terrain sont analysées et les résultats d'une étude de l'érosion par le splash sont presentés pour les sols sablo-limoneux et les sols argileux sous les conditions du sol nu et avec des récoltes de céréales au centre du Bedfordshire, Angleterre. La comparaison des résultats de ces expériences avec celles faites sur le terrain et au laboratoire par d'autres chercheurs qui ont fait des recherches semblables montre que les conditions sur le terrain peuvent être simulées convenablement au laboratoire au cas où l'érosion par le splash est une réponse simple à l'énergie de la pluie. En case où une action réciproque a lieu entre le processus du splash et une croûte à la surface du sol, ou avec l'action du gel ou avec un couvert végétal, les données des recherches du laboratoire n'ont qu'une valeur limitée sur le terrain. Avec des modifications légères dans ses dispositions la petite cuve pour mesurer le splash fourni une méthode convenable pour les mesures sur le terrain.

INTRODUCTION

Although splash erosion is of fundamental importance as the first phase of sediment production on hillslopes, few studies have been made of the process in the field. In contrast, numerous investigations have been carried out in the laboratory by agricultural engineers and geomorphologists but, without field evidence to support them, the validity of the results of these studies remains questionable. Addiction to the laboratory has been dictated by the need for controlled and repeatable experimental conditions which cannot be obtained in the field, for research into the mechanics of the process, and by the lack of any satisfactory method of field measurement.

This paper approaches the problems of field measurement by: (a) considering the design requirements of a field measurement device, a topic hitherto neglected; (b) describing and presenting the results of a field study of splash detachment in mid Bedfordshire, England, using one device, the field splash cup; and (c) comparing the results with those from field and laboratory experiments of other workers in order to assess the validity of laboratory studies and the direction to be taken in future work.

DESIGN REQUIREMENTS

The basic design requirement of any field measurement device is that it should provide data on the total weight of soil particles splashed by raindrops, i.e. splash detachment. To do this the system must adequately isolate splash from the effects of sediment movement by overland flow and runoff creep; it must not be affected by relative changes in the height of the device with respect to the soil surface as a result of ground lowering, compaction, frost or swelling and shrinking of the soil, the so-called rim effect, characteristic of splash cups used in laboratory experiments where, as the soil level in the cup falls, soil particles are less and less likely to bounce over the rim; and it must not interfere with the properties of the rainfall close to the ground surface. It should also be acceptable environmentally.

The design requirements depend on whether the objective is solely to determine splash detachment or to obtain sufficient information to model the splash process, in which case, data are required on the direction, height and distance of movement of the splashed particles (Moeyersons & De Ploey, 1976).

Splash erosion has been measured in the field by splash boards (Ellison, 1944; Kwaad, 1977); small funnels or bottles inserted in the soil (Sreenivas *et al.*, 1947; Bolline, 1975; Gorchichko, 1977); monitoring painted stones (Kirkby & Kirkby, 1974); and radioactive tracers (Coutts *et al.*, 1968; De Ploey, 1969). Because these methods meet few of the design requirements (Table 1), particularly that of isolating the splash process, a splash cup was designed, modelled directly on the splash cup used in laboratory experiments, for use in the field. This device,

Table 1 Design requirements for a field measuring device for splash erosion

Method	Measurement constraints				Measurement requirements		
	Isolation of splash	Rim effect	Rainfall interference	Environmental acceptability	Total splash	Direction of splash	Height/distance of splash
Splash boards	—	○	—	+	+	+	—
Bottles/funnels	—	—	+	+	+	—	—*
Marked stones†	—	○	+	+	+	+	+
Tracers	—	○	+	—§	+	+	+
Field splash cups	+	○	○	+	+	+	—

+ points favouring technique; ○ points of no strong influence; — points against technique.

* Gorchichko's device (1977) provides data on the height of the splashed particles.

† Not feasible for soil particles.

§ Radioactive tracers.

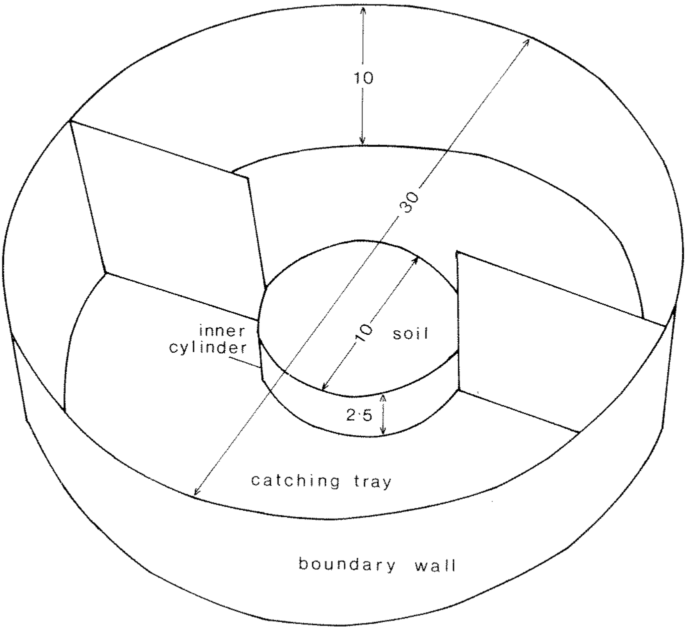

Fig. 1 The field splash cup (dimensions in centimetres).

described fully in Morgan (1978) consists of an inner hollow cylinder, 110 mm long and 100 mm in diameter, pushed into the ground until flush with the soil surface, surrounded by a circular catching tray, 300 mm in diameter, with a 100 mm high boundary wall, and partitioned into upslope and downslope compartments. When set up on a horizontal surface as shown in

Fig. 1, the apparatus will catch all particles splashed from the soil in the inner cylinder for distances less than the radius of the catching tray and those particles splashed greater distances with angles of ejection up to 20°. This compares with a mean value for the ejection angle of splashed particles of 13° (De Ploey & Savat, 1968). The apparatus will also prevent the splash-in of 90% of the soil particles detached by raindrop impact outside the catching tray.

Soil is collected separately from the upslope and downslope compartments of the catching tray, dried and weighed. The upslope and downslope weights combined are a measure of splash detachment. The downslope weight minus the upslope weight is a measure of the net downslope splash transport. Data may be expressed on a unit width or a unit area basis (Table 2 footnote).

EXPERIMENTAL SET UP

Measurements were made at four sites: Silsoe, on a sandy soil with bare ground; Woburn, on a sandy loam soil under cereals; and Meppershall and Pulloxhill, on clay soils under cereals. Details of the soils, plant cover, slope angles, slope position and duration of measurement are presented in Table 2. Although

Table 2 Mean annual rates of splash detachment

Site	Soil	Crop cover	Slope	Splash detachment	
				($g\ cm^{-1}$)	($kg\ m^{-2}$)
Silsoe 1/5/73 to 17/8/79	Sandy variant of the Cottenham series derived from Lower Greensand	None	Upper convex (9°)	44.64	36.46
			Mid slope (11°)	37.77	30.85
			Lower concave (11°)	35.50	28.99
Woburn 1/3/77 to 9/5/79	Sandy loam of the Cottenham series derived from Lower Greensand	Winter oats, winter wheat, winter beans	Upper convex (6°)	27.64	22.57
			Mid slope (7°)	22.48	18.34
			Lower concave (4°)	22.47	18.35
Meppershall 1/3/77 to 9/5/79	Calcareous gley (clay) soil of Hanslope series derived from Boulder Clay	Winter wheat, spring barley	Mid slope (10°)	5.77	4.71
			Lower concave (6°)	5.17	4.22
Pulloxhill 21/11/76 to 9/5/79	Calcareous gley (clay) soil of Wicken series derived from Gault Clay overlain by gravelly drift	Spring barley	Mid slope (10°)	7.60	6.21
			Lower concave (7°)	5.39	4.40

Notes Unit width measurements ($g\ cm^{-1}$) are obtained by assuming that the side of a square of the same area as that enclosed by the inner cylinder of the splash cup represents the width across which splash takes place. Unit area measurements ($kg\ m^{-2}$) are based directly on the area enclosed by the inner cylinder.

splash detachment and transport were measured, only detachment is considered here. The data are derived from two field splash cups installed at each slope position.

Rainfall data were obtained from an autographic gauge at the National Institute of Agricultural Engineering, Silsoe. Although this site is respectively 10, 5, 3 and 2 km from the field sites at Woburn, Meppershall, Pulloxhill and Silsoe, it provides the best rainfall information available. It was not possible to set up raingauges in the field. Values of rainfall energy are calculated from the 10 min rainfall intensity values read from the raingauge charts, using the formula of Hudson (1965). Rainfall energy is expressed by the KE>10 index, defined as the total kinetic energy of all rains falling at intensities of 10 mm h^{-1} or greater for durations of 10 min or longer.

The mean annual values are 555 mm for rainfall amount and 1050 J m^{-2} for rainfall energy. Rainfall amount was below average during the study period but rainfall energy was close to the average value.

Data on rainfall energy and splash detachment were obtained for consecutive 100 day periods.

RESULTS

Annual rates of splash detachment vary from 30-45 g cm^{-1} on the bare sandy soils to 5-8 g cm^{-1} on the clay soils under cereals (Table 2). Most detachment on the bare sandy soils occurs in summer during intense storms with rainfall energies over 100 J m^{-2} and rainfall totals above 10 mm. Detachment rates for 100 day periods are 15-50 g cm^{-1} in summer compared with 2-9 g cm^{-1} in winter (Fig. 2). In contrast, maximum detachment on the clay soils occurs in winter when the 100 day rates reach 7-10 g cm^{-1} compared with 0.3-5 g cm^{-1} in summer. The seasonal difference is less marked on the sandy loam soils under cereals where the 100 day rates range from 0.5-5 g cm^{-1} in winter to 5-20 g cm^{-1} in summer.

When the 100 day rates of splash detachment are related to the kinetic energy of the rainfall by a best-fit power function (Table 3), the value of exponent b is seen to vary widely, being positive for bare soil conditions but negative where a crop cover exists. This effect of a crop is even more marked if the data are considered seasonally. Whilst the values for the bare sandy soil are positive in winter and summer, those for the sandy loam soil under cereals are positive in winter when the crop cover is poor but negative in summer when the crop cover exceeds 40%. The clay soils show negative values for both winter and summer and although the annual value is positive, it is close to zero and, given the very poor correlation between splash detachment and kinetic energy for the annual data, is virtually meaningless. The influence of crop cover is also indicated by combining the data for the sandy and sandy loam soils for the period for which crop cover measurements are available and determining the exponent values for different crop cover groups.

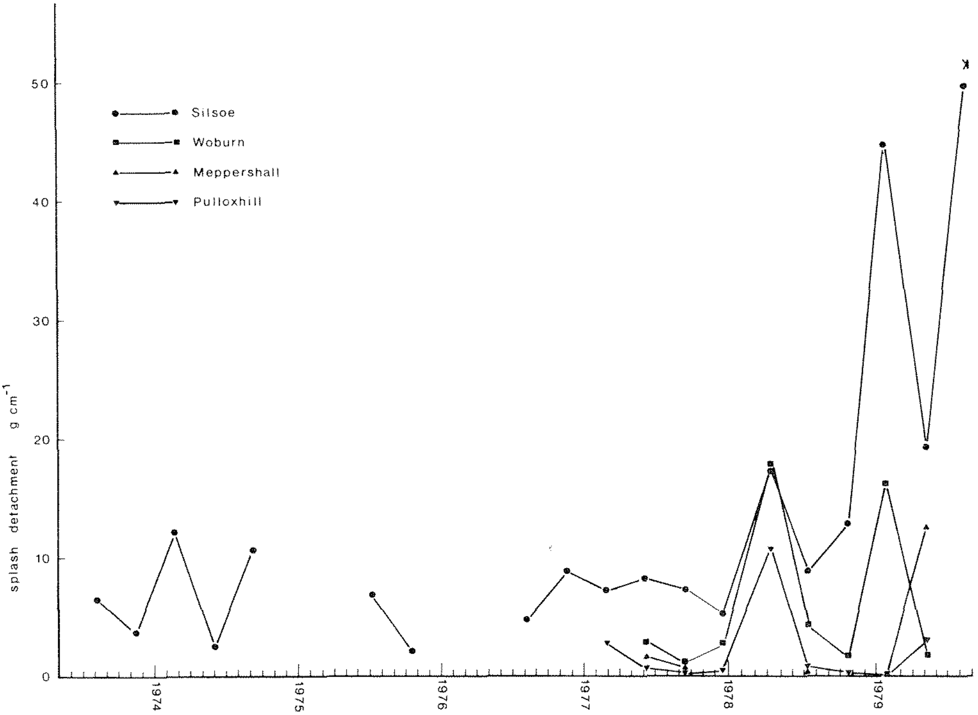

Fig. 2 Rates of splash detachment on mid-slope positions. Data are plotted for the last day of consecutive 100-day periods.

The exponent is negative for covers less than 2%, positive for covers of 2-20% and negative for covers greater than 20%, although no significant relationship exists between splash detachment and kinetic energy for the latter group.

Table 3 Values of b in the relationship between splash detachment (SDET) and kinetic energy of the rainfall (KE) in the form SDET = aKE^b

Site	Soil	Crop cover	Season	b	r	n	P
Silsoe	Sand	None	All year	0.26	0.34	57	0.02
			Summer	0.63	0.80	30	0.001
			Winter	0.02	0.01	27	NS
Woburn	Sandy loam	Cereals/beans	All year	−0.45	−0.41	24	0.05
			Summer	−0.76	−0.55	12	0.10
			Winter	0.90	0.32	12	NS
Meppershall-Pulloxhill combined	Clay	Cereals	All year	0.004	0.002	29	NS
			Summer	−1.02	−0.56	14	0.05
			Winter	−0.29	−0.22	15	NS
Silsoe-Woburn combined*	Sand-sandy loam	Under 2%	Winter	−1.42	−0.66	11	0.05
		2-20%	All year	0.55	0.57	27	0.02
		Over 20%	All year	−0.03	0.02	13	NS

*Data for 1 March 1977-17 August 1979.
NS: Correlation coefficient (r) not significant at 10% level.

DISCUSSION

It is difficult to comment on the rates of splash detachment measured in this study because the only comparable field data with natural rainfall come from Bolline's (1978) study over a 2 year period on loessic soils in Belgium. The results for the sandy and sandy loam soils in this study show much greater consistency and generally higher values than the Belgian data. Mean annual rates of splash detachment on the bare sandy soils at Silsoe are 29-37 kg m^{-2} compared with annual totals of 9.5-40 kg m^{-2} on fallow Belgian loess. The respective rates for cereals are 18-23 kg m^{-2} on the sandy loam soils at Woburn and 1.2-4 kg m^{-2} under winter wheat in Belgium. The ranking of the sites with increasing detachment from clay under cereals, through sandy loams under cereals to bare sandy soils is as expected, considering the effects of crop cover in reducing raindrop impact at the ground surface and the greater cohesiveness of clay soils.

The values of exponent b are not as expected, given the results from other field and laboratory investigations. These indicate a spectrum of values from 0.8 for sandy soils to 1.8 for clays (Free, 1960; Bubenzer & Jones, 1971). However, none of the other studies covers the same range of conditions. Further, direct comparison of field and laboratory studies is not always justified because the latter are designed to assess the soil response solely to raindrop impact, whereas other factors may interact with this response in the field.

Crop cover is clearly an important interactive factor. Only Sreenivas *et al.* (1947) and Bolline (1978) have previously studied splash detachment under crops but even in these investigations the relationship between detachment and rainfall parameters has been determined only for bare soil plots. Thus, the existence of negative values for exponent b is a new and unexpected finding. Explanation of these values, however, will have to await further studies being carried out on the effects of crop covers on the energy of the rainfall actually reaching the ground surface. This will obviously be a more meaningful parameter than the rainfall energy in open ground, the parameter used here. Nevertheless, it is clear that the commonly assumed explanation for the reduction in splash detachment with a crop cover must be false. The reduction cannot be attributed to proportional increases in crop cover bringing about proportional increases in the interception and absorption of rainfall energy. Whilst this explanation would result in a reduction in the value of exponent b with increasing crop cover, it would not make the exponent negative.

A second interactive factor, affecting the clay soils, is frost. This accounts for the greater detachability of these soils in winter at which time frost heave and the formation of ice crystals beneath raised soil clods has been observed in the field. What is not clear from this study, however, is whether the higher detachment rates are the result of frost action weakening the soil, rendering it less resistant to raindrop impact, or simply the result of heaving of the soil above the rim of the splash cup so that soil particles fall into the catching tray.

A third factor interacting with the splash process is surface crusting. This affects mainly the bare sandy and sandy loam soils and is the most likely cause of the negative value of exponent b for crop covers less that 2% during the winter period. During this time rainfall energies are low, totals of less than 150 J m^{-2} for a 100 day period, and raindrop impact compacts rather than disrupts the soil surface. During the summer, rainfall energies are much higher and sufficient to break up the crust so that, even where the crop cover remains less than 2%, values for exponent b are positive.

Only the exponent values for the sandy and sandy loam soils with crop cover between 2 and 20% are comparable with those of other researches. Even here the values are on the low side but this could be because the soils are much sandier than those used in previous studies. The sand content is 92% at the Silsoe site. It is only under these conditions that splash detachment in the field can be interpreted as a simple response to raindrop impact.

EQUIPMENT APPRAISAL

The equipment functioned reasonably well. The inner cylinder was small enough to prevent the generation of runoff and, by adjustment of the level of the lip of the cylinder at 100 day intervals to bring it flush with the soil surface, rim effects were avoided. Problems were encountered with rainwater being unable to drain from the catching tray. Rates of evaporation were too low to remove the water rapidly, particularly in winter, and standing water resulted in premature rusting of the equipment. Occasionally, so much water accumulated that it washed over the soil in the inner cylinder. Fortunately, such events were rare and do not seriously affect the results, but they would preclude the universal use of the apparatus in this form.

For future use it is recommended that the floor of the catching tray be replaced with a wire mesh sheet covered with muslin. This will allow free drainage of the rainwater whilst still allowing the collection of splashed particles. If desired, the mesh floor could be rested on metal supports welded on to the side of the catching tray to enable the complete mesh-muslin unit to be removed and replaced. The facility to change units in this way would considerably speed up the collection of the splashed soil particles in the field.

CONCLUSIONS

The field splash cups, with the modifications described above, provide a satisfactory method of measuring splash erosion but data can only be obtained over long time periods. For instantaneous values, ideally required for modelling the splash process

(Moeyersons & De Ploey, 1976), laboratory studies remain essential. The results of these studies can only be applied directly to field conditions, however, if splash erosion is a simple response to raindrop impact. If surface crusting, frost action or crop cover influence this response, the results cannot be used to predict what will happen in the field. For this reason, the laboratory investigations of splash erosion are not an adequate alternative to field study. Field measurements will continue to be needed to validate laboratory experiments, at least until the time when the effects of interactive factors can be properly simulated in the laboratory. Recognition of these factors and their effects is vital for soil conservation practice because measures designed to control splash erosion will be less than effective if factors other than the soil's response to raindrop impact influence the process.

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