

RESULTS AND INTERPRETATION OF SOIL LOSS MEASUREMENTS FROM STEEP SLOPES IN THE PHILIPPINES

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Abstract

Measurements of runoff-event soil loss and one-minute rates of rainfall and runoff are reported for runoff plots installed on the tropical Philippine island of Leyte. Plots were either under traditional crops cultivated using farmer practices, or kept bare. Plots were of length 12 m and at slopes of 50% to 70%. Soil loss for the cultivated crop was 35 t ha⁻¹ y⁻¹, and 63 t ha⁻¹ y⁻¹ for the bare soil plots. An erodibility parameter β calculated for bare-plot data exceeded the value 1 for lower stream power events, indicating enhancement of flow-driven erosion by other processes, such as rainfall impact. This conclusion held whether an original erosion model was employed, or a subsequent model development designed to acknowledge the special effects of very high sediment concentrations and shallow flows common at the site.

Additional Keywords: steepland, soil erosion, soil erodibility, farmer practice, high sediment concentrations, erosion model.

Introduction

Cultivation of tropical steeplands is expanding due to increasing population and other factors, typically in the Philippines. Most research on water-driven erosion and soil conservation has been on slopes less than about 20%, reflecting land-use practices in the western world. This paper reports measurements of rates of rainfall, runoff and soil loss from soil erosion plots at slopes of 50% to 70% over a three-year period on the island of Leyte in the Philippines. Runoff and soil loss are compared for corn (*Zea mays*) and sweet potato grown using existing farmer practices and for plots kept bare using local cultivation and weed control practices. Soil loss from the bare soil plots is interpreted using two related methodologies (Presbitero, 2003).

Materials and Methods

The site of instrumented runoff plots was the Visayas State College of Agriculture (ViSCA) on the Philippine island of Leyte (10°44'N, 124°48'E, altitude 30 m asl). The three basic soil plots were of length 12 m and slopes of 50%, 60% and 70% approximately. The soil, derived from igneous (mostly basaltic) rock, is an Oxic Dystropept. This friable clay soil has good structural stability and a high infiltration capacity (Presbitero *et al.*, 1995). The settling-velocity characteristic of the soil, used in data analysis, was measured using the modified bottom-withdrawal-tube method (Lovell and Rose, 1988).

Runoff and its sediment load were collected in a low-slope, modified Gerlach trough in which coarser sediment (the "bedload") was trapped as net deposition. Water, with its remaining finer sediment, then passed through a tipping-bucket type flow-rate recorder, and a splitter-type sediment subsampler, which, when added to the bedload, gave total soil loss for the event. The experimental methodology, including rate recording at one-minute intervals, is detailed by Ciesiolka *et al.* (1995) and Ciesiolka and Rose (1998), and the full range of experiments is described by Presbitero *et al.* (1995) and Presbitero (2003).

Data on soil loss from bare rilled plots are interpreted using both the original theory of Hairsine and Rose (1992b) and an enhancement of this model designed to accommodate effects due to the high sediment concentrations and shallow flows typical of runoff events at the site (Rose *et al.*, 1997; Yu *et al.*, 1997). The computer-based methodology of Yu and Rose (1997) is employed.

Results and Discussion

The steep slopes of the site necessitated the construction of substantial structures, including cement walls of depth one metre. The possibility that the installation of a concrete Gerlach trough collecting runoff might induce

exfiltration of subsurface flowing water was examined and found to be negligibly small except on one plot during a typhoon (Presbitero, 2003). Since the soil was highly permeable, and runoff a small fraction of rainfall received, artificially induced exfiltration could have introduced uncertainties in the interpretation of the experimental data.

Table 1 shows the effect of traditional cropping practices compared to soil kept bare. Whilst runoff is greater with cropping, soil loss is almost halved, though still high at 76 t ha⁻¹ or 35 t ha⁻¹ y⁻¹. Furrows formed by up and downslope cultivation of corn was probably responsible for the increased runoff (Presbitero *et al.*, 1995).

Table 1. Comparing runoff and soil loss from traditional cropping with that from soil kept bare of vegetation on 50% slopes. Figures are means for the period October 1989 to September 1991.

Treatment	Runoff (mm)	Soil loss (t/ha)	Average sediment concentration (kg/m ³)
Bare soil	111	137	124
Traditional cropping	167	76	46

Since average annual rainfall at the site is 2240 mm, the small runoff shown in Table 1 indicates a very permeable soil and quite shallow depths of overland flow. The feature of shallow flow was confirmed by the authors during observation of some runoff events, frequent lightning strikes often making field observation unsafe. Under such conditions, it is difficult to directly measure overland flow velocity or depth. This problem was overcome by use of the continuous measurement of rates of rainfall and runoff that were a feature of these experiments. Yu *et al.* (2000) showed that, although in principle Manning's n can vary with time in natural rainfall events, an effective average value of n can be calculated from the observed time lag κ between a burst of rainfall falling on a land surface and its appearance at the end of a runoff plot. The relationship for Manning's n is:

$$n = \frac{S^{0.5}}{L} \left(\frac{8\kappa}{5} \right)^{5/3} Q^{2/3} \quad (1)$$

where S is the slope, L length of runoff plot, and Q an effective runoff rate per unit area for the event. The average time lag κ in these experiments was close to 2.6 minutes. Using this method of hydrological analysis yielded an average value of Manning's n of close to 0.1 m^{-1/3} s. Using this value of n in Manning's equation, and combining this equation with that of mass conservation of water provides two equations from which the two unknowns, the velocity and depth of water flow, can be calculated.

Such calculations can only be carried out with some confidence when observations are made. A maximum flow depth of only some 5 mm was calculated for rill flow. Consideration of the possible consequences for erosion theory of such shallow flows was undertaken using appropriate models.

Table 1 also indicates such high measured sediment concentrations on these steep-slope plots (50-70%), that the density of overland flow would be significantly enhanced over that of water alone. This has the effect of enhancing the stream power of the flow, augmenting its ability to erode soil. However, in order to maintain such high sediment concentrations also requires a saltation stress which detracts from the surface shear stress effective in flow-driven erosion. The saltation stress is the shear stress component which supports the momentum of saltating soil.

As shown by Presbitero (2003), it turns out that the effects of density enhancement and saltation stress almost cancel each other out. Similarly, erosional effects associated with shallow flow are also self-compensating to a large extent (Presbitero, 2003). Hence there are only modest differences between the values of the sediment concentration at the transport limit calculated by the original theory of Hairsine and Rose (1994) and its subsequent GUEST model (Yu *et al.*, 1997; Yu and Rose, 1997) which acknowledge the effects of shallow flow and high sediment concentration.

The erodibility parameter β , defined by Rose (1993) and widely used in erosion studies (e.g. Soil Technology, 1995; Coughlan and Rose, 1997), is given by

$$\beta = \ln \bar{c} / \ln \bar{c}_t \quad (2)$$

where \bar{c} is the flux-weighted average value of the sediment concentration during the erosion event, and \bar{c}_t is the corresponding average value of sediment concentration at the transport limit. Whilst \bar{c} is a measured quantity, \bar{c}_t is calculated assuming that flow-driven erosion is the dominant erosion process. If this is so, then Eqn (2) indicates that β has a maximum value of 1. However, the value of β acknowledges the effect of any mechanism which enhances erosion in the observed event yielding a mean sediment concentration of \bar{c} , and has the advantage of indicating the contribution of other non-flow-driven erosion processes if the calculated value of β exceeds unity.

Figure 1 shows values of β calculated for each erosion event in the ViSCA data for which rills were recorded and measured following the event. Values of β which exceed the theoretical limit of one for flow-driven erosion alone indicate a contribution from other erosion mechanisms, with rainfall-driven erosion being a most likely source because of shallow flows and generally high rates of rain falling in convective storms. The apparent decline in β at higher stream powers has been observed previously (Yu *et al.*, 1999).

Rockwell (2002) and other investigators whom he quotes, indicate that subsurface as well as surface flow hydraulics can play a significant role in affecting rates of erosion. Pore water pressure influences on surface soil shear strength appear to be involved in such interactions. In the experiments at the ViSCA site, a large fraction of rainfall received infiltrated into the very permeable soil. Thus there is the possibility that effects such as those investigated by Rockwell (2002) may be another mechanism, as well as rainfall-driven erosion, which could enhance the value of β in Figure 1.

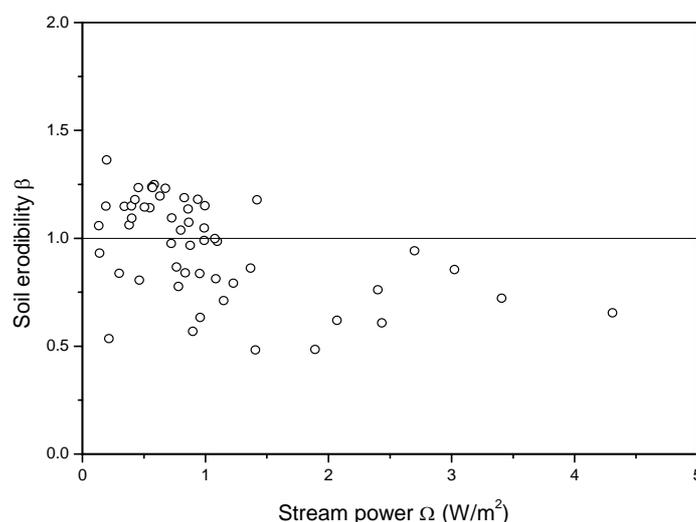


Figure 1. Values of β calculated for each erosion event with observed rilling plotted against the mean stream power, Ω , for the event.

Conclusions

Whilst runoff was low in relation to rainfall at this ViSCA site, traditional cropping practices increased runoff by 50% over that from soil kept bare by weeding. However, soil loss was reduced by cropping treatments, but is still very high at $35 \text{ t ha}^{-1}\text{yr}^{-1}$, that, as found elsewhere, sustainability of crop yield is threatened. Soil loss from the bare-soil treatment plots is interpreted using existing models of soil erosion. The values of a calculated erodibility parameter indicated that, especially at stream powers less than about 1 W m^{-2} , non-flow-driven erosion mechanisms, such as rainfall impact, contributed to the mean sediment concentration measured for each erosion event. The presence of high sediment concentrations and shallow flows appeared to have a less than expected effect on erosion theory which ignored their consequences, a conclusion supported by the application of a more detailed model which did accommodate these effects.

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