Soil crusting and infiltration on steep slopes in northern Thailand

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Introduction

Most recent models to predict soil erosion from small catchments require data on the spatial variability of soil infiltrability. These GIS-based models use infiltration attributes for each main soil units. Such approach may be uncertain when applied to steep slopes because under such conditions a soil map unit is rarely homogenous in terms of soil texture, soil depth and crustability. Likewise, predicting soil infiltrability only from topographic parameters is hazardous because conflicting relations between slope gradient and infiltrability have been reported. Some authors observed no impact of slope gradient upon infiltration (e.g., Mah et al., 1992). Although field observations or experiments more commonly showed a decrease in infiltration with increasing slope angle due to a decrease in overland flow depth and surface storage (e.g. Chaplot and Le Bissonnais, 2000), Fox *et al.* (1997) observed decreasing infiltration rates until a slope threshold and then a steady infiltration rate independent from slope. More surprising are the studies which showed increasing infiltration with slope gradient (e.g., Poesen, 1984; Bradford and Huang, 1992). For interrill conditions, this has been ascribed to lower crusting processes because on steeper slopes, raindrops fall soil with a higher impact angle, and thus a lower kinetic energy

Although agricultural activities are gradually extending into steeplands in many parts of the world, only few field studies on infiltrability have been conducted on steep slopes. This may be due to the inadequacy of classical field methods to assess hydraulic conductivity under these conditions. The objectives of this study were: (i) to investigate the impact of slope gradient on soil infiltrability, (ii) to test various hypotheses regarding the role of surface storage and crusts upon infiltration on steep slopes.

Materials and Methods

Field research was conducted in the Mae Yom experimental catchment located near Phrae, in northern Thailand. The mean annual rainfall, recorded over the last 26 years, is 1 072 mm with most of the rainfall occurring during the Monsoon season during May to September. Convex hills are intensively cropped with soybeans and mungbeans without any period of fallow. The soils developed on shales are mainly sandy loam. Organic matter content ranges from 3.7 to 4.7%. The upper part of the hillslopes is characterized by gentle slopes, the zone immediately below by steep slopes. Fifteen 1-m_ plots were established along such a sequence with slope gradient ranging from 16% to 63%. The surface was hoed to a depth of 0.07-0.10 m and planed with aggregates crushed to less than 4 mm. The plots were subjected to simulated rainfall using the ORSTOM type simulator, with kinetic energy similar to those of the tropical rainfall of similar intensities. Experiments were conducted during the dry season. The first run, on dry soils, lasted one hour at an intensity of 60 mm h^{-1}, the second run, 22 hours later, lasted 30 minutes at an intensity of 120 mm h^{-1} . Soil moisture was monitored on five plots along the hillslope to a depth of 0.95 m, prior to rainfall, and 0.5 hr, 1hr, 2 hrs, 1, 2, 3, 10 and 15 days after the second run. Soil surface features were surveyed using the method of Casenave and Valentin (1992), and surface random roughness was assessed using a laser relief-meter with an accuracy of 1 mm on a 5 cm grid.

Results

Prior to the first rainfall simulation, initial soil moisture conditions (mean 4.6%, st.dev. 1.4%) and bulk density (mean 1.28 g cm^{-3}, st. dev. = 0.07 g cm^{-3}). were similar for the 15 plots. The two rainfalls generated runoff on each plot. Rills did not occur at any stage of the experiment. We corrected the observed volume runoff and infiltration intensity by the cosine of the slope angle to account for the lower rainfall received on steeper slopes (the horizontal length of a 63% slope is 85% of the horizontal length for a flat slope). The steady final infiltration rate measured on each plot (Fnc) tended to increase with slope gradient for the two rain storms (Fig.1). Conversely, the runoff coefficient (runoff-rainfall ratio) calculated for the two runs (Krc) decreased from 76% on gentler slopes to 5% on steeper slopes. The runoff volume from the plots after the stop of the rainfall simulation, which reflects the mean overland flow depth, sharply decreased with increasing slope. Slope gradient had no significant impact on soil depth, total surface gravel percentage and random roughness. By contrast, a clear relation could be established between slope gradient and percentage of embedded gravel (i.e. included in a surface crust, Fig. 2). A significant trend could also be found between slope gradient and percentage of erosion crust. More than 90% of the variance of Fnc and Krc could be thus explained by percentages of embedded gravel and erosion crust.

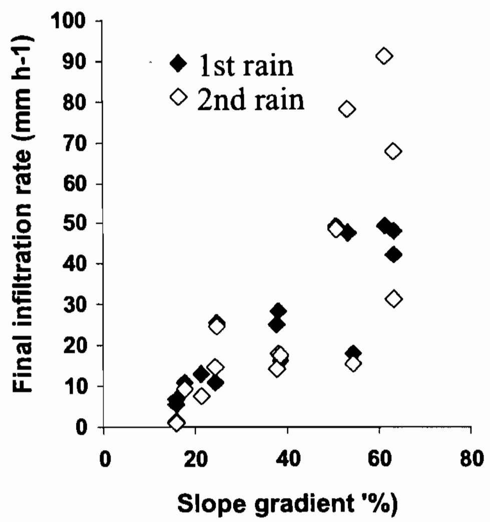

Fig. 1. Final infiltration rate measured during the two rainfalls.

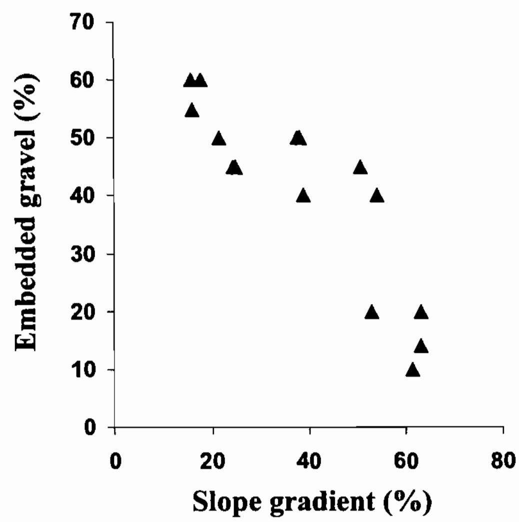

Fig. 2. Percent of embedded gravel as affected by slope gradient.

Discussion

The variations of Fnc between the two rainfalls (Fig.1) indicate that infiltration on gentle slope was less dependent on soil moisture and rainfall intensity than on steep slopes. Similar increasing trend of infiltrability with slope gradient has been also reported in northern Laos under natural rainfall during a rainy season (Huon and Valentin, 2000). This might be achieved by micro-step like profiles due to local mass movement (creeping), or to rilling, but our field observations and surface roughness data did not substantiate these two hypotheses. Rather than the effectiveness of depression storage which could not be confirmed because soil surfaces remained relatively smooth and well inclined.; experimental data supported the hypothesis of decreasing crusting on steeper slopes (Fig.2). These results suggest that for convex landforms, the steep midslope zone can play the role of infiltration trap for runon from upper gentler zone. This may have substantial impacts not only on flow volume generated from small watersheds but also on water quality.

Conclusions

Using similar soil moisture and surface conditions, but different soil depth and slope gradient conditions, rainfall simulation experiments showed that in steep soils prone to crusting, infiltrability decreases with increasing slope gradient whilst crusting intensity greatly decreases.

Keywords

Steep slope, infiltration, surface crust, gravel, Sout-East Asia, Thailand

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