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Rainfall-induced soil erosion and sediment sizes of a residual soil under 1D and 2D rainfall experiments

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Abstract

Raindrop impact and surface flow trigger the downstream movement of soil particles by the processes of rainfall-induced soil erosion. A set of laboratory simulated rainfall experiments was carried out to study soil loss and size characteristics of discharged sediments of a soil under a rainfall intensity of 70 mm/h, controlled initial soil suctions and moistures. The rainfall simulation was instrumented with tensiometers and moisture sensors. A new device capable of deriving impact force, velocity, and kinetic energy of a falling waterdrop was developed. Sediment sizes in runoff were characterized by a laser particle size analyzer in order to correlate with the properties of rainfall. 1D simulated rainfall experiments were also employed to study soil detachment and soil susceptibility to rainfall under both saturated and unsaturated soil conditions. The processes of soil erosion and outflow size characteristics of sediments relating to effect of suction were discussed. The proposed set of experiments will be a viable tool for measuring soil loss, sediment runoff, and sediment sizes discharged from a farmland pertaining to properties of rain, soil and flow.

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Keywords: Soil erosion; Soil erodibility; Sediment sizes; Drop impact force; Unsaturated soil;

1. Introduction

Global warming effect triggers a change in climate and is likely to shift the characteristics of heavy and extreme rainfall in forms of pattern, amount, duration, frequency and intensity. The potential shift is strongly expected to influence the characteristics of soil erosion, surface runoff, and sizes of discharged sediments (Nearing et al. 2004). Rain is a natural dynamic movement of water that varies spatially and temporally under amounts and intensities. Rain is also considered as one of the most key erosion factors under all natural conditions in term of erosive and destructive power to cause soil particle detachment and movement from soil surface (Zachar, 1982). Rain-impacted soil detachment and flow are mutually responsible for sheet and interrill erosion areas. The size distributions of primary particles discharged by rain-impacted flows have been observed to be finer (including nutrient and chemical particles) than those in the soil matrix (Kinnell, 2009). Therefore, the soil erosion and removal of the fine particles affect farming productivities and water quality of the receiving aquatic environments.

Rainfall-induced soil erosion (RISE) for a bare soil is a complex energy-dependent process resulting from the combined effect of raindrop properties, soil components and soil-water interaction. Impact of raindrop is associated with the raindrop kinetic energy and has been widely studied to characterize soil resistance to impacting rainfall and runoff flow or soil erodibility (Hinkle, 1989; Nearing & Bradford,

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1984; Sharma & Gupta, 1989). The drop impact also attributes to the onset of particle movement through coupling soil detachment and sediment transport (Fig. 1).

Soil erodibility or susceptibility of a soil against erosive forces or erosion is a dynamic parameter of a soil that depends on hydraulics of raindrop and surface flow. Soil erodibility is temporally and spatially influenced by soil type, organic matter content, soil structure and permeability (Wischmeier & Smith, 1978). Antecedent soil conditions also influence soil erodibility and produce hysteresis in characteristics of soil loss and sizes of sediment discharged (Vilayvong et al. 2014). For example, cycles of wetting and drying of soils, which are partially underpinned by temporal variation of suction and soil moisture. Unsaturated soils with varying contents of air and water possess a negative pore water pressure or soil suction. Dry soils with high soil suction increases aggregate stability and shear strength of the surface soil. However, high soil moisture might increase aggregate slaking and breakdown during rainfall due to rapid wetting which is exacerbated by soil detachment and transport induced by rainfall and surface flow (Le Bissonais et al. 1989).

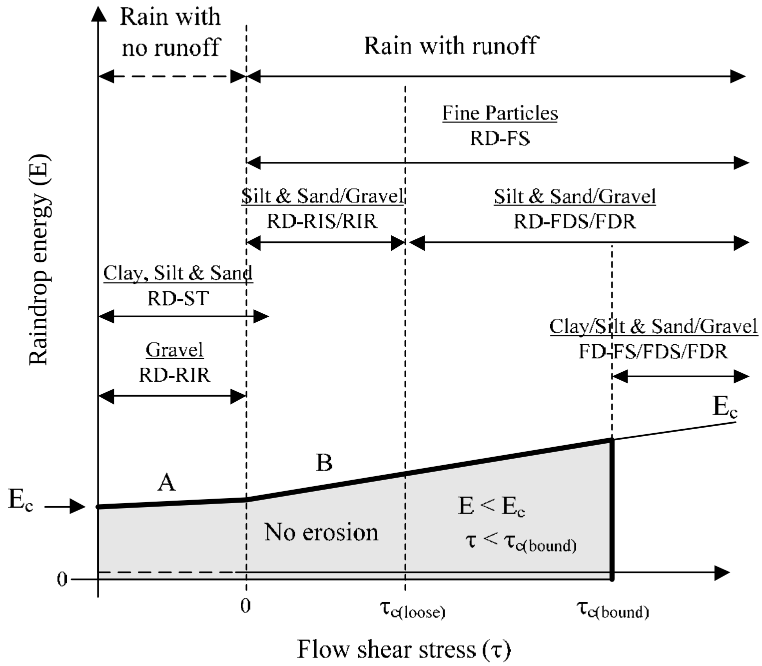

Fig. 1. Mechanism of soil erosion due to impact of rainfall and flow (Kinnell, 2009)

Nomenclature

E_c = critical raindrop energy to cause detachment.
$\tau_{c(loose)}$ = critical flow shear stress required to transport loose (pre-detached) soil particles.
$\tau_{c(bound)}$ = critical shear stress required to detach particles bound within the soil surface (held by cohesion and inter-particle friction).
RD–ST = raindrop detachment and splash transport.
RD–RIR = raindrop detachment and raindrop induced rolling.
RD–RIS/RIR = raindrop detachment and raindrop induced saltation or rolling.
RD–FDS/FDR = raindrop detachment and flow driven saltation or flow driven rolling.
RD–FS = raindrop detachment and flow suspension.
FD–FS/FDS/FDR = flow detachment and flow suspension or flow driven saltation or flow driven rolling

Many process-based soil erosion models such as WEPP (Flanagan & Nearing 1995) consider the effect of runoff on erosion explicitly and require the rainfall properties (the drop size distribution, velocity, kinetic energy and intensity) and soil properties (soil moisture, soil suction, and permeability)