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Research Paper

Effect of soil type, peat, and compaction effort on soil strength and splash detachment rates

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The effect of incorporation of peat into soils of diverse texture on soil strength and splash detachment rates during simulated rainfall was examined in the laboratory. Soil penetration resistance (an index of soil strength) and splash detachment by raindrops were measured on three soils (a sandy loam, a clay loam and the other clay) with peat added at 0, 4%, 8% and 12% (by mass), and pre-compacted at 159 kPa, 425 kPa and 638 kPa before being exposed to four rainfall durations of 4, 8, 12 and 20 min. The rainfall intensity was 92 mm h^{-1}. Splash detachment increased with increasing rainfall duration with the largest values occurring in the sandy loam and the lowest in the clay loam soil. Soil penetration resistance initially increased up to 4 or 8 min of rainfall and then decreased as rainfall duration increased further. Splash detachment declined, while soil penetration resistance increased, with increasing compaction of the soil. Both parameters decreased with increasing peat content. Splash detachment rates declined with increasing rainfall duration, with the maximum reduction occurring in soils with low peat contents, low compaction levels and high sand content. An equation was derived to relate splash detachment rates of the three soils to the product of soil penetration resistance and duration of rainfall.

1. Introduction

Soil erosion is severe on most landscapes in the steep sloping and mountainous topography of the Caribbean (Ahmad & Breckner, 1974) mainly due to extensive deforestation over the years (Wuddivira, Ekwue, & Stone, 2010). This has caused soil loss, breakdown in soil structure, as well as a reduction in nutrients and organic content. This decline in fertility has resulted in increased fertiliser use, decreased food production and food security and a substantial decline in land values. This leads to increased costs largely due to both on-site and offsite effects of erosion (Morgan, 2005). On-site effects are particularly important for agricultural lands.

Soil erosion by water is made up of splash detachment and transport by raindrops and runoff. Since splash detachment is the first step in the soil erosion process, control measures are best aimed at decreasing it (Quansah, 1981). Splash detachment is a more sensitive test than other physical measurements for evaluating changes in soil erodibility (Rachman, Anderson, Gantzer, & Thompson, 2003). Erosion control measures take the form of mechanical, agronomic and soil management measures (Morgan, 2005). The mechanical

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measures utilise engineering structures like check dams and terraces, while agronomic measures use mainly vegetation to reduce soil erosion. Soil management measures are aimed at finding methods of cultivating the soil without destroying the soil structure (Morgan, 2005). The other soil erosion control measures aim to find ways of protecting the soil whilst soil management measures improve the soil properties related to erosion.

The incorporation of organic materials into the soil is a soil management measure and is aimed at improving the soil fertility and structure (Brady & Weil, 2007). Organic matter helps in establishing soil aggregates and increasing their stability (Brady & Weil, 2007). Ekwue (1990a) and others like Ohu, Raghavan, Mckyes, and Mehuys (1986) have shown that peat organic material does not increase soil aggregate stability. Ekwue (1990a) observed that while all organic materials reduce splash detachment, two major processes are involved. Organic materials like grass form colloidal soil organic matter and reduce splash detachment by increasing soil aggregate stability. Fibrous materials like peat that hardly decompose, decrease aggregate stability, but also reduce splash detachment by forming part of the bulk soil which is not easily splashed by raindrops. Since the studies mentioned above utilised soils with large sand components (>60 per cent) in England, it is unclear whether peat incorporated into soils with lower sand contents, like the ones that exist in the Caribbean and elsewhere, would have significant effect on splash detachment.

Soil erosion mechanics, and splash detachment in particular, are strictly linked to indices of soil strength (Brunori, Penzo, & Torri, 1989; Cruse & Larson, 1977; Luk & Cai, 2003; Mouzai & Bouhadef, 2011; Nearing & Bradford, 1985). Soil strength is dependent on cohesive forces that exist between soil particles (Knapen, Poesen, Govers, Gyssels, & Nachtergaele, 2007). Cruse and Larson (1977) established that soil detachment is a quadratic function of soil shear strength. They also stated that detachability could be altered by varying soil bulk density, matric water potential and by adding polyvinyl alcohol. Al-Durrah and Bradford (1981) and Bradford, Truman, and Huang (1992) established soil detachment as a function of the ratio of kinetic energy to the shear strength of the soil. Al-Durrah and Bradford (1982) extended their study to nine soils and found that for each soil, detachment varied with the same ratio but that there was no single equation that could be utilised to relate soil detachment of the nine soils to the ratio already identified. Nearing and Bradford (1985) obtained a single equation for all their soils by reducing the fall cone resistance term by an empirically-derived triaxial friction term.

Most of these studies are limited since they considered only single-drop effects of rainfall, which neglect the soil wetting that occurs in continuous rainfall (Stuttart, 1984). Soil wetting during rainfall reduces soil shear penetration resistance (Cruse & Larson, 1977). This is expected to increase soil infiltration but continued rainfall leads to aggregate breakdown and seal formation (Bryan & Poesen, 1989; Farres, 1978). Slaking is also very important particularly when the soil is originally dry (Wuddivira et al., 2010). This means that the rates of soil detachment and soil strength may change during an actual rainfall event (Fan, Lei, Shainberg, & Cai, 2008; Schultz, Jarrerr, & Hoover, 1985). Ekwue and Ohu (1990) observed that the splash detachment rates decreased with increasing rainfall duration and obtained five separate equations relating splash detachment rates to soil shear strength for the five soils with high sand contents (>60%) they tested. They only obtained a single equation that related the two parameters for the five soils when they introduced a parameter called aggregate breakdown rates during rainfall. Since peat is known to decrease soil strength, it is unclear what effect peat would have on splash detachment rates. Ekwue, Bharat, and Samaroo (2009) and Ekwue and Harrilal (2010) reported that although peat decreases soil strength in the form of penetration resistance, it decreases wash erosion by increasing soil infiltration rates and reducing runoff. It is not clear how this will affect the relationship between splash detachment rates and soil strength during a rainfall event. This study aims at examining the effect of the incorporation of peat into soils of diverse texture on soil strength (using penetration resistance as its index) and splash detachment rates during simulated rainfall. Different values of soil penetration resistance were generated by using different soils with peat incorporated at different rates, pre-compacted by different pressures, and exposing them to different rainfall durations.

2. Materials and methods

Three soils, Piarco sandy loam, Maracas clay loam and Talparo clay (Table 1), collected from the top 20 cm of the soil profile, were utilised to represent some of the major cultivated soils in Trinidad. Air–dry soil samples were ground to pass 5 mm sieve openings. Particle size distribution (Table 1) was determined using the hydrometer method (Lambe, 1951). Organic matter content in the samples was measured using the Walkley and Black (1934) method.

A factorial experimental design in the laboratory was used to assess the splash detachment rates of the three soil types, each mixed with dry sphagnum peat moss (with 0.08 t m^{-3} air dry density and fibrosity of 83%) at 0, 4%, 8% and 12% rates and pre-compacted to 159 kPa, 425 kPa and 638 kPa stresses and exposed to rainfall durations of 4 min, 8 min, 12 min and 20 min. These short duration rainfalls are common in tropical areas like Trinidad. Peat fibrosity is expressed as the dry fibre content greater than 0.1 mm in diameter (Farnham & Finney, 1965). After the soils were mixed with peat at the stated rates, they were oven-dried at 105 °C for 48 h and weighed. Water was added up to the optimum moisture contents earlier determined by Ekwue and Stone (1994) using the Proctor test (Lambe, 1951). They were then packed into splash cups (73 mm diameter, 50 mm depth). The splash cups had drainage holes at the bottom which allowed water to drain from them during rainfall. The soils in the splash cups were thereafter compacted using 3, 8 and 12 Proctor hammer blows which are equivalent to 5, 15 and 25 blows used in previous work by Ekwue and Stone (1994). The compaction blows were calculated as efforts of 159 kPa, 425 kPa and 638 kPa. Since compaction stresses due to agricultural traffic on farms seldom exceeds 490 kPa (Gupta & Larson, 1985), 638 kPa represents severe soil compaction. Bulk density of the soils was