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Indirect and direct effects of soil properties on soil splash erosion rate in calcareous soils of the central Zagross, Iran: A laboratory study

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ABSTRACT

Detachment of soil particles by means of raindrop impact is mainly affected by soil properties especially in the absence of vegetation cover. This study was conducted to investigate the direct and indirect effects of soil properties on splash erosion rate in calcareous soils of low vegetation cover in Lordegan region, Iran. For this purpose, Total Soil Splash (TSE), downslope (DSE) and upslope (USE) Splash erosion rate are measured under the following four conditions that comprised different values of Slope (S:%) and Rainfall Intensity (RI:mm h^{-1}): 5–50, 5–80, 15–50, 15–80, respectively, using Multiple Splash Sets (MSS). As potential estimating parameters, Surface Shear Strength (SSS), Mean Weight Diameter (MWD), Organic Matter (OM), calcium carbonate, clay content, silt and sand fractions were estimated. The effects of soil estimators on soil splash erosion rate were quantified using a path analysis and Multi-Linear Regression (MLR) approaches applied to data collected from 105 points of soil profiles (A horizon). The results showed that the particle size distribution, SSS and MWD are sensitive to some of the parameters for estimating TSE, DSE and USE rate. MWD carried the highest direct effects while SSS the highest indirect ones (via MWD) on splash erosion. Particle size effects on soil splash weren't in general observed in higher slopes and rainfall intensities. The Particle size has in general a more direct rather than an indirect effect on splash erosion. Fine silt exerted an ambivalent role on splash erosion: A high detachability of fine silt directly increases splash erosion while its capability to form a surface crust, reduces splash erosion. Indirect effect of OM through its association with MWD and SSS is more than it's direct effects. Positive direct effect of calcium carbonate is more than its indirect negative effect via its association with MWD, probably due to the presence of calcium carbonate within the size of silt and fine sand in the studied soils, causing an increase in soil detachability.

1. Introduction

Splash erosion is considered in such erosion models as EUROSEM (Morgan et al., 1998), LISEM (De Roo, 1996), and TEST (Van Dijk and Bruijnzeel, 2003). The accuracy of the splash detachment as an input parameter in these models significantly affects the model outputs.

The detachment process can be conceptually divided into two subprocesses including aggregate breakdown (Le Bissonnais, 1996) and movement initiation of the breakdown products (Kinnell, 2005). Soil detachment depends on raindrop size and mass (Ellison, 1944; Bisal, 1960), drop velocity (Ellison, 1944; Bisal, 1960), rainfall intensity (Ting et al., 2008), kinetic energy (Kinnell, 2003; Fernández-Raga et al., 2010), runoff depth (Torri et al., 1987; Kinnell, 1991, 2005), crop covers (Bancy, 1994; Gharemani et al., 2011), wind speed (Erpul et al., 2000) and experimental area (cup size) (Leguedois et al., 2005; Luk, 1979; Torri and Poesen, 1988). Many studies have been conducted to evaluate the relationship between splash and slope (Bryan, 1979; Torri and Poesen, 1992; Wan et al., 1996). The splash–slope relationship is very complex, however, there are two basic relationships between the splash erosion and slope. Fu et al. (2011) demonstrated that slope significantly affects splash erosion as well as its components. Specifically, the downslope splash loss, total splash loss and net downslope splash loss, all increased with slope gradient and then decreased following a maximum value reached. Furthermore, the upslope splash loss and lateral splash loss decreased as the slope steepness increased. Torri and Poesen (1992) reported that in steep slope, the gravity force adds to the drops detaching force and decreases soil resistance, consequently increases splash erosion rate with increase in the slope.

Soil splash erosion is also strongly influenced by soil properties including soil particle size distribution (Mazurak and Mosher, 1968; Legout et al., 2005; Fan and Li, 1993), soil shear strength (Cruse and Larson, 1977; Al-Durrah and Bradford, 1981; Ekwue and Ohu, 1990), soil cohesion(Torri et al., 1987), soil organic matter content and aggregate size (Ekwue and Maidugury, 1991; Qinjuan et al., 2008), soil aggregate stability (Qinjuan et al., 2008), as well as surface crust (Qinjuan et al., 2008).

Particle size, plays an important role in splash erosion. Mazurak and Mosher (1968) found that when particle size decreased from 4.76–3.36 to 0.149–0.105 mm in diameter, the number of particles detached

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increased. The results obtained by Legout et al. (2005) demonstrated that the splash process puts particles up to 2000 μm in diameter into motion. Also 200–1000 μm particles were preferentially put into motion, but raindrops put particles into motion in proportion to the mass of particles provided through aggregate breakdown.

Torri et al. (1987) confirmed an inverse relationship between soil detachment vs its soil cohesion. Some researchers expressed the detachment of soil particles by rainfall, as linked to soil shear strength. Cruse and Larson (1977) showed soil detachment rate as a quadratic function of shear strength. Also Al-Durrah and Bradford (1981) found out soil splash as a function of the ratio of kinetic energy to the shear strength of the soil. Ekwue and Ohu (1990) presented the equation for predicting soil detachment rate using aggregate breakdown rates and surface shear strength parameters. This relationship is presented as:

$$\mathrm{SDR} = 0.46\left(\mathrm{ABR}/\sqrt{\tau}\right)0.67 \quad (1)$$

Where SDR is Soil Detachment Rate (kg m^{-2} min^{-1}); ABR is Aggregate Breakdown Rate (% min^{-1}); and τ the shear strength (KN m^{-2}).

Qinjuan et al. (2008) showed that a minimum splash erosion occurs in soils with high aggregate content, aggregate stability and high organic matter content, and while a maximum splash erosion in soils with a high content of sand particles. Ekwue and Maidugury (1991) evaluated the effects of organic matter content, aggregate size and rainfall duration on soil detachment. Their results obtained, showed that mean soil detachment declined with both increasing organic matter content and increase in aggregate size, and while being increased with increasing rainfall duration. Ekwue and Maidugury (1991) derived the multiple regression equation as:

$$\mathrm{D} = \mathrm{aE}^{\mathrm{b}} - \mathrm{M}^{\mathrm{c}} \quad (2)$$

in which D is soil detachment (kg m^{-2}); E total rainfall kinetic energy (J m^{-2}), M the organic matter content, and a, b, c the empirically derived constants.

The variation in splash erosion rates reflects soil surface changes, specifically fluctuations of splash erosion rates correspond to soil crust development. In soils that are susceptible to crust formation, after a short period of rainfall, soil crust starts to develop and splash erosion rate decreases (Qinjuan et al., 2008). Soil detachment ratio also depends on such physico-chemical characteristics as infiltration capacity, the nature of soil aggregates and crust, organic matter content, texture, cohesion and porosity, capacity of ionic interchange as well as clay content (Poesen and Torri, 1988).

One strategy that can be employed to explore indirect vs direct effects is path analysis, this technique having been used to quantify the relative importance of the indirect and direct effects of predictor variables on response variables in many ecosystems (Mitchell, 1992; Wootton, 1994; Bakker et al., 2003; Vogel et al., 2010). Path analysis is similar to multiple regression, as it is based on the analysis of correlations, but unlike multiple regression, it allows the partitioning of the effects of predictor variables on a response variable into their direct vs indirect components. The relative magnitude of these components can be determined. The total effect of a predictor on a response variable consists of the sum of direct and indirect effects (Quinn and Keough, 2002). Because path analysis uses correlations to calculate path coefficients, this method can only test how the data fit the proposed causal pathways, and not prove the causality.

Because of such human activities as overgrazing, untimely grazing, burning, and tillage degraded forests as well as rangelands in Lordegan region, Iran, soil erosion rate (25 mg per hectare per year) is four times its average in the world within this area (Abbaszadeh Afshar et al., 2010). Although there is a plethora of studies on splash erosion, studies to assess the effects of soil properties on the splash detachment in calcareous soils have not been attended to yet. Thus, this study was done in the central Zagross, Iran to: (1) quantify the direct and indirect effects of some soil properties on splash erosion, and (2) to determine soil splash erosion specifically in calcareous soils.

2. Materials and methods

2.1. Study site

Lordegan subwatershed is located in south Chaharmahal Bakhtiari, Iran (50°15′–51°51′ N and 31° 20′–32°53′ E) with an area of approximately 275 km^2. The elevation ranges between 1870 and 1980 m above the sea level. The average annual rainfall and temperature in the region amount to around 600 mm and 14.2 °C, respectively. Forest, rangeland, degraded rangeland and degraded forest (68% of area) dominate the land use of the study areas while agriculture accounting for only 32% of the land use. The forest and rangeland in the Lordegan subwatershed are extraordinarily rich in species *Quercus brantii*, *Astragalus* sp., *Bromus* sp. and *Q. macrocarpa* are the most common trees. According to USA soil taxonomy system, soil types include Typic Calcixerepts, Calcic Haploxerepts, Fluventic Haploxerepts, Calcic Haploxeralfs, Calcic Haploxerolls, Pachic Calcixerolls,Typic Calciaquolls,Typic Xerorthents, Haplic Xerarentsc and Mollic Xerofluents.

2.2. Experimental design

The project was initially divided into similar Land Unit Tracts (LUT). This is defined as an area of land where the attributes are sufficiently uniform and distinct from those of the neighboring areas to justify the delineation a map or an image (Gunn and Aldrick, 1988). These attributes include soil, geology, topography, and land use. The stratifying procedure was conducted using a map of geology with a resolution of 1:100,000, topography map at 1:50,000, land use map at 1:250,000, and land capability map with a resolution of 1:250,000. GIS9.1 was employed for data analysis and production of thematic map layers. Altogether 25 LUT layers were created. Supervised random sampling was applied to collect samples from every land unit. A total of 105 samples were collected to produce a measure of diversity of soil properties within each LUT. A sample localization map is shown in Fig. 1.

2.3. Physicochemical attributes

Soil samples were collected from the A_P or A horizon. The samples were air-dried at room temperature, then the air dried sub-samples were passed through a 2 mm sieve. Particle size distribution of soils was determined through pipette method (Gee and Bauder, 1986), organic matter content (OM) through dichromate oxidation technique, Walkley–Black procedure (Nelson and Sommers, 1986), and calcium carbonate content measured through calcimetric method (Loeppert and Suarez, 1996). Aggregate size distribution was determined through wet-sieving. For this, the air-dried soil sample was gently sieved through an 8 mm sieve. A total of 60 g of air dry sub-sample (<8 mm) was placed on a nest of sieving with opening size of 4, 2, 1, 0.5 and 0.25 mm respectively arranged from top to bottom. At first for prevention from sudden breakdown of the aggregate the sieving nest was placed in a cool steam apparatus for 2–3 h until soil samples got gently saturated with vapor, then slowly submerged in water while connected to a wet-sieving apparatus. The sieve operation was accomplished in 10 min at a frequency of 30 Hz and vertical stroke (the vertical distance that the sieve set moved up and down in water) of 38.1 mm. The soil remains on the sieves were collected, oven dried at 105 °C, weighed and corrected for sand content. The aggregate MWD was obtained from the equation:

$$\mathrm{MWD} = \sum_{i=1}^{n} W_i \bar{X}_i \quad (3)$$