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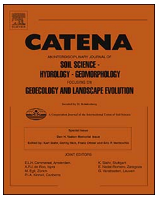

Combined effect of rain temperature and antecedent soil moisture on runoff and erosion on Loess

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ABSTRACT

The effect of antecedent soil moisture content on runoff and soil erosion was investigated in many previous studies. These studies revealed contradictory findings. The present study investigated the combined effect of raindrop temperatures and antecedent soil moisture on interrill flow generation and erosion of a loamy soil (Loess), using a rotating disk rain simulator. The experiments were applied to soil with two pre-prepared moisture conditions: hygroscopic and field capacity. For each condition, three rainfall temperatures were applied: 2 (cold), 20 (mid-temperature), and 35 °C (hot).

The effect of antecedent soil moisture on soil erosion found to be depended on rainfall temperature. For the cold rainfall, the sediment yield of the dry soil was 5.2 times greater than that of the pre-wetted soil, whereas for the mid-temperature and for the hot rainfall it was 1.5 and 1.2, respectively. For the pre-wetted soil, the sediment yield in the mid-temperature rainfall was 3 times greater than in the cold one. In the light of the predicted changes in global climate characteristics, an increase in rainfall temperature might lead to enhanced soil loss in Loess.

1. Introduction

Many studies investigated the effect of antecedent soil moisture content on runoff and soil erosion, (Ben-Hur and Lado, 2008; Martínez-murillo et al., 2013), and it was intensively studied with loamy soils. The complexity of this effect, probably led to contradictory results (Le Bissonnais et al., 1995). This effect depends on the wetting degree (Cousen and Farres, 1984), wetting method (Gusli, 1995), aging (Auerswald, 1993; Mamedov et al., 2006), wetting rate (Fan et al., 2008; Han et al., 2016; Lado et al., 2004) and clay content (Lado et al., 2004; Shainberg et al., 2003).

The temperature of raindrop can vary greatly from freezing to that of the wet bulb (Anderson et al., 1998; Flament and Sawyer, 1995; Gosnell et al., 1995; Kincaid and Longley, 1989) and is controlled by a number of factors such as season, time of day, anthropogenic activities and climate regime (Khain et al., 2010; Lee and Feingold, 2010; Mengistu et al., 2016; Rosenfeld, 2000).

When rain drops land on a soil surface, the higher the drop temperature the greater the reduction in water viscosity and surface tension. As a result, hydraulic conductivity increases (Constantz, 1982; Constantz and Murphy, 1991; Gao and Shao, 2015; Hopmans and Dane, 1986; Levy et al., 1989; Nimmo and Miller, 1986; Romero et al., 2001). In clayey soil with a high water content, the effect of water temperature on hydraulic conductivity may be greater than in coarser soils (Zhang et al., 2003).

There are seven mechanisms whereby rainfall temperature can have an impact on aggregate stability: 1) according to Lado et al. (2004) and Le Bissonnais (2003), as water temperature increases and viscosity decreases, aggregate wetting rate increases. As a result, the differential pressure caused by trapped air bubbles and deferential swelling of clay minerals is enhanced, and slaking increases (Le Bissonnais and Arrouays, 1996); 2) rapid wetting of dry aggregates releases heat that causes aggregate slaking (Collis-George and Lal, 1971; Lal and Shukla, 2004). High rainfall temperature likely to strengthen this mechanism, while cold one can weaken it; 3) soil surface solution temperature increases in parallel with raindrop temperature. As a result, the thermal motion of ions adsorbed on the clay particles intensifies so that the electrical double layer of the clay expands, leading to diminution of aggregate stability (Constantz, 1982); 4) high water temperatures may reduce aggregate stability by increasing the potential to break down unstable organic matter, such as polysaccharides, which cement soil particles (Cheshire, 1979; Debosz et al., 2002); 5) the solvent temperature affects the solubility of various ions. For example, whereas the solubility of NaCl slightly increases with increasing water temperature, that of $CaCO_3$ decreases. Accordingly, modifications of water temperature differentially affect the solubility of sodium, potassium,

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Table 1
Soil properties.

Grain size distribution (%)			EC (dS cm^{-1})	pH	Soluble cations (mg g^{-1})				CaCo$_3$ (kg kg^{-1})	OM (kg kg^{-1})
Clay	Silt	Sand			Ca^{2+}	Mg^{2+}	Na^{+}	K^{+}		
25	35	40	937	7.7	$7.2 * 10^{-2}$	$1.3 * 10^{-2}$	$8.6 * 10^{-2}$	$3.4 * 10^{-2}$	0.15	0.014

calcium and magnesium. This in turn changes the exchangeable sodium percentage of the soil and its electrolyte concentration (Coto et al., 2012); 6) the impact of raindrops decreases with their temperature because of the decrease in surface tension and viscosity, which decreases the drops impulse (Sachs and Sarah, 2017); 7) thermophoresis is a mass flow driven by a thermal gradient (Vigolo et al., 2010). When there is large difference between rain drop temperature and soil surface temperature, thermophoresis may decrease aggregates stability (Sachs and Sarah, 2017).

Early sprinkling experiments in both field and laboratory settings were carried out by Duley and Domingo (1944). They used a routine flower sprinkler at 4, 21, and 43 °C. The method did not simulate raindrops impact and they modified the water temperature after reaching a final infiltration rate. They found no effect of rain temperature on soil intake, which was attributed to increased swelling associated with increasing rain temperature that counteracted the effect of lowered water viscosity.

A handful of other investigations delved into the effect of rain temperature on soil erosion. Levy et al. (1989) investigated the effects of simulated rainfall temperatures at 10 and 45 °C on infiltration rate and crust formation but no effect was found on either. Kemper and Koch (1966) found that aggregate stability decreased insignificantly with increasing water temperatures from 20 to 30 °C. Their work used wet sieving experiments on 27 different soils. Bruce-Okine and Lal (1975) investigated the effect of water temperature and antecedent soil moisture potential on the structural stability of two tropical soils – clayey soil and sandy clay loam. They used a single water drop method with water temperatures at 30, 40, and 50 °C and found that an increase in water temperature increased the erodibility of both soils. Blair (2010) applied water temperatures of 15–36 °C to assess aggregate stability of three types of soils that contained 18, 46, and 54% of clay, respectively. The results agreed with those of Bruce-Okine and Lal (1975). What is common in all these studies is that they were conducted for temperatures > 15 °C, despite that in most rain events the rainfall temperature is below this value. Sachs and Sarah (2017) used a rainfall simulator to investigate the effect of rain temperature on runoff and erosion on clayey soil with hygroscopic and field capacity water content. The difference between rainfall temperature and soil temperature was found to affect interrill flow and soil erosion only when the soil was pre-wetted. The decreased aggregates stability was attributed to thermophoresis, a mechanism which is limited to high quantity of clay particles.

The overarching aim of the present study was to investigate the combined effect of raindrop temperatures and antecedent soil moisture on interrill flow generation and erosion of a loamy soil (Loess). It was hypothesized that the study loamy soil would differ in its response to various rain temperatures from clayey soil.

2. Materials and methods

2.1. Soil properties

Samples were obtained for a Palexeralf soil (Loess) from a rain-fed agricultural field located near Rohama (31.48 E, 34.71 N), Israel. Soil electrical conductivity, soluble ion concentrations, and pH were determined in a 1:1 extract (Rowell, 1994). Electrical conductivity was measured with a conductometer (Cyberscan 510, EUTECH INSTRUMENTS, Singapore). Na^{+} and K^{+} concentrations were determined with a flame photometer (Flame Analyzer model FGA-330; Gallenkamp, GSIS Inc. Ontario Canada). Mg^{2+} and Ca^{2+} concentrations were determined with an atomic absorption spectrophotometer (Perkin-Elmer Model 560, Norwalk, Connecticut USA). Soil texture was determined by the sedimentation method according to Black (1965). Soil organic matter, calcium carbonate, and soil moisture content were determined by the wet combustion dichromate method (Rowell, 1994), a manometer calcimeter (Loeppert and Suarez, 1996), and gravimetrically, respectively.

Soil properties are presented in Table 1. The soil was loamy, calcic, non-salty, non-sodic (SAR of 1:1 soil extraction = 2.44), and contained low amounts of organic matter.

Aggregate stability was tested by soaking aggregates of 1–2 and 5–6 mm diameter in water in glass vessels at 2, 20, and 35 °C, and then observing their disintegration (Emerson, 1967). The dry aggregates contained hygroscopic moisture (pF = 5.2, 0.03 m^3 m^{-3}), and wet ones with a pF = 2.4, 0.31 m^3 m^{-3}. The latter aggregates were slow-wetted for 24 h on filter paper placed on wet sand. Twenty replicates were measured for each aggregate size at each temperature.

2.2. Rain simulator experiments

Ten 1 × 1 m squares were randomly chosen within the field site. Soil was completely removed from each square from 0 to 10 cm depth (a total of 1 m^3). These samples were mixed and used for the rain simulator experiments (Fig. 1) and for soil analyses. The Rain simulator experiment design is described in details in Sachs and Sarah (2017).

The bulk density of the packed soil ranged between 1570 and 1650 kg m^{-3}. The soil was kept at room temperature, i.e. the initial soil temperature varied between 19.5 and 23 °C.

Sprinkling experiments were conducted on soil samples having two initial water contents: hygroscopic (0.035 m^3 m^{-3}) and field capacity (0.36 m^3 m^{-3}). The sediment yield was calculated by oven-drying the overland flow water for 24 h at 105 °C and weighing the sediments left in the vessel. The sediment yield weight (kg) was then subtracted from the total weight (of runoff water plus sediment) to determine the runoff

Fig. 1. The rain simulator soil boxes and the buffer area in their vicinity. Each plot is 116.5 × 55 cm.