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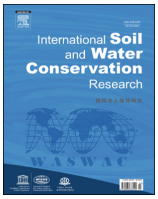

Original Research Article

Influence of freeze-only and freezing-thawing cycles on splash erosion

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ABSTRACT

Soil erosion is recognized as one of the most important types of land degradation in the world particularly in many developing countries like Iran. Water erosion is initiated by splash erosion triggered by raindrop impact. Understanding the process of splash erosion under freezing and thawing conditions is essential to unravel soil erosion mechanisms under temperate conditions leading to appropriate planning of soil and water conservation projects. The present study aimed to study the individual effects of freeze-only as well as freezing-thawing cycle on splash erosion in a loess soil from an erosion prone area in mountainous northern regions of Iran. The study was conducted under laboratory conditions using erosion plots. The erosion plots were subjected to freeze only and freeze-thawing treatments by simulating cold conditions using a large cooling compartment system specifically manufactured for this purpose. The splash erosion under a designed simulated rainfall ($1.2\ \mathrm{mm\ min^{-1}}$ for 30 min) was then measured as upward, downward and net splash erosion in splash cups. The results showed that freeze only decreased the upward, downward and net splash erosion by 0.81 ± 0.43, 0.82 ± 0.29 and 0.85 ± 0.23% while freezing-thawing cycle decreased splash erosion to 0.93 ± 0.83, 0.61 ± 0.43 and 0.57 ± 0.36%. This may be attributed to temporary increase in soil strength and stability or surface sealing during freezing process leading to reduced splash erosion.

1. Introduction

Soil erosion has long been identified as a serious environmental problem, worldwide (Angulo-Martínez, Beguería, Navas, & Machín, 2012; Hazbavi & Sadeghi, 2017; Hu et al., 2018). Rainfall is the main factor responsible for soil erosion by water and the main agent of detachment of soil particles (Honarbakhsh & Hayavi, 2018; Jomaa et al., 2010; Morgan, 2005). In the same vein, splash erosion -soil detachment and transport by impacting rain drops- is an important and initial step in soil erosion process (Hu et al., 2018; Qinjuan, Qiangguo, & Wenjun, 2008; Sadeghi, Kiani-Harchegani, & Asadi, 2017). Soil splash rate increases exponentially during rainfall event due to decreasing soil shear strength at the surface as the soil water content approached saturation (Schultz, Jarrett, & Hoover, 1985). The splash erosion process has been extensively studied from different viewpoints mostly in connection with rainfall intensity (e.g., Kiani-Harchegani, Sadeghi, & Asadi, 2016), soil textures (e.g., Angulo-Martínez et al., 2012), slope steepness (e.g., Mizugaki, Nanko, & Onda, 2010), soil physical and chemical characteristics (e.g., Hoffman, Yizhaq, & Boeken, 2013) as well as particle size distributions of splashed soils (e.g., Sadeghi et al., 2017). The ability of a soil to resist erosion depends on numerous factors including soil-particle size and distribution (e.g., Sadeghi et al., 2017), soil structure and structural stability (e.g., Müller-Lupp & Bölter, 2003), soil permeability (e.g., Qinjuan et al., 2008), water content (Lawrence & Michael, 2003), organic matter content (Lal & Elliot, 1994), and mineral and chemical constituents (Mazurak & Mosher, 1968).

During freezing and thawing process, under natural conditions, as air temperature drops, heat is lost from the soil surface. When sufficient heat is lost, the water in the soil begins to freeze (Ferrick & Gatto, 2005). Three conditions must exist for ice to become a substantial component of a soil mass including source of soil water, sufficiently cold air temperature to cause heat loss from a soil and subsequent freezing of soil water, and a frost-susceptible soil (Al-daood, Bouasker, & Al-Mukhtar, 2014; Angin, Aksakal, Oztas, & Hanay, 2013; Kamei, Ahmed, & Shibi, 2012; Lawrence & Michael, 2003;

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Li & Fan, 2014; Musa, Ya, Anzhi, & Cunyang, 2016). Researches have shown that during periods of wetting-drying and freezing-thawing, soil pores are filled with water and re-arrangement and polished are invariably occurred. So, these phenomena can influence soil resistance (e.g., Oztas & Fayetorbay, 2003), particle cohesion (e.g., Li & Fan, 2014), mechanical strength (e.g., Kamei et al., 2012) and aggregate size (e.g., Oztas & Fayetorbay, 2003) and the pores size (e.g., Newman & Thomasson, 1979). Many researchers opined that the positive effect of freezing on aggregation is due to cryosuction and contraction of micro soil aggregates in response to cooling process (i.e., Lehrsch, 1998; Lehrsch, Sojka, Carter, & Jolley, 1991; Mbagwu & Bazzoffi, 1989; Müller-Lupp & Bölter, 2003). However, detrimental effects of freezing-thawing on soil aggregates have been reported by Musa et al. (2016) and Angin et al. (2013), Angin, Sari, and Aksakal (2016). Kok and McCool (1990) and Lal (1990) have reported that erodibility increased under winter conditions. Additionally, it has been shown that maximum changes in soil physical behavior occurred in the first few freezing-thawing cycle (Kamei et al., 2012; Lehrsch et al., 1991).

Sigrun and Lillian (2006) studied the influence of freezing-thawing cycles on aggregate stability of three soils in Norway and reported that freezing and thawing decreased the rainfall stability of all soils, but the effect was more severe on the silty soil. Further, Jabro, Iversen, and Evans (2012) comprehensively evaluated the dynamic of freezing-thawing cycles on soil compaction in a clay loam soil during three years of study. Results showed that frequent freezing-thawing cycles over the winter alleviated a majority of soil compaction at the 0–20 cm depth. Dagesse (2013) investigated the impact of freezing-thawing process on water stability of soil aggregates for three soils of Tavistock sandy loam, Jeddo clay loam and Welland clay in Italy. They found that the freeze-only and freezing-thawing treatments respectively increased and decreased the aggregate stability compared to the not frozen control treatment. Li and Fan (2014) in China reported that the effects of freeze-thaw on aggregate stability depended on the initial moisture content of the soil. Sterpi (2015) corroborated the increase in hydraulic conductivity for a series of clayey silt samples as the consequences of cyclic freezing due to the compaction level and subsequent fracture networks development. The beneficial effects of freeze–thaw process through water enrichment in freezing layers of soil and making it accessible to vegetation covers in sandy land habitats of Horqin Sandy Land, north China were also documented by Musa et al. (2016). In addition, Ban, Lei, Liu, and Chen (2017) studied the effect of four slope gradients of five, 10°, 15° and 20° and three flow rates of one, two and four L min^{-1} on soil erosion by concentrated meltwater flow over thawed and non-frozen soil surfaces. Sediment yield increased rapidly with the slope length to the maximum value as the slope gradient increased. Recently, Behzadfar, Sadeghi, and Khanjani (2017) studied the effectability of runoff and soil loss from soil amendment application under freezing-thawing cycle. The results proved the significant effects of zeolite application on the hydrological behavior of an induced freezing-thawing soil.

Reviewing of literatures showed that there have been many studies on freezing-thawing cycles effect on soil properties and soil erosion. There were also many studies verified that one of the processes affecting soil aggregate breakdown as the first key step of splash erosion is freezing and thawing process. Nonetheless, no study has been documented in literature about the behavior of splash erosion induced by freezing and thawing process, yet. Knowledge about the splash erosion processes under different freezing and thawing conditions is of significant importance for unraveling soil erosion mechanisms to provide a sound scientific basis for policy development on soil and water management, and improving the soil erosion prediction models (Heilig et al., 2001; Kinnell, 1990). Therefore, the present research has been formulated to investigate the effects of freezing-thawing processes on splash erosion of a loess soil which is representative for erosion prone highland areas in northeastern Iran.

2. Materials and methods

2.1. Soil characteristics

Point soil samples were collected from the top 30 cm layer of a rangeland area from Badranlou Region (57° 11′ E and 37° 29′ N) with a slope of 20% located 10 km from Bojnourd City, the capital of Northern Khorasan, northeast of Iran. The soil samples were then transferred to the laboratory and were passed through a three-mm sieve after air-drying according to previous literature (Behzadfar et al., 2017) in the same field of study and even similar soil origin and more adapted to the soils in mountainous regions. Soil properties were studied in the soil laboratory. Soil texture according to a hydrometer method was determined as silty-loam soils. The organic matter, EC and pH of soil samples were found 0.15%, 137.30 $\mu S\ m^{-1}$ and 8.20, respectively (Behzadfar et al., 2017; Hazbavi, Sadeghi, & Younesi, 2012). The total soil organic carbon (SOC) was measured by the Walkley and Black method (Nelson & Somers, 1982). Then, soil organic matter was obtained by multiplying total SOC by 1.72. Additionally, the pH and electrical conductivity (EC) were determined in a soil:water suspension (1:2) by pH and EC meters (Hati, Biswas, Bandyopadhyay, & Misra, 2007).

2.2. Experimental setup

The study was conducted under controlled laboratory conditions with a simulated rainfall at the Soil Erosion and Rainfall Simulation Laboratory, Tarbiat Modares University, Iran. The study was conducted at small plot scale for better controlling of the conditions and facilitating adapting experimental conditions.

The maximum efforts were also made to mimic natural conditions to get access to results with high level of fidelity (Hawke, Price, & Bryan, 2006; Shoemaker, 2009). At first the plant residues were removed from the soil samples to achieve the similar conditions for all plots and avoid from unpredictable errors. Then, the sieved soil was poured in small erosion boxes with 0.5 × 0.5 × 0.3 m dimensions. A thick filter, draining the lower 20 cm of the soil profile was generated using mineral pumices. The prepared soil sample was evenly packed into the soil plots by a hand- made roller (a small PVC-pipe roller filled with cement and sand) at a bulk density of 1.3 $g\ cm^{-3}$ similar to that measured under field conditions. It is important to note that the packing process were done for several time and after every soil layer pouring into the study plot. The plots were then placed in saturated pool for 24 h and then left to be drained to achieve an average moisture content of 35% similar to moisture content recorded for the study area (Hazbavi et al., 2012; Sadeghi, Hazbavi, Younesi, et al., 2016; Sadeghi, Hazbavi, & Kiani-Harchegani et al., 2016). A detailed pictorial presentation is shown in Fig. 1. Based on the analysis of freezing temperature at various soil depths at Boujnourd climatological station, the maximum soil frost depth of 10 cm with frequency of 92% (Behzadfar et al., 2017; Behzadfar, Sadeghi, Khanjani, & Hazbavi, 2012) was used for simulation processes.

2.3. Freezing-thawing setting and rainfall experiments

Two prepared erosion boxes were placed in a freezer designed and manufactured based on the study conditions for three days to achieve a uniform temperature of − 10 °C throughout the soil profile. One of these plots was then placed at laboratory ambient temperature (≈ 10–20 °C) for 48 h to conduct melting process. Three plots (one with freezing-thawing cycle, one with only freeze cycle and one