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Research paper

Effects of heating on compositional, structural, and physicochemical properties of loess under laboratory conditions

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ABSTRACT

Wildfires are swept-wing across the world is increasing in recent time, causing serious environmental, ecological and socioeconomic impacts due to alterations in soil properties. Currently, wildfires are increasing in landscapes over the Chinese Loess Plateau. This study examined the changes in loess properties at laboratory temperatures ranging from 20 to 1000 °C. Various tests were performed on the raw and heated loess, including mineral and chemical compositions, color, scanning electron microscopy (SEM), particle size distribution, bulk and particle densities, particle flow velocity, specific surface area (SSA) and cation exchange capacity (CEC), along with electric conductivity (CE) and pH of its 1:5 extracts. The test results showed that heating couldn't produce notable changes in various loess properties below 400 °C, although slight changes have been observed resulting from loss of physically free and absorbed water. In contrast, higher temperature heating can induce important changes in loess properties due to the formation of aggregation as a result of changes in structure and composition. The analysis of results indicated that there has a close relation between microscopic characteristics of heated samples and its macroscopic behaviors. These findings are important to an initial understanding of wildfire-induced alterations in loess properties and then can afford useful posthoc estimate to such as erosion and debris flow geohazard processing in the fire-affected loess areas.

1. Introduction

Wildfires are sweeping across the world with a stronger posture in recent time, causing serious environmental, ecological and socioeconomic impacts. It can give rise to significant losses of human lives and homes (Gill et al., 2013). Meanwhile, it can profoundly impact soil properties by physical, chemical, biological, and mineralogical alterations (Certini, 2005; Mataix-Solera et al., 2011; Zavala et al., 2014), sequentially, following severe erosion and debris flow geohazards (Cannon, 2001; Gabet and Bookter, 2008; Lourenço et al., 2015). Hence, enhanced understanding of wildfire-induced alterations on soil properties is of growing importance to ecosystem restoration and geohazard mitigation.

There has been considerable research into understanding the effects of wildfire on soil properties, but much of this effort has focused on the water repellency and its impacts on hydrologic responses, including infiltration, runoff and erosion, and even water quality (DeBano, 2000; Doerr et al., 2006; Gabet and Bookter, 2008; Zavala et al., 2010; Cawson et al., 2016; Mast et al., 2016). There has also been an increasing interest in the effects of water repellency on debris flow initiation in burned landscapes (Cannon, 2001; Gabet, 2003; Lourenço et al., 2015). Meanwhile, there was a continuous concern to the effects of wildfire on aggregate stability (Zavala et al., 2010; Mataix-Solera et al., 2011) and organic matter (González-Pérez et al., 2004; Knicker, 2007). Moreover, the most important wildfire impacts also include changes in structure and soil components (Zavala et al., 2014), which are closely related to other physical, chemical and biological alterations (Certini, 2005; Zavala et al., 2014), as well as aggregate stability (Mataix-Solera et al., 2011). However, few attempts have been made to examine the changes in structure and component of burned soils and its relations with other properties (Ulery and Graham, 1993). Also, it is a lack of special attention to particular properties of burned soils, such as its flowability and specific surface area, which are important to particle material flow. Hence, Mataix-Solera et al. (2011) and Zavala et al. (2014) particularly emphasized that it is necessary to study effects of wildfire on the inclusion of other parameters. As, it can facilitate to understand the wildfire-induced alterations on soil properties and their complicated interactions (Zavala et al., 2014), as well as the hydrological responses and geohazards in fire-affected areas.

Studies on heating effects on soil properties include laboratory

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controlled experiments, prescribed and experimental field fires, and sampling after wildfires. Relations between heating and soil properties are rarely tested in the field where lead to more complex responses to fire (Cawson et al., 2016). Also, the sampling after wildfires can result in variation in studies on wildfire effects on soil properties (Badía-Villas et al., 2014). Consequently, laboratory controlled experiments are necessary to control relevant variables accurately and to differentiate the effects caused directly to various properties by fire (Badía-Villas et al., 2014). Additionally, laboratory experiments are more convenient to the soil sampling after the fire (González-Pérez et al., 2004; Mataix-Solera et al., 2011). Thus, the laboratory measurements are important that the relations between heating and soil properties are linked to provide a useful posthoc estimate of wildfire.

Wildfire has been an important factor in landscape evolution in arid and semi-arid loess ecosystems (Huang et al., 2006). In the Chinese Loess Plateau, charcoal records of fire history can be tracked to the last glacial period and the early Holocene (Huang et al., 2006; Tan et al., 2013). Local wildfires frequently occurred before 8500 years BP, and natural wildfires largely reduced during the middle Holocene between 8500 years BP and 3100 years BP (Huang et al., 2006; Tan et al., 2013). Between 3100 years BP and 1500 years BP, prescribed wildfires have frequently been applied to vegetation clearance for land reclamation, since then human burning of the landscape has been reduced (Huang et al., 2006). Currently, wildfires have frequently been reported in the Chinese Loess Plateau. For example, a few wildfires occurred simultaneously at different loess places in Gansu Province of China in 2016, some of them continued for a week (Xinhuanet, 2016). Consequently, wildfires are increasing in the Chinese Loess Plateau. None the less, a detailed research has not been conducted to wildfire effects on loess properties, and an adequate understanding of their complicated relations and interactions remains an ambition.

This study presents preliminary results from heating-induced alterations on loess properties under laboratory conditions. The laboratory tests examine the effects of desired temperatures on compositional, structural, and physicochemical properties of heated loess samples. This study aims to understand wildfire-induced alterations on loess properties, and their complicated relations and interactions and, secondly, the link of the microscopic characteristics with its macroscopic behaviors. If changes in properties loess heated in the laboratory are similar to those in the field, the results presented in this study can afford an initial understanding of wildfire-induced alterations on loess properties, as well as some geohazard processings, such as erosion and debris flow in the fire-affected loess areas.

2. Material and methods

2.1. Tested sample

The sample examined in this study was deposited on loess from the Quaternary age and taken in Lanzhou City, Gansu Province, China. This kind of loess widely distributes in the Chinese Loess Plateau, so it was used in the preliminary laboratory study. The sample contains approximately 10% clay (< 0.002 mm), 89% silt (0.002–0.075 mm), and 1% sand (0.075–0.1 mm).

2.2. Sample preparation

The sample was first allowed to air dry at room temperatures about 20 °C. The sample was passed through a sieve with a 0.5 mm aperture for heat treatment. About 500 g air-dried samples were thermally treated in a muffle furnace at temperatures of 100, 200, 300, 400, 600, 800, and 1000 °C. The heating rate was 10 °C/min until the set temperature level, and this temperature was maintained for 1 h to ensure the specimens heated evenly. The heated samples were then naturally cooled to room temperature and, used for various laboratory tests.

2.3. Tested methods

2.3.1. Composition

Changes in the mineralogical composition of the raw and heated samples were examined by X-ray diffraction (XRD) and thermogravimetric analysis (TGA). A Philips PW 3710 diffractometer was used for XRD analysis. The diffraction patterns were determined using Cu-Kα radiation with a Bragg angle (2θ) range of 5°–45° running at a rate of 0.03°/s. Thermogravimetric analysis, including mass loss (TG) and its derivative (DTG), was examined using an analyzer (Perkin-Elmer Instrument, Waltham, MA). The raw sample was heated at a constant rate of 10 °C/min from an ambient temperature to 1000 °C. The chemical composition of major elements of the raw and heated samples was determined using an X-ray fluorescence (XRF) analyzer (Panalytical Magix PW2403). Also, their total carbon content was measured using Elementar Vario EL element analyzer.

2.3.2. Structural properties

The micro- and macro-structures of the raw and heated samples were examed. The micro-morphology and micro-size were observed on the powder samples after metallization with gold powder using a JSM-5600LV Scanning Electron Microscope (SEM). The macroscopic particle size distributions of these samples were determined using the sieve and sedimentation methods following ASTM D422-63 (2007).

2.3.3. Physicochemical properties

The physicochemical properties of the raw and heated samples were examined including SSA, CEC, flowability, and densities of the samples, as well as pH and CE of its extracts. The total SSA and CEC of the samples were measured using methylene blue spot test method. The test procedure for determining the total SSA of soil was described by Santamarina et al. (2002), and its CEC was calculated by the formula suggested by Çokça and Birand (1993). The flowability of dry particles was tested using a hall-flowmeter with orifices of 5.0 mm in diameter (ISO4490, 2001; ISO3923-1, 2008). This procedure was repeated five times, and an average value of flow time and volume at the same weight of 50 g was determined, and mass flow rate and bulk density were calculated. The particle density was determined following the standards of Japanese Geotechnical Society (JGS, 2010). Chemical properties were measured using a water quality monitor for the extracts from 1:5 soil to water.

3. Results

3.1. Mineralogical composition

The thermal behavior of the raw loess sample is presented in Fig. 1. The TG and DTG curves detect changes in three temperature domains. The first domain presents two sharp DTG peaks, which locate at 60 °C

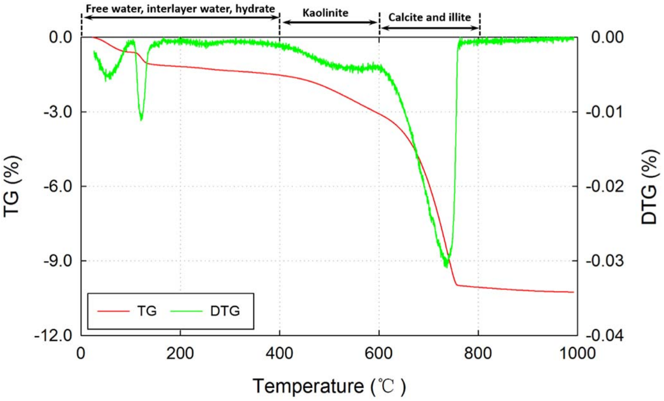

Fig. 1. TG and DTG curves of the raw loess.

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