Catena 167 (2018) 429–439

Contents lists available at ScienceDirect

Catena

journal homepage: www.elsevier.com/locate/catena

Spatial variation of topsoil features in soil wind erosion areas of northern China

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ARTICLE INFO

Keywords:
Soil texture
Soil organic matter
Soil calcium carbonate
Gravel coverage
Soil wind erosion
Northern China

ABSTRACT

The particle size distribution (PSD), contents of soil organic matter (SOM) and calcium carbonate ($CaCO_3$), and surface gravel coverage (GC) are the crucial factors affecting topsoil features, and consequently, these factors influence soil wind erosion and land use. The aim of this study is to understand the topsoil features in northern China, which is one of the regions of the world that experiences the most severe soil wind erosion. We used the topsoil data of the PSD, SOM content, $CaCO_3$ content and GC derived from 610, 608, 503 and 2372 topsoil sampling sites, respectively. The results of the calculations and statistics showed that the particles in the topsoil were generally coarse; the areas of sandy loam, loam, loamy sand and silty loam accounted for 39.53%, 21.05%, 16.31% and 12.15% of the total area, respectively, and the other eight types of soils combined accounted for 10.96% of the total area. The areas with SOM contents of ≥5%, 1–5% and < 1% accounted for 5.58%, 52.62% and 41.79% of the total area, respectively. The areas with $CaCO_3$ contents of ≥10%, 5–10%, 1–5% and < 1% accounted for 19.46%, 32.98%, 39.30% and 8.26% of the total area, respectively, in which sandy loam and silty loam soils with a $CaCO_3$ content of 1–5% were the most susceptible to wind erosion. The areas with GC of 50–100%, 20–50%, 5–20% and < 5% accounted for 10.77%, 12.80%, 18.90% and 57.53% of the total area, respectively; the areas with GC of > 20% were mainly distributed in the northwest regions, which were occupied by Gobis and gravel deserts with rare vegetation. The areas with higher intensity levels of soil wind erosion were mainly distributed in the areas with higher values of gravel coverage; this seemingly abnormal phenomenon is caused by an abundance of erodible particles (0.02–0.84 mm in diameter) hiding amongst the gravels, rare vegetation and long duration of effective wind speeds that cause erosion.

1. Introduction

Topsoil refers to the upper layer of a soil; its features have a profound impact on land use and soil wind erosion. Topsoil, like the entire soil layer, contains mineral particles, organic matter, water and air, and additional gravel coverage. The combination of these components determines the features of topsoil. The most important components affecting topsoil features are particle size distribution (PSD) and soil organic matter (SOM). PSD determines the texture of a soil and can be used to estimate the hierarchical structures and hydraulic properties of a soil (Arya and Paris, 1981; Assouline et al., 1998; Nemes and Rawls, 2006; Ghanbarian-Alavijeh and Hunt, 2012), as well as the thermal conductivity as a key parameter (Lu et al., 2014). SOM content contributes indirectly to soil texture and affects other soil properties in many ways. For example, SOM is negatively charged and forms micelles capable of hydrating and adsorbing cations amongst other organic carboxylic and phenolic groups (Duan and Xiao, 2000; Franzluebbers, 2002; Sequeira and Alley, 2011); its composition and breakdown rate affect the soil porosity, water infiltration rate, moisture holding capacity, diversity and biological activity of soil organisms, and plant nutrient availability (Bot and Benites, 2005). Calcium carbonate ($CaCO_3$) is one of the factors controlling the stability of soil at the micro-aggregate level and affects the absorption rate of water (Al-Ani and Dudas, 1988; Nwadialo and Mbagwu, 1991). Additionally, the effects of gravels covering a soil surface on hydrological processes, thermal properties, soil erosion and plant growth have been significant (Lamb and Chapman, 1943; Jury and Bellantuoni, 1976a, 1976b; Nachtergaele et al., 1998; Li, 2003). Knowledge of these components is of great

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https://doi.org/10.1016/j.catena.2018.05.022
Received 2 November 2017; Received in revised form 9 March 2018; Accepted 17 May 2018
0341-8162/

significance to guide land use and management.

In arid and semi-arid areas, soil wind erosion, which was profoundly affected by topsoil features (Chepil, 1950, 1954, 1955a, 1955b; Hagen et al., 1996; Fryrear et al., 1998; Li and Liu, 2003), resulted in land degradation because the wind drove and transported topsoil particles far away, and the transported fine particles were the carriers of soil nutrients (Pimentel et al., 1995). Therefore, it is of great significance to understand the PSD, contents of SOM and $CaCO_3$, and gravel coverage (GC) of topsoil because the topsoil is prone to wind erosion. As far as the effect of PSD on wind erosion, the particles with diameters of > 0.84 mm were difficult to erode by wind, the particles with diameters of < 0.02 mm increased cloddiness and decreased wind erodibility; the particles with diameters of 0.005–0.01 mm had the greatest degree of cloddiness and resistance to wind erosion (Chepil, 1953a, 1955a). This indicates that the particles with diameters of 0.02–0.84 mm were erodible particles, in which the particles with diameters of 0.05–0.50 mm were the most easily eroded particles (Skidmore and Powers, 1982). However, the proportions of sand (0.05–2.00 mm in diameter), silt (0.002–0.050 mm in diameter) and clay (< 0.002 mm in diameter) particles in topsoil have a great influence on the erodibility. Additions of clay to silt decreased erodibility if the clay did not exceed 20%, and further additions of clay to silt increased the erodibility substantially. A greater erodibility than that of mixtures containing > 75% fine sand was produced when there was no proportion of clay to silt, because silt has the greatest degree of soil cloddiness (Chepil, 1955a). The results above indicated that the contents of sand, silt and clay played an important role in the erosion of topsoil by wind. The effects of $CaCO_3$ content on wind erosion was different based on the soil types. A $CaCO_3$ content of 1% to 5% in silt loam and sandy loam soils caused a substantial disintegration of soil cloddiness, decrease in the mechanical stability of clods, and an increase in erodibility by wind. Soil cloddiness and the mechanical stability of clods increased with an increase of $CaCO_3$ content, but the erodibility of loamy sandy soil and the mean weight diameter of aggregates in Mollisols decreased (Chepil, 1954; Al-Ani and Dudas, 1988). The addition of SOM increased the proportion of water-stable aggregates of > 0.84 mm diameter and appreciably decreased the proportion of water-stable particles of < 0.02 mm; consequently, this increased the susceptibility of soils to wind erosion. The influences of SOM on erodible granule formation was amplified in soils containing a high proportion of $CaCO_3$ (Chepil, 1954). The PSD, $CaCO_3$ and SOM had mutual influences on topsoil erodibility by wind, and it was well known that the addition of GC decreased topsoil erodibility by an increase in aerodynamic roughness and decrease in erodible surface area (Dong et al., 2010; Zhang et al., 2014); however, wind erosion hardly occurred when GC was larger than 50% (Tan et al., 2013; Zhang et al., 2014).

The most of northern China is classified as arid, semi-arid and partly sub-humid climate and is one of the regions in the world with the most serious soil wind erosion (Shi et al., 2004). Soil wind erosion is one of the important processes in land degradation, desertification and mineral dust emissions in northern China (Shi et al., 2004; Wang et al., 2008; Hoffmann et al., 2011). However, the areas that were severely and extremely eroded were still controversial in sandy land, grass land or gravel covered land (Laurent et al., 2005, 2006; Zhang et al., 2008; Wang et al., 2012). According to the Standards for Classification and Gradation of Soil Erosion (Ministry of Water Resources of China, 2008), wind erosion moduli of the weakly eroded level, slightly eroded level, moderately eroded level, highly eroded level, severely eroded level, and extremely eroded level were < 200 $t\,km^{-2}\,a^{-1}$, 200–2500 $t\,km^{-2}\,a^{-1}$, 2500–5000 $t\,km^{-2}\,a^{-1}$, 5000–8000 $t\,km^{-2}\,a^{-1}$, 8000–15,000 $t\,km^{-2}\,a^{-1}$ and > 15,000 $t\,km^{-2}\,a^{-1}$, respectively. The recent census results showed that the total area of wind erosion in northern China was approximately $1.6559 \times 10^6\,km^2$; this datum did not include the complex area of erosion by wind and water and was further categorized into $7.160 \times 10^5\,km^2$ of slightly eroded level, $2.174 \times 10^5\,km^2$ of moderately eroded level, $2.182 \times 10^5\,km^2$ of highly eroded level, $2.204 \times 10^5\,km^2$ of severely eroded level and $2.839 \times 10^5\,km^2$ of extremely eroded level (Ministry of Water Resources, P. R. China, and National Bureau of Statistics, P. R. China, 2013). These census results also showed that the severely and extremely eroded levels were mainly distributed in sandy deserts and a part

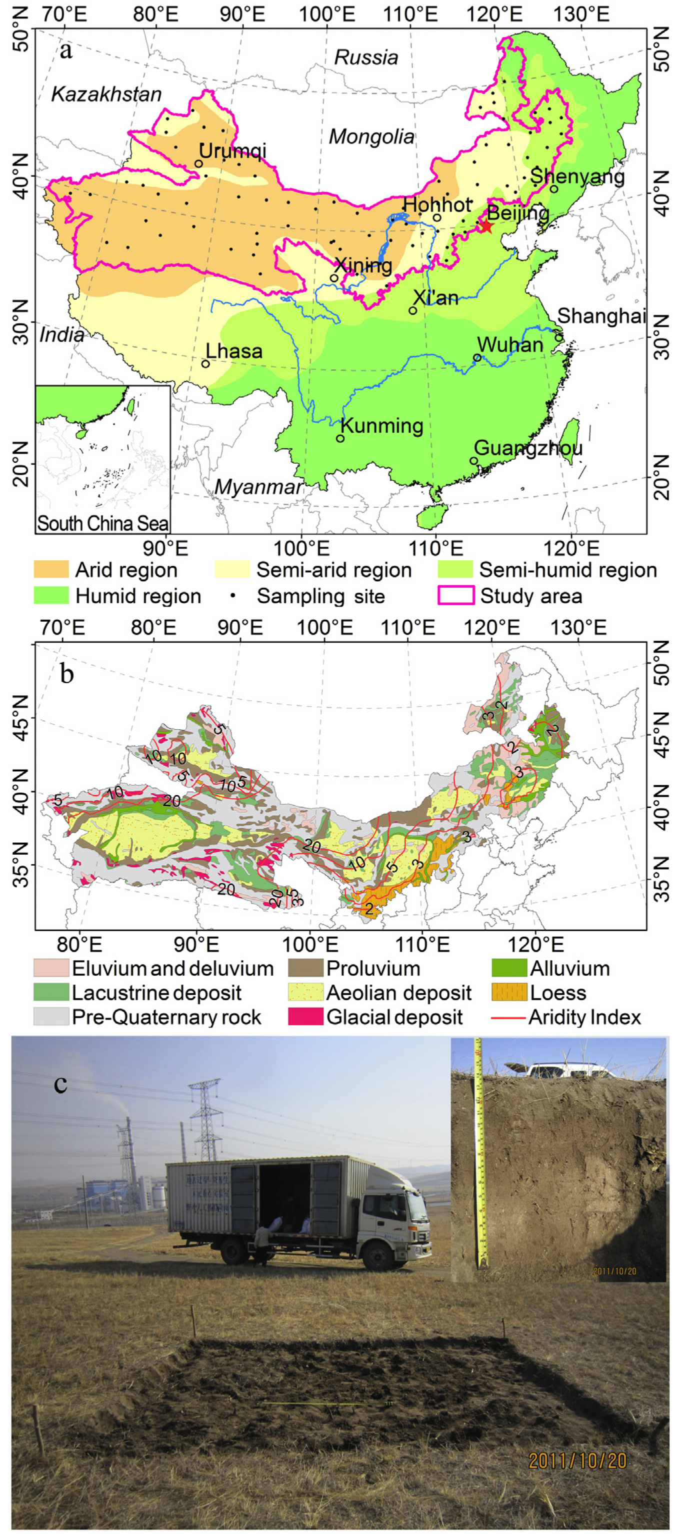

Fig. 1. The general situations of the study area. (a) The study area and 84 topsoil sampling sites (black spots). (b) Distribution of Quaternary deposition (soil parent material) revised from Zhang et al. (1990) and aridity index contour. (c) A topsoil sample collection (sampling site: N 45.50069°, E 119.64643°).