Soil & Tillage Research 170 (2017) 147–156

Contents lists available at ScienceDirect

Soil & Tillage Research

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

The temporal variation of farmland soil surface roughness with various initial surface states under natural rainfall conditions

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ARTICLE INFO

Keywords:
Soil surface roughness
Rainfall
Farmland

ABSTRACT

Soil surface roughness not only affects the hydrological and erosive behavior of soils, but also influences their spectral reflectivity in the optical and microwave bands. Field measurement of soil surface roughness is time-consuming, laborious, costly, and, for vegetated areas, impractical. We attempt to find a method to predict the dynamics of soil surface roughness for various soil surface states for black soils in Northeast China. In this study, four soil surfaces with different roughness were designed, and three kinds of roughness parameters, root-mean-square height (*rmsh*), correlation length (*cl*) and *rmsh/cl*, of each soil surface were measured. The results of soil surface roughness were as follows: (1) a decrease over time was observed for *rmsh* and *rmsh/cl* as well as an increase in *cl* over time; (2) an exponential relationship was confirmed between roughness parameters (*rmsh*, *cl*, and *rmsh/cl*) and cumulative rainfall (CR) for soil plots without ridge, as well as for the relative change (RC) of roughness parameters and CR; (3) a significant difference in change of soil surface roughness with CR existed for soil surfaces with ridge and without ridge, and a Gaussian function was more suitable for describing the dependence of soil roughness evolution on CR than an exponential function. These results indicate that the temporal change of soil surface roughness in the black soil of Northeast China could be predicted by CR based on the empirical relationship achieved in this study regardless of whether soil surface has a ridge and of different initial roughness.

1. Introduction

Surface roughness is a key element in the hydrological and erosive behavior of soils (Helming et al., 1998), and it plays an important role in many processes, such as infiltration, run-off, detachment of soil due to water or wind, gas exchange, evaporation, and heat flux (Huang and Bradford, 1992). For optical remote sensing, soil reflectance properties under field conditions are strongly affected by the roughness of the soil surface. Matthias and Fimbres (2000) and Piekarczyk et al. (2016) observed a decrease in reflectance with increasing surface roughness, possibly due to shadows cast on the surface and a greater proportion of diffuse scattering of light. This decrease in reflectivity also occurred in the microwave band (Choudhury et al., 1979). Thus, accurately measuring and predicting soil surface roughness is important for agricultural as well as for remote sensing scientists.

Variation of soil surface roughness is mainly controlled by soil properties, farming practices, and natural conditions. Soil properties, including the presence of clay, biota, soil organic matter content, sesquioxides, ionic bridging, and carbonates, control soil aggregation, which affects rearrangement of particles, flocculation, and cementation (Pardini, 2003; García Moreno et al., 2008a,b). Farm practices quickly change soil surface roughness by different tillage methods and, natural conditions (e.g. rainfall and wind) slowly change soil surface roughness (Zobeck and Onstad, 1987; Bauer et al., 2015; Martinez-Agirre et al., 2016).

Besides farming, the change of soil surface roughness is affected by soil properties and natural conditions. Dalla Rosa et al. (2012) analyzed the evolution of soil roughness with time in different tillage systems under simulated rainfall using a semivariogram-based index, measured with a portable laser scanner with a 1 cm horizontal resolution for 1 m × 1 m area. Similarly, Darboux et al. (2001) and Vermang et al. (2013) found that experimental semi-variograms showed a gradual lowering of semivariances in a homothetic way after each additional rainfall. In addition, Bauer et al. (2015) analyzed their results of roughness decay by using the widely used linear and exponential equation proposed by Zobeck and Onstad (1987), and confirmed the equation between relative change (RC) of roughness (also named ratio of random roughness – *RRR*) and cumulative rainfall. Although lots of

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http://dx.doi.org/10.1016/j.still.2017.03.015
Received 12 May 2016; Received in revised form 4 March 2017; Accepted 31 March 2017

Fig. 1. Soil surface roughness states of black soil in this study. Plot A denotes soil surface roughness with ridge, Plot B denotes very rough soil surface, Plot C denotes medium rough soil surface and Plot D denotes slightly rough soil surface.

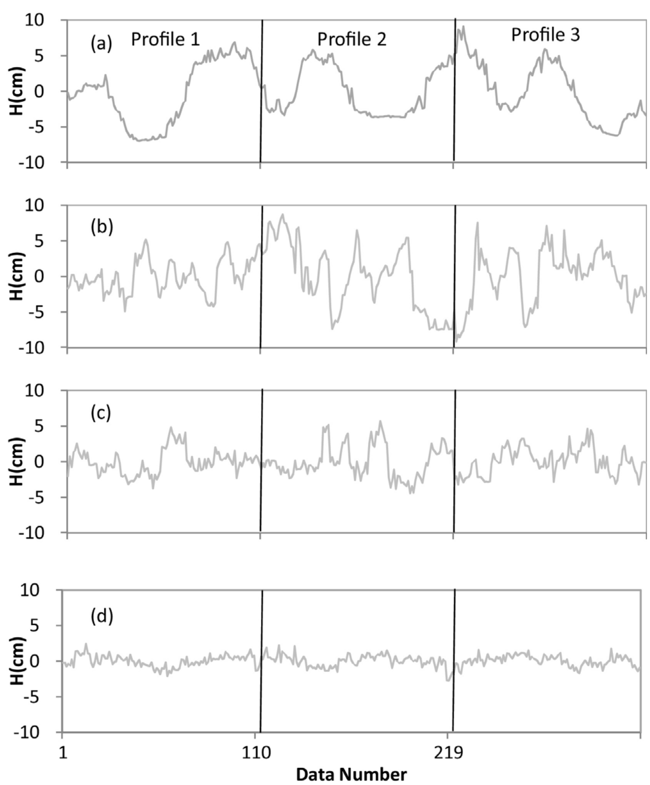

Fig. 2. Height (H) of four soil surface roughness states with 327 data points, consisting of three profiles end to end, called Profile 1, Profile 2 and Profile 3.

work on soil surface roughness research has been carried out on a global scale, little attention has been devoted to Northeast China with its temperate continental climate, one of the three black soil regions in the world. Furthermore, in previous studies more attention was spent on the effect of surface roughness on soil erosion (Helming et al., 1998; Zobeck and Popham, 1998; Römkens et al., 2001). Thus, future studies on soil surface roughness are still necessary for black soil regions in Northeast China, especially for relationships between soil spectral reflectance and soil surface roughness.

Development of a soil surface roughness prediction method is useful to estimate the temporal change of soil surface roughness of farmland under natural conditions. In this study, according to the demands of remote sensing (Zheng et al., 2014; Shi et al., 2005; Zribi et al., 2000) and the classification standard of soil surface roughness (Smith, 2014; Martinez-Agirre et al., 2016), three roughness parameters: root-mean-square height (*rmsh*), correlation length (*cl*), and the ratio of *rmsh* to *cl* (*rmsh/cl*) (Smith, 2014; Martinez-Agirre et al., 2016). The ratio *rmsh* describes the vertical dimension of roughness or the magnitude of the elevation variations of the points at the soil surface (vertical parameters); *cl* reflects the horizontal dimension of roughness or the relation between the height of a point and that of its neighbors (horizontal parameters); the ratio of *rmsh/cl* combines both horizontal and vertical dimensions and denotes the combined roughness parameter.

In light of the above, the aims of this research were to evaluate the changing characteristics of soil surface roughness with time for black soil regions in Northeast China, to quantify the changing rate of soil surface roughness for various initial soil surface states under natural rainfall, and to evaluate whether the change of soil surface roughness can be predicted in a simple way for various surface conditions.

2. Materials and methods

2.1. Study area

The study area is located in cropland around Changchun city, China (125.35° E, 43.88° N). The area belongs to the Jingyuetan Remote Sensing Test Station, Northeast Institute of Geography and Agroecology, Chinese Academy of Sciences. The soil type in the experimental area is chernozem, with soil organic content of 10 g/kg and a bulk density of 1.03 g/cm^3. The percentage of sand, clay, and silt is 25%, 62%, and 13%, respectively. This experimental area belongs to a temperate zone continental climate, with an average January temperature of −15.2 °C and an average July temperature of 24.3 °C. The average annual rainfall is 582 mm, and rainfall is concentrated in summer. For studying the change of soil surface roughness with time and rainfall, we made four different soil surfaces, named Plot A, Plot B, Plot C, and Plot D. Plot A is soil surface with ridge, and the width and