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Study of an on-line measurement method for the salt parameters of soda-saline soils based on the texture features of cracks

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ABSTRACT

The Songnen plain in China has a typical soda-saline soil that frequently shrinks and cracks under natural conditions during water evaporation. Contrast (CON) is a typical gray level co-occurrence matrix (GLCM) texture feature, which can well represent the cracking degree of dried soil surface and is highly related with the salt content of soda-saline soils. In order to make a quantitative analysis of the effects of salt content on the cracking behavior of soda-saline soils, laboratory controlled and field verification experiments on the soda-saline soil of the Songnen plain were conducted in the present study. The laboratory experiment included 56 samples and was conducted to establish the relationships between the CON values of laboratory-generated crack patterns of soil samples and some primary salt parameters, such as the electrical conductivity (EC), Na^+ content, Cl^- content, CO_3^{2-} content, HCO_3^- content and total salinity. The field verification experiment included 48 samples and was conducted to establish the relationships between the CON values of field-generated crack patterns of soil samples and the salt parameters. For both laboratory experimental samples and field samples, the CON values were computed from the binary images of the cracked patterns and were significantly linearly correlated to the EC, Na^+ content and salinity (coefficient of determination [R^2] >0.87); the relationship between the CON values of soil samples and the Cl^- content was also quite linear (R^2 >0.73). An online measurement method for rapid and accurate determination of salt contents of soda-saline soils was then proposed based on the results of the laboratory experiment. After that, the salt parameters of 48 field samples were estimated using the online method and fitted against the actual measured values. The fitting results relating the CON values and Na^+ content, Cl^- content, EC and salinity showed high prediction accuracy (R^2 >0.91, RPD >4.49); the measurement method for CO_3^{2-} content also had reasonable prediction accuracy ($R^2 = 0.86$ and RPD = 2.42) but with relatively poor stability and poor reliability. However, the measurement method for HCO_3^- content showed very poor prediction accuracy ($R^2 = 0.51$ and RPD = 1.31).

1. Introduction

In arid and semiarid regions, soil salinization as well as secondary soil salinization are severe land degradation processes that severely damage the soil properties, significantly decrease crop yields and have a relatively large detrimental impact on the ecological environment (Feikema and Baker, 2011; He et al., 2014). Therefore, it is urgent and important to determine the area of saline soils as well as rapidly and accurately measure the salinity of these soils.

Most of the conventional methods of measuring salinity in saline soils involve sampling in the field and analyzing the samples in the laboratory (Mugai, 2004; Vukadinovic and Rengel, 2007). However, the conventional methods are disadvantageous because of their long measurement cycles, tedious testing processes and high labor intensity. Since it can quickly reflect the salinity of soils through measurements of the EC without requiring contact, the earth conductivity meter (EM-38) has been used extensively in studies on the soil salinity (Ding and Yu, 2014). However, because of its relatively high instrument sensitivity, the EM-38 is easily affected by the physical properties of soil (such as the soil moisture and the soil temperature) and some external measurement environment during the measurement process (Padhi and Misra, 2011; Zhu et al., 2010). The remote-sensing approach can measure the degree of soil salinization using unique diagnostic spectral characteristics of different types of salt minerals in certain spectral bands (Farifteh et al., 2008; Sidike et al., 2014). However, the measurement accuracy of

Abbreviations: GLCM, Gray level co-occurrence matrix; CON, contrast; EC, electrical conductivity.

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remote-sensing approaches can be affected by many factors, such as mixed pixel problems and the low spectral resolution of most remote-sensing data sources (Metternicht and Zinck, 2003). Therefore, the remote-sensing approach is mostly used in fields such as the identification of spatial distributions of soil salinity and classification of soil salinization degrees (Michot et al., 2013).

Under natural conditions, it is very common that clayey soils shrink and crack during water evaporation. In agricultural production, soil cracks can reduce the yield of crops to a large degree, specifically, this is because soil cracks decrease the water evaporation and permeability of soils; in addition, the degree and morphology of soil cracks can also change the migration process of soil moisture, nutrients and microbes, which inhibit the growth of crops. Moreover, soil cracks can also increase the pollution of groundwater and the waste of irrigation water. To date, numerous studies have been conducted on the identification and measurement of soil crack characteristics as well as the effects that environmental conditions and physical-chemical properties of soils have on the cracking degree. For the measurement of crack characteristics, early researches focused on manually measuring cracks in the field (Novak, 1999; Ringrose-voase and Sanidad, 1996); with the development of computers, image-processing technology has become increasingly advantageous in extracting crack characteristics because of its rapid, accurate and non-destructive detection. Velde (1999) evaluated the fractal dimension of surface crack patterns in various types of soils using box counting method and found that cultivated soils showed the greatest irregularity for a given porosity; Vogel et al. (2005) measured the angle distribution of a crack network and used it to identify the blocks segmented by cracks; Xiong et al. (2008) extracted the connectivity index to express the development intensity of soil cracks and describe the morphological complexity of crack patterns quantitatively; Liu et al. (2013) developed special software CIAS to extract the geometric characteristics of crack patterns such as crack area, crack length, crack width and crack direction automatically, the software showed a great potential to study the generation and development of soil crack patterns. Although it is known as a very common characteristic to distinguish the surface patterns of objects, the texture feature, however, has never been used to describe the extent of soil cracking. For the effects of environmental conditions on soil desiccation cracking, Tang et al. (2008, 2010, 2011a, 2011b) conducted laboratory experiments to study the effects of factors such as temperature, evaporation rate and soil sample thickness on the occurrence and development process of clayey soil cracks; Nahlawi and Kodikara (2006) discussed the effects of soil sample thickness on the cracking rates of saturated soil samples, their results showed that the desiccation rate decreased as the layer thickness increased under similar environmental conditions; Lakshmikantha et al. (2012) and Li et al. (2014) found that the overall strength of soils increases when the specimen size decreases and the scale effects will be significantly weakened as the specimen size increasing, which makes the soil cracks more similar with those soil cracks generated under field conditions. Among the chemical-physical soil properties, clay content is considered as the main factor of the shrink-crack capacity of soils. Many researchers studied the volumetric changes of soil undergoing desiccation and pointed out that soil cracks increase with increasing clay content (Rayhani et al., 2007; Tay et al., 2001). However, Bovin et al. (2004) concluded the opposite results for both repacked and undisturbed soil samples, particularly for clay contents below 40%. Yule and Richie (1980) showed that no relationship can be found between clay content and shrink-crack capacity for Texas vertisols. On the other hand, Ross (1978); Gray and Allbrook (2002) represented that the shrink-crack potential of clayey soils is more related with clay mineral compositions than is related to clay content.

Soda-saline soil is a typical type of salinized soil which has a relatively strong shrinkage and crack property. Therefore, after a rainfall, it is very common for soda-saline soils that the soil surface begins dry-shrinking and cracking as water evaporates. As the main chemical characteristic of salinized soils, the salt contents (especially the exchangeable cations in the soil solution) affect and reflect, to a large extent, the soil cracking process. However, very limited studies have focused on the relationship between soil crack characteristics and soil salinity (Panayiotopoulos and Leinas, 2009), although soil salinity is considered as a main chemical characteristic of soda-saline soils, which can affect the soil cracking process and largely reflects the soil cracking degree.

In the present study, we began by conducting a desiccation cracking experiment and then studying the relationships between the salinity and the crack characteristics, after that we proceeded to investigate the quantitative relationships between the salt parameters and a representative GLCM texture feature (CON) of soda-saline soils in the Songnen plain, China, which is proposed as a new parameter to characterize the cracking conditions of the soil specimens and to further establish prediction models for the main salt parameters of soda-saline soils. Based on the established models, we proposed a method of calculating the salt parameters of soils rapidly and accurately using the CON value of crack patterns as an online non-destructive field measurement of the salt parameters of soda-saline soils under natural conditions.

2. Materials and methods

2.1. Study area and soil sampling

The Songnen plain is located in the central region of Northeast China. Because of the inadequate drainage, high groundwater level and high mineralization, soil salinization is very severe in the Songnen plain. The Songnen plain is one of the major soil salinization areas in China as well as one of the three major accumulation areas of soda-saline soil in the world. The soda-saline soil of the Songnen plain is primarily composed of $NaHCO_3$ and Na_2CO_3, this kind of soil largely prevents salt moving downwards due to its bad infiltration capacity, which indicates the properties of soil from the top 15 cm soil layer are very stable (Li et al., 2007). Based on the effects of soil sample heterogeneity and environmental factors, we selected 56 sample points with different degrees of salinization in Da'an city, a city suffering from severe soil salinization, located in the western region of Jilin province, China in July 2013 and April 2014 (these sample points were used as the experimental sample points in the present study, Fig. 1). In addition, we collected soil samples (0–15 cm depth) from these 56 sample points for the laboratory soil-cracking experiment. The soil samples collected from the experimental sample points were air-dried, ground and sieved through a 0.9 mm mesh. Subsequently, the treated soil samples were divided into two parts, with one part used to determine the salt parameters of the soil and the other part used in the laboratory-controlled soil cracking experiment. We also selected 48 cracked soil sample points in April 2014 that had been formed under natural conditions in the study area (these sample points were referred to as the field sample points in the present study, Fig. 1), which were used for verification and comparison with the laboratory experimental results. All of the field sample points were photographed to identify the soil-cracking conditions under natural conditions (Fig. 2). We also collected soil samples (0–15 cm depth) from these field points to determine the salt parameters of the soil. Note that all the experimental samples and the field samples were obtained within a small region (123°42′33″E ~ 124°6′1″E and 45°23′57″N ~ 45°39′57″N) to reduce the effects of the clay content and the clay mineral on soil desiccation cracking.

2.2. Measurement of the salt parameters

In the present study, the salt parameters of the soil measured in the laboratory refer to the contents of eight major ions (Na^+, K^+, Ca^{2+}, Mg^{2+}, SO_4^{2-}, HCO_3^-, CO_3^{2-} and Cl^-), pH and ECs of the soil sample solutions. Note that the soda-saline soil of the Songnen plain is almost devoid of SO_4^{2-}; therefore, the SO_4^{2-} content was neglected