Pedosphere **26**(5): 699–708, 2016
doi:10.1016/S1002-0160(15)60078-9
ISSN 1002-0160/CN 32-1315/P

Published by Elsevier B.V. and Science Press

PEDOSPHERE

www.elsevier.com/locate/pedosphere

Mapping Soil Texture Based on Field Soil Moisture Observations at a High Temporal Resolution in an Oasis Agricultural Area

YANG Renmin[1,2], LIU Feng[1], ZHANG Ganlin[1,*], ZHAO Yuguo[1], LI Decheng[1], YANG Jinling[1], YANG Fei[1,2] and YANG Fan[1,2]

[1] *State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008 (China)*
[2] *University of Chinese Academy of Sciences, Beijing 100049 (China)*

(Received April 7, 2015; revised June 20, 2016)

ABSTRACT

Due to the almost homogeneous topography in low relief areas, it is usually difficult to make accurate predictions of soil properties using topographic covariates. In this study, we examined how time series of field soil moisture observations can be used to estimate soil texture in an oasis agricultural area with low relief in the semi-arid region of northwest China. Time series of field-observed soil moisture variations were recorded for 132 h beginning at the end of an irrigation event during which the surface soil was saturated. Spatial correlation between two time-adjacent soil moisture conditions was used to select the factors for fuzzy *c*-means clustering. In each of the ten generated clusters, soil texture of the soil sample with the maximum fuzzy membership value was taken as the cluster centroid. Finally, a linearly weighted average was used to predict soil texture from the centroids. The results showed that soil moisture increased with the increase of clay and silt contents, but decreased with the increase of sand content. The spatial patterns of soil moisture changed during the entire soil drying phase. We assumed that these changes were mainly caused by spatial heterogeneity of soil texture. A total of 64 independent samples were used to evaluate the prediction accuracy. The root mean square error (RMSE) values of clay, silt and sand were 1.63, 2.81 and 3.71, respectively. The mean relative error (RE) values were 9.57% for clay, 3.77% for silt and 12.83% for sand. It could be concluded that the method used in this study was effective for soil texture mapping in the low-relief oasis agricultural area and could be applicable in other similar irrigation agricultural areas.

Key Words: digital soil mapping, fuzzy *c*-means clustering, low relief, particle-size distribution, semi-arid region, water content

Citation: Yang R M, Liu F, Zhang G L, Zhao Y G, Li D C, Yang J L, Yang F, Yang F. 2016. Mapping soil texture based on field soil moisture observations at a high temporal resolution in an oasis agricultural area. *Pedosphere*. **26**(5): 699–708.

INTRODUCTION

Soil texture affects soil water and nutrient processes and thus is an important input for many hydrological modelling and climate change predictions (Prentice *et al.*, 1992; Potter *et al.*, 1993; Chen and Dudhia, 2001). Traditional soil mapping requires field survey and particle-size distribution (PSD) laboratory analysis, which is labor-intensive, time-consuming and expensive. This makes it difficult to correctly represent the spatial variation of soil texture considering the limited number of samples.

Many studies on digital soil mapping (DSM) have been carried out based on soil-landscape models (Boer *et al.*, 1996; McKenzie and Ryan, 1999; Chaplot *et al.*, 2000; Carré and Girard, 2002; Henderson *et al.*, 2005). The soil-landscape models intend to model the relationships between soil properties and soil-forming factors (McBratney *et al.*, 2003). However, in low-relief areas, topographical covariates usually show little spatial variability, making it difficult to predict soil texture using these covariates (Liu *et al.*, 2010, 2012; Zhu *et al.*, 2010).

There are three main approaches for mapping soil texture over low-relief areas. The first approach is based on geostatistical interpolation of a large number of soil sampling points. Geostatistical techniques are frequently used for soil texture mapping (Oberthür *et al.*, 1999; Meul and Meirvenne, 2003; Liu *et al.*, 2006). The soil property at unsampled sites is predicted by modeling spatial structure of the property from soil samples and then applying a Kriging interpolator with the fitted model. A large number of samples are generally needed to adequately model the spatial variation of soil, and well-distributed samples are usually required to interpolate over the study area with acce-

---

[*] Corresponding author. E-mail: glzhang@issas.ac.cn.

ptable uncertainty.

The second approach is based on single-date multispectral remote sensing data. By analyzing the relations between spectral reflectance and soil properties, models have been established using data from various sensors, including Landsat Thematic Mapper (TM), SPOT, IKONOS, Advanced Very High Resolution Radiometer (AVHRR) and airborne spectroscopy (Coleman *et al.*, 1993; Barnes and Baker, 2000; Odeh and McBratney, 2000; Sullivan *et al.*, 2005; Demattê *et al.*, 2007, 2009).

The third approach is based on time-series remote sensing images. Mattikalli *et al.* (1998) developed a regression model for the ratio of clay and effective saturated hydraulic conductivity in terms of time-series changes in brightness temperature and soil water content. Chang and Islam (2000) constructed two Artificial Neural Network models to classify soil texture into three categories from time series of soil moisture. They found that different soil texture classes can be distinguished from the range of soil moisture from field capacity to permanent wilting point during the soil drying phase. To improve the classification accuracy and classify soil into more than three groups, Chang *et al.* (2003) used a simple prototype-based classifier to classify soil texture into six categories by using multiple-drying-cycle brightness temperature. A calibration method was proposed to infer soil texture and hydraulic properties using remotely sensed estimats of soil moisture in relation to the soil drying (Santanello *et al.*, 2007). Liu *et al.* (2012) mapped soil texture over low-relief areas using environmental covariates derived from time series of moderate-resolution imaging spectroradiometer (MODIS) data after a rainfall event.

To reduce the influence of vegetation, the above remote sensing approaches usually limit their applications in areas with bare soil or sparse vegetation coverage. However, for areas with dense vegetation coverage such as agricultural cropping areas, the approaches show obvious limitations. In addition, the temporal resolution of these datasets was no finer than the daily scale. This may miss the initial stage of soil moisture changes in areas with high potential evapotranspiration and rapid drying, such as in arid and semi-arid environments, and thus may be imprecise. To address these challenges, high temporal resolution field-observed soil moisture data may be an alternative approach. However, few studies have addressed the capacity of such dataset to map soil texture in spatial domain.

The aim of this study was to examine the potential use of high-temporal resolution field-observed soil moisture for representing soil texture variability across a semi-arid and low-relief agricultural area. The basis of our proposed method was as follows. We had high temporal resolution soil moisture at a large number of sites in the area (n = 125, average density = 5 km^{-2}). We chose a time period when the soil is drying after being saturated by a large irrigation event. We spatially interpolated soil moisture over time to the sites where we had texture measurements. Finally, we mapped the distributions of sand (> 0.05 mm), silt (0.002–0.05 mm) and clay (< 0.002 mm) contents from time-series soil moisture maps using a fuzzy *c*-means (FCM) clustering method.

MATERIALS AND METHODS

Study area

The Heihe River Basin, the second largest inland basin in China, has complicated landscapes including mountains, oases and deserts from upper to lower reaches. Our 25-km^2 study area (38.84°–38.89° N and 100.33°–100.41° E) is located in the oasis of the Hexi Corridor of Gansu Province, China (Fig. 1). The mean annual air temperature is about 7.3 °C, with an average temperature of 28 °C in summer and −10 °C in winter. The mean annual precipitation is 129 mm, with rainfall mainly in July and August. The potential evaporation is about 2 200 mm, which massively exceeds precipitation (Jia *et al.*, 2008; Jiang *et al.*, 2008). The elevation is between 1 505 and 1 591 m gently sloping from west to east. The soils are classified as Haplanthrepts and Haplocryids according to US Soil Taxonomy (Soil Survey Staff, 2014). This area is a part of the alluvial fan formed by the Heihe River that brings nutrients from the upper reaches. Therefore, the Hexi Corridor is an important grain-producing area, where the major crops are wheat, corn, rape and soybean, with water being predominantly supplied by irrigation from the Heihe River. According to our field survey, corn is a dominated crop covering a very large area.

Soil samples

A total of 74 surface (0–15 cm) soil samples used in this study were collected in August 2012 and August 2013, with their spatial extent shown in Fig. 1. In 2012, twenty-five soil samples were collected on 1 km × 1 km regular grids. In 2013, forty-nine soil samples at finer resolutions were collected within three 1 km × 1 km grids in the center of the study area, with grids of 500 m × 500 m, 250 m × 250 m, 125 m × 125 m and 62.5 m × 62.5 m. Soil samples were a composite of five samples taken from the center and four vertices