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Spatial variability of soil electrical conductivity in a small watershed on the Loess Plateau of China

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ABSTRACT

Knowledge of soil electrical conductivity of saturated paste extract (ECe) pattern is important to effectively managing farmland and improving crop productivity. The objectives of this study were (1) to characterize the spatial patterns of ECe and electrical conductivity of saturated paste (ECs) and (2) to determine the factors that affect significantly in the estimation of soil ECe. Soil samples were taken at various soil depths (0.1, 0.2, 0.4, 0.6, and 0.8 m) of 124 locations in a small watershed. Besides ECe and ECs, various soil, topographical, and vegetation properties were measured. Geostatistical techniques were used to characterize the spatial patterns of ECe and ECs. Ordinary least squares (OLS) and generalized least squares (GLS) models were used to perform multiple regression analyses between ECe and other properties. The OLS model belongs to a non-spatial regression, whereas the GLS model is a spatial regression which considers the autocorrelation in the residuals. Results showed that both ECe and ECs presented moderate variability at the watershed scale. The ECe presented weak to moderate spatial dependency, whereas the ECs presented moderate to strong spatial dependency. The ratio of ECe to ECs differed with soil texture, and it was greater for sand texture than for loam texture. A fair to moderate spatial agreement existed between ECe and ECs at all depths except for 0.2 m, where ECe presented a more random distribution. Heteroscedasticity in the residuals between two land uses (grass land and shrub land) and autocorrelation in the residuals only existed at 0.4 m soil layer where the GLS model did not improve significantly over the OLS model in terms of explaining variations in ECe. Electrical conductivity of saturated paste was the dominant factor in explaining ECe variation for all depths, while soil separate significant affected the estimation of ECe at 0.1 m as well. It is concluded that ECs may be used as a surrogate for ECe especially for homogeneous soil textures. This would greatly reduce the work involved in ECe measurement due to the easier availability of ECs. Our study implies that ECe can be used as an index of soil fertility condition in this area. In addition, OLS model can be accurate enough to describe the relationships between ECe and other properties due to the absence of strong spatial dependency of ECe in this area.

1. Introduction

Soil electrical conductivity of saturated paste extracts (ECe) is a standard laboratory estimate of the concentration of ions in the soil (USDA, 1954). For saline soils, ECe is largely related to the salt concentration. For non-saline soils, ECe is an invaluable tool that provides information for soil quality assessment and precision agriculture applications because it is primarily a function of soil texture, water content, bulk density, and cation exchange capacity of soil (Corwin and Lesch, 2005; Sudduth et al., 2013). Therefore, knowledge of soil ECe is crucial to plant growth irrespective of soil salinity (Mondal et al., 2001).

Spatial variability of soil ECe has been widely recognized at various scales in different areas. Past studies mainly focused on classical and geostatistical description (Cetin and Kirda, 2003; Sylla et al., 1995; Utset et al., 1998; Zheng et al., 2009), influencing factors (Sylla et al., 1995; Zheng et al., 2009), and its spatial prediction (Cetin and Kirda, 2003; Douaik et al., 2005; Lesch et al., 1995; Zheng et al., 2009). Most of their studies were closely related to soils that suffered from obvious saline and sodic harm. In the Chinese Loess Plateau, semi-arid climate and deep ground water table (up to 40 to 100 m) coexist. There is a knowledge gap in spatial distribution of soil ECe at different soil depths in the natural landscape. Questions on what are the factors that significantly affect the estimation of soil ECe and whether soil ECe affects vegetation yield remain uncovered in this region.

Pearson correlation and multiple regression analyses have been used to determine the relationships between soil electrical conductivity and various properties (Officer et al., 2004; Zheng et al., 2009). However, their relationships were usually determined by ignoring spatial autocorrelation in the residuals. Studies with ecological data have

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shown that the Type I statistical error rate is increased and the regression coefficients and their uncertainties are biased when the non-spatial regression models such as ordinary least squares (OLS) are used (Beale et al., 2010). Therefore, the possible existence of spatial autocorrelation in the errors should be considered in estimating ECe. Many spatial regression models are available to deal with the spatial autocorrelation (Beale et al., 2010). Among which, the generalized least squares (GLS) model was recommended by Beguería and Pueyo (2009).

Electrical conductivity of saturated paste extracts is commonly accepted as the best surrogate to study the influences of soil salinity on plant growth (Chen et al., 2009; Katerji et al., 1996). However, the preparation of saturation paste extracts is time consuming. Therefore, extracts of different soil to water ratios by weight, e.g., 1:1, 1:2.5, and 1:5, were prepared and their electrical conductivity was converted to ECe (Sonmez et al., 2008). Instrument such as Field Scout Soil EC Probe & Meter (Automatic Temperature Compensation) can produce an instant and accurate measurement of electrical conductivity of saturated paste (ECs), known as bulk soil electrical conductivity (De Benedetto et al., 2013). Therefore, ECs can be a good predictor for ECe if significant correlation exists between them.

Therefore, the objectives of this study were (1) to describe the spatial patterns of soil ECe and ECs at various soil depths using geostatistics and (2) to determine which factors contribute significantly to the estimation of soil ECe using the OLS or GLS model depending on whether autocorrelation in the residuals exists or not.

2. Materials and methods

2.1. Watershed description

A small watershed with an area of 20 ha was selected inside the larger Liudaogou watershed (110°21′ to 110°23′E and 38°46′ to 38°51′N), Shenmu County, Shaanxi Province, China (Fig. 1). This area has severe soil erosion by water and wind. The Liudaogou watershed is characterized by a large number of deep gullies and undulating loess slopes. Climatic conditions are characterized by a mean annual temperature of

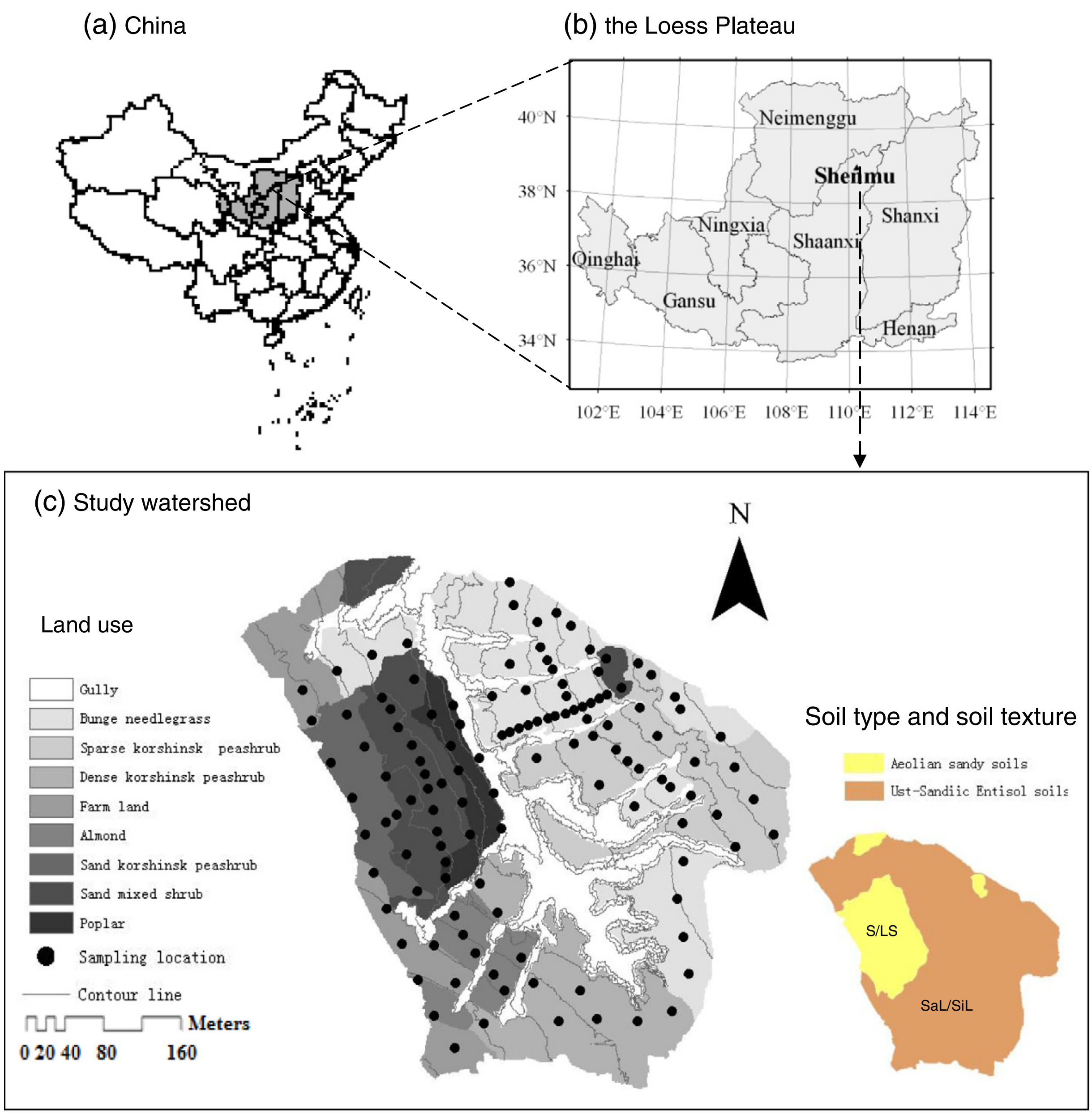

Fig. 1. Location of the small watershed, sampling locations on different land uses, soil type and soil texture (S—Sand; LS—Loamy sand; SaL—Sandy loam; SiL—Silt loam).