Scale-location specific relations between soil nutrients and topographic factors in the Fen River Basin, Chinese Loess Plateau

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Abstract Understanding scale- and location-specific variations of soil nutrients in cultivated land is a crucial consideration for managing agriculture and natural resources effectively. In the present study, wavelet coherency was used to reveal the scale-location specific correlations between soil nutrients, including soil organic matter (SOM), total nitrogen (TN), available phosphorus (AP), and available potassium (AK), as well as topographic factors (elevation, slope, aspect, and wetness index) in the cultivated land of the Fen River Basin in Shanxi Province, China. The results showed that SOM, TN, AP, and AK were significantly inter-correlated, and that the scales at which soil nutrients were correlated differed in different landscapes, and were generally smaller in topographically rougher terrain. All soil nutrients but TN were significantly influenced by the wetness index at relatively large scales (32–72 km) and AK was significantly affected by the aspect at large scales at partial locations, showing localized features. The results of this study imply that the wetness index should be taken into account during farming practices to improve the soil nutrients of cultivated land in the Fen River Basin at large scales.

Keywords soil nutrients, wavelet coherency, wetness index, spatial variation, cultivated land

1 Introduction

Soil organic matter (SOM), total nitrogen (TN), available phosphorus (AP), and available potassium (AK) are indicators of soil fertility which play a crucial role in plant growth in cultivated lands. The natural contents of soil nutrients are influenced by soil-forming processes, which are controlled by climate, topography, parent material, vegetation, and biotic factors (Jenny, 1941). Topography, which is controlled by drainage, runoff, and soil erosion, may affect the transposition and re-distribution of soil nutrients along the surface (Umali et al., 2012), so topographic factors including elevation, slope gradients, aspect, and wetness index can characterize these flow paths and variability of soil nutrients (Moore et al., 1993).

Certain controlling factors (e.g., microtopography) of soil nutrients may operate at short distances, while others (e.g., meteorological conditions) are likely to operate at larger scales (Holmes et al., 2005). To this effect, the influences of topographic factors on soil nutrients may be site-specific and scale-dependent. Due to complex combinations of human activity and natural processes, however, the location- and scale-dependent relationships among soil nutrients and environmental factors are highly complex – especially in cultivated lands. For efficient, effective, and environmentally responsible agricultural management, it is necessary to establish a full understanding of the multi-scale influences of topographic factors on soil nutrients.

The linear model of co-regionalization (LMC) can decompose a system of spatial variability into several different components pertaining to different scales, and as such, has been widely used to examine scale-specific relations (Goulard and Voltz, 1992). For example, Holmes et al. (2005) examined the spatial correlations of soil nutrients (soil organic carbon, nitrogen, phosphorus, and potassium) with land cover and terrain attributes at four spatial scales. Liu et al. (2013) identified that soil nutrients (soil organic carbon, total nitrogen, and total phosphorus) are controlled by factors at both scales of 12 km and 84 km. While the LMC is able to identify the dominant scales of soil nutrients, it limits the number of separated spatial components and loses location-specific information.
Wavelet coherency is a method of measuring the relationships between two spatial variables at different locations and scales (Grinsted et al., 2004; Si and Zeleke, 2005) that has been successfully used to elucidate the location- and scale-dependent relationships between two time or spatial series in soil water (Shu et al., 2008), soil saturated hydraulic properties (Si and Zeleke, 2005), and soil nitrous oxide emissions (Yates et al., 2007). The spatial relationships between soil water and environmental factors such as precipitation (Wu et al., 2002; Andreo et al., 2006), drought index (Tang and Piechota, 2009), and topography (Biswas and Si, 2011) have been explored via wavelet coherency, as well as the temporal impact of climate on carbon fluxes (Van Gorsel et al., 2013). To the best of our knowledge, there has been no previous study to use wavelet coherency to examine the scale- and location-specific control of topographic factors on soil nutrients.

The Fen River Basin, which is located in the eastern part of the Loess Plateau in China, is characterized by a complicated landform. Its cultivated land, which has suffered long-term tillage with an area of 11,591 km², accounts for one third of the total area of the basin and is the main production source of crops and vegetation of Shanxi Province. In effort to better and more comprehensively understand the spatial patterns of soil nutrients in the Fen River Basin cultivated lands, we aimed to explore the scale- and location-specific relationships between soil nutrients (SOM, TN, AP, and AK) and topographic factors for topsoil (0–20 cm).

2 Materials and methods

2.1 Site description

The study was conducted at the Fen River Basin (35°20′–39°00′ N latitude, 110°30′–113°32′ E longitude) in Shanxi Province, North China (Fig. 1). The Fen River is one of the largest tributaries of the Yellow River in its middle reach, joining the Yellow River in Hejing County. The river basin is bounded by Taihang Mountain to the east, and Lvliang Mountain to the west, which also forms the boundary between Yellow River and Fen River. The basin contains two large grabens: Taiyuan Graben in the upper reach, and Linfen Graben in the lower reach (Bureau, 1988); the Linshi highland, similar to a gorge, incises the two grabens (Yang, 1987). The highest elevation of the area is 2786 m in the north and the lowest is 240 m in the south. Located in the eastern Loess Plateau of China, the climate of the Fen River Basin is temperate and sub-humid, with mean annual temperature between 6°C and 13°C and mean annual precipitation of 450 mm (Geography, 1985). In this area, the landforms are usually capped by a thick layer of loess due to dust deposition during the Quaternary (Hu et al., 2005). According to the FAO-90 soil classification system (Nachtergaele et al., 2008), the major soil types in the basin are Calcaric Cambisols and Calcaric Fluvisols, which are highly alkaline.

Fig. 1 Geographic location of study site and the extracted sampling location.