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Spatial distribution of soil organic carbon and analysis of related factors in croplands of the black soil region, Northeast China

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Abstract

Little is known concerning the spatial variability of soil organic carbon (SOC) and the relationship between SOC and landscape aspects, in the black soil region of Northeast China, at county level. For this reason, the spatial characteristics of soil organic carbon and related factors, i.e. land use, topography, and soil type, etc., were explored using GIS and geostatistics, taking Dehui County, Northeast China, as a study area. Soil organic carbon in topsoil samples were taken at 354 locations in croplands of Dehui County. SOC concentrations follow a log-normal distribution, with an arithmetic mean of 1.61% and geometric mean of 1.55%. The experimental variogram of SOC has been fitted with an exponential model. Lower SOC concentrations were associated with larger gradient. Chernozems have the highest SOC concentrations, and those under aeolian soils have the lowest SOC values. The spatial distribution pattern of SOC concentrations interpolated by Kriging, indicated that after being divided into two parts along the Yinma River, samples in the western part have statistically higher SOC contents than those in the eastern part. This pattern is approximately consistent with the spatial structure of topography and land use type.

Keywords: Soil organic carbon; Geostatistics; GIS; Spatial distribution; Black soil region; Northeast China

1. Introduction

Food security and sustainable development are two fundamental and strategic goals in China. Among the factors that may heavily affect these two goals, land degradation is a crucial one (Huang and Rozelle, 1998; Hubacek and Sun, 2001). China's food security can be threatened by losses of cultivated land due to disasters, soil erosion, and chemical and physical deterioration. Although there have been controversies over food demand and supply in China for the next 30 years, there is an agreement that loss of arable land and land degradation are undermining China's food production capacity (Gardner, 1996; Rozelle and Huang, 1997). Agricultural over-exploitation and industrial pollution also exacerbate these degradation problems.

In recent years, considerable interests have been generated in assessment of the physical, chemical, and biological quality of agricultural soils (Carter et al., 1997; Haynes et al., 2003). Soil organic carbon (SOC) is a dynamic component of terrestrial systems, with both internal changes and external exchanges with the atmosphere and the biosphere (Zhang and McGrath, 2004). SOC plays an important role in enhancing crop production (Stevenson and Cole, 1999) and mitigating greenhouse gas emissions (Lal et al., 1995; Flach et al., 1997; Post and Kwon, 2000). Like other soil properties, SOC levels exhibit variability as a result of dynamic interactions between parent material, climate and geological history, on regional and continental scale (Wang et al., 2001). However, landscape attributes including slope, aspect, elevation, and land use may be the

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dominant factors of SOC in an area with the same parent material and single climate regime (Rezaei and Gilkes, 2005). Landscape attributes affect organic activity, run-off and run-on processes, condition of natural drainage, and exposure of soil to wind and precipitation (Buol et al., 1989). The SOC content in cropland is also strongly dependent upon crop and soil management practices, such as crop species and rotation, tillage methods, fertilizer rate, manure application, pesticide use, irrigation, and drainage, and soil and water conservation (Batjes, 1998; Bruce et al., 1999; Lal et al., 1999; Bergstrom et al., 2001; Lal, 2002; Heenan et al., 2004). All these practices control the SOC input from crop residue and addition of organic amendments, and the SOC output through decomposition into gases and transportation into aquatic ecosystems via leaching, run-off, and erosion (Turner and Lambert, 2000).

To study the relationship between SOC and these factors and to quantify the spatial distribution patterns of SOC, statistics and geostatistics have been applied widely (Van Meirvenne et al., 1996; Saldana et al., 1998; Chevallier et al., 2000; Frogbrook and Oliver, 2001; McGrath and Zhang, 2003; Zhang and McGrath, 2004). Based on the theory of a "regionalized variable" (Matheron, 1963; Goovaerts, 1997; Webster and Oliver, 2001), geostatistics provides advanced tools to quantify the spatial features of soil parameters and to carry out spatial interpolation. Geographic information systems (GIS) are useful to produce the interpolated maps for visualization, and for raster GIS maps, algebraic functions can calculate and visualize the spatial differences between the maps.

A better understanding of the spatial variability of SOC is important for refining agricultural management practices and for improving sustainable land use (McGrath and Zhang, 2003). It provides a valuable base against which subsequent and future measurements can be evaluated. The black soil region of Northeast China is located in the central part of the Northeast Plain, as one of the main agricultural regions in China, its crop sown area and total yield now accounting for 12 and 16%, respectively, of the nation's total. The black soil before cultivation has a high organic matter content due to its parent material, climate, and natural vegetation characteristics. However, croplands in this region have been affected by human-induced degradation to a serious degree after about 300 years of tillage. After long-term reclamation and tillage, SOC in this region has declined much. Conventional tillage increases aeration and breaks up aggregates exposing organic matter to microbial attack that was previously physically protected and it can also favor losses of soil through erosion (Haynes and Beare, 1996).

In the black soil region of Northeast China, many efforts have been made to analyze the stock of soil organic carbon in croplands, the distribution of SOC in organic–mineral complex, the dynamics of SOC, and effects of cultivation on SOC (Xin et al., 2002; Fang et al., 2003; Liang et al., 2000; Yu et al., 2004; Zhao et al., 2005). However, in this region, the spatial variability of SOC and influences of natural and anthropogenic factors on SOC have received very little attention. The objectives of this study were to investigate (1) the spatial distribution characteristics of soil organic carbon in croplands of Dehui County, a typical agricultural area in Northeast China, and (2) the possible factors influencing SOC stocks, such as soil type, slope and topography, with the help of GIS and geostatistics.

2. Materials and methods

2.1. Study area

Dehui County (125°45′–126°23′E, 43°32′–44°45′N) is located in the middle part of Jilin Province, Northeast China (see Fig. 1). The county has an altitude between 149 and 241 m with an area of 3435 km^2. The study area is characterized with a temperate, semi-humid continental monsoon climate. The mean annual temperature is about 4.4 °C and the average annual precipitation is 520 mm. The average of sunshine each year is 2695 h and average wind speed is about 3.2 m s^{-1}. The frost-free period is about 130–140 days. In this county, The Second Songhua River, the Yitong River, and the Yinma River flow through the area and then into the Songhua River. The soils are black soil (Luvic Phaeozem, FAO), chernozem (Haplic Chernozem, FAO), meadow soil (Eutric Vertisol, FAO), and aeolian soil (Arenosol, FAO).

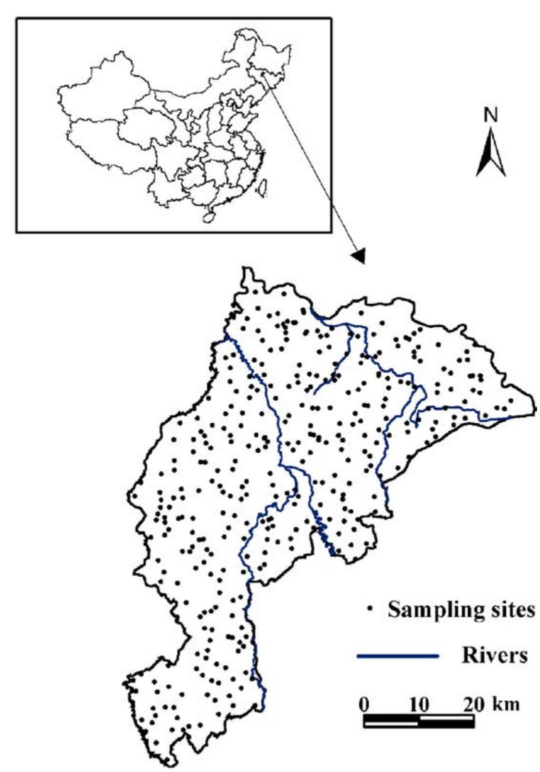

Fig. 1. Soil sampling locations in Dehui County, Northeast China (n = 354).