Geoderma 154 (2010) 302–310

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

Response of soil organic carbon spatial variability to the expansion of scale in the uplands of Northeast China

D.D. Wang [a,b,d], X.Z. Shi [a,*], X.X. Lu [c], H.J. Wang [a], D.S. Yu [a], W.X. Sun [a], Y.C. Zhao [a]

[a] State Key Laboratory of Soil and Sustainable Agriculture, Institute of Soil Science, Chinese Academy of Sciences, Nanjing 210008, China
[b] College of Remote Sensing, Nanjing University of Information Science & Technology, Nanjing 210044, China
[c] Department of Geography, National University of Singapore, 119260, Singapore
[d] Graduate University of the Chinese Academy of Sciences, Beijing 100039, China

ARTICLE INFO

Article history:
Received 21 August 2008
Received in revised form 14 September 2009
Accepted 24 October 2009
Available online 27 November 2009

Keywords:
Scale
Category
CV (coefficient of variation)
Variability
Upland
SOC density

ABSTRACT

Soil organic carbon (SOC) plays an important role in maintaining and improving soil fertility and quality as well as mitigating climate change. Understanding SOC density spatial variability is fundamental for describing soil resources and predicting SOC. Three categories were used to create spatial scales: administrative category (county, city, province and region scale), soil taxonomic category (family, subgroup, great group and order scale) and soil type (zonal soil and azonal soil)-administrative category. Soil organic carbon density variability and its response to the expansion of scales in the topsoil (0–20 cm) and soil profile (a depth of 1 m) layers in the uplands of Northeast China were examined based on coefficient of variation (CV) values using data of 1041 profiles obtained from the Second National Soil Survey of China. The results depicted that SOC density variability increased not only in the topsoil layer but also in the soil profile layer with the expansion of scales in all categories. In the administrative category, there was a strong logarithmic relationship between upland areas or administrative areas and mean SOC density CV. Though mean SOC density CV within each soil order increased from family to order, the trend and range of increase varied greatly. Soil organic carbon density variability for zonal and azonal soils was similar in terms of trends but different in terms of rate with increasing scale from county to region. A strong logarithmic relationship between upland area and mean SOC density CV was also observed. These relationships indicated that reducing upland area by five orders of magnitude would halve the CV. Therefore, when estimating the SOC pool in uplands, both administrative and soil type scales should be considered in the sampling design, especially for azonal soil.

1. Introduction

Soil organic carbon (SOC) plays an important role in maintaining and improving soil fertility and quality (Gregorich et al., 1994; Bhupinderpal-Singh et al., 2004) as well as mitigating climate change (Lal, 2004). Soil properties are controlled by the five soil-forming factors (Jenny, 1941), including human activities (Liang et al., 2007; Yang et al., 2008), which create the large spatial variation of SOC identified through extensive research (Burrough, 1993; Grimm et al., 2008). Moreover, SOC density variability is scale dependent (Beckett and Webster, 1971; Seyfried and Wilcox, 1995; Schöning et al., 2006; Corstanje et al., 2007; Lufafa et al., 2008; Momtaz et al., 2009). Hence, estimating SOC density variability at different scales is important for effective soil survey sampling design and SOC change prediction. This is also the basis for scaling up from plots to ecosystems.

Progress has been made in the studies of the SOC spatial variability, but mainly at a single scale or a selected area. According to the size of study areas, scales can be divided into the plot scale, landscape scale, and regional scale. At the plot scale, for example, Schöning et al. (2006) studied SOC spatial variability in forested Luvisols with an area of 10,000 m^2 and concluded that spatial variability of SOC stocks at the forest stand level was high and that field work should be done with sampling intervals less than 5 m. At the landscape scale, Davis et al. (2004) carried out research on forested soil with a 640 km^2 area and found that there appeared to be nearly as much variability in the SOC pool within a delineation (CV's ranged 9–30%) as among delineations (CV's ranged from 15 to 31%) for the same land cover and soil type. This spatial variability suggests that instead of sampling at multiple locations within a single delineation to obtain the average SOC for a map unit, a more useful approach may be to sample from a significant number of delineations of the same series.

Liu et al. (2006) reported that SOC CV in cropland within a county was 29.7%. At the regional scale, the mean SOC pool estimated using the MLRA (Major Land Resource Area)-taxonomic approach was 10.2 ± 2.8 kg C m^{-2} with a CV of 28% in Ohio State (Tan et al., 2004). The

---

[*] Corresponding author. Fax: +86 25 86881000.
E-mail address: xzshi@issas.ac.cn (X.Z. Shi).

0016-7061/$ – see front matter © 2009 Elsevier B.V. All rights reserved.
doi:10.1016/j.geoderma.2009.10.018

relative spatial variability of SOC in the conterminous United States increased as soil depth increased and decreased as taxonomic categories decreased in all soil orders (Guo et al., 2006).

Recent studies on SOC spatial variability at different scales have been reported. Garten et al. (2007) found that spatial variability of soil properties does not always increase with increasing spatial scale in forest ecosystems. Spatial variability of whole soil C in particulate organic matter, soil C-to-N ratio, and mineral-associated organic matter C-to-N ratio fractions among 11 properties increased from small (1 m) to large (1 km) spatial scales in a temperate, mixed-hardwood forest ecosystem in east Tennessee, USA. The CV in grassland soils in the USA increased with increasing scale and was 39% at the county scale (Dundy County, Nebraska), 54% at the state scale, and 63% at the national scale (Conant and Paustian, 2002).

In summary, SOC spatial variability at one single scale has been widely reported, but little information is available on multiple scales. Moreover, there is limited research on undisturbed woodlands or grass lands soils (Conant and Paustian, 2002; Garten et al., 2007). Further information on SOC spatial variability considering both soil type and administrative categories on the upland soils with much human disturbance is also lacking.

The aims of this paper are to describe SOC density spatial patterns and variability in the uplands of Northeast China at three scales including the administrative category, soil taxonomy category, and soil type (zonal/azonal soil)-administrative category, and to examine how variability changes with the expansion of scales. Data used in this study were obtained from the Second State Soil Survey of China. The results provide a theoretical basis for soil resources survey and estimation of SOC pool change and potential sequestration.

2. Materials and methods

2.1. Study area

Northeast China (38°40′–53°30′N, 115°05′–135°02′E) covers an area of 1.24 million km^2, including Heilongjiang Province, Liaoning Province, Jilin Province, and Eastern Inner Mongolia (Fig. 1). It has a temperate monsoon climate, but varies across the region. From north to south there is a 1600 km temperature gradient which is composed of three increasingly warm zones. Further, from east to west there is a 1400 km moisture gradient including humid, sub-humid, and semi-arid areas.

Northeast China is surrounded by the Great Khingan Mountains, the Lesser Khingan Mountains, and the Changbai Mountain in the west, north, and east directions, respectively. The center of the region includes the Northeast Plain toward to the southward extension. The black soil (Phaeozems) (Shi, et al., 2009) zone, distributed in the east and northern piedmont mesa of the Songnen plain in the center of northeast China, is one of the major grain producing areas due to high fertility. Midwest Songnen Plain is an area predominantly underlain by Chernozems. Meadow soils (Cambisols) (Shi, et al., 2009) are also widely distributed in this area. Corn, soybean and sugar beet are the main crops in Northeast China.

2.2. Data sets

The data used for this study were obtained from the Second National Soil Survey of China conducted in the 1980s including 1041 upland soil profiles taken from the Soil Series of China (National Soil Survey Office, 1993a, 1994a, 1994b, 1995a, 1995b, 1996) and the Soil Series of Provinces (Soil Survey Office of Heilongjiang Province, 1990; Soil and Fertilizer Workstation of Liaoning Province, 1991; Soil Survey Office of Inner Mongolia Autonomous Region, 1994; Soil and Fertilizer Workstation of Jilin Province, 1997), cities and counties in Northeast China. According to the Genetic Soil Classification of China (GSCC), these profiles were classified into 102 families, 56 subgroups, 17 great groups, and 7 orders. The 17 great groups include 8 zonal soils and 9 azonal soils. Among the selected soil profiles, there are 309, 161, 126, and 138 profiles of meadow soils, brown soils (Luvisols) (Shi, et al., 2009), chernozems, and black soils, respectively. There are 2 profiles of volcanic ash soils (Andosols) (Shi, et al., 2009) which have the fewest number of profiles among all the great groups. The data were gathered to create a soil profile database (SPD) which included the information on sampling location, longitude and latitude, soil type,

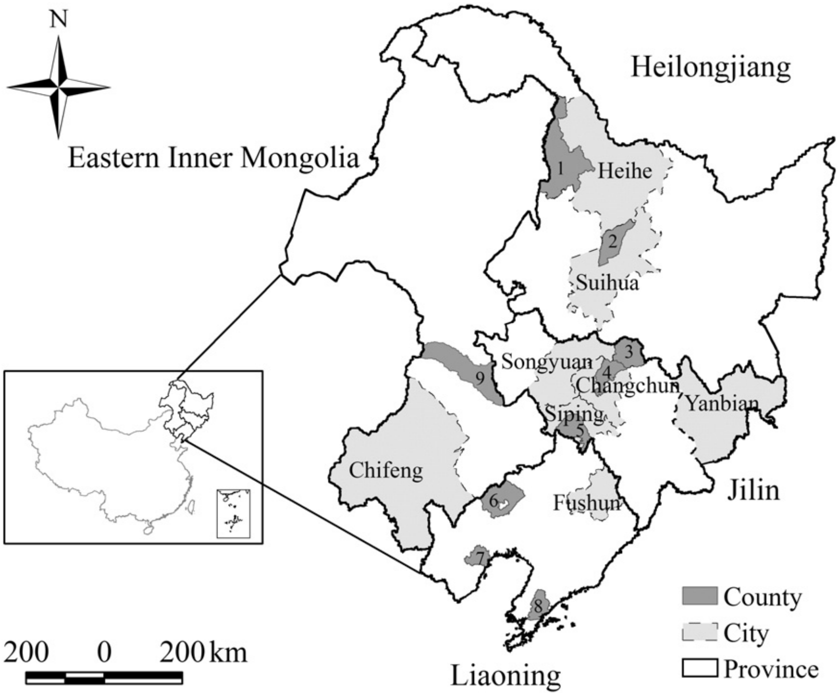

Fig.1. Location of typical cities and counties in the study area (note: the number from 1 to 9 refers to Nenjiang, Hailun, Yushu, Dehui, Lishu, Fuxin, Jinxi, Xinjin, and Keyouzhongqi county, respectively).