

Soil organic carbon under different landscape attributes in croplands of Northeast China

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ABSTRACT

Soil organic carbon (SOC) was measured in topsoil samples of agricultural soils from 311 locations of Jiutai County, Northeast China. The spatial characteristics of SOC were studied using the Geographic Information Systems and geostatistics. Effects of other soil physical and chemical properties, elevation, slope, soil type and land use type were explored. SOC concentrations followed a lognormal distribution, with a geometric mean of 1.50%. The experimental variogram of SOC has been fitted with an exponential model. Our results highlighted total nitrogen and pH as the soil properties that have the greatest influence on SOC levels. Upland eroding areas have significantly less SOC than soils in deposition areas. Results showed that, soil type had a significant relationship with SOC, reflecting the effect of soil parent materials. Soil samples from paddy fields and vegetable fields had higher SOC concentrations than those from dry farming land.

Keywords: soil organic carbon; geostatistics; GIS; spatial distribution; Jiutai County; Northeast China

In recent years, considerable interest has been generated in assessment of the physical, chemical and biological quality of agricultural soils (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 and mitigating greenhouse gas emissions (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 and elevation, and land use may be the dominant factors impacting SOC content in areas with homogeneous parent material and a single climate regime (Rezaei and Gilkes 2005). These attributes affect organic activity, runoff and runoff 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 spe-

cies and rotation, tillage methods, fertilizer rate, manure application, pesticide use, irrigation and drainage, and soil and water conservation (Heenan et al. 2004). All these practices control the SOC input from crop residues and the addition of organic amendments, and the SOC output through decomposition into gases and transportation into aquatic ecosystems via leaching, runoff, 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 widely applied (Zhang and McGrath 2004). Based on the theory of a "regionalized variable" (Matheron 1963), 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 interpolated maps for visualization, and for raster GIS maps, algebraic functions can calculate and visualize the spatial differences between the maps.

Terrestrial ecosystems in the mid-latitudes of the Northern Hemisphere act as a large carbon sink of atmospheric CO₂ (Ciais et al. 1995). Northeast

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China (> 40°N) is one of the main agricultural regions in China and it plays an important role in the global carbon budget. Owing to its agricultural importance, it is particularly susceptible to future land-use changes and projected climate change. Its cultivated land and total yields of corn and soybean currently account for 19 and 30%, respectively, of the nation's total. Soils in this region including black soil, meadow soil and chernozem have high organic matter concentrations due to their parent material and climate. However, cropland in this region has been affected by human-induced degradation after 100 years of tillage. After long-term reclamation and conventional tillage, SOC in this region has greatly declined. 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).

A better understanding of the spatial variability of SOC is important for refining agricultural management practices and for improving sustainable land use. It provides a valuable base against which subsequent and future measurements can be evaluated. Soil organic carbon content and its relation to site characteristics are important in evaluating current regional, continental, and global soil C stores and projecting future changes (Feng et al. 2002). Relating SOC to site characteristics may help in formulating and evaluating process models, and in assessing the effect of land use and climate change on soil C stores. Relations between soil organic C and site characteristics have been studied extensively at both local and regional scales (Spain 1990, Grigal and Ohmann 1992). In Northeast China, the relationship between SOC and environmental factors in the soils of croplands has only recently been investigated (Liu et al. 2006).

For this reason, the objectives of our study were to explore the spatial distribution characteristics of SOC in croplands of Jiutai County, Northeast China, and to elucidate the possible landscape characteristics influencing SOC status, such as soil type, slope and topography, using GIS and geostatistics.

MATERIAL AND METHODS

Study area

Jiutai County (125°42'–126°49' E, 43°85'–44°61' N) is located in central Jilin Province, Northeast China

(Figure 1). The county has an altitude between 147 and 580 m with an area of 3376 km². The study area is characterized with a temperate, semi-humid continental monsoon climate. Seasons alternate between dry and windy springs, humid and warm summers with intensive rainfall, windy and dry autumns and long, cold dry winters. The mean annual temperature is about 4.8°C and the average annual precipitation is 582 mm. The average annual sunshine is 2571 h and average wind speed is about 3.3 m/s. The frost-free period ranges between 130–140 days. In this county, the Second Songhua, the Mushi, the Wukai and the Yinma rivers flow through the area and into the Songhua river. The main soils are dark brown forest soil (Haplic Luvisol, FAO), meadow soil (Eutric Vertisol, FAO), aeolian soil (Arenosol, FAO), black soil (Luvic Phaeozem, FAO) and paddy soil (Hydric Anthrosol, FAO).

As a representative agricultural county of Northeast China, more than 70% of the total area of Jiutai County is used as cultivated land. The current fertilization and management style have prevailed for more than 20 years. In this area, single crops were replanted annually with continuous spring maize, *Zea mays* L., as the prevailing cropping system. Other cropping systems include continuously cropped rice, *Oryza sativa* L., and continuously cropped vegetables. The average nitrogen (N) input is 225, 210 and 240 kg/ha for dry farming lands growing maize, paddy fields and vegetable lands, respectively. The average phosphorus fertilizer (P) input is 90, 75 and 0 kg/ha for dry farming lands, paddy fields and vegetable lands, respectively. Overall, the average yield for the county is about 9000, 8600 and 36000 kg/ha for maize, rice and vegetables, respectively. In the study area, hoeing by hand is a common field practice.

Soil sampling and analysis of SOC

The surface soil had been disturbed dramatically by reason of cultivation in this area since 1900s, when native vegetations were demolished completely for agriculture. Meng et al. (2003) found that, in this region, SOC concentration within 0–20 cm depth of soil accounted 58% for that of the whole soil profiles (0–140 cm depth). In addition, the 0–20 cm depth of soil is the plowed layer for agricultural production in this region, and SOC in this layer is important for crop growth. The main objective of this paper is to explore the

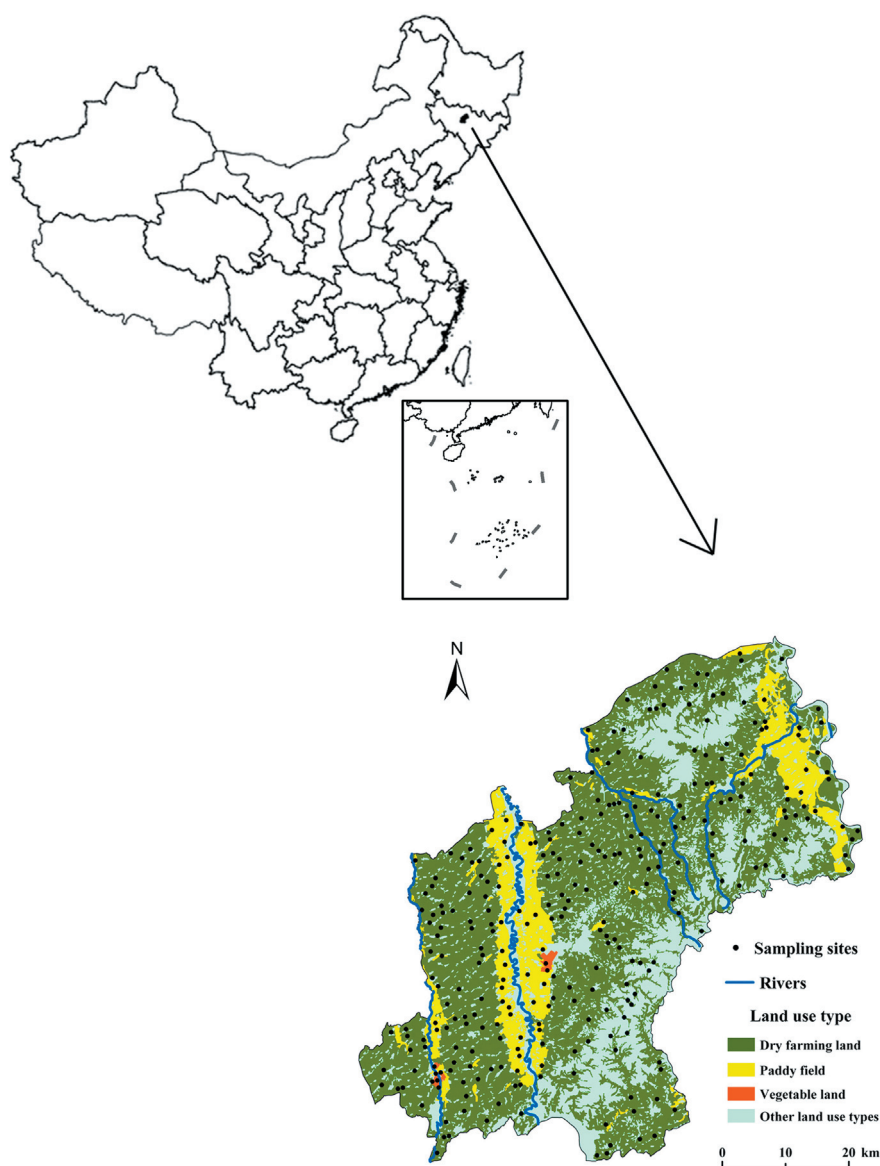


Figure 1. Soil sampling locations in Jiutai County, Northeast China ($n = 311$)

quality of surface soil by studying the variability of SOC in relation to landscape locations and land use types. Considering these reasons, only the soil within 0–20 cm depth was examined. The SOC data were collected during a regional soil fertility investigation. Samples of 0–20 cm depth from 311 sites were taken in October 2004. Among 311 points, 260 locations are used for dry farming land, 37 for paddy fields and 14 for vegetables. Five replicate samples were homogenized by hand, sieved air dried and used for the determination of SOC. SOC was determined by the Walkley-Black method (Nelson and Sommers 1982). Soil pH was measured with a glass electrode in a 1:2.5 soil water suspension. Total nitrogen (TN) was determined by the semi-micro Kjeldahl method. The Olsen method was used to determine extractable phos-

phate using a molybdate reaction for colorimetric detection (Olsen and Sommers 1982). The neutral 1N ammonium acetate extraction method was used to determine exchangeable potassium (Knudsen et al. 1982). Cation Exchange Capacity (CEC) was determined for soil samples by replacement of exchangeable cations by ammonium acetate (Thomas 1982). The locations of the cropland sampling sites are shown in Figure 1.

Statistical and geostatistical methods

Means, standard deviations, variances, coefficients of variation and maximum and minimum values were generated for each of the variables studied. Data were tested for the normal frequen-

cy distribution, by examining the coefficients of skewness and kurtosis. The Pearson correlation coefficients were estimated for all possible paired combinations of the response variables to generate a correlation coefficient matrix. A stepwise multiple linear regression procedure was used to examine the contributions of each variable. Factors affecting SOC were assessed using ANOVA and the Duncan's multiple range *ad hoc* procedure was used to separate means at the $\alpha < 0.05$ level of significance.

A semi-variogram was generated using the Geostatistics method to quantify the spatial variation of a regionalized variable, providing the input parameters for the spatial interpolation method of kriging (Krige 1951). Kriging was chosen because it provides information about the spatial structure as well as the input parameters. In general, it provides a theoretical weighted moving average of the input parameter over the distance between sampling sites (lag distance).

The geostatistical analyses were carried out using GS+ (version 3.1a Demo), and maps were produced with GIS software ArcView (version 3.2a) and its extension module of Spatial Analyst (version 2.0).

RESULTS AND DISCUSSION

Descriptive statistics

Histograms of SOC of both the raw and the logarithmically transformed data showed that, the statistical distribution of the raw data of SOC is positively skewed, but the log-transformed data are near normal. A strong deviation from the straight

line for raw data of SOC was observed for a P-P plot. However, the log-transformed data are close to the straight line. These results imply that the SOC concentrations in the croplands of this study area generally follow a lognormal distribution.

We also analyzed the quantitative parameter of the probability distribution and significance level of the Kolmogorov-Smirnov test for conformance to a normal distribution for the variable. The probability distribution of SOC is positively skewed (skewness = 2.14) and has a sharp peak (kurtosis = 7.73). The log-transformed data have rather small skewness (0.76) and kurtosis (1.52), and pass the K-S normal distribution test at a significance level higher than 0.05 ($P = 0.00$).

The coefficient of variation, standard deviation, and basic statistical parameters of percentiles and means showed that SOC has a relatively higher CV (30.8%), which could be linked to the heterogeneity of land use pattern, fertilizer or erosion. SOC concentration ranges from 0.68 to 4.60%, with the arithmetic mean of 1.56%. The geometric mean and median of SOC are 1.50% and 1.47%, respectively. SOC has the log-normal feature here, making the geometric mean and median more representative for the average value of SOC than the arithmetic mean.

Relation of SOC to other soil properties

Simple Pearson (linear) correlation coefficients between the eight variables are given in Table 1, together with corresponding significance levels. Overall, soil organic carbon was significantly correlated with almost all other properties.

Table 1. Correlation coefficient matrix for soil physical and chemical variables

Variable	SOC	BD	pH	TN	P	K	CEC
SOC	1	NS	**	**	**	**	**
BD	-0.179	1	NS	*	*	**	NS
pH	0.394	-0.119	1	**	NS	**	**
N	0.783	-0.211	0.346	1	**	**	**
P	0.174	-0.231	0.100	0.259	1	**	NS
K	0.386	-0.285	0.400	0.459	0.457	1	**
CEC	0.409	-0.140	0.360	0.347	0.087	0.366	1

SOC – soil organic carbon; BD – bulk density; pH – soil pH; TN – total nitrogen; P – extractable phosphorus; K – exchangeable potassium; CEC – cation exchange capacity; NS – not significant

*, **significance at the 0.05 and 0.01 levels, respectively. The number of observations for all variables except BD was 311. For BD, the number of observations was 102

Multiple linear regression analysis between SOC and other soil properties as determined by a stepwise analysis resulted in the following equation with the best fit of each term:

$$\text{SOC} = -1.146 + 15.856 (\text{SE} = 1.008) \times \text{TN} + 0.332 (\text{SE} = 0.094) \times \text{pH}, r^2 = 0.75 \quad (1)$$

In this equation, the significant factors were TN (total nitrogen) and pH. Other soil properties that were significant in simple linear regression analyses, namely P, K and CEC were dropped during the stepwise multiple regression analyses, probably because of colinearity with pH and/or TN. Therefore, soil organic carbon increased with increasing total nitrogen and increasing soil pH.

Analysis of spatial dependence of SOC

For SOC, the best-fitted semi-variogram model is shown in Figure 2. SOC indicated positive nugget, which can be explained by sampling error, short range variability, random and inherent variability. In general, the nugget-to-sill ratio is used to classify the spatial dependence of soil properties. The variable is considered to have a strong spatial dependence if the ratio is less than 25%, and has a moderate spatial dependence if the ratio is between 25% and 75%; otherwise, the variable has a weak spatial dependence. In this study, the nugget-to-sill ratio demonstrated a moderate spatial dependence for SOC (70%), possibly attributed to extrinsic factors (soil fertilization and cultivation practices) and intrinsic (soil-forming processes).

Effects of landscape attributes

GIS software ArcView was used to analyze the spatial distribution of SOC with different elevation. The samples were assigned to two elevation groups: class 1 (152–287 m) and class 2 (287–422 m); this classification was based on which contour line the sampling location is close to. ANOVA results indicated that the mean value of SOC was not significantly different for elevation classes ($P = 0.122$) (Table 2).

In Northeast China, soil erosion is considered one of reasons affecting the SOC decline (Tang 2004). To explore this, the difference between SOC concentrations under different slopes was carried out. ArcView software was used to assign

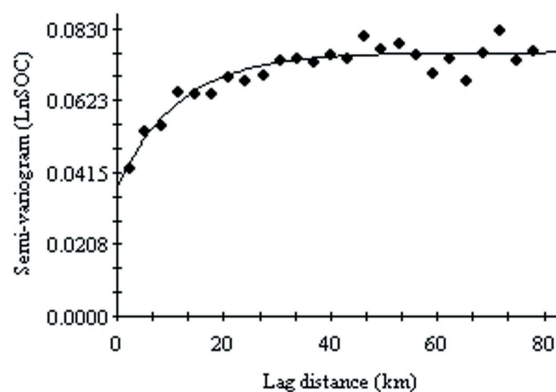


Figure 2. Omni-directional experimental variogram of LnSOC

the samples to two slope groups: group 1 (0–3°) and group 2 (> 3°). Results showed that, there was no difference for SOC in different slope groups. Although SOC did not show a significant relation to slope class, slope class 1 (0–3°) had noticeably

Table 2. Classification of the means of soil organic carbon for different classes of landscape attribute using the Duncan method at $P < 0.05$

Factors	Classes	SOC (%)
Elevation	152–287 m	1.55 ± 0.03
	287–422 m	1.86 ± 0.29
Slope gradient	0–3°	1.57 ± 0.03
	> 3°	1.48 ± 0.09
Slope position	summit	1.53 ± 0.04 ^b
	side slope	1.41 ± 0.4 ^b
	foot slope	1.50 ± 0.06 ^b
	toe slope	1.75 ± 0.03 ^a
	dark brown forest soil	1.42 ± 0.06 ^b
Soil type	meadow soil	1.71 ± 0.07 ^{a, c}
	aeolian soil	1.44 ± 0.06 ^{b, c}
	black soil	1.49 ± 0.03 ^{b, d}
	paddy soil	1.89 ± 0.13 ^{a, d}
Land use type	dry farming land	1.48 ± 0.03 ^b
	paddy field	1.91 ± 0.09 ^a
	vegetable land	2.13 ± 0.13 ^a

Data represented by mean ± standard error (SE). The lower-case letters indicate classes where significant differences ($P < 0.05$) exist among classes for soil chemical variables within factor (no letter for variables with no significant differences within factor). Means followed by the same letter are not significantly different

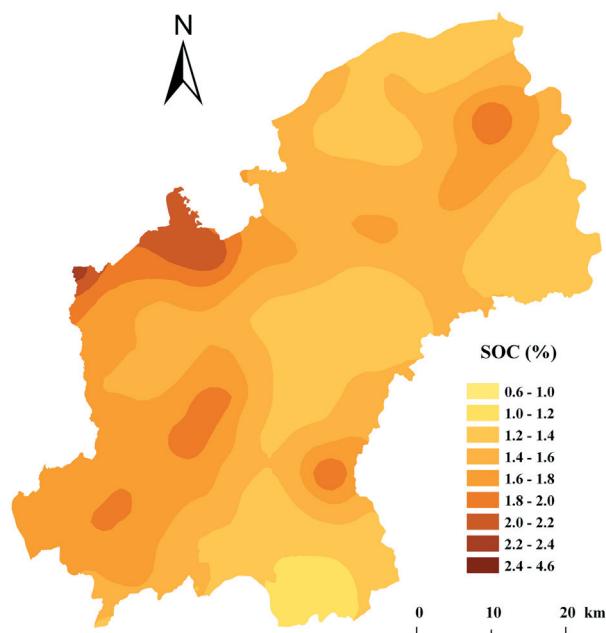


Figure 3. Spatial distribution map of SOC concentrations in croplands of Jiutai County, Northeast China

higher SOC concentrations (mean value of 1.57) than slope class 2 ($> 3^\circ$) (mean value of 1.48).

To further explore the soil organic carbon variations across the agricultural landscapes where water, tillage and wind erosion redistributes soil and SOC across the landscape, the relationship between SOC values and slope position was investigated. In this study, soil samples were collected from four slope positions: summit, side slope, foot slope and toe slope. Analyses indicated that there are significant differences between SOC values of soil samples from different slope positions. Soils from flood plain (depositing) have statistically higher SOC than those from upland areas (eroding). These results confirmed that topographic patterns could be used to help understanding of SOC dynamics in the landscape, as described previously (i.e. Pennock and Veldkamp 2006).

Soil type had a significant relationship with SOC (Table 2). This result reflects the effect of soil parent materials on condition of soil variables.

One-way ANOVA was applied to analyze effects of land use pattern on SOC concentrations. Results indicated that land use type significantly affects SOC status ($P < 0.05$). Soil samples from paddy fields and from vegetable lands have higher SOC concentrations than those from dry farming lands. The effect of different land use on the organic matter status is dependent on a balance between organic matter input and the degradative effect of tillage and harvest. In general, paddy fields have

a higher SOC concentration due to their greater dry matter production than dry farming lands. In this area, for vegetable lands, farmers often apply manure to maintain soil fertility and increase vegetables output, accounting for the increase in SOC levels.

The lower organic matter content in maize fields reflects the lower organic matter inputs for the maize crop. This occurs because of the wide spacing of maize plants, their sparse root system and the removal of substantial amounts of dry matter at harvest (Haynes and Francis 1993). Almost all aboveground plant biomass is typically removed, and manure inputs have decreased over recent years. Hence with decreased C inputs (plant residue, manure) and accelerated decomposition through cultivation, carbon levels have decreased over time. Fortunately, since the early 1990s, more attention has been paid to the importance of the protection of soil fertility, pulverization and the turnover of maize stubble post-harvest has been widely adopted.

Spatial distribution of SOC content

The parameters of the exponential model were used for kriging to produce the spatial distribution map of SOC content in soils of the study area. A search region of 12 nearest-neighbours was applied. The final result of this spatial inter-

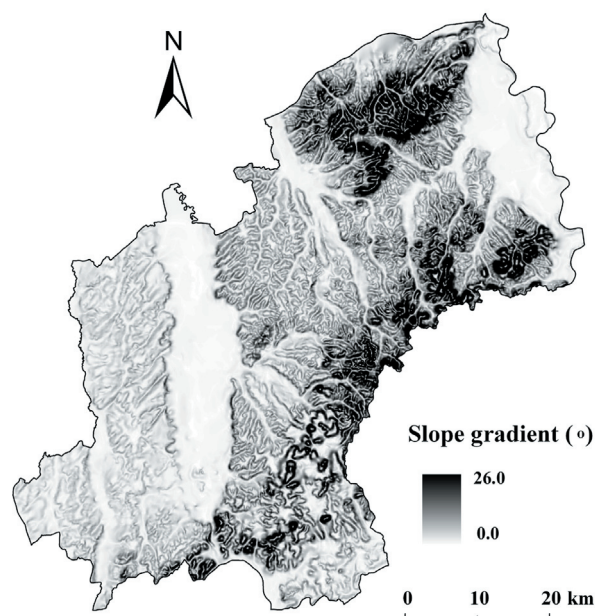


Figure 4. Map of slope gradient of Jiutai County, Northeast China

polation process is shown in Figure 3. To explore the spatial difference of SOC, the study area was divided into western and eastern parts, using the Yinma river as a border. Kriging results showed that SOC values are higher in the west quadrant than those of the eastern part. In comparing the slope gradients (map of slope gradient is shown in Figure 4), the difference between SOC of samples from the western part and those from the eastern part is generally consistent with the changing trend of slope gradient in the study area. In the eastern part, water and tillage erosion may be an important reason for SOC decline due to the relatively greater water and soil loss and inadequate protection from tillage management.

The SOC concentrations in croplands of Jiutai County, Northeast China, show a log-normal distribution, and have a geometric mean of 1.50%. Regression analyses highlighted soil total nitrogen and pH as the factors that most greatly influence SOC. The nugget-to-sill ratio revealed a moderate spatial dependence for SOC in the study area. Slope position, soil type and land use type also affect the SOC concentrations significantly.

REFERENCES

- Buol S.W., Hole F.D., McCracken R.J. (1989): Soil Genesis and Classification. Iowa State University Press, Ames.
- Ciais P., Tans P.P., Trolier M., White J.W.C., Francey R.J. (1995): A large northern hemisphere terrestrial CO₂ sink indicated by the ¹³C/¹²C ratio of atmospheric CO₂. *Science*, 296: 1098–1101.
- Feng Q., Endo K.N., Cheng G.D. (2002): Soil carbon in desertified land in relation to site characteristics. *Geoderma*, 106: 21–43.
- Grigal D.F., Ohmann L.F. (1992): Carbon storage in upland forests of the lake states. *Soil Sci. Soc. Am. J.*, 56: 938–942.
- Haynes R.J., Beare M.H. (1996): Aggregation and organic matter storage in meso-thermal, humid soils. In: Carter E.M., Stewart B.A. (eds.): *Advances in Soil Science: Structure and Organic Matter Storage in Agricultural Soils*. CRC Press, Boca Raton: 213–262.
- Haynes R.J., Dominy C.S., Graham M.H. (2003): Effect of agricultural land use on soil organic matter status and the composition of earthworm communities in KwaZulu-Natal, South Africa. *Agric. Ecosyst. Environ.*, 95: 453–464.
- Haynes R.J., Francis G.S. (1993): Changes in microbial biomass C, soil carbohydrate composition and aggregate stability induced by growth of selected crop and forage species under field conditions. *J. Soil Sci.*, 44: 665–675.
- Heenan D.P., Chan K.Y., Knight P.G. (2004): Long-term impact of rotation, tillage and stubble management on the loss of soil organic carbon and nitrogen from a Chromic Luvisol. *Soil Till. Res.*, 76: 59–68.
- Knudsen D., Peterson G.A., Pratt P. (1982): Lithium, sodium, and potassium. In: Page A.L. (eds.): *Methods of Soil Analysis*. American Society of Agronomy, Madison: 225–246.
- Krige D.G. (1951): A statistical approach to some basic mine valuation problems on the Witwatersrand. *J. Chem. Metallurg. Mining Soc. South Africa*, 52: 119–139.
- Liu D.W., Wang Z.M., Zhang B., Song K.S., Li X.Y., Li J.P., Li F., Duan H.T. (2006): Spatial distribution of soil organic carbon and analysis of related factors in croplands of the black soil region, Northeast China. *Agric. Ecosyst. Environ.*, 113: 73–81.
- Matheron G. (1963): Principles of geostatistics. *Econ. Geol.*, 58: 1246–1266.
- Meng K., Zhang X.Y., Sui Y.Y. (2003): Impedient factors in black soils in the northern part of Northeast China. *Soils*, 35: 145–151. (In Chinese)
- Nelson D.W., Sommers L.E. (1982): Total carbon, organic carbon, and organic matter. In: Page A.L. (eds.): *Methods of Soil Analysis*. American Society of Agronomy, Madison: 539–579.
- Olsen S.R., Sommers L.E. (1982): Phosphorus. In: Page A.L. (eds.): *Methods of Soil Analysis*. American Society of Agronomy, Madison: 403–430.
- Pennock D.J., Veldkamp A. (2006): Advances in landscape-scale soil research. *Geoderma*, 133: 1–5.
- Post W.M., Kwon K.C. (2000): Soil carbon sequestration and land-use change: processes and potential. *Glob. Chang. Biol.*, 6: 317–327.
- Rezaei S.A., Gilkes R.J. (2005): The effects of landscape attributes and plant community on soil chemical properties in rangelands. *Geoderma*, 125: 167–176.
- Spain A.V. (1990): Influence of environmental conditions and some soil chemical properties on the carbon and nitrogen contents of some tropical Australian rainforest soils. *Aust. J. Soil Res.*, 28: 823–833.
- Tang K.L. (2004): Soil and Water Conservation in China. Science Press, Beijing. (In Chinese)
- Thomas G.W. (1982): Exchangeable cations. In: Page A.L. (eds.): *Methods of Soil Analysis*. American Society of Agronomy, Madison: 159–164.
- Turner J., Lambert M. (2000): Change in organic carbon in forest plantation soils in eastern Australia. *For. Ecol. Manage.*, 133: 231–247.
- Wang J., Fu B., Yang Q., Chen L. (2001): Soil nutrients in relation to land use and landscape position in the

semi-arid small catchment on the loess plateau in China. *J. Arid Environ.*, 48: 537–550.

Zhang C.S., McGrath D. (2004): Geostatistical and GIS analyses on soil organic carbon concentrations in

grassland of southeastern Ireland from two different periods. *Geoderma*, 119: 261–275.

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