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ORIGINAL ARTICLE

Temporal and spatial variability of soil organic matter and total nitrogen in a typical oasis cropland ecosystem in arid region of Northwest China

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Abstract Soil degradation resulted from unreasonable land use has been a serious problem in the arid region of Northwest China. This paper seeks to understand the relationship between topsoil properties and farming practices for land management targeting at improving soil quality in this region. The temporal and spatial variation of soil organic matter (SOM), total nitrogen (STN) were analyzed with classical statistics and geostatistics methods in Linze County, Gansu Province, an typical oasis agricultural area in arid region of northwest China, as affected by farming practices using the data from 1982 to 2008. The results of classical statistics indicated that the average SOM and STN concentrations were 12.78 ± 4.38 g kg^{-1} and 0.72 ± 0.21 g kg^{-1} in 1982, 13.76 ± 4.02 g kg^{-1} and 0.81 ± 0.20 g kg^{-1} in 2008, respectively. The net carbon and nitrogen increased at an average rate of 0.104 Mg C ha^{-1} $year^{-1}$ (1 Mg = 10^6g) and 0.014 Mg N ha^{-1} $year^{-1}$ in the past 26 years. Geostatistical analyses showed that the spatially related areas of SOM and STN were expanded by effect of farming practices. The spatial distributions of SOM and STN contents were influenced by regional soil parent materials. Temporal variation maps of SOM revealed a change trend was closely related to the amount of the application of organic manures. It was concluded that the applications of chemical fertilizers were effective for increasing of STN, and the continuous applications of chemical fertilizers combining with applications of organic manures (approximately 45 m^3 ha^{-1}) every other year were helpful in accumulating soil organic carbon.

Keywords Soil organic matter · Total nitrogen · Temporal variability · Spatial variability · Geostatistical analysis · Linze oasis

Abbreviations

SOM	Soil organic matter
STN	Soil total nitrogen
SOC	Soil organic carbon
GPS	Global positioning system
SD	Standard deviation
CV	Coefficient of variation
RSS	Residual sums of squares

Introduction

In an agricultural ecosystem, soil organic matter (SOM) and total nitrogen (STN) are the major determinants and indicators of soil fertility and quality (Reeves 1997; Susanne and Michelle 1998; Al-Kaisi et al. 2005; Huang et al. 2007a), which play a crucial role in sustaining soil quality, crop production and environmental quality (Doran and Parkin 1994). In addition, changes in soil organic carbon (SOC) can affect the concentration of atmospheric CO_2, which is the principal contributor to global climate change (Janzen et al. 1998; Knorr et al. 2005; Tan and Lal 2005). Generally, climate conditions and water and wind erosion

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are the main reasons for a decline in organic carbon, but land management practices are also contributors. Inappropriate land use or poor soil management and cropping practices can cause a decline in soil quality and the loss of SOC (Lal 2004; Su 2007).

Cultivation has decreased SOC and STN contents of topsoil in semiarid regions throughout the world (Rasmussen and Collins 1991; Quiroga et al. 1996; Buschiazzo et al. 2001; Wezel and Rath 2002; Valentin et al. 2004; Igue et al. 2004; Vågen et al. 2005; Doraiswamy et al. 2007; Henry et al. 2009). These losses have triggered increasing concern for sustainable soil use because they not only affect soil productivity but also have negative environmental consequences (Urioste et al. 2006; Jia et al. 2006). Intense cultivation, without the addition of fertilizers or organic matter, may result in rapid decreases in SOC and STN (Buyanovsky and Wagner 1998). However, appropriate land use and soil management can contribute to an increase in SOC, improve soil quality and partially mitigate the rise of atmospheric CO_2 (Lal and Bruce 1999; Tschakert 2001; Ardö and Olsson 2003). Several studies have shown that the use of mineral fertilizers and organic amendments in arid region may have a synergistic effect that leads both to higher yields and SOC content (Palm et al. 2001; Vågen et al. 2005; Bationo et al. 2007).

A better understanding of the temporal and spatial variability of SOM, STN, and related factors is important for improving sustainable land use management (McGrath and Zhang 2003), providing a valuable base against which subsequent and future measurements can be evaluated (Huang et al. 2007a). Informed soil protection or conservation decisions cannot be made without maps that show land properties (Henry et al. 2009). It is recognized that samples cannot be recorded everywhere and hence the drive to predict properties in the unsampled neighborhood of measured values has necessitated an appreciation of the spatial dependence of the variables of interest. As a result, geostatistical methods have been developed that allow the spatial dependence between observed values to be expressed in terms of a variogram (Webster 1985). A variogram describes the average similarity between pairs of points within given separation classes and forms the basis for kriging techniques that allow the values of unsampled regions to be derived through interpolation (Yost et al. 1982; Cressie 1990; Goovaerts 1998). Based on these geostatistical techniques, many studies of the spatial variation of soil properties have been undertaken in recent years (Trangmar et al. 1985; Wei et al. 2006; Huang et al. 2006; Huang et al. 2007a; Liu et al. 2008; Zhao et al. 2009).

During the period from the middle to the end of the last century, increases in population and a consequent increase in food demand in the arid region of northwest China, the transition from virgin desert to agricultural use has intensified (Luo et al. 2002; Li et al. 2006; Huang et al. 2007b; Su et al. 2010). Excessive land exploitation and subsequently poor land management has triggered serious ecological problems (Qin et al. 2002), including shortage of water resources, land salinization and desertification, that threaten oasis stability and sustainable development (Li et al. 2006; Wang et al. 2008). Linze oasis is a representative area of intensive agriculture in arid region of northwest China. The temporal and spatial variability of typically variables (SOM and STN) throughout the oasis agricultural areas have received little attention, even though the distribution of carbon and the effect of carbon sequestration have been partly studied (Wang et al. 2004; Nan and Zhang 2007; Su 2007; Su et al. 2009). The objectives of the present study were (1) to obtain basic data to provide theoretical guidance for sustainable development and rational management of oasis agricultural areas; (2) to assess the main factors that impact the spatial distribution of SOM and STN; and (3) to estimate the change in the soil carbon and nitrogen pools over the past 26 years. The study focuses on Linze County, which is representative area of oasis cropland ecosystem in arid region of northwest China, could provide available insights for other similar semiarid and arid regions.

Materials and methods

Study area

The study area is located in Linze County (between 38°57′ and 39°42′N, and 99°51′ and 100°30′E) in the middle reaches of the Heihe River Basin, Gansu Province, Northwest China. The county covers an area of approximately 2,730 km^2 at an altitude of 1,370–2,200 m above mean sea level. On the north of the county are the gravel Gobi desert and sand dunes. This region has a typical desert climate characterized by cold winters and dry hot summers with a mean annual precipitation of 117 mm and a mean annual evaporation of 2,390 mm; the area has abundant sunshine (mean of 2,965 h per year) and solar radiation (mean of 146.2 kcal cm^{-2}), with distinct temperature variations between day and night. The mean temperature is 7°C and there are 178 frost-free days per year. The mean annual wind velocity is 3.2 m s^{-1}; gales with wind velocity above 17 m s^{-1} occur about 15 days per year (Su et al. 2010).

The main soil types within the study area are Aridisol and Plaggept. In the low-lying plains of the Heihe River, there are small tracts of Swamp soil, large tracts of Haplumbrept soils and saline-alkaline soil. A small tract of Camborthids exists in the southern mountainous area, these areas had plentiful precipitation and small temperature variations, and the soil fertility was relatively high. Due to

Table 1 Fundamental data of population and agriculture in the study area in 2005

Name of irrigated district	Population	Agricultural area (ha)	Livestock (cattle)	Dry Organic Manures (m^3 ha^{-1})
Pingchuan Town	20,200	3,020	10,500	30
Banqiao Town	17,466	2,672	15,000	49
Liaoquan (and Linze farm) Town	17,706	2,424	9,000	33
Yanuan (and Xiaotun) Town	20,244	3,729	5,426	13
Xinhua Town	18,400	1,951	17,700	79
Shahe Town	21,985	2,298	16,500	63
Nijiaying Town	9,270	1,971	17,700	79

long-term encroachment of drift sand from Badanjilin Desert and deposition of aeolian sand, Psamments developed in the edges of the oasis (such as the north area of Pingchuan and Banqiao Town) and sandy lands formed. Since 1960s, sandy lands were gradually reclaimed for agriculture use, so a relatively short-term cultivation history (8–70 years) of land use for crop production in the area; these soils had a loose structure, very low organic matter content, and were very susceptible to wind erosion (Su 2007).

Farming practices and land management

Statistical data showed that arable land, cropping cultivation patterns, and the quantities of chemical fertilizers application occurred significant changes between 1982 and 2008. For example, in 1982, there was 1.58×10^4 ha of cropland in Linze County; by 2008, this number had increased by approximately 0.85×10^4 ha both because of economic reasons and population growth. The pattern of cultivation also revealed changes over time. In 1982, cropland was managed by county government group leaders, as was the case throughout China. Specifically, farming activities such as tillage, seeding, fertilization, crop rotation, irrigation and harvest were carried out in a uniform manner. In 1982, the main crops were wheat, maize and soybeans. However, after 1984, administrative and management systems allowed individual farmers to rent land and decide which crops to plant and how to manage the cropland. Because the area rented by a farmer's household was small, significant differences in management took place within a large geographic area. Maize (grown for seed), cotton, sugar beets, grapes and tomatoes have been the main crops in recent years (for example, the main crops in the saline soils were sugar beets and grapes) due to the suitable climatic conditions and high profit. A traditional farming models have been employed since 1982, with both the stalk and roots of the maize removed after harvest.

There have also been changes in the application of chemical fertilizer and organic materials. In the early 1980s, the cropland has been received applications of 140 kg N ha^{-1}, 65 kg P_2O_5 ha^{-1} per year; very limited number of organic manures were applied in that time (according to the census data in the 1983 statistical yearbook of Linze County). The rate of fertilizers applied for maize was about 300–450 kg^{-1} N ha^{-1} and 90–150 kg P_2O_5 ha^{-1} each year in recent 10 years (Su et al. 2010). Potassium and micronutrients were also generally applied. The basic data of 2005 represent the current management system in recent years (Table 1). Approximately 30–80 m^3 ha^{-1} of dry organic manures were applied to the cropland every other year. The application of organic fertilizers appeared to be closely related to the numbers of cattle. Investigation results in 2008 showed that the manures produced by five cattle in 1 year can provide for 0.5 ha cropland (approximately 45 $m^3 ha^{-1}$), whereas the cattle's food was satisfied from the maize straw of 1 ha cropland. Therefore, the dry organic manures were applied to the cropland once every other year due to limited food.

Soil sampling and analysis

Based on the Second National Soil Survey in 1982, a total of 287 topsoil samples were collected throughout locations in 2008 (Fig. 1). In accordance with the sampling performed in 1982, the samples were collected at spring before the cropping season in order to avoid the effects of direct fertilization during crop cultivation in 2008. Each soil sample was a composite of sub-samples taken from 6 to 8 points within an approximate surface area of 350 m^2 of arable land that had been disturbed by tillage (depths of 0–20 cm). The latitude and longitude of each sampling site were recorded by a hand-held global positioning system (GPS), and related information such as land-use history and crop was recorded in detail. The bulk density was determined using a cutting ring (volume of 100 cm^3).

To ensure good comparability of data over the two sampling periods, the analysis method of samples in 2008 was employed based on the method in 1982. Soil samples were air-dried and hand-sieved through a 2-mm screen to remove roots and other debris. A portion of the air-dried

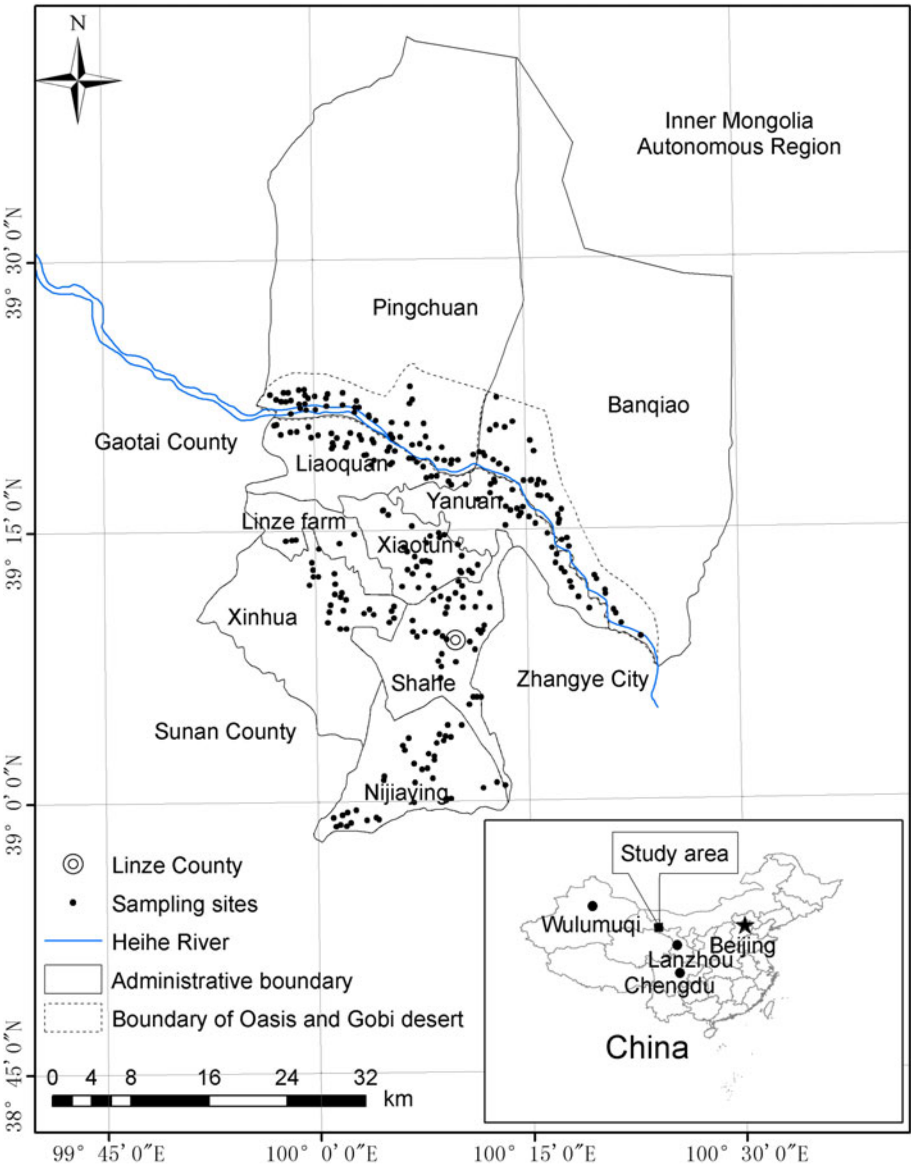

Fig. 1 The distribution of soil sampling sites in Linze County

samples was ground to pass 0.25 mm sieve and was then analyzed for SOM by the $K_2Cr_2O_7$–H_2SO_4 oxidation method of Walkley–Black (Nelson and Sommers 1982) and for STN by the Kjeldahl procedure (Bremmer and Mulvaney 1982).

Statistical analysis

Mean, median, standard deviation (SD) and coefficient of variation (CV) were determined for all data sets. The distribution of the data was tested for normality using the Kolmogorov–Smirnov test. A paired samples *t* test was used to assess differences between the two sampling periods. All statistical analyses were carried out with the software program SPSS 11.5 for Windows.

In the present study, spatial patterns of SOM and STN for the data sets were determined using geo-statistical analysis. Semivariograms were constructed using GS^+ software (1998) to examine the degree of spatial continuity of soil properties among data points and to establish their range of spatial dependency. Data that were not normally distributed were logarithmically transformed. Information generated from the semivariograms was used to calculate sample-weighing factors for spatial interpolation by a kriging procedure (Isaaks and Srivastava 1989) using the geostatistical analysis extension of ArcGIS 9.2 software. An experimental semivariogram for the given separate distance *h* was calculated according to the following formula:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [Z(x_i) - Z(x_i + h)]$$

where $\gamma(h)$ is the semivariance at a given distance h; $Z(x_i)$ is the value of the variable Z at the x_i location, and $N(h)$ is the number of pairs of sample points separated by the lag distance *h*.

Three parameters were used to interpret the spatial dependence of each variogram. The nugget effect (C_0) represented random variation caused mainly by measurement error or variation that could not be detected at the minimum sampling distance. Usually, semivariance increases with sampling distances and then approaches a constant value called the sill ($C + C_0$) (Trangmar et al. 1985). The separation distance at which the sill is achieved is called the range of spatial dependence. The range establishes the outer limit at which points in space still interact spatially and the sill represents the total priori variance (Webster and Oliver 2000). Samples separated by distances closer than the range are spatially related, while samples separated by greater distances are not spatially related.

Several standard models are available to fit the experimental semivariogram (spherical, exponential, Gaussian, linear and power models). Selection of semivariogram models were made based on the regression coefficients of determination (R^2) (Liu et al. 2008). In this study, the fitted exponential model and spherical model were used most frequently.

Results

Descriptive statistics

On the basis of the samples analyzed in 1982 and 2008, the average content of SOM and STN throughout the whole county significantly increased during the 26-year period from 12.78 to 13.76 g kg^{-1} ($p < 0.001$) and from 0.72 to 0.81 g kg^{-1} ($p < 0.001$); this represent increases of 7.7% for SOM and 12.5% for STN (Table 2).

Table 2 Descriptive statistics parameters of SOM and STN in 1982 and 2008 ($n = 287$)

Soil properties	Year	Mean	Median	SD	CV (%)	Paired-samples *T* test	
						t	*P*
SOM (g Kg^{-1})	1982	12.78	12.58	4.39	34	3.90	<0.001
	2008	13.76	13.50	4.02	31		
STN (g Kg^{-1})	1982	0.72	0.73	0.21	29	7.17	<0.001
	2008	0.81	0.81	0.20	25		
Ratio of C/N	1982	10.3	10.4	1.43	14	−5.42	<0.001
	2008	9.71	9.70	0.97	10		
Bulk density	1982	1.39	1.38	0.08	5.9	–	–
	2008	1.46	1.47	0.12	8.3		

SD standard deviation, *CV* coefficient of variation

The standard deviation (SD) and coefficient of variation (CV) of SOM in 2008 were slightly lower (4.02 g kg^{-1} and 31%, respectively) than these in 1982 (4.39 g kg^{-1} and 34%, respectively). The SD and CV of STN in 2008 (0.20 g kg^{-1} and 25%, respectively) were also slightly lower than these in 1982 (0.21 g kg^{-1} and 29%, respectively). The CVs of both SOM and STN exceeded 20%, indicating considerable variability of SOM and STN in cropland. Although overall SOM and STN increased significantly from 1982 to 2008, the C/N ratio decreased significantly, from 10.27 to 9.71. The average soil bulk density increased from 1.39 to 1.46 g cm^{-3}, and the CV of the bulk density increased from 5.9 to 8.3%.

Spatial variability of SOM and STN

The semivariograms for SOM and STN in different years are shown in Fig. 2; their attributes are summarized in Table 3. The theoretical model for SOM in 2008 was best fitted to a spherical model; an exponential model was the optimum theoretical model for the other semivariograms. The residual sums of squares (RSS) for all variograms were close to zero. Nugget variances (C_0) for semivariance of SOM and STN were 0.0404 and 0.0081 in 2008, 0.0148 and 0.0119 in 1982. The ratio of $C_0/(C + C_0)$ for SOM increased distinctively from 0.093 in 2008 to 0.375 in 2008, and it for STN increased slightly, from 0.103 in 1982 to 0.116 in 2008. The range of SOM and STN increased from 7.14 and 4.95 km in 1982 to 19.6 and 10.3 km in 2008, respectively (Table 3).

Spatial distributions of SOM during two time periods were similar at the county scale (Fig. 3). The lowest SOM contents were found in the transition area between the northern oasis and the Gobi desert (northern area of Banqiao and Pingchuan Town), which were lower than 8.4 g kg^{-1}. In contrast, the highest SOM contents distributed in the middle of Linze oasis (Shahe Town), with ranging from 18 to 27 g kg^{-1}. Moderate SOM contents were found in the north central regions of Linze oasis (Linze farmland, Liaoquan and Xiaotun Town), ranged from 12 to 18 g kg^{-1}. However, the STN had the similar spatial distribution during the two time periods (Fig. 3).

Stocks change of SOC and STN

The SOC and STN pool was calculated by the bulk density and the contents of SOC and STN. Bemmelen index of 0.58 was used to convert SOM content to SOC content. At a depth of 0–20 cm, the average SOC and STN pool values were 20.6 Mg C ha^{-1} and 2.01 Mg N ha^{-1} in 1982, whereas these have risen to 23.3 Mg C ha^{-1} and 2.37 Mg N ha^{-1} in 2008. Using the mass of SOC and STN in the cropland as a reference point, net C increased at an average rate of 0.104 Mg C ha^{-1} year^{-1}, and net N increased at an average rate of 0.014 Mg N ha^{-1} year^{-1}.

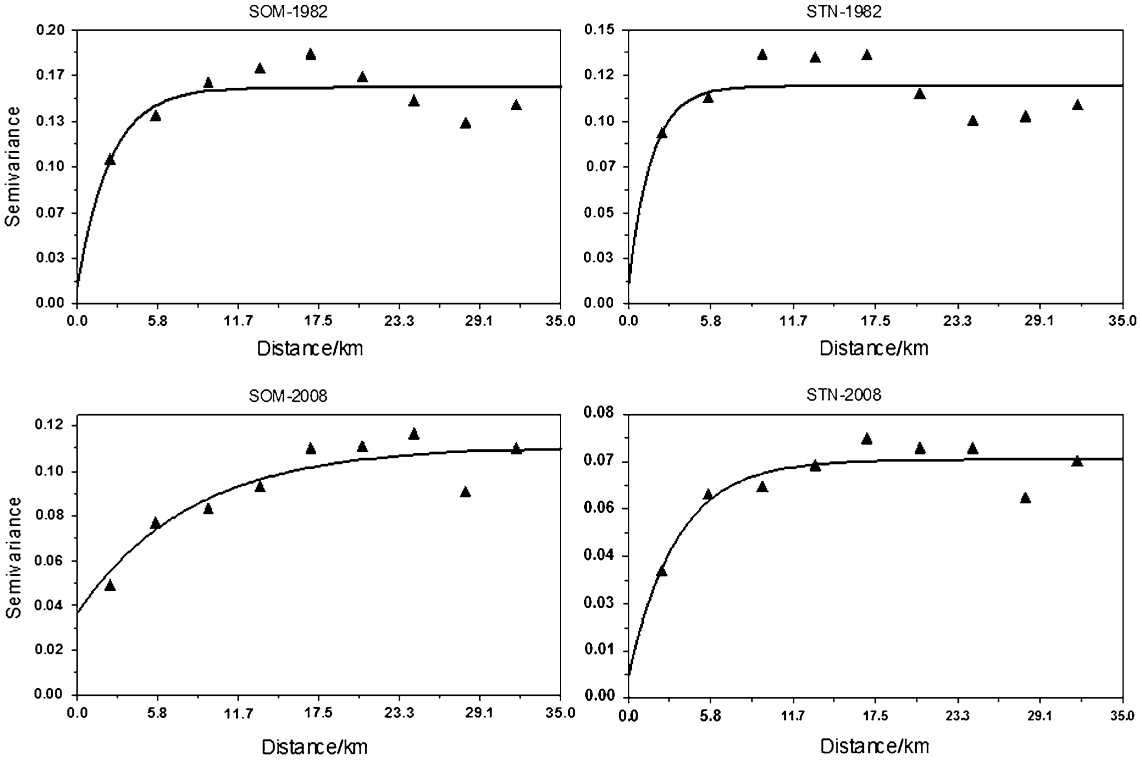

Fig. 2 The semivariograms of soil organic matter (SOM) and soil total nitrogen (STN) in Linze County

Table 3 Parameters of theoretical variogram models for SOM and STN

Soil properties	Year	Theoretical model	C_0	$C + C_0$	$C_0/(C + C_0)$	Range (km)	R^2	RSS
SOM	1982	Exponential	0.0148	0.159	0.093	7.14	0.568	1.84×10^{-3}
	2008	Spherical	0.0404	0.108	0.375	19.6	0.864	5.14×10^{-4}
STN	1982	Exponential	0.0119	0.116	0.103	4.95	0.279	1.47×10^{-3}
	2008	Exponential	0.0081	0.070	0.116	10.3	0.809	2.09×10^{-4}

Discussion

Semivariance analysis

The RSS for all the measured values were roughly equal to zero (Table 3), which indicated a good fit between the theoretical variogram and experimental variogram. Spatial dependencies differed among the SOM and STN at various times, as illustrated by the nugget and sill values, as well as the ranges (Table 3). The range of SOM and STN increased from 7.14 and 4.95 km in 1982 to 19.6 and 10.3 km in 2008, respectively, revealed that the spatial structure was expanded by effect of soil management practices.

The ratio of nugget (C_0) variance to sill ($C + C_0$) can be regarded as a criterion for classifying the spatial dependence of soil properties. If this ratio is less than 0.25, the variable has strong spatial dependence; if the ratio is between 0.25 and 0.75, the variable has moderate dependence; if over 0.75, the variable has weak dependence (Cambardella et al. 1994). The ratio of $C_0/(C + C_0)$ for SOM exhibited strong spatial dependence in 1982 but moderate spatial dependence in 2008. This slight weakening in the spatial variability of organic matter characteristics was mainly due to the influence of long-term cultivation on the balance of SOM input and output, and the same result was found in Yangtze River Delta region (Huang et al. 2007a). For STN, the $C_0/(C + C_0)$ ratio is <0.25 in both 1982 and 2008 indicated strong spatial dependence, this is may be primarily due to uneven and concentrated fertilizer application.

Spatial distribution and impact factors

The distribution patterns of SOM were similarity in 1982 and 2008 (Fig. 3). Many researchers have pointed out that soil parent materials, crop, fertilization, cropping history and other factors could influence the variability of the

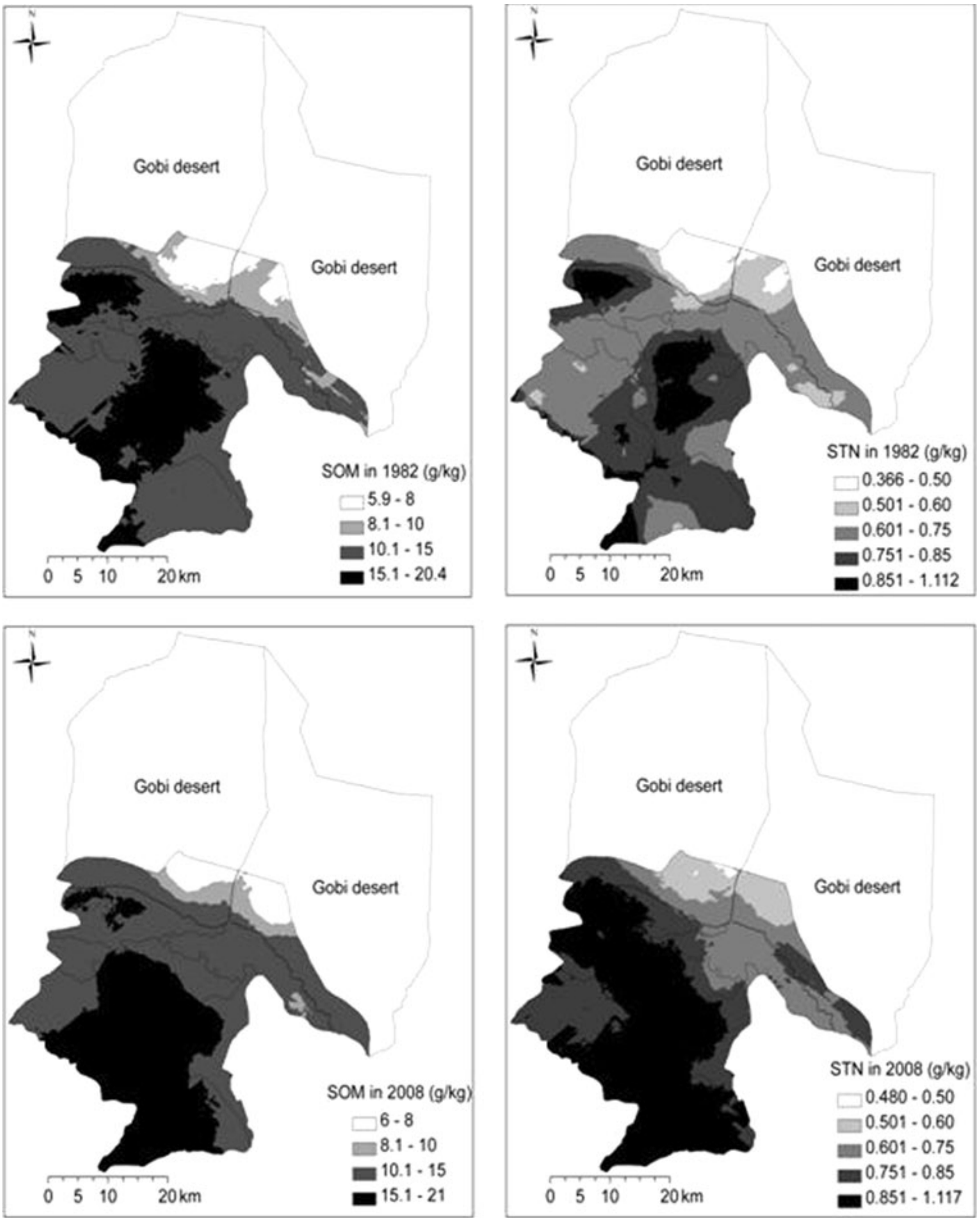

Fig. 3 Distributions of soil organic matter (SOM) and total nitrogen (STN) in Linze County in 1982 and 2008

physical and chemical properties of fields (Huang et al. 2007a; Zhao et al. 2009). Large differences in soil parent materials and farming practices were likely the major causes of soil variability within the study area (Huang et al. 2007a; Liu et al. 2008). In this study, the soil parent materials were the main factor to influence the distribution of SOM in Linze County. The lowest SOM contents (in the transitional area between the northern Linze oasis and the Gobi desert, north of Banqiao and Pingchuan Town) were found in areas where long-term encroachment of drift sand from the Badanjilin desert and the deposition of aeolian sand has facilitated the development of Quartisamment soils (Su et al. 2010). Even after cultivation (for a relatively short-term period), the surface horizons of these soils still showed typical characteristics of desert soil. The soils are characterized by very low nutrient concentrations (Su 2007). The highest SOM contents were distributed in the center of the Linze oasis (Shahe Town). This area, now mostly urban, is part of the old oasis and consists mainly of Plaggept soils, which has been cultivated for many years and has relatively high soil fertility. Medium SOM contents were distributed in the north central part of the Linze oasis (Liaoquan, Linze farm and Xiaotun) where Haplumbrept and saline soils predominated because of high water table, poor soil permeability, and slow mineralization process of organic matter. The distributions of STN were similar to these of SOM (Fig. 3).

Temporal variability of spatial distribution and impact factors

The SOM content increased in much of the Linze oasis from 1982 to 2008. Significant increases occurred in Nijiaying Town, located in the southern of Linze oasis. This area is characterized by high elevations, low temperatures, and especially in 1982, low SOM and a thin layer of arable soil. The allocations of water resources and agricultural tillage levels have resulted in an increase of the arable soil layer thickness and then a significant increase in SOM in recent years, However, the contents of SOM have declined in some area; as the case in Xiaotun Town, Linze farm, and the northern transitional area between the oasis and the Gobi desert. The soil parent materials were the main factor to cause the decline in those areas, and the inappropriate farming practices and limited manures supply was the secondary cause. The inappropriate farming practices and intense cultivation aggravated soil salinization led to the decrease of SOM in Xiaotun Town and Linze farm. As for the northern transitional area between the oasis and the desert, the soils were characterized by very low nutrient concentrations and a loose sandy structure, which were poor capacity of fertility retention. In addition, because large area of the Gobi desert land in the north of oasis has been reclaimed for agricultural cropland over the past 26 years (Su et al. 2010), the intensive cultivation and insufficient application of organic manure may be the other reasons for the decrease in SOM in these adjacent areas.

The increasing number of livestock provides more sources of manure, which is an important factor for the rapid increase of SOM in some soils (Huang et al. 2007a). Cattle were the main sources of organic manure, which played a crucial role in the accumulation of SOM. Manure <35 m^3 ha^{-1} was applied in Pingchuan, Yanuan and Liaoquan Town (Table 1), it was not surprised that SOM decreased (Fig. 4). In contrast, organic manures exceeded 60 m^3 ha^{-1} were applied in Xinhua, Shahe and Nijiaying Town (Table 1), and then SOM increased (Fig. 4). This suggest that insufficient organic manures occurred in Pingchuan, Yanuan and Liaoquan Towns; the vice versa for Xinhua, Shahe and Nijiaying Towns. In Linze County, the food for cattle was the limited factor for the manures supply (see "Farming practices and land management"). Consequently, the study team recommended that farmers should plant more alfalfa in the saline soils and transition area between oasis and desert, because alfalfa can provide enough food for cattle, and then to obtain more manures. Furthermore, the alfalfa planting can improve the soil quality (Su et al. 2009).

In comparison to the temporal variation in SOM, the temporal variation in STN was relatively simple (Fig. 4). STN increased due to the large amounts of nitrogen fertilizer applied (see "Farming practices and land management") throughout the county. However, STN decreased in Yanuan Town, where are largely saline-alkali soils. The aggregating of soil salinization due to inappropriate tillage practices caused the STN decrease. Meanwhile, the supply of organic manures in this area was low, which was the other reason.

Contributions to soil carbon and nitrogen cycling

At the depth of 0–20 cm, the average SOC density (because the coefficients of variation of SOM and STN were not very high, we use average value to represent the level of the study area) in 2008 (23.3 Mg C ha^{-1}) was similar to that in Africa (average 23.7 Mg C ha^{-1} in 0–30 cm) (Henry et al. 2009), however, it was far lower than the average value in China (39.8 Mg ha^{-1} with an area-weighted depth of 19 cm) (Xie et al. 2007). The results indicated that the overall levels of both of SOC and STN densities were low compared to agricultural soils in most temperate areas. Though the increase of average SOM and STN contents from 1982 to 2008 documented (Table 2) was very small in magnitude, it could impact carbon sequestration due to cumulative effect at large tracts of land in arid zones. Furthermore, the previous study also reported that appropriate land use such as the conversion of cropland to alfalfa forage land could contribute to an increase in SOC and improve soil quality in this area (Su 2007). It is concluded that there is great potential to sequester carbon in the oasis cropland ecosystem of Linze County.

Net carbon increased at an average rate of 0.104 Mg C ha^{-1} $year^{-1}$ and net N increased at an average rate of 0.014 Mg N ha^{-1} $year^{-1}$ indicated that the present farming practices can improve the level of SOC. Because the application of mineral fertilizers was inadequate to maintain the levels of SOC and nutrients under conventional management without aboveground crop residues returned to the soil (Su et al. 2006), we attributed it to the fertilizer application system. From 1982 to 2008, the correlation between the amount of organic manure applied every other year (Table 1) and the SOM content (Fig. 4) was good; this implied that the continuous application of mineral fertilizer combined with organic manures every other year may be a rational approach to sustain or increase SOC and N pool. This result also supported that the application of both chemical fertilizers and organic manures contribute to an increase in SOC and STN content. As an experiment in northern China, Meng et al. (2005) reported that a balanced application of chemical fertilizers and organic manure significantly increased SOC and STN accumulations to averages of 0.1 Mg C ha^{-1} and 1.01 Mg N ha^{-1}, respectively, in a 13-year period. An experiment

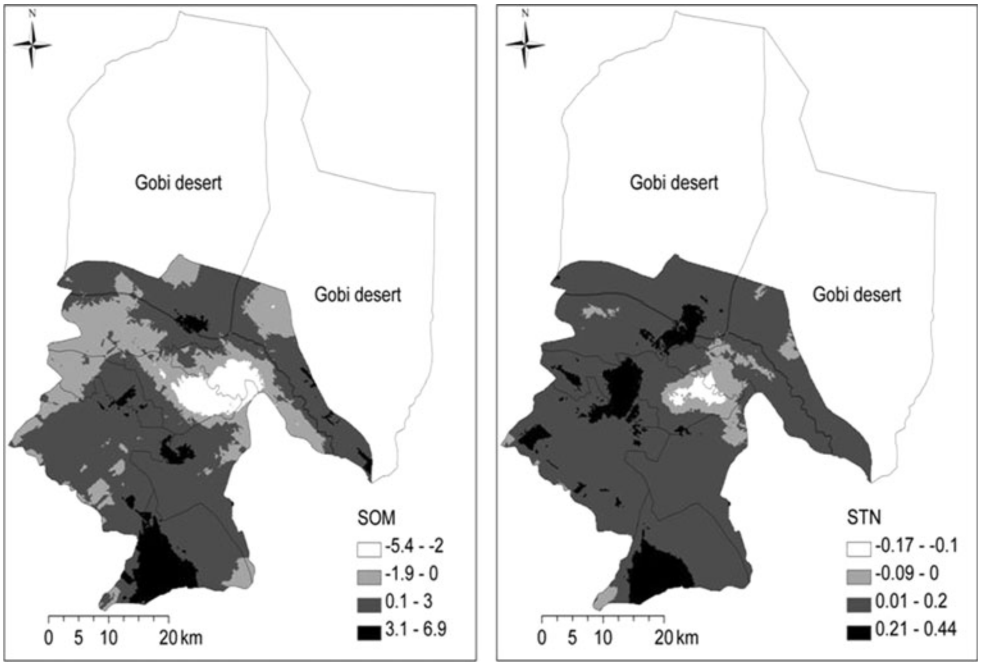

Fig. 4 Temporal variation maps of soil organic matter (SOM) and total nitrogen (STN) from 1982 to 2008

(wheat–wheat–maize cropping system) in the middle of the Heihe River has shown that the long-term application of organic manure alone or combined with mineral fertilizers improved SOC and STN (Su et al. 2006). Nevertheless, Van der Hoek and Bouwman (1999) have pointed out the influence of scale on nutrient balance results and stressed that soil nutrient balances could be quantified at field scales only. More research is therefore needed to study on the impact of continuous mineral fertilizer combined with manure application every other year on SOC contents and soil nutrient at regional scale.

Conclusions

Soil organic matter and STN contents increased significantly in the large part of sampling areas of the Linze oasis from 1982 to 2008. The spatial patterns of SOM and STN were obvious, which could be seen from their spatial distribution maps and the understanding such structure may provide new insights into rational soil management. Temporal variation maps of SOM revealed an increasing trend in areas where organic manures were plentiful and chemical fertilizers were regularly applied, and a decreasing trend where the application of organic manures was deficient or the soil salination were aggravating. STN increased due to the large amounts of nitrogen fertilizer applied. It is concluded that the continuous application of chemical fertilizer in combination with organic manures (approximately 45 m^3 ha^{-1}) every other year is a proper cultivation method for increasing the SOC and STN pool in the Linze County. Also, it appeared that the agricultural ecosystem in the oases of semi-arid regions has the potential capacity to accumulate organic carbon only if the appropriate or sustainable soil management measures are effectively conducted, especially in areas with limited cropland and dense population. The study team recommended that farmers plant more alfalfa in the saline soil area and transition area between oasis and desert, because alfalfa can provide food for cattle and its planting can improve the soil quality.

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