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Full Length Research Paper

Effect of land use and soil management practices on soil fertility quality in North China cities' urban fringe

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The objective of this study was to explore the spatial variation of soil fertility quality and the influence factors of human land use and soil management practices on soil fertility quality in North China cities' urban fringe of Beijing using data for 2007 and grey relational analysis (GRA) and geographic information systems (GIS). Soil total nitrogen, available phosphorus, available potassium, available copper, zinc, iron and manganese, soil organic matter and pH were measured. The GRA was used to calculate the grey relational degree and Kriging method was applied to map the spatial patterns of soil fertility quality. The distribution map of soil fertility quality showed that soil fertility quality was best in the southeast and well in the North, South, Northwest and East. The area of first-grade quality (I), second-grade quality (II) and third-grade quality (Ⅲ) was 120.10, 734.37 and 184.53 km^2, respectively. The main factors influencing the spatial distribution of soil fertility quality were land use and soil management practices. The increasing trend of soil fertility quality might be attributed to the widespread practices of straw returning and organic manure applications.

Key words: Soil fertility quality, spatial variability, land use, soil management practices, urban fringe, North China plain.

INTRODUCTION

Soil as a vital natural resource which performs key environmental, economic, and social functions. It is non-renewable within human time scales. Soil quality has been defined as the capacity of the soil to function within ecosystem and land use boundaries, to sustain biological productivity, maintain environmental quality and promote plant, animal and human health (Doran et al., 1996). High quality soils not only produce better food and fibre, but also help establish natural ecosystems and enhance air and water quality (Griffiths et al., 2010). Soil fertility changes and the nutrient balances are taken as key indicators of soil quality (Jansen et al., 1995). Soil fertility is commonly defined as the inherent capacity of a soil to supply plant nutrients inadequate amounts, forms, and in suitable proportions required for maximum plant growth (Von Uexkuell, 1988). Soil fertility quality varies spatially from field to larger region scale, and is influenced by both land use and soil management practices (Sun et al., 2003). Revealing spatial variability of soil fertility quality and its influencing factors are important to improve sustainable land use strategies (Qi et al., 2009).

It is reported that differences in fertilization, cropping system and farming pracices were the main factors influencing soil fertility quality at field scale (Liu et al., 2010). Some studies also showed the spatial variability of soil fertility quality at regional scale in China, such as in Yellow River Delta (Liu et al., 2006), Sichuan basin (Peng et al., 2009) and alluvial plain in Yangtze River Delta Region (Darilek et al., 2009). Changes in soil fertility quality were also reported in small watershed in Loess Plateau (Wang et al., 2009), low hilly red soil in subtropical region (Sun et al., 2003) and the black soil region in Northeast China (Zhang et al., 2007). In other areas, Amare et al. (2005) showed the spatial variability of soil fertility on mixed farming systems in Ethiopia. Samaké et al. (2005) also reported the spatial changes of soil fertility quality on different cultivation practices in Sahel of Mali.

The aforementioned studies were mostly conducted on

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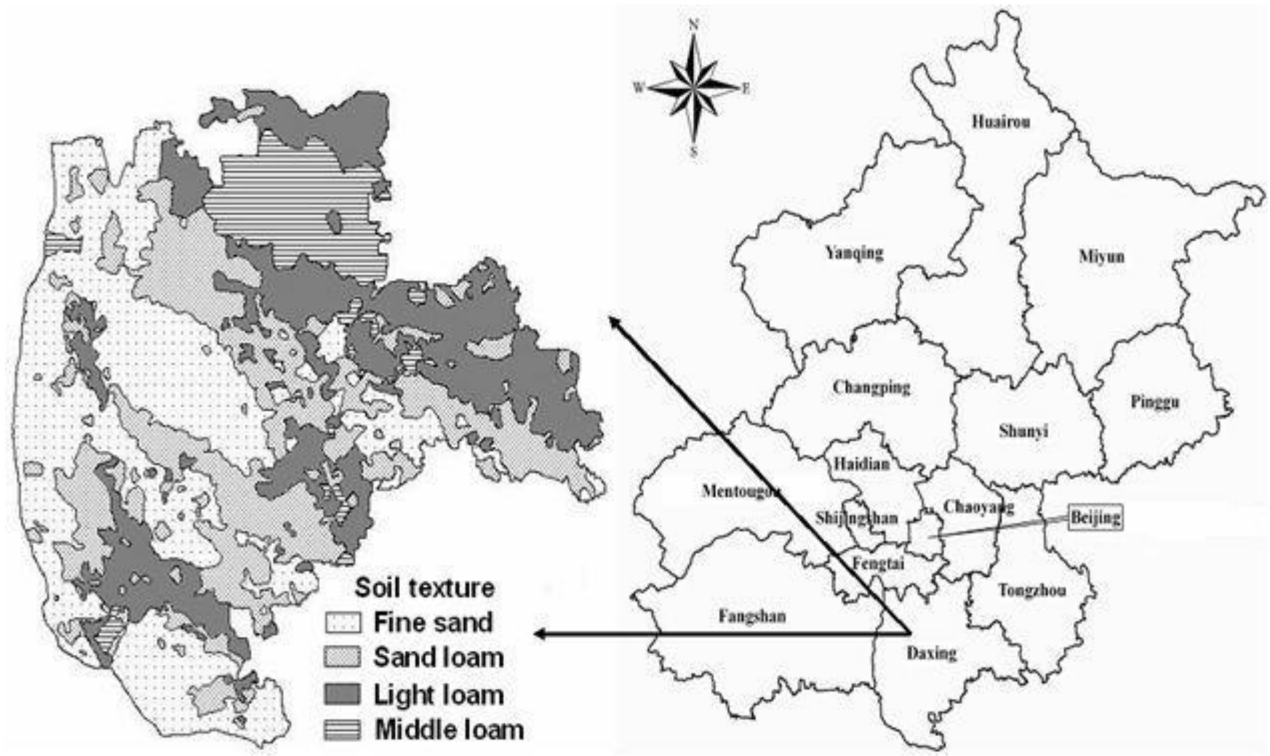

Figure 1. Map of soil texture in Daxing District, Beijing.

the changes of soil fertility quality at county level, with a study area varying from a few to several thousand square kilometers. These studies revealed the effects of parent materials, topography, land use and soil management practices on soil fertility quality spatial variability. Other studies also showed the impacts of land use and climatic condition change on the variability of soil fertility quality (Geissen et al., 2009; Wang et al., 2007). However, little attention has been paid to the changes of comprehensive quality of soil fertility using geographic information systems (GIS) combined with mathematical model at a larger scale in North China cities' urban fringe.

Urban areas have intensive human activities, and soil quality in urban areas is closely related to human health and food safety (Hu et al., 2006, 2007). In the cities' urban fringe, accelerating urbanization has led to highly intensified use of lands in those areas in recent years, resulting in significant effects on soil quality in these fringe zones (Hu et al., 2004; Pan and Zhao, 2007; Cao et al., 2007). Daxing district is located in the south of the Beijing urban area. It is a typical cities' urban fringe of Beijing, China. With the rapid growth of the economy, it has experienced rapid changes in land use and soil management practices which have influenced the soil fertility quality and spatial distribution patterns in the cities' urban fringe areas. This study investigated the spatial variability of soil ferility quality in Daxing district using grey relational analysis (GRA) and GIS in 2007. The purpose of this study were to assess soil fertility quality changes in space, and to explore the influencing factors of human land use and soil management practices on spatial variation of soil fertility quality. Results could be helpful for better use and management of soil resource in the cities' urban fringe areas.

MATERIALS AND METHODS

Study sites

The study area was in Daxing district, Beijing, with a total area of 1039 km^2. It is the nearest district to the capital Beijing among all districts. The Jingjintang highway, Jingkai highway, and the No. 104 national highway run across the district (Figure 1), which have been developed into urban zones (Hu et al., 2007; Kong et al., 2009). With the social economic development, the population in Daxing district increased from 480 thousand in 1980 to 576 thousand in 2007. The gross domestic product (GDP) was increased from 2.19 billion RMB in 1980 to 214.5 billion RMB in 2007. Daxing district has been a cities' urban fringe area over 20 years. This district supplies grain, vegetable and fruits to Beijing.

The study area lied between 39°26′ to 39°51′ N and 116°13′ to 116°43′ E on the east bank of the Yongding River on the North China Plain. In this region, the altitude slightly from the Northwest to the Southeast, with elevations ranging from 15 to 45 m. A slope was only 0.08 and 0.10%. Soil is sandy in the west and it is loamy in the Northeast (Figure 1). In the area, the climate was warmly temperate and semi-humid with a monsoon with an annual temperature of 11.5°C, and a frostless period of 190 days. The mean annual precipitation was569 mm with an uneven distribution, of which 76.2% was concentrated from July to September each year (Hu et al., 2006).

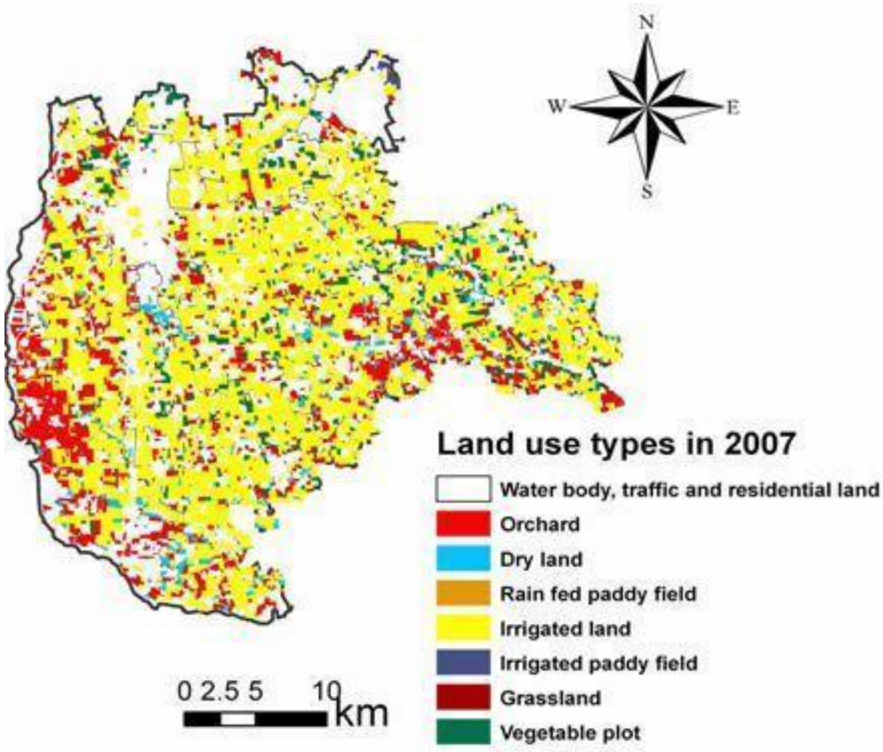

Figure 2. Land use map of Daxing disrtict in 2007.

At the beginning of 1980s, paddy fields (wheat and corn) were dominant in the land use types of at this region. Since then, however, with economic development, the economic crops (fruits and vegetables) have been encouraged by the local government in and around Beijing. Orchards and irrigated land are now common in Daxing district (Figure 2).

Data presentation

Data used in this study include some thematic maps such as land use maps, soil type, some textual materials of social-economic and soil management practices. The land use maps were compiled in 2007 (Figure 2). The textual materials in the study area plus knowledge obtained in field investigation were used to determine weight matrix for evaluation of soil fertility quality evaluation.

Soil sampling and soil analysis

In this study, 201 samples were collected after crops were already harvested in September 2007 (Figure 3). The land use forms and management practices of each soil sample site were investigated when sampling soil. Samples were taken at depths from 0- to 0.2-m depth. The longitude and latitude of each sample were located by global positioning system (GPS). Soil samples were air-dried, divided and passed through a 2-mm nylon sieve for measuring available phosphorus, available potassium, available iron, and soil pH. Part of the air-dried and sieved samples were grounded and passed through either a 1-mm or a 0.25-mm nylon sieve for determining available copper, available zinc, total nitrogen and soil organic matter (SOM). The fresh samples were used for measuring available manganese.

The SOM and total nitrogen were detetermined using the hydrometer method (Gee and Bauder, 1986) and the semi-micro Kjeldahl method (Bremmer and Mulvaney, 1982), respectively. Available phosphorus was determined by the Burriel-Hernando method (Díez, 1982). Available potassium was got by extracting soil with 1mol L^{-1} ammonium acetate (NH_4Ac) and then measured by an atomic absorption spectrometer (Sun et al., 2003). Soil pH was determined from a 1:1 soil: water mix using a standard pH meter and electrodes (Robert et al., 2008). Soil available copper, zinc, iron and manganese were extracted using diethylenetriamine penta-acetic acid (DTPA) and measured using atomic absorption spectrophotometry method (Lindsay and Norvell, 1978).

Methodology for evaluation of changes in soil fertility quality

Soil fertility quality indicators selection

Soil quality indicators have been defined as soil processes and properties that are sensitive to changes in soil functions (Doran and Jones, 1996; Aparicio and Costa, 2007). Considering the natural conditions of Daxing District, nine indicators were selected in this study (Table 1). They are total nitrogen, available phosphorus, available potassium, SOM, pH and available copper, zinc, iron and manganese. Soil organic matter, total nitrogen and available phosphorus, potassium, copper, zinc, iron and manganese show the nutrient status of the soil for plants. SOM and pH inflence the habitat of soil organisms. Therefore, these factors were adopted to reflect the various aspects of soil fertility quality with respect to plant growth.

Weights of the indicators

The contribution of each indicator for soil fertility quality is usually

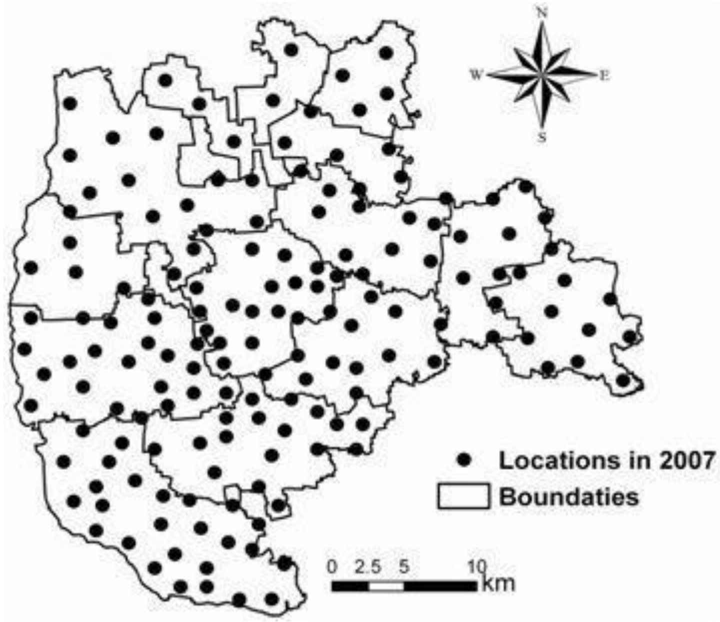

Figure 3. Soil sampling locations in 2007.

Table 1. Assessment indicators for soil fertility quality.

Indicator	TN	AP	AK	SOM	pH	Fe	Mn	Cu	Zn
Weight	0.1910	0.1188	0.1187	0.2207	0.0999	0.0639	0.0632	0.0647	0.0591

TN, total nitrogen; AP and AK, available phosphorus and potassium; SOM, soil organic matter; Fe, Mn, Cu and Zn, available iron, manganese, copper and zinc.

different, which can be indicated by a weight value. The analytical hierarchy process (AHP) was used to determine the weights of each factors in this study (Yang et al., 2008). AHP was developed by Saaty (1977) in 1970s for environmental assessment, and was a system analysis tool for solving decision problems (Li et al., 2004). Based on the hierarchy structure, the relative importance of the indicators was analyzed according to the advice given by 20 experts having related backgrounds.Then the relations between every possible pair of factors were obtained, and the comparison matrix of nine factors was established. The eigenvector of matrix was seeked using sum-product method and consistency check to determine the weight value.

GRA evaluation of changes in soil fertility quality

Soil fertility evaluation is a process of judgment and identification for high or low of fertility. To solve the uncertainties of soil fertility quality evaluation, the GRA method was used in this study (Yang et al., 2008). The mathematics of GRA is derived from space theory (Deng, 1988). GRA is a method by which the complex multiple response optimization can be simplified into the optimization of a single response grey relational coefficient (Yang et al., 2008; Zeng et al., 2007). It is carried out to obtain the relationship between the main indicators and other reference indicators in a given system. The GRA can be expressed as:

Let the reference sequence be

$$x_0 = (x_0(1), x_0(2) \ldots, x_0(n)) \qquad (1)$$

Denote the m sequences to be compared as:

$$x_i = (x_i(1), x_i(2) \ldots, x_i(n)), \quad i=1,2,\ldots,m \qquad (2)$$

Normalize the sequences to ensure that all of them are in the same order, and the normalised sequences can be denoted as:

$$x_i^* = (x_i^*(1), x_i^*(2), \ldots, x_i^*(n)), \quad i=1,2,\ldots,m \qquad (3)$$

The grey relational coeffcient between the compred squence, x_i and the reference sequence, x_0, for the jth factor, (j=1,2,…,n), is estimated as:

$$\xi_i(j) = \frac{\min_i \min_j \left| x_0(j) - x_i^*(j) \right| + \sigma \max_{ij} \max \left| x_0(j) - x_i^*(j) \right|}{\left| x_0(j) - x_i^*(j) \right| + \sigma \max_{ij} \max \left| x_0(j) - x_i^*(j) \right|} \qquad (4)$$

where $\xi_i(j)$ is grey relational coeffcient and its value range is [0,1], $x_i^*(j)$ is the value of factor j of grid i, σ is resolution coefficient and its value range is [0,1], and generally, the value is assumed to be 0.5.

Thus, the grey relational degree of soil fertility evaluation model can be written as follows:

$$R_i = \sum_{j=1}^{n} W_j \cdot \xi_i(j) \qquad (5)$$

Table 2. Soil fertility quality classification.

Value	[0.85, 1.00]	[0.70, 0.85]	[0.55, 0.70]	[0.40, 0.55]	[0.00, 0.40]
Classification	Best (Ⅰ)	Better (Ⅱ)	Well (Ⅲ)	Worse (IV)	Worst (V)

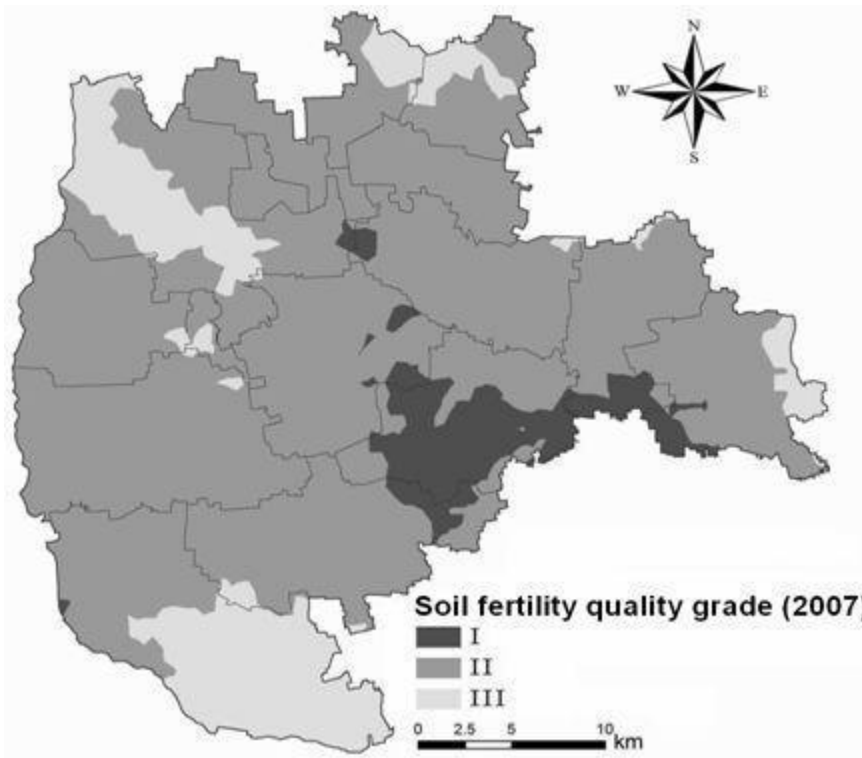

Figure 4. Distribution map of soil fertility quality in 2007.

where R_I is grey relational degree of grid *i*, W_J is the weight for factor *j* of grid *i*, and R_I [0,1].

Supported by the spatial analysis module of ArcGIS 9.3, the grey relational degree R_I could be determined by Equation (5). The relational coefficient of indicators was calculated by selecting the optimum value of every evaluating indicator as the referring value. According to soil fertility quality classifications of FAO (FAO, 1976), the grey relational degree of every evaluation unit was divided into five classes (Table 2) to obtain the spatial distribution map of the soil fertility quality (Figure 4).

RESULTS

Spatial distribution features of soil fertility quality

Evaluation of soil quality was often used to solve particular problems, such as soil erosion, soil pollution and soil nutrient depletion (Doran and Jones, 1996). Soil fertility is a key function of soil quality. In this paper, the distribution maps of soil fertility quality classification in 2007, generated by using GRA and Kriging method, showed that the spatial distributions of soil fertility quality (Figure 4). A trend in soil fertility quality was obvious: it decreased gradually from South-east to North-west. The first-grade quality (I) was mainly distributed in the South-east of Daingxing district (Anding), and the area was 120.10 km^2, or 11.56% of the total area, better quality (II) was widely distributed in the research area, and the third-grade quality (III) was mainly in the North (Jiugong and Yizhuang), South (Yufa), Northwest (Huangcun), East (Changziying and Caiyu) and middle part (Tiantanghe) (Figure 4), which covers 184.53 km^2, or 17.76% of the total area. Based on the grade distribution, the second-grade quality (II) occupied most of the area in 2007.

Influence factors of soil fertility quality

The land use types would be a main influence factor responsible for soil fertility quality. There were a total of eight land use types in 2007 (Figure 2). The land use types in Daxing district within the last 20 years had a fundamental change. There was a large decrease in paddy field from 273.24 km^2 in 1980 to 19.82 km^2 in 2007. This was because of the water shortage caused by considerable reduction of inflows from upstream of Yongding River (often run-dry) (Hu et al., 2007). The irrigated land increased from 199.50 km^2 to 512.73 km^2 (or 49.35% of total area), and it has become the dominant land use type in Daxing district. The areas of dry land had somewhat reduced. The vegetable plot has increased from 2.90 to 18.74% of total area and the orchard area had greatly increased greatly from 8.98 to 128.00 km^2.

The soil fertility quality was significantly different among land use types (Figures 2 and 4). The soil fertility quality in irrigated land and orchard was significantly higher than other land use types. The soil fertility quality in traffic and residential land was the lowest. In 2007, the land use types of Yufa, Jiugong, Yizhuang and Huangcun town mainly on traffic and residential lands, with vegetable plots and orchands subsidiary. Its fertility quality was well (III) because of intensive use as traffic and residential land by people. This human activities enhanced the mecapedocompaction, pedoturbation and trampling, leading to declining in the fertility quality (Schuler et al., 2000), and the intensive inputs and management for vegetable lands and orchards by farmers to improve the fertility quality (Hu et al., 2007).

With the economic development, these lands became irrigated lands and orchards to supply foods for Beijing City. According to the investigation results, the orchands area of Daxing was 128.00 km^2, (12.32 % of the total area) and vegetables area were 194.67 km^2, accounting for 18.74% of the total area in 2007. Moreover, Anding town was important base producing grain, vegetable and fruit production in Daxing district. To achieve bigger yield and improve the quality of the grain crops, vegetables and fruits, local farmers applied large amounts of organic manure for many years (Hu et al., 2007), resulting in best fertility quality in Anding town.

In addition, the different soil management practices would also be one of the main factors affecting the soil fertility quality. Since 1980s, introduction of the household responsibility system, the organic manure applications increased over years and the area with crop straws into soil reached 6258 km^2 in 2007. More chemical fertilizer (300 to 500 kg N ha^{-1}) was also used to produce high crop yields (Hu et al., 2007), cropping intensity also increased to two crops per year. Positive relationships between long-term nitogen fertilizer additions and soil fertility quality have been reported (Fan et al., 2005). In 2007, the yield of winter wheat was 4931 kg ha^{-1} and maize yield was 5507 kg ha^{-1}. A lot of crop straws were returned to land. In the Southeast (Anding), due to the better soil management practice which applied a huge amount of organic manure and crop straws to improve the SOM (Karlen et al., 2006; Naranjo de la et al., 2006), resulting the excellent quality in 2007. We suspect that, the addition of organic manure and high use of chemical fertilizer would have exceeded lots of crops returned to land, which would have contributed to building up the high soil fertility quality. Our results supported the idea that, soil fertility quality was mainly affected by land use patterns and soil management practices in North China cities' urban fringe (Li et al., 2004; Huang et al., 2007).

DISCUSSION AND CONCLUSIONS

In the same climatic region, the land use types and soil management practices would be the main influence factor responsible for soil quality (Riley et al., 2005; Reynolds et al., 2007; Mostafa et al., 2009). In many studies, it was found that the soil fertility quality was high in the irrigated land and orchard of various land use types in Daxing district (Zhang, 1996; Wang, 2002; Kong et al., 2005; Kong et al., 2006). Similar results were aslo obtained in our study.

This research, selecting Daxing district in Beijing as study area, assessed the spatial variability of soil fertility quality and explored the variation features of soil fertility quality under different land use and soil management practices. Soil fertility quality in the cities' urban fringe (Daxing district) of Beijing changed significantly in 2007. The Kriging-interpolated maps showed that, soil fertility quality was high in the Southeast, was low in the Northern, Southern, Northwest and Eastern of this district.

The main factors influencing soil fertility quality were land use and soil management practices. The spatial distribution pattern of soil fertility quality matched the distribution of land use. Among various land use types, irrigated lands and orchards had the best quality.

We concluded that the potential soil productivity was studied in this paper. For the fact that soil fertility was a complex process, there was need for it to be corrected by soil physical, biochemistry and environmental factors to form the actual productivity of land. In addition, land use change and soil management practice and their influences on soil fertility quality are rather a complicated process, and require further research.

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