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Full Length Research Paper

Spatial and temporal patterns of soil fertility quality and analysis of related factors in urban-rural transition zone of Beijing

Jing-wei Jin[1,2,3], Hui-chun Ye[1], Yue-fei Xu[2], Chong-yang Shen[1] and Yuan-fang Huang[1]*

[1]Department of Soil and Water Science, College of Resources and Environment, China Agricultural University, Beijing 100193, China.
[2]Northwest A& F University, Yangling, Shaanxi 712100, China.
[3]Institute of Soil and Water Conservation; Chinese Academy of Sciences & Ministry of Water Resources, Yangling, Shaanxi 712100, China.

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The objectives of this study were (i) to assess soil fertility quality changes in time and space using grey relational analysis (GRA) and geographic information systems (GIS) in the urban-rural transition zone of Beijing and (ii) to explore the variation features of soil fertility under different land use types and soil management practices. The distribution map of soil fertility quality showed that soil fertility quality was best in the north, south, southeast and middle part of the district in 1980. The first-grade quality (I) was mainly in the southeast and the third-grade quality (III) was mainly in the north, south, northwest, east and middle part of the district. The area of first-grade quality (I) and the third-grade quality (III) increased from 79.17 to 120.10 km^2 and from 111.59 to 184.53 km^2 from 1980 to 2007, respectively, while the area of second-grade quality (II) decreased from 81.64 to 70.68% of the total land area from 1980 to 2007. 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-temporal variability, geographic information systems (GIS), grey relational analysis (GRA), urban-rural transition zone, land use, soil management practices.

INTRODUCTION

Soil as a vital natural resource, performs key environmental, economic and social functions. It is non-renewable within human time scales, develops slowly and changes gradually over time, showing great spatial variability (Borut et al., 2008). The high quality of soil does not only produce better food, but also helps establish natural ecosystems and enhance air and water quality (Griffiths et al., 2010). Soil fertility is commonly defined as the inherent capacity of a soil to supply plant nutrients in adequate amounts, forms and in suitable proportions required for maximum plant growth (Von, 1988). Soil fertility changes and the nutrient balances are taken as key indicators of soil quality (Jansen et al., 1995). Soil fertility quality varies spatially and temporally from field to region scale, and is influenced by both land use and soil management practices (Sun et al., 2003). Understanding variability of soil fertility quality and its distribution 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 have also shown the spatial or temporal 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 theblack soil region in northeast China (Zhang et al., 2007). In other areas, Amare et al. (2005) showed the

*Corresponding author. E-mail: yfhuang@china.com.

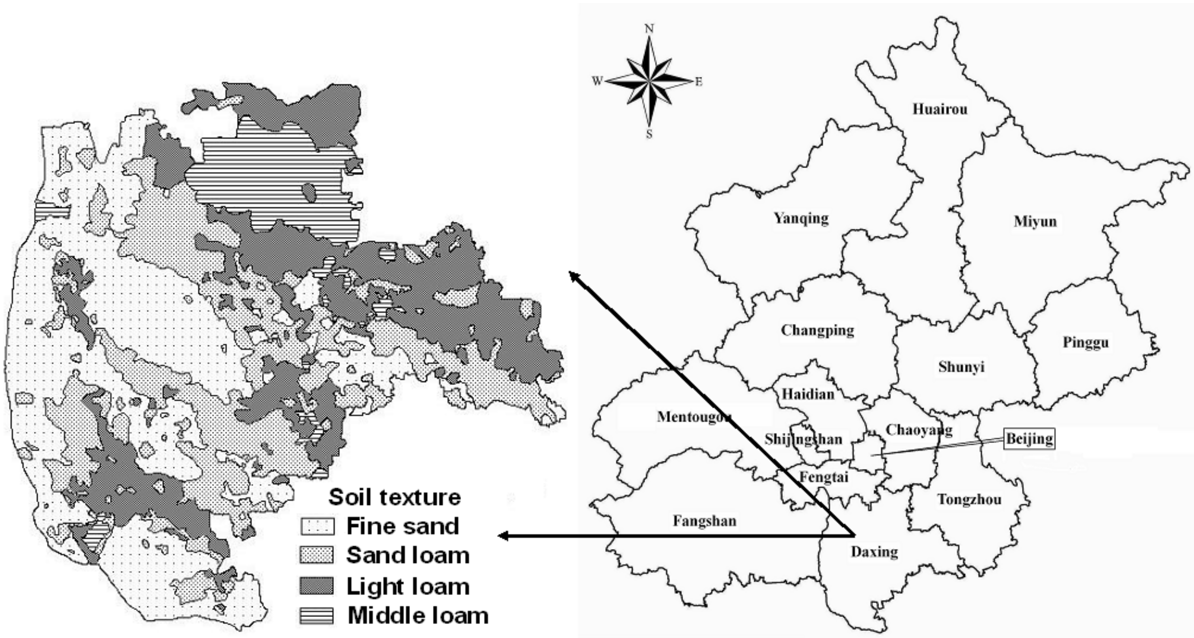

Figure 1. Map of soil texture in Daxing District, Beijing

spatial variability of soil fertility on mixed farming systems in Ethiopia. Samaké et al. (2005) also reported the spatial-temporal variability of soil fertility quality for different cultivation practices in Sahel of Mali.

The aforementioned studies were mostly conducted on the changes of soil fertility parameters at county level, with a study area varying from a few to several thousand aquare kilometers, and the temporal scale was a long-term between 10 and 20 years. These studies revealed the effects of parent materials, topography, land use and soil management practices on spatial variability of soil. Other studies also showed the impacts of land use and climatic condition change on the variability of soil quality (Wang et al., 2007; Geissen et al., 2009). However, little attention has been paid to the long-term changes of comprehensive quality of soil fertility using geographic information systems (GIS) combined with mathematical model at a larger scale in transition zone between urban and rural areas.

Urban areas have intensive human activities, and soil quality in herein is closely related to human health and food safety (Hu et al., 2006, 2007). In the urban-rural transition zone, 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 transition zones (Hu et al., 2004; Pan and Zhao, 2007; Cao et al., 2007). The objectives of this research were to assess soil fertiliy quality changes in time and space using GIS and grey relational analysis (GRA) in Daxing district, China, from 1980 to 2007, and explore the influence factors of land use types and soil management practices on spatio-temporal variation of soil fertility quality.

MATERIALS AND METHODS

Study area

The study area was in Daxing district, a typical urban-rural transition zone of Beijing, China, with a total area of 1039 km^2. Between Beijing and Daxing district, there are Fengtai and Chaoyang district (Figure 1), which have been developed into urban zones (Hu et al., 2007). With the development of society and economy, it has experienced rapid changes in land use and soil management practices which might have influenced the soil fertility quality and spatial distribution patterns in this study. The population in Daxing district increased from 480,000 in 1980 to 576,000 in 2007. The Gross domestic product (GDP) also increased from 2.19 billion RMB in 1980 to 214.5 billion RMB in 2007. Daxing district has been an urban-rural area over 20 years. This district supplies grain, vegetable and fruits to Beijing.

The study area lies 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 increases from the northwest to the southeast, with elavations ranging from 15 to 45 m. The slope was only 0.08 and 0.10%. Soil is sandy in the west and loamy in the northeast (Figure 1). In the area, the climate was warm temperate semi-humid monsoon with an annual temperature of 11.5℃ and a frostless period of 190 days. The mean annual precipitation was 569 mm with an uneven distribution, of which 76.2% was concentrated from July to September each year (Hu et al., 2006).

At the beginning of the 1980s, paddy fields (wheat and corn) were dominant land use types at this region (Figure 2). Since then, however, with economic development, the economic crops (fruits and vegetables) have been encouraged by the local government in and around Beijing so that orchards and irrigated land are now common in Daxing district (Figure 3).

Data presentation

Land use data were derived from several sources: aerial photo-

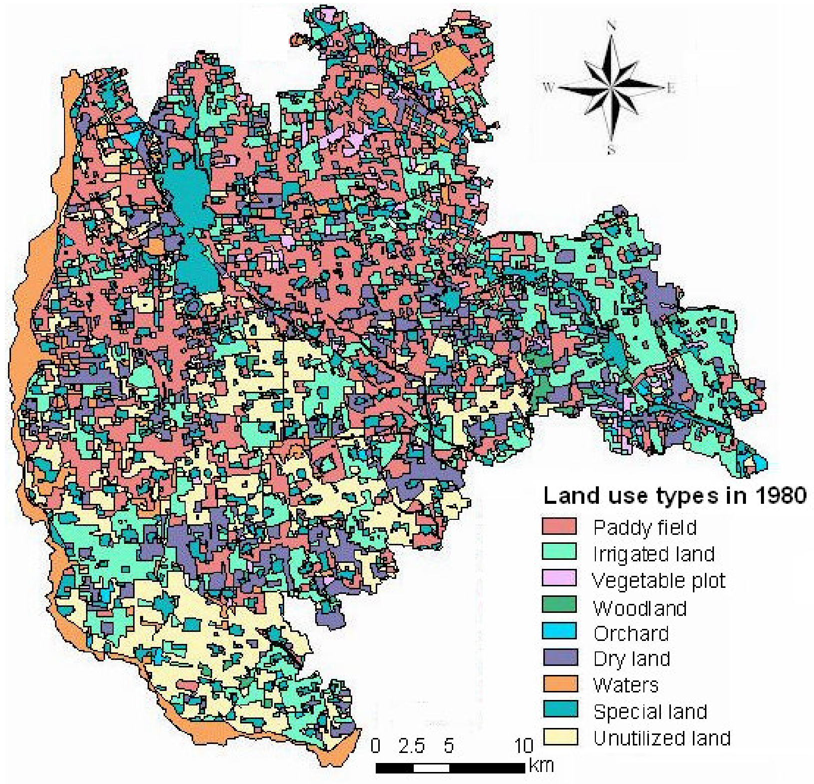

Figure 2. Land use map of Daxing District in 1980.

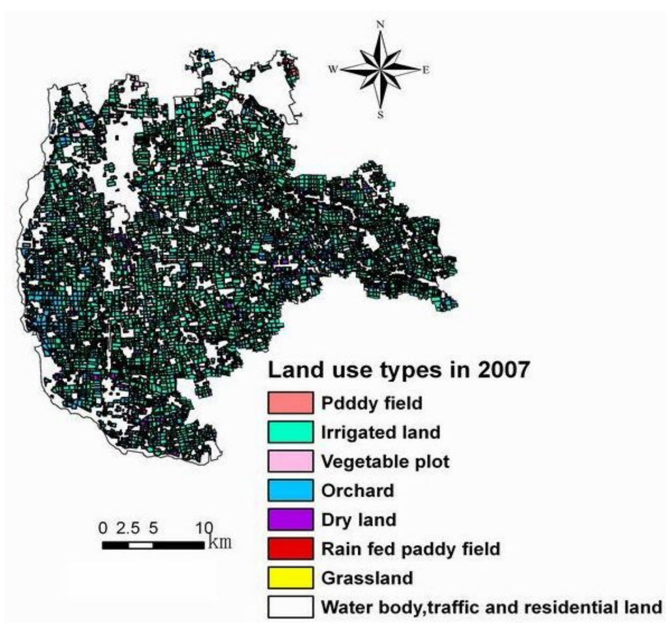

Figure 3. Land use map of Daxing District in 2007.

graphs, current land use map, Second National Soil Survey (SNSS) map, and fieldwork. The aerial photographs, 1:10,000 for both 1980 and 2007, were obtained from the Department of Surveys and Mapping (DSM). These had been scanned and / or digitized into computer. The land use was classified into nine and eight primary types according to "National Technical Regulation of the Current Survey of Land Use in China" in 1980 and 2007, respectively (Figures 2 and 3). The soil management practices in

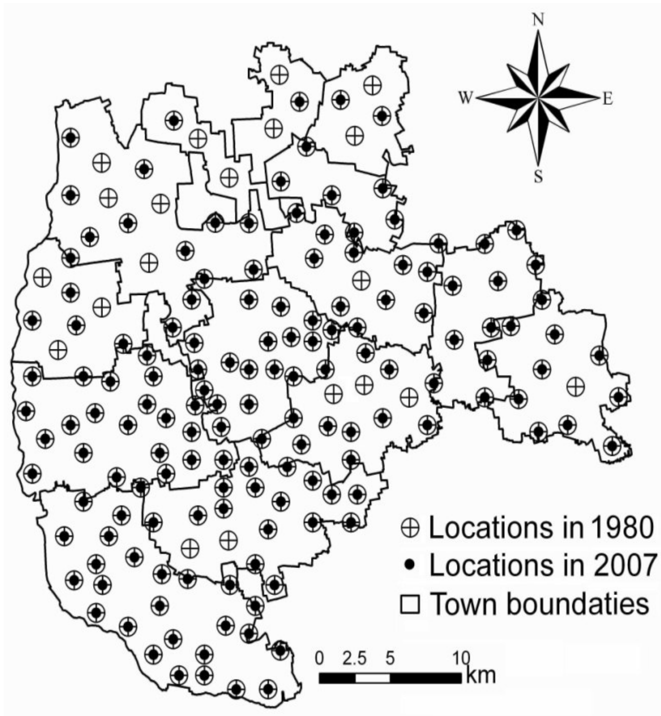

Figure 4. Soil sampling locations in 1980 and 2007.

the study area in addition to knowledge obtained in field investigation were used to determine weight matrix for evaluation of soil fertility quality.

Soil sampling and analyzing

Soil samples were taken in two different years in Daxing district, China. The first sampling took place in 1980 and a total of 221 samples were obtained through retrieving the datasets released by the National Soil Survey (NSS, 1995). The second sampling was conducted in 2007 and a total of 201 sampling sites were set as closely as possible to the sampling sites in the NSS in 1980 (Figure 4). The geographic coordinates of each sample were obtained by Global Positioning System (GPS). The soil samples were collected from 0 to 20 cm depth. The land use forms and management practices of each soil sample site were investigated when sampling soil. 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 or 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 measured by the Olsen method (Olsen et al., 1954). Available potassium was gotten by extracting soil with 1 mol L-1 ammonium acetate (NH_4Ac) and then measured by an atomic absorption spectrometer (Sun et al., 2003). Soil pH was determined by a pH meter after extraction from a soil - water ratio of 1:1 (Robert et al., 2008). Soil available metallic micronutrients (copper, zinc, iron and manganese) were extracted with diethylenetriaminepentaacetic acid (DTPA) and then analyzed by atomic absorption spectrophotometry (Lindsay and Norvell, 1978).

Soil fertility quality indicators selection and weights of the indicators

Soil quality indicators have been defined as soil processes and properties that are sensitive to changes in soil functions (Doran et al., 1996; Aparicio and Costa, 2007). Considering the natural conditions of Daxing District, nine indicators (Table 1) were selected in this study. The contribution of each indicator for soil fertility quality is usually different, which can be indicated by a weight value. The analytical hierarchy process (AHP) was used to determine the weights of each factor in this study (Yang et al., 2008). 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 judgement 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 follows;

Let the reference sequence be;

Table 1. Assessment indicators for soil fertility quality.

Indicator	Total nitrogen ($g\ kg^{-1}$)	Available phosphorus ($mg\ kg^{-1}$)	Available potassium ($mg\ kg^{-1}$)	SOM ($g\ kg^{-1}$)	pH	Available iron ($mg\ kg^{-1}$)	Available manganese ($mg\ kg^{-1}$)	Available copper ($mg\ kg^{-1}$)	Available zinc ($mg\ kg^{-1}$)
Weight	0.1910	0.1188	0.1187	0.2207	0.0999	0.0639	0.0632	0.0647	0.0591

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

Denote the *m* sequences to be compared as

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

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

$x_{i^*}=(x_{i^*}(1), x_{i^*}(2),\ldots, x_{i^*}(n)),\ i = 1,2,\ldots,m$ (3)

The grey relational coefficient between the compared sequence, x_i, and the reference sequence, x_0, for the *j*th factor, (*j*=1, 2,…, *n*), is estimated as:

$$\xi_i(j) = \frac{\min_i \min_j \left|x_0(j)-x_i^*(j)\right| + \sigma \max_i \max_j \left|x_0(j)-x_i^*(j)\right|}{\left|x_0(j)-x_i^*(j)\right| + \sigma \max_i \max_j \left|x_0(j)-x_i^*(j)\right|} \quad (4)$$

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

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

$$r_i = \sum_{j=1}^{n} w_j \times \xi_i(j) \quad (5)$$

Where r_i is grey relational degree of grid *i*, w_j is the weight for factor *j* of grid *i*, and $r_i \in [0, 1]$.

RESULTS

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 evaluting indicator as the referring value. According to soil fertility quality classifications of FAO (FAO, 1976) (Table 2), the grey relational degree of every evaluation unit was divided into five classes to obtain the spatial distribution map of the soil fertility quality (Figures 5 and 6).

Spatial and temporal distribution features of soil fertility quality

Soil fertility is a key function of soil quality. In this paper, the distribution maps of soil fertility quality classification between the two time intervals, generated by using GRA and Kriging method, show that the spatial distributions of soil fertility quality across the 27 years were comparable (Figures 5 and 6). In 1980, the best quality (I) was mainly distributed in the north, better quality (II) was widely distributed in the research area, and well quality (III) was mainly found in the central part, southeast and the southernmost region (Figure 5). The area in the north (Jiugong and Yizhuang) had higher quality than others. In 2007, the first-grade quality (I) was in southeast (Anding), 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 6). From 1980 to 2007, significant changes of soil fertility quality took place in Daxing district. It was improved in southeastern part and declined in northern, northwestern and eastern parts.

The area of first-grade quality (I) was 79.17 km^2, or 7.62% of the total area in 1980 (Table 3). In 2007, the area of second-grade quality (II) decreased (Figures 5 and 6), part of which was transformed to the first-grade quality (I). The area of the first and second-grade quality covered 11.56 and 70.68% of the total area, with a combined total area of 854.47 km^2, approximately equal to the second-grade quality (II) land area in 1980. The area of third-grade quality (III) increased from 111.59 in 1980 to 184.53 km^2 in 2007. Based on the grade distribution, the second-grade quality (II) occupied most of the area in 1980 and 2007. The areas of the first and third-grade quality occupied 18.36 and 29.32% of the total areas in 1980 and 2007, respectively.

Influence factors of soil fertility quality

We analyzed the land use changes from 1980 to 2007 and found remarkable changes in land use

Table 2. Classification of soil fertility quality of Daxing District.

Grey relation degree	Classification
0.85 - 1.00	Best (I)
0.70 - 0.85	Better (II)
0.55 - 0.70	Well (III)
0.40 - 0.55	Normal (IV)
0.00 - 0.40	Worse (V)

area in Daxing district. There was a large decrease in paddy field from 273.24 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 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 and vegetable plot had somewhat reduced. The orchard area had greatly increased from 13.29 to 146.82 km^2.

The soil fertility quality was significantly different among land use types (Figures 2, 3, 5, and 6).The soil fertility quality in paddy field, irrigated land and orchard was significantly higher than other land use types in 1980 and 2007. The soil fertility quality in unutillized land, dry land, traffic and residential land was the lowest. The soil fertility quality changed when land use type was changed; the soil fertility quality was improved when untillized lands were changed to irrigated lands and dry lands were changed to irrigated land and orchards, but declined when paddy fields were changed to traffic and residential lands (Figures 5 and 6).

The soil fertility quality in towns of Tiantanghe was improved after cultivation of irrigated land. Although when unutilized lands were changed to traffic and residential land in Yufa town, its soil fertility quality is still ordinary. In 1980, the northern part (Jiugong and Yizhuang) of Daxing district was occupied by paddy fields, where the soil fertility quality was best (I), and the northwestern part (Huangcun) was ccupied by paddy fields and dry lands, where the soil fertility quality was better (II). In 2007, the land use types of three towns were 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.

With the economic development however, 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 an important base producing grain, vegetable and fruit production in Daxing district. To achieve bigger yield and improve the quality of the grain crops, vegetable and fruit, 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. The small area of first-grade quality (I) in 1980 reflected a long history of cultivation with little or no fertilizer input (average 30 to 40 kg N ha^{-1} per year) and lower crop intensity (one crop per year or three crops over 2 roration) before 1980 (Hu et al., 2007). Most crop straws were also taken off the land and used as fuel for cooking and heating (Hu et al., 2007). Since the 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) and cropping intensity also increased to two crops per year. Positive relationships between long-term nitrogen fertilizer additions and soil fertility quality have been reported (Fan et al., 2005). Over the years, the yield of winter wheat in Daxing increased from 1500 in 1980 to 4931 kg ha^{-1} in 2007, and the maize yield increased from 3000 in 1980 to 5507 kg ha^{-1} in 2007. 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), excellent quality resulted in 2007. We suspect that during this time, the addition of organic manure and high use of chemical fertilizer would have exceeded the lots of crops returned to land, which would have contributed to bulid up the high soil fertility quality. Our results supported the idea that soil fertility quality was mainly affected by land use types and soil management practices in the urban-rural transition zone (Li et al., 2004; Huang et al., 2007). Since the adoption of best management practices in 1980s, the soil fertility quality in the soils in Daxing district had been improved and this should be attributed to the widespread practices of mulching and organic manure application.

DISCUSSION

In the same climatic region, the land use types and soil management practices would be main influence factor responsible for soil quality (Riley et al., 2005; Reynolds et al., 2007; Mostafa et al., 2009) and the changes in land use should contribute to the temporal variability in soil quality (Riley et al., 2005). In many studies, it was found that the soil fertility quality was high in the paddy field, irrigated land and orchard of various land use types in Daxing district (Zhang, 1996; Wang 2002; Kong et al., 2005, 2006). Similar results were also obtained in our study. Previous studies indicated that the soil fertility quality declined when the unutilized lands were reclaimed (Sun et al., 2003), but our results indicate that the soil fertility quality was improved when the unutillized lands were reclamed. The soil texture of unutillized land was

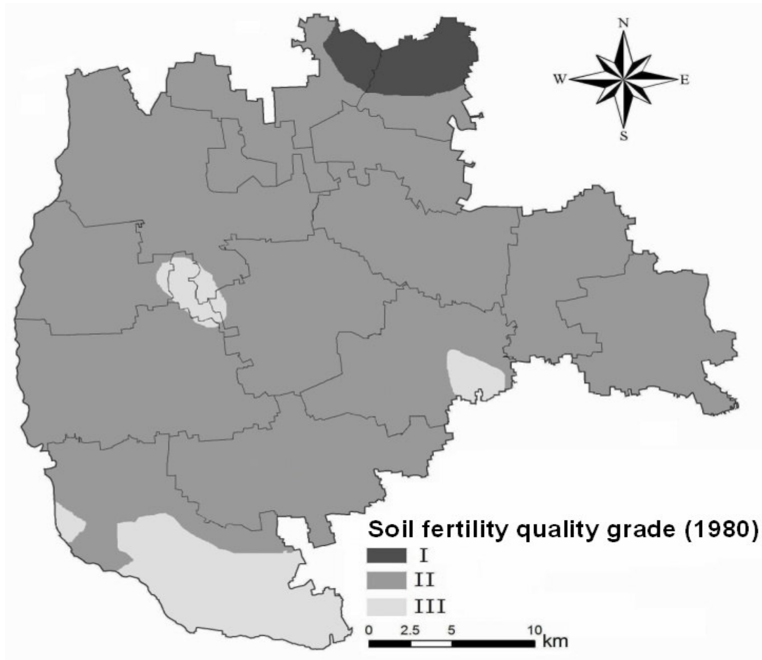

Figure 5. Distribution map of soil fertility quality in 1980.

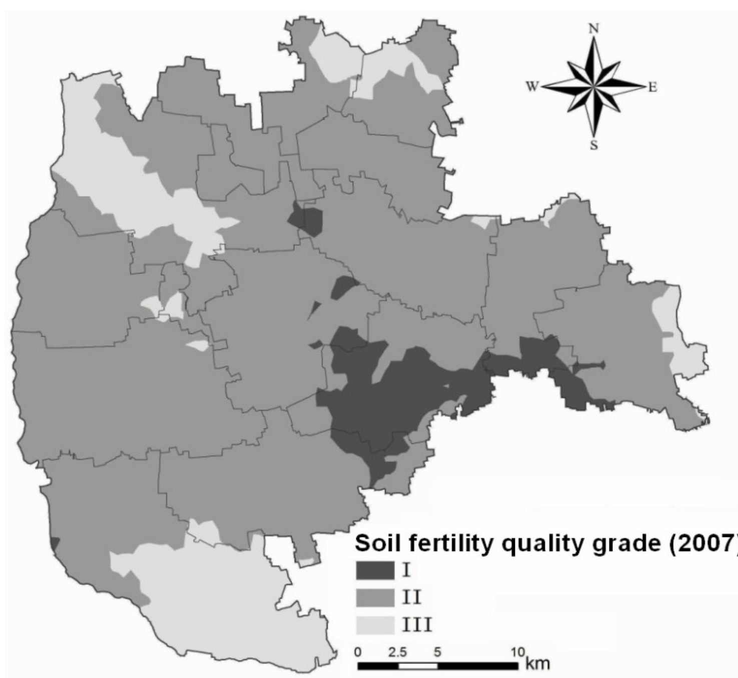

Figure 6. Distribution map of soil fertility quality in 2007.

sandy in the study area (Figure 1) and with the organic manure applications, the soil feritility quality was improved.

Although previous studies on soil fertility quality changes in China have shown the capture of the improving trend of soil feritility quality in the recent two decades (Wang 2002; Sun et al., 2003), they did not find the decreasing trend of soil fertility quality in some areas due to the intensive use land in recent years. Our study has well captured this trend, and this result would be useful for establishing better future management strategies for soil fertility quality in urban-rural transition

Table 3. Statistical results of soil fertility quality content for different grades at different times in Daxing District.

Time	Area and percentage	Soil fertility quality grade		
		I	II	III
1980	Area (km^2)	79.17	848.24	111.59
	Percentage (%)	7.62	81.64	10.74
2007	Area (km^2)	120.10	734.37	184.53
	Percentage (%)	11.56	70.68	17.76

zones.

Conclusion

This research, selecting Daxing district in Beijing as study area, assessed the spatial and temporal variability of soil fertility quality and explored the variation features of soil fertility quality under different land use and soil management pracices. Soil fertility quality in the urban-rural zone (Daxing district) of Beijing changed significantly during 1980 and 2007. The Kriging-interpolation maps showed that there was a decreasing trend for soil fertility quality from the north to the south across the district in 1980. The soil fertility quality was high in the southeast and low in the north, south, northwest and east in 2007. The soil fertility quality, classified into three classes, demonstrated that during the last 27 years, the area of first-grade quality (I) changed from 7.62 to 11.56% of the total area, second-grade quality (II) changed from 81.64 to 70.68% of the total area and third-grade quality (III) changed from 10.74 to 17.76% of the total area.

The main factors influencing soil fertility quality were land use and soil management practices, and the spatial distribution pattern of soil fertility quality matched the distribution of land use. Among various land use types, paddy fields, irrigated lands and orchards had the best quality. We therefore conclude that the changes in soil fertility quality appear to be a long term process and thus require a long standing study on the spatio-temporal variability of soil fertility quality. Meanwhile, land use change and soil management practice and their influences on soil fertilty quality are complicated processed and therefore require further research.

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