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Spatiotemporal Variability of Soil Organic Matter, Phosphorus and Potassium in Cultivated Fields of Southern Shenyang, China

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Abstract: Aimed to have a rational soil management of the cultivated fields in Sujiatun District, Shenyang, Liaoning Province of China, 358 soil samples (0-20 cm) were collected from the same sampling sites of the District in both 1980 and 2000, with each sample representing 100-120 ha of cultivated fields and the spatiotemporal variability of their Soil Organic Matter (SOM), available phosphorus (AP) and potassium (AK) over the two decades was investigated by using geostatistics and geographic information system. In both 1980 and 2000, the SOM and AK fitted normal distribution, AP fitted lognormal distribution and spherical models for semivariogram fitted all the variables. Semivariograms indicated that the SOM changed from a moderately spatial dependence in 1980 to a strongly ones in 2000. The AP was a little more, while the AK was a little less spatially dependent in 2000 than in 1980. The maps obtained with kriging showed a decreasing trend for SOM and AK and an increasing trend for AP over 20-year period. The spatiotemporal variability of these parameters might be affected by both intrinsic (soil formation factors) and extrinsic factors (soil management practices) and the input of chemical and organic fertilizers was thought to be one of the key factors affected the spatiotemporal variability of test soil properties. It was suggested that P application induced the increase of the spatial heterogeneity of AP in test area, while the low input of organic fertilizer and K made SOM and AK more homogeneous.

Key words: Geostatisics, phosphorus, potassium, soil organic matter, soil use, China

INTRODUCTION

Soils are characterized by a high degree spatiotemporal variability of their physical, chemical and biological properties[1-4]. The spatial variability occurs not only from pedogenetic processes, but also as a result of land use and soil management[5-7]. As for the temporal variability, it depends on the duration of natural and anthropogenic interference. As a consequence, soils exhibit remarkable spatiotemporal variability at either micro-or macro-scales[8] and the spatiotemporal variability at various scales is thought to be one of the principal explanations for the status and dynamics of some soil properties[9-11]. Rational soil management requires a deep understanding of how soil properties vary across space and time and soil sampling and testing could be used to develop maps that delineate the areas which we can benefit from, or to identify the areas of particular concern such as nutrient deficiency. The inherent issue in developing maps is the assumption that a soil property measured at a given place and a given time represents the surrounding unmeasured neighborhoods. The validity of this assumption depends on the spatiotemporal variability of the soil property. Geostastistics combined with Geographic Information System (GIS) has been proven to be useful in predicting the spatiotemporal distribution of soil properties in fields having a limited number of soil samples. The commonly used interpolation technique is kriging[12-14] and cokriging is also applied to predict the spatial distribution of soil properties[15,16]. In most previous studies, the application of geostatistical techniques was focused on relatively small-scale soil survey data[13,17], but in the recent years, some case studies on large-scale soil survey data also applied these techniques[3,6,18].

In this study, soil survey was made in 1980 and 2000 on the contents of Soil Organic Matter (SOM), available phosphorus (AP) and available potassium (AK) in cultivated fields (0-20 cm soil layer) in Sujiatun District, Shenyang, China and by means of geostatistics combined with GIS, the data collected were mapped to illustrate their geographic distribution and spatiotemporal variability, aimed to have a rational management on these soils.

MATERIALS AND METHODS

The survey was conducted in Sujiantun District, Shenyang, Liaoning Province, China. This District has a

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total area of 761 00 ha, of which, 40 369 ha are cultivated fields. It is located in the continental temperate monsoon zone, with dry-cold winters and warm-wet summers. Its annual mean temperature is 7.0°C, annual precipitation is 700 mm, 70% of which occurs from May to September and annual non-frost period is around 150 days. The soil in the east of this District is classified as Hapli-Udic Agrosols (brown soil) and those in the west are Stagnic Anthrosols (paddy soil) and Hapli-Udic Cambosols (meadow soil), according to Chinese Soil Taxonomy[19]. Maize (*Zea mays* L.) and rice (*Oryza sativa*) are the main crops in the southeast and southwest, respectively and vegetables dominate in the north of this District.

The average organic fertilizer input was estimated to be 28.5 and 15.0 kg ha^{-1} in 1980 and 2000, respectively,

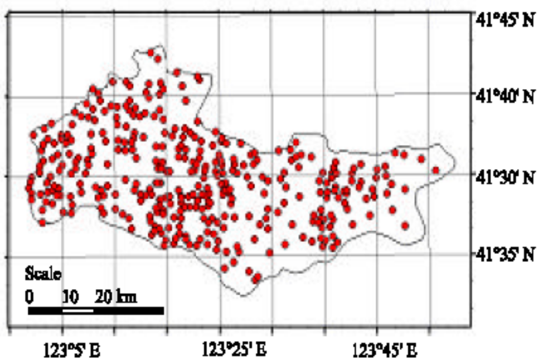

Fig. 1: Location of survey area and sampling sites

but in 2000, most of the organic fertilizer was applied to vegetable greenhouse fields that were not considered as cultivated fields in this study. The average chemical P and K fertilizer inputs were 15.0 kg P ha^{-1} and 7.5 kg K ha^{-1} in 1980, while those in 2000 were 39.2 kg P ha^{-1} and 28.4 kg K ha^{-1}, respectively[20,21].

358 soil samples (0-20 cm) were collected from the same sites in the survey area both in the Spring of 1980 and in April 2000, with the help of 1: 50 000 soil maps and GPS, each sample representing 100-120 ha of cultivated fields, which consisted of nine cores, one taken at the point located by GPS and the another eight taken within a rough cycle of about 100 m radius. The location of the survey area and the sampling sites were shown in Fig. 1.

All samples collected were taken to the laboratory for routine soil chemical analyses. Soil organic carbon concentration was determined by wet combustion and converted it into SOM content by multiplying 1.724; AP content was extracted with 0.5 mol L^{-1} $NaHCO_3$ solution at a nearly constant pH of 8.5 and determined by ascorbic method and AK was extracted with neutral 1 mol L^{-1} ammonium acetate solution and determined by atomic absorption spectrometry[22].

The soil spatial variability was characterized by determining the *semivariogram* and then, a modeled semivariogram was used in kriging, a weighted linear interpolation method with weights determined by semivariogram and variance minimization.

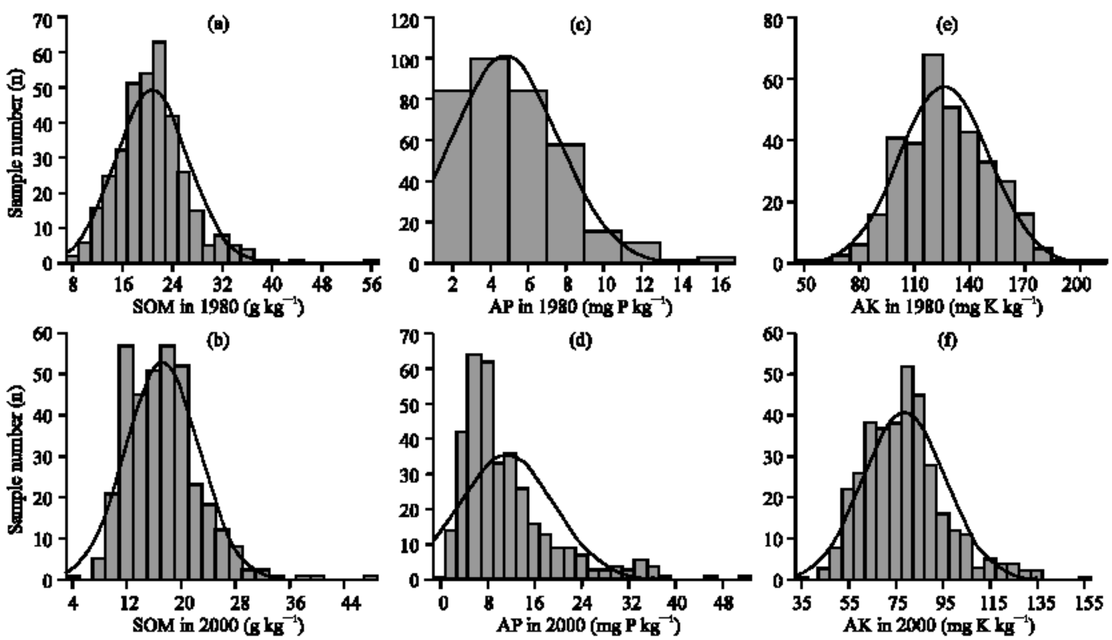

Fig. 2: Histogram (bars) and theoretical normal distribution (lines) of soil organic matter, available phosphorus and available potassium in 1980 and 2000

Table 1: Descriptive statistics of soil organic matter, available phosphorus and available potassium in 1980 and 2000

Variable	Year	N	Mean	S.D.	C.V.	Median	Minimum	Maximum	Skewness	Kurtosis
SOM (g kg^{-1})	1980	358	20.88	5.774	33.337	20.50	8.00	56.20	1.111	4.353
SOM (g kg^{-1})	2000	358	17.29	5.401	29.175	16.90	3.60	48.00	1.156	3.416
AP (mg P kg^{-1})	1980	358	4.82	2.820	7.951	4.00	1.00	16.00	0.877	1.009
AP (mg P kg^{-1})	2000	358	11.42	8.010	64.171	8.90	0.68	51.89	1.728	3.501
AK (mg K kg^{-1})	1980	353	126.5	24.384	594.59	125.00	45.00	205.00	0.115	0.215
AK (mg K kg^{-1})	2000	358	78.80	17.474	305.35	77.92	36.65	154.00	0.817	1.293

SOM, soil organic matter; AP, available phosphorus; AK, available potassium; S.D., standard deviation; C.V., coefficient of variance.

The experimental semivariogram in this study was obtained from omnidirectional semivariances, $\gamma(h)$, of a set of spatial observations, $z(x_i)$, which were calculated as:

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

where N(h) was the number of observations separated by a lag distance h. Semivariance estimations depended on such parameters as lag intervals, number of lags, anisotropy, etc. and experimental semivariograms were fitted by theoretical models that have well-known parameters nugget C_0, sill C_0+C and range of spatial dependence a[6].

Ideally, semivariance increases with the distance between sample locations, or lag distance (h), until a more or less constant value (the sill or total semivariance) at a given separation distance, called the range or spatial dependence. Samples separated by distances closer than the range are related spatially and those separated by distances further than the range are not spatially related. Semivariance ranges depend on the spatial interaction of soil process affecting each property at sampling scale used. The semivariance at h = 0 is called the nugget variance. It presents field or experimental variability, or random variability, which is undetectable at the scale of sampling.

Traditional statistical parameters and the distribution frequency of nutrients were calculated using SPSS (Statistical Package for the Social Sciences, 10.0, SPSS inc., 1999). Geostatistical parameters and the maps were obtained with kriging by using grid functions of Arc/Info software.

In this study, all data showed positive skewness and kurtosis statistics, indicating that the data of SOM and AK basically fitted normal distribution (Table 1 and Fig. 2). AP seemed to depart slightly from the normal distribution, but it fitted lognormal distribution (not shown).

RESULTS AND DISCUSSION

Descriptive statistics: The frequency distribution histograms for the data sets were shown in Fig. 2 and the descriptive statistics for the data of SOM, AP and AK in 1980 and 2000 were listed in Table 1. The mean and median were used as the primary estimate of central tendency and the Standard Deviation (SD), coefficient of variance (CV %) and the maximum and minimum values were used as the estimation of variability. Among the three pairs of data of SOM, AP and AK, available P had the greatest CV. The highest variability of AP might be attributed to fertilization, which was in line with the previous studies conducted by Chien *et al.*[5] and Sun *et al.*[7].

The mean and median for SOM and AK in both 1980 and 2000 were similar, with the median having smaller values than the mean, which indicated that the central tendency of SOM and AK distributions was not dominated by the outliers in cultivated fields. The mean and median values for AP in both 1980 and 2000 were quite different and the mean values were much greater than the median values (Table 1). The similarity of means and medians had been reported by Lascano and Hatfield[23] for soil water evaporation, Sutherland *et al.*[24] for natural soil ^{15}N abundance and Parktin *et al.*[25] for natural soil denitrification. However, Parkin *et al.*[25] also reported an occasional difference in the mean and median values of denitrification and they attributed this difference to the presence of localized areas with extremely high rate of denitrification.

The mean and median of SOM and AK were smaller in 2000 than in 1980, indicating a decreasing tendency of SOM and AK contents over the twenty years of cultivation and soil management, while those of AP were much greater in 2000 than in 1980, indicating an increasing tendency of AP contents in cultivated fields over the twenty years (Table 1 and Fig. 2).

Semivariogram Analysis: The experimental and model-fitted semivariograms for SOM, AP and AK in 1980 and 2000 were shown in Fig. 3 and the corresponding parameters in the fitted models Table 2. The best fitted models for all the semivariograms were spherical models. As determined by their semivariograms in Fig. 3, soil nutrients showed differences in their spatial dependence.

The ratio of C_0 to C_0+C for SOM content in 2000 was 24.11%, indicating that a strongly spatial dependence

Table 2: Parameters for best-fitted semivariogram models of soil organic matter, available phosphorus and available potassium in 1980 and 2000

Variable	Year	Model	Nugget C_0	Sill C_0+C_1	Nugget/sill $C_0/(C_0+C_1)$, (%)	Range a, (km)
Soil organic matter	1980	Spherical	14.559	45.253	32.17	19.341
Soil organic matter	2000	Spherical	10.223	42.407	24.11	26.051
Available phosphorus	1980	Spherical	5.795	8.466	68.44	13.128
Available phosphorus	2000	Spherical	42.484	69.915	60.77	15.132
Available potassium	1980	Spherical	547.250	1019.450	53.68	28.286
Available potassium	2000	Spherical	224.030	380.860	58.82	23.813

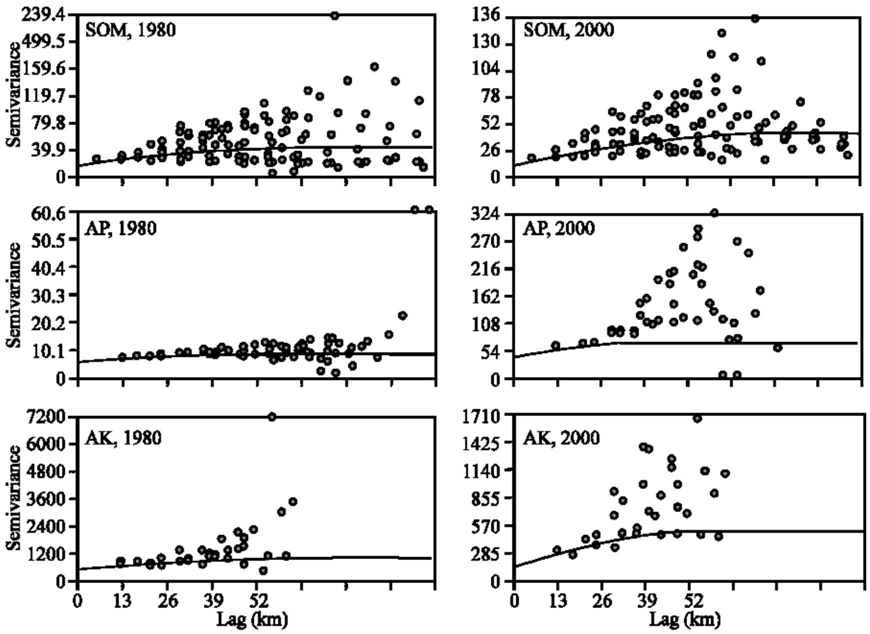

Fig. 3: Experimental and model fitted semivariograms for soil organic matter, available phosphorus and available potassium in 1980 and 2000

existed for SOM distribution. The ratio of C_0 to C_0+C for SOM content in 1980 and that for AP and AK contents in both 1980 and 2000 varied from 32.17 to 68.44% and hence, these five variables could be considered as moderately spatial dependence (Table 2 and Fig. 3). The spatial variability of soil properties may be affected by both intrinsic factors (soil formation factors, such as soil parent material, climate, topography and soil type) and extrinsic factors (soil management practices, such as fertilization, cultivation and irrigation). Usually, the strongly spatial dependence of soil properties could be attributed to intrinsic factors and the weakly spatial dependence could be attributed to extrinsic factors[5]. Therefore, there is generally a moderate spatial dependence among soil properties[13].

The ratio of C_0 to C_0+C for SOM content in 2000 was decreased by 8.06%, compared with that in 1980, indicating that SOM content was affected more by intrinsic factors than by extrinsic factors. This might be due to the change of fertilization system, in which, organic materials combined with chemical fertilizers was the leading way before 1980, but more and more chemical fertilizers and less and less organic materials were applied to the cultivated fields since the China's Land Reform Policy was taken into effect in the early 1980's. It suggested that the low organic material input into soils should reduce the influence of extrinsic factors on the SOM distribution.

The ratio of C_0 to C_0+C for AP content decreased by 7.67%, from 68.44% in 1980 to 60.77% in 2000, indicating that the influence of extrinsic factors on AP distribution had been playing more and more role over the past two decades. This also might be due to the change of fertilization regimes. Only a small part of the studied area applied phosphorus fertilizers before 1980, while P fertilizers application was almost all over the studied area in 2000, which might have led to a random variability for soil phosphorus distribution.

The ratio of C_0 to C_0+C for AK content increased from 53.68% in 1980 to 58.82% in 2000, which was quite different from that of SOM or AP. It also could be explained by the change of fertilization regimes. Almost

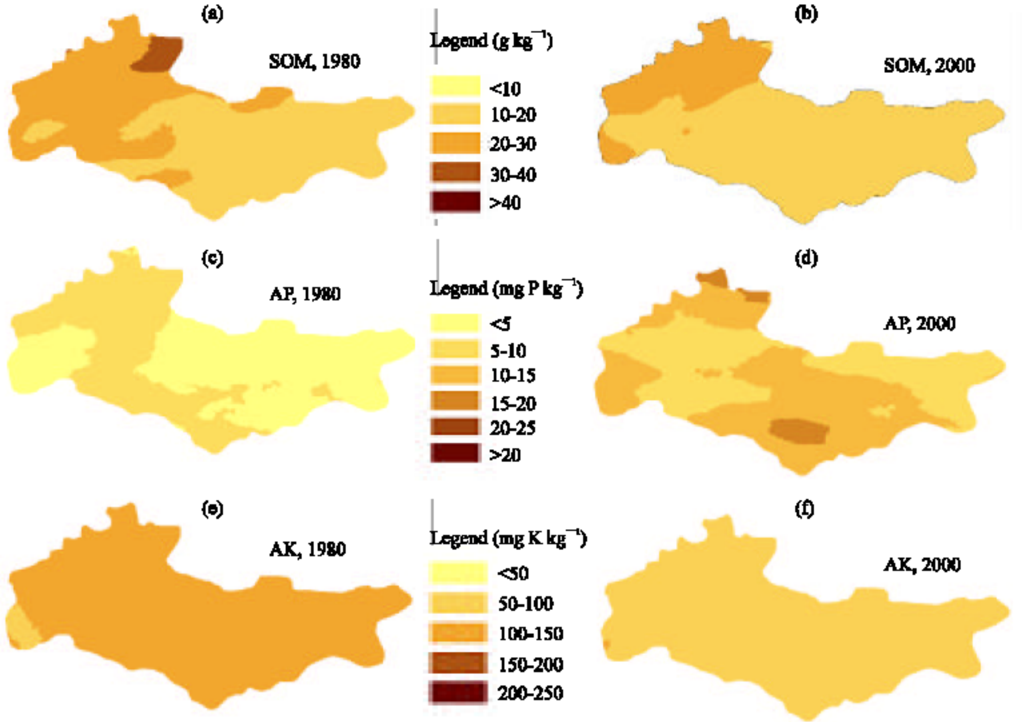

Fig. 4: Maps obtained with kriging showing different levels of soil organic matter, available phosphorus and available potassium in 1980 and 2000

no chemical potassium fertilizer was added to cultivated fields before 1980, but potassium fertilizer had been drawn great attentions since land reform conducted in early 1980s. As one of the extrinsic factors, fertilization could have contributed to the increase of the ratio value.

The range values indicating the distance over which the soil nutrients were spatially dependent varied from 13.13 km to 28.29 km. The shortest one was for AP content in 1980, while the longest one was for AK content in 1980. The ranges for the three pairs of nutrient (SOM, AP and AK) contents in both 1980 and 2000 were similar (Table 2). The range for SOM was increased from 1980 to 2000, indicating that the distribution of SOM was more homogeneous when less or no organic material was applied. The range for AK decreased from 28.27 km in 1980 to 23.81 km in 2000, indicating that the structural heterogeneity for the distribution of AK was enlarged over the two decades in the agroecosystem. Of all the three pairs of variables, AP showed the shortest distance of spatial correlation, which could be attributed to the fact that it was influenced more by soil management (e.g., P-fertilizer application). A study on the distribution of AP conducted by Chien *et al.*[5] in mid-west Taiwan soils showed the same result.

Interpolation via Kriging: Figure 4 showed the group maps of SOM, AP and AK at different levels of nutrient contents in 1980 and 2000 by interpolation via kriging. As shown in Figs. 4a and b, the pattern of much greater spatial variability in 1980 was evident. In 1980, three different blocks with differences in SOM contents, ranging from 10-20 to 30-40 g kg^{-1}, were mapped, while there were only two blocks ranging from 10-20 to 20-30 g kg^{-1}. SOM contents could be outlined by interpolation via kriging. A declining trend of SOM content could be shown clearly from the maps obtained with kriging (Fig. 4a, b) and as from SOM distribution frequency as well (Fig. 2a, b), with the average content of 20.88 g kg^{-1} in 1980 decreasing to 17.29 g kg^{-1} in 2000. The loss of SOM might be due to the high output of crop, low input of organic material and the degradation of SOM in the agroecosystems[7]. In 1980, the organic fertilizer input in test soils was averaged by 28.5 t ha^{-1}, but it had been decreased due to the rapid increase of chemical fertilizers input since China's Land Reform implemented in early 1980s. In recent years, organic fertilizer input was estimated to be less than 15.0 t ha^{-1}, most of which was applied to vegetable greenhouse fields (not belonging to cultivated fields in this study). Due to the low input of organic fertilizers, the SOM contents had decreased a lot over the two decades, which might be one of the key factors affected the spatial and temporal variability of SOM in test area. Our result is in line with Sun *et al*.[7] who conducted a spatial and temporal change of SOM in the hill region of subtropical China.

The maps obtained with kriging for AP in 1980 and 2000 were shown in Fig. 4c, d, from which, we can see a clear spatial variability of AP: seven blocks with AP contents ranging from 5-10 to 20-30 mg P kg^{-1} in 2000, but only two blocks with AP contents ranging from <5 to 5-10 mg P kg^{-1} in 1980. It indicated that a strong structural heterogeneity was formed over the two decades. The heterogeneity could be attributed to the soil management practices, as the traditional agriculture depends on more P-fertilizer[5,26,27]. The average content of AP was 2.37 times as much in 2000 (11.42 mg P kg^{-1}) as in 1980 (Table 1). The input of P was much greater than the output of P in test area, e.g., the average input of P-fertilizer was about 39.2 kg P ha^{-1} yr^{-1} in maize fields during 1993-2000[21], while the average output of P by maize and stalk were estimated at only 21.3 kg P ha^{-1} yr^{-1} (the average maize and straw yields were estimated at 7500 and 14000 kg ha^{-1}, containing 1.9 and 0.5 g P kg^{-1}, respectively) and hence, P was enriched in soils, which might contribute much to the heterogeneity of AP in test area.

Figure 4f and g the maps of AK in both 1980 and 2000 showed homogeneous distributions based on the K content grade scales. Two blocks with AK contents ranging from 50-100 to 100-150 mg K kg^{-1} in 1980 were obtained with kriging, but the area with AK content of 50-100 mg K kg^{-1} only accounted for a small part. It showed a highly homogeneity for AK contents within 50-100 mg K kg^{-1} in 2000. The structural homogeneous for AK could be related to the stable intrinsic factors, e.g., soil types and soil textures. Although there existed a homogeneous similarity for AK in both 1980 and 2000, the contents of AK had decreased over the two decades, with the average contents of AK of test samples from 126.54 in 1980 to 78.80 mg K kg^{-1} in 2000 (Table 1). The decrease of soil AK content could be due to the insufficient input of K-fertilizers. The output was much greater than the input of K in agroecosystems in test area. For example, in 2000, the rice and straw output averaged 16 600 kg ha^{-1}, with an average output of 106.0 kg K ha^{-1}, but the average K input was only 35.3 kg K ha^{-1}, of which, 28.4 kg K ha^{-1} was by chemical fertilizer input and 6.9 kg K ha^{-1} was from irrigation water in test paddy fields[20] and thus, the net loss of soil K was estimated up to 70.7 kg K ha^{-1}. The deficit part of K was fundamentally provided by soil, which might be the main reason for the decrease of AK and the changes of AK heterogeneity in test soils.

CONCLUSION

Semivariance analysis and maps obtained with kriging demonstrated that there were similarities and differences for the patterns of the spatial and temporal variability of SOM, AP and AK contents in test cultivated fields. Over the twenty years from 1980 to 2000, the SOM contents changed from moderately spatial dependence with the ratio of nugget to sill of 32.17% to a strongly one with the ratio of nugget to sill of 24.11%, AP contents were a little more spatially dependent, while AK contents were a little less spatially dependent. From the maps obtained with kriging, we can find a decreasing trend for the contents of SOM and AK and an increasing trend for the contents of AP. The evolution of the spatiotemporal variability of these nutrients was supposed to be a combined effect of the intrinsic factors such as soil parent materials, topography and soil types with the extrinsic factors such as fertilization, cropping and cultivation systems. For instance, P application had induced the increase of the spatial heterogeneity of AP distribution in the study area. From this study we can believe that geostatistics and GIS will be indispensable in characterizing and summarizing the information of soil properties and giving supports to policy decision and making for the rational management of agriculture, environment and natural resources. It is suggested that the study region should pay more attention to organic and K fertilizer input so as to preventing further degradation of soil fertility in the regional scale.

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