Spatial and temporal characteristics of soil nutrients in Tai'hu region of China

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INTRODUCTION

Soil nutrients are closely related to crop growth and productivity formation, and accurate assessment of the spatiotemporal change in soil nutrients can provide the basis for decision making on management strategies to maintain soil fertility and balance soil nutrients. In this paper, the Tai'hu Region in Jiangsu Province, P.R. China, was used as a case study eco-site, to (1) analyze the changes in statistical characteristics of the spatial soil nutrients data, including soil organic matter (SOM), total nitrogen (TN), available phosphorus (AP), and available potassium (AK), from 1980 to 2004; (2) investigate the reasonable sampling numbers required for spatial interpolation of soil nutrient indices; (3) compare the accuracy of four different interpolation methods for producing spatial distributions of each soil nutrient index; and (4) investigate how the spatiotemporal variations have been influenced by agricultural production practices from 1980 to 2004.

MATERIALS AND METHODS

Soil nutrient data were collected at soil depth of 0-20 cm from soil samples of 2342 and 2614 in the years of 1980 and 2004 in Tai'hu region of Jiangsu province in P.R. China. Firstly, the log-transform method was used to get a near normal distribution of soil data, and the Cochran's formula was used to calculate the optimal sample size for spatial interpolation. Then, based on the platform of ArcGIS 9.2, the interpolation effects of four different methods as Inverse Distance Weighted (IDW), Global Polynomial (GP), Ordinary Kriging (OK) and Simple Kriging (SK) for four soil nutrient indices were compared. In addition, the optimal theoretical model was established for each soil nutrient index to approximate its semi-variogram based on the least Residual Sum of Squares (RSS), Finally, the best fitted semi-variogram models and the best interpolation method were used to create regional maps for four soil nutrient indices in 1980 and 2004 to analyze the spatiotemporal changes in these indices.

RESULTS

The results showed that comparing with the soil nutrient data in 1980, the mean value of the SOM, TN, AP, and AK was increased by 15.85%, 79.55%, 195.72% and 10.37%, respectively (Table 1). Compared with the data in 1980, the spatial variability of SOM and TN declined, while that of AP and AK increased. This is consistent with the trend of change of the soil nutrient level, indicating impacts of nutrient inputs in agricultural production systems through fertilization.

Table 1 Changes in statistics of soil nutrient indices at the Tai'hu region of Jiangsu Province from 1980 to 2004

Soil nutrient index	Data form	Year	Min	Max	Mean	SD	Kurtosis	Skewness	CV (%)
Organic matter	Original	1980	0.90	78.70	21.13	8.23	3.13	0.33	38.95
(g kg^{-1})		2004	2.80	112.10	24.48	7.54	8.08	0.99	30.80
	Logarithm	2004	1.03	4.72	3.15	0.33	2.70	-0.88	10.48
Total nitrogen	Original	1980	0.05	7.00	0.88	0.59	3.78	0.44	67.05
(g kg^{-1})		2004	0.11	21.34	1.58	0.63	442.57	14.76	39.87
	Logarithm	2004	-2.18	3.06	0.41	0.31	5.64	-0.36	75.61
Available-P	Original	1980	0.50	245.90	8.31	9.51	221.79	11.41	105.71
(mg kg^{-1})		2004	0.30	275.00	18.66	24.43	25.11	4.28	130.92
	Logarithm	1980	-3.00	5.50	1.05	1.60	-0.19	0.99	152.38
		2004	-1.39	5.62	2.49	0.87	0.91	0.37	34.94
Available-K	Original	1980	5.20	433.50	88.17	30.89	9.42	1.56	35.03
(mg kg^{-1})		2004	1.90	905.40	97.31	57.55	41.71	4.79	59.14
	Logarithm	1980	1.65	6.07	4.42	0.36	4.94	-0.91	8.14
		2004	0.64	6.81	4.47	0.44	4.35	0.36	9.84

At 95% confidence level with 5% relative error, the soil sample size (2342 sample numbers in 1980 and 2614 in 2004) were satisfactory for spatial interpolation of the soil nutrient indices, except for AP. At 95% confidence level with 10% relative error, the sampling numbers of all the four soil nutrient indices were satisfactory for spatial interpolation. (Table 2).

Table 2 Required sample size for spatial interpolation of soil nutrient indices at 95% confidence level

Soil nutrient indices	Year	Required sample size	
		Relative error at 5% level	Relative error at 10% level
Organic matter	1980	234	42
(g kg^{-1})	2004	145	27
Total nitrogen	1980	691	122
(g kg^{-1})	2004	245	44
Available-P	1980	3491	310
(mg kg^{-1})	2004	2634	361
Available-K	1980	189	36
(mg kg^{-1})	2004	538	100

Table 3 shows the performance of four interpolation method. For SOM and TN, simple kriging (SK) is the best spatial interpolating method, while for AP and AK, the ordinary kriging (OK) is the best spatial interpolating method, with the minimum MAE and RMSE and maximum correlation.

Table 4 shows the RSS and r^2 for the fitted semi-variogram models for each of the soil nutrient indices. The exponential model was the best fitted for SOM and AK in both 1980 and 2004, while the spherical model was the best for TN and AK.

Table 5 shows the parameters of the best fitted semi-variogram model for each of the soil nutrient indices. The nugget/sill ratio for SOM in both 1980 and 2004 were less than 25%, showing strong spatial dependence, and indicating strong impact of structural factors (parent material, terrain etc.). However, TN and AP became increasingly influenced by human input and management (fertili-zation). AK was affected by both structural and input factors.

Table 3 Performance of four interpolation methods on spatial prediction accuracy of soil nutrient indices

Year	Soil nutrient index	Prediction error	IDW	GP	OK	SK
1980	Organic matter (g kg^{-1})	r	0.597	0.341	0.589	0.607
		MAE	4.24	5.34	4.36	4.24
		RMSE	5.96	6.96	5.99	5.89
	Total nitrogen (g kg^{-1})	r	0.406	0.341	0.446	0.446
		MAE	0.27	0.30	0.25	0.26
		RMSE	0.56	0.58	0.55	0.55
	Available-P (mg kg^{-1})	r	0.283	0.179	0.336	0.332
		MAE	12.48	13.32	11.37	11.74
		RMSE	23.5	23.48	22.52	22.56
	Available-K (mg kg^{-1})	r	0.359	0.311	0.422	0.422
		MAE	30.08	31.17	28.16	28.16
		RMSE	55.60	54.98	52.49	52.52
2004	Organic matter (g kg^{-1})	r	0.626	0.442	0.635	0.635
		MAE	4.13	5.02	4.12	4.12
		RMSE	5.60	6.42	5.54	5.53
	Total nitrogen (g kg^{-1})	r	0.632	0.473	0.629	0.636
		MAE	0.24	0.29	0.25	0.24
		RMSE	0.35	0.39	0.35	0.34
	Available-P (mg kg^{-1})	r	0.276	0.179	0.335	0.332
		MAE	12.25	13.07	11.20	11.48
		RMSE	23.10	23.03	22.09	22.13
	Available-K (mg kg^{-1})	r	0.386	0.342	0.440	0.439
		MAE	28.42	29.49	26.66	26.68
		RMSE	47.31	46.96	44.89	44.92

Table 4 The fitted semi-variogram model for the spatial distribution of soil nutrient indices

Year	Model	Organic matter		Total nitrogen		Available-P		Available-K	
		RSS	r^2	RSS	r^2	RSS	r^2	RSS	r^2
1980	Spherical	4.35E-04	0.70	2.00E-02	0.74	1.65E-05	0.20	1.64E-06	0.22
	Exponential	4.28E-04	0.71	2.22E-02	0.71	1.75E-05	0.17	1.61E-06	0.23
	Gaussian	4.50E-04	0.69	2.11E-02	0.72	1.72E-05	0.18	1.68E-06	0.19
	Linear	4.36E-04	0.70	2.00E-02	0.73	1.65E-05	0.19	1.64E-06	0.22
2004	Spherical	8.22E-04	0.65	7.10E-02	0.70	1.13E-06	0.18	5.79E-06	0.17
	Exponential	8.19E-04	0.65	7.14E-02	0.66	1.13E-06	0.11	5.73E-06	0.21
	Gaussian	8.25E-04	0.57	7.10E-04	0.69	1.14E-06	0.11	5.73E-06	0.17
	Linear	8.22E-04	0.63	7.11E-04	0.64	1.13E-06	0.10	5.76E-06	0.18

Fig.1 shows the spatial-temporal distribution of soil nutrient indices in Tai'hu Region, created with the best interpolation method. It can be clearly seen that SOM has been increased in more than 85% area, and TN and AP have been increased in almost everywhere. However, in about half of the region, AK was decreased from 1980 to 2004. The results indicate that the current agricultural and management systems lead to an addition of N and P into the soil in most areas, while mining of K from soil in a significant part of the region, particularly in the eastern areas.

Table 5 The parameters of semi-variogram of soil nutrient indices at the Tai'hu region of Jiangsu province, P.R. China

Soil nutrient index	Year	Model	Nugget	Sill	Nugget/Sill (%)	Range (km)
Organic matter	1980	Exponential	21.17	91.44	24.24	152.2
(g kg^{-1})	2004	Exponential	0.09	0.12	13.15	32.6
Total nitrogen	1980	Spherical	0.05	0.40	10.52	46.7
(g kg^{-1})	2004	Spherical	0.06	0.09	52.55	34.9
Available-P	1980	Spherical	0.36	3.42	81.11	199.1
(mg kg^{-1})	2004	Spherical	0.52	0.85	60.96	74.4
Available-K	1980	Exponential	0.07	0.14	61.78	102.7
(mg kg^{-1})	2004	Exponential	0.10	0.20	48.21	67.3

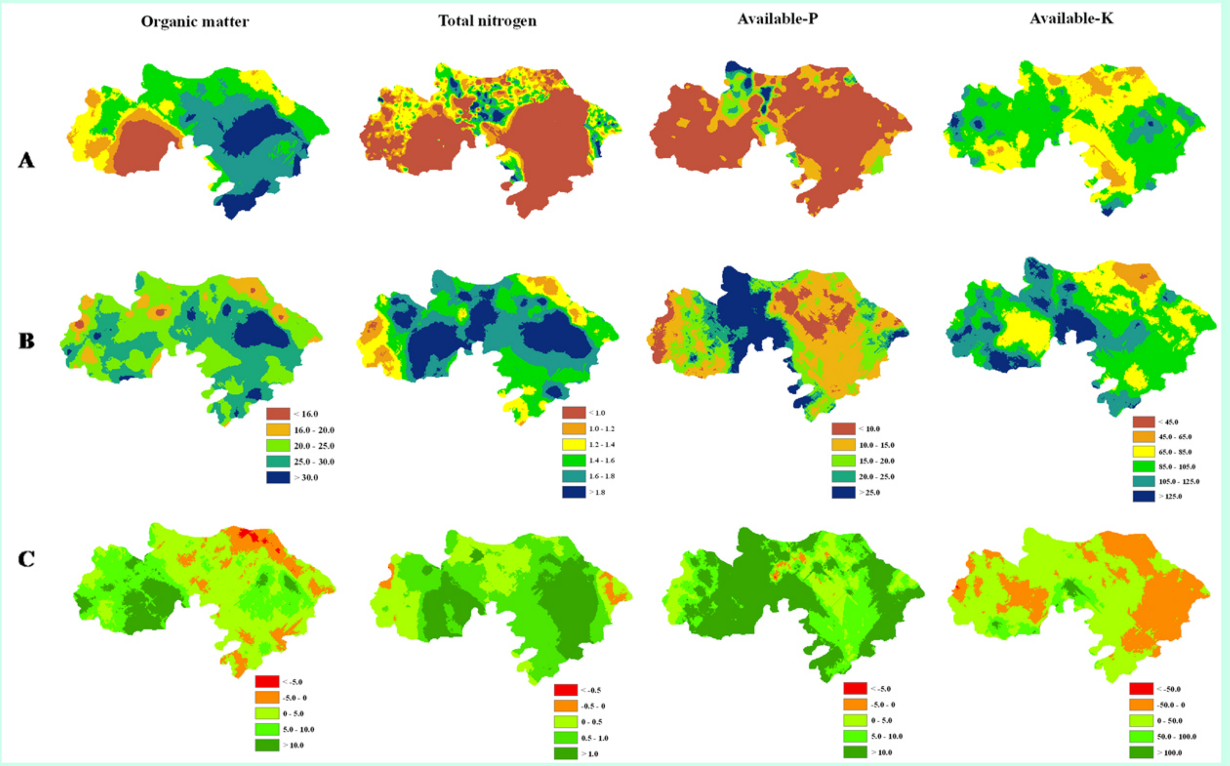

Fig.1 Spatial distribution map of SOM, TN, AP and AK contents at the Tai'hu region of Jiangsu province, P.R. China, in 1980 and 2004 (A. 1980, B. 2004, C. Difference between 2004 and 1980)

ACKNOWLEDGEMENT

We acknowledge the financial support of the New Century Exceptional Talent Program of China (NCET-08-0797), National Natural Science Foundation of China (30871448) and National Hi-tech Research and Development Plan of China (2006AA10Z219, 2007AA10Z225).

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