Spatial variability and affecting factors of soil nutrients in croplands of Northeast China: a case study in Dehui County

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ABSTRACT

This paper addressed the spatial distribution characteristics of organic matter, total nitrogen, extractable phosphorus and extractable potassium in agricultural soils of Northeast China. The related factors were explored using geostatistics and geographic information systems. The results showed that the log-transformed data of the four soil nutrients followed a normal distribution. Soil extractable phosphorus had a higher coefficient of variation. The experimental variogram of the log-transformed data of soil organic matter, total nitrogen and extractable phosphorus was fitted with an exponential model, while soil extractable potassium was fitted to a spherical model. Soil samples from smaller slope gradients had higher organic matter and total nitrogen. Soil type affected the four soil nutrients significantly. Soil samples from dry farming land had significantly higher total nitrogen and extractable potassium than soil from paddy fields, while the contrary was found for extractable phosphorus. Along the Yinma River, soil samples from the western part have statistically higher values for organic matter, total nitrogen and extractable potassium than those collected from the eastern part.

Keywords: soil nutrients; landscape attributes; geostatistics; GIS; Dehui County, Northeast China

Almost all soil properties exhibit variability as a result of the dynamic interactions between natural environmental factors, i.e., climate, parent material, vegetation, and topography (Jenny 1941). Significant differences in the soil nutrients from areas with uniform geology are known to be related to landscape position (Jenny 1941, Rezaei and Gilkes 2005). Soil properties, and in turn plant growth, are significantly controlled by the variation in landscape attributes including slope, aspect, and elevation. These influence the distribution of energy, plant nutrients and vegetation by affecting organic activity, runoff and runon processes, the condition of natural drainage, and the exposure of soil to wind and precipitation (Buol et al. 1989, Rezaei and Gilkers 2005).

For studies on the spatial distribution patterns of soil properties, techniques such as conventional statistics and geostatistics were widely applied (Saldana et al. 1998, McGrath and Zhang 2003, Sepaskhah et al. 2005, Liu et al. 2006), and based on the theory of a regionalized variable (Matheron 1963, Webster and Oliver 2001), geostatistics provides advanced tools to quantify the spatial features of soil parameters and allows for spatial interpolation to be conducted. The research benefits of the geographic information systems (GIS) approach were illustrated by many ecological and agricultural studies (Bradshaw and Muller 1998, Wang et al. 2006). Geographic information systems can be utilized to spatially analyze the characteristics of the objectives in study. In addition, GIS are useful to produce interpolated maps for visualization.

Northeast China is one of the main agricultural regions in China. The cultivated land and total crop

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yield currently account for 19% and 30% of the nation's total, respectively. A better understanding of the spatial variability of soil nutrients of this region is important for refining the agricultural management practices and for improving sustainable land use (McGrath and Zhang 2003). Moreover, it provides a valuable base against which subsequent and future measurements can be evaluated. The aim of this work was to study the spatial variability of soil nutrients and to explore how soil nutrients are controlled by natural environmental factors and anthropogenic land use in the agricultural soils of Northeast China, using Dehui County, a typical agricultural county, as a case study. We achieved this aim by using geostatistical methods and GIS to study the spatial distribution characteristics of soil organic matter (OM), total nitrogen (TN), extractable phosphorus (EP), extractable potassium (EK) and other possible factors including elevation, slope, soil type and land use.

MATERIAL AND METHODS

Study area. Dehui County (125°45′–126°23′E, 43°32′–44°45′N) is located in the middle part of the Jilin Province, Northeast China (Figure 1). The

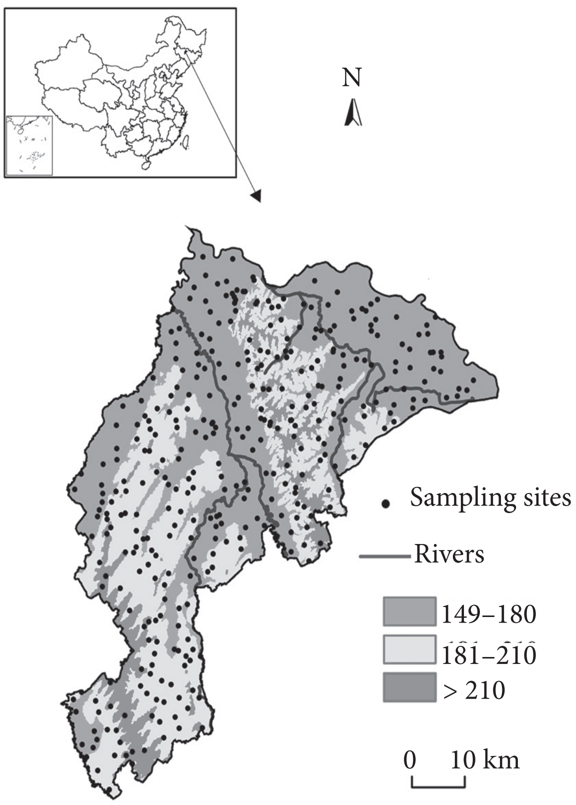

Figure 1. Soil sampling locations in Dehui County, Northeast China (*n* = 352)

county has an altitude between 149 and 241 m and an area of 3435 km^2. The study area is characterized by a temperate, semi-humid continental monsoon climate. The mean annual temperature is about 4.4°C and the average annual precipitation is 520 mm. The average of sunshine each year is 2695 h and the average wind speed is about 3.2 m/s. The frost-free period is about 130–140 days. In this county, the Second Songhua River, the Yitong River, and the Yinma River flow through the area and empty into the Songhua River. The soils are comprised of black soil (Luvic Phaeozem, FAO), chernozem (Haplic Chernozem, FAO), meadow soil (Eutric Vertisol, FAO), aeolian soil (Arenosol, FAO) and paddy soil (Hydragric Anthrosol, FAO).

Soil sampling and analysis. As an agricultural county, more than 80% of the total area of Dehui County is used as cropland. In this study, the soil nutrients data were collected in a regional soil fertility investigation. The locations of the cropland sampling sites are shown in Figure 1. Samples of the depth of 0–20 cm from a total of 352 sites were taken in November 2003. Among the 352 points, 265 locations were used for dry farming land of maize and 87 locations were paddy fields. Five replicate samples were collected from each point and homogenized by hand mixing and were sieved after being air-dried. The organic matter was determined using the $K_2Cr_2O_7$ titration method (Editorial committee 1996). The TN was determined by the semi-micro Kjeldahl method. The Olsen method was used to determine extractable phosphorus using a molybdate reaction for colorimetric detection (Olsen and Sommers 1982). The neutral 1N ammonium acetate extraction method was used to determine exchangeable potassium (Knudsen et al. 1982).

Statistical and geostatistical methods. Some main statistical parameters, which are generally accepted as indicators of the central tendency and spread of the data, were analyzed. These include description of the mean, standard deviation, variance, coefficients of variation (CV) and extreme maximum and minimum values. To decide whether or not the data followed the normal frequency distribution, the coefficients of skewness and kurtosis were examined (Paz-Gonzalez et al. 2000). These statistical parameters were calculated using EXCEL 2000 and SPSS 8.0.

Geostatistics uses the semi-variogram to quantify the spatial variation of a regionalized variable, and provides the input parameters for the spatial interpolation. A detailed description of geostatistics can be found in McGrath and Zhang (2003),

Table 1. Shape parameters of the probability distributions (n = 352)

	Raw data		Log-transformed data	
	skewness	kurtosis	skewness	kurtosis
OM	2.57	9.62	1.00	2.99
TN	6.75	66.23	1.85	10.32
EP	1.06	0.86	–0.51	0.14
EK	0.34	0.06	–0.62	0.89

Zhang and McGrath (2004), Liu et al. (2006). In our study, the geostatistical analyses were carried out with GS+ (Version 3.1a Demo), and maps were produced using the GIS software ArcView (Version 3.2a) and its extension module of Spatial Analyst (Version 2.0).

RESULTS AND DISCUSSION

Descriptive statistics. For OM, TN, EP and EK, the histograms of the raw data were positively skewed. However, after log-transformation, the data were near normal. Table 1 indicates the quantitative parameters of the probability distributions for the four variables. After log-transformation, the data showed small skewness and kurtosis. A P-P plot of a variable shows the cumulative proportions against the cumulative proportions of the normal distribution. The probability plot is generally used to determine whether the distribution of a variable matches the normal distribution. If it does, the points cluster around a straight line. In our study, the P-P plots (Figure 2) showed that for the raw data of each soil nutrient, there was a significant deviation from the straight line. However, the log-transformed data were close to the straight line. These results implied that the soil nutrients in the croplands of the study area followed lognormal distribution. Therefore, the log-transformed data sets of OM, TN, EP and EK were used for the following analyses concerning the factors of influence.

The coefficient of variation, standard deviation, and the basic statistical parameters of the percentiles and means for each of the soil properties were determined and were shown in Table 2. Among the four soil nutrients, extractable P showed the highest CV, while extractable K had the lowest. The larger CV for extractable P could be linked to the heterogeneity of the land use patterns, fertilizers or erosion; this is in agreement with studies by Chien et al. (1997) and Sun et al. (2003).

Correlation between soil chemical variables. Pearson (linear) correlation coefficients between the four variables and latitude and longitude were given in Table 3, together with the corresponding significance levels. Many authors indicate a positive relationship between soil organic matter and the capacity of the soil to supply essential plant nutrients including nitrogen, phosphorous, and potassium (Rezaei and Gilkers 2005). In this study, the Pearson linear correlation analysis indicates highly significant positive relationships between soil organic matter and total nitrogen (r = 0.50), and extractable potassium (r = 0.34). Thus, it can be concluded that soil organic matter within the cropland system provides nutrients for plant growth, resulting in a positive feedback as more plant biomass is likely to produce more soil organic matter. In this study, soil organic matter, total nitrogen and extractable potassium demonstrated a significant negative correlation with latitude and longitude, which may reflect the effect of different levels of rainfall and air temperature. For these reasons, future research is needed.

Analysis of spatial dependence of soil nutrients. The semivariogram models and best-fit model parameters for the four soil nutrients investigated were shown in Table 4 and Figure 3. All soil nutrients showed positive nugget, which can be explained by sampling error, short-range variability, and random and inherent variability. In general, the nugget-to-sill ratio can be used to

Table 2. Coefficient of variation (CV), standard deviation (S.D.), and the basic statistical parameters of organic matter (OM), total nitrogen (TN), extractable phosphorus (EP) and extractable potassium (EK) (n = 352)

Variables	CV	S.D.	Min	5%	25%	Median	75%	95%	Max	Mean	GeoMean
OM (%)	29.86	0.83	1.34	1.89	2.33	2.62	2.95	4.28	7.63	2.78	2.62
TN (%)	33.33	0.05	0.08	0.10	0.13	0.14	0.16	0.21	0.78	0.15	0.14
EP (m/kg)	62.00	11.42	2.11	4.27	10.21	15.34	24.78	42.31	59.34	18.42	13.74
EK (mg/kg)	28.76	37.13	36.00	72.65	102.00	127.00	153.00	196.35	240.00	129.11	135.46

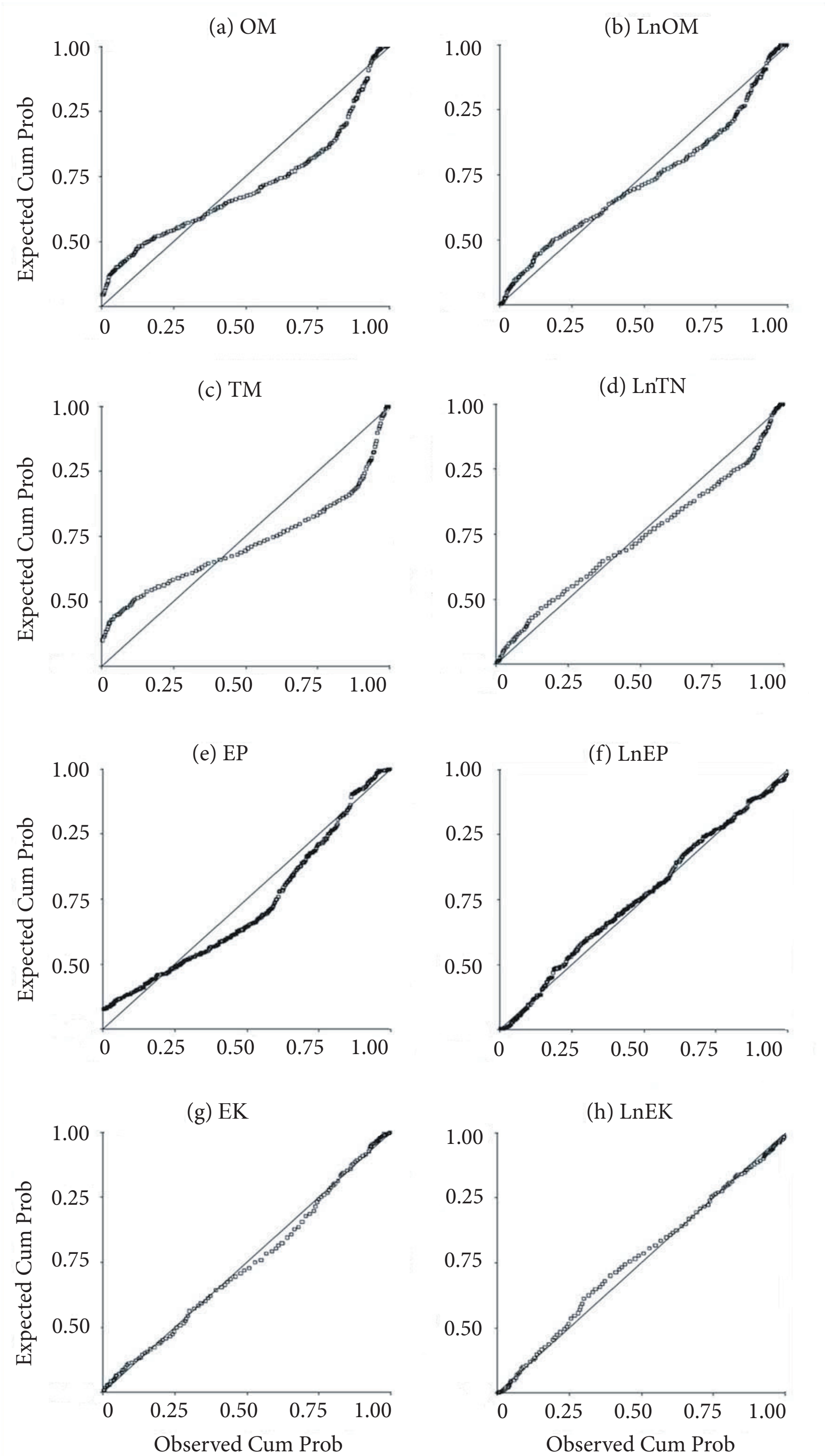

Figure 2. P-P plots of the soil nutrients in the croplands of Dehui County, China: (a) organic matter (OM); (b) LnOM; (c) total nitrogen (TN); (d) LnTN; (e) extractable phosphorus (EP); (f) LnEP; (g) extractable potassium; (h) LnEK

classify the spatial dependence of soil properties (Cambardella et al. 1994). A variable is considered to have a strong spatial dependence if the ratio is less than 0.25, and to have a moderate spatial dependence if the ratio lies between 0.25 and 0.75; otherwise, the variable has a weak spatial dependence. In the study area, the nugget-to-sill ratios of TN, EP and EK showed moderate spatial dependence (0.50, 0.74 and 0.61 respectively), which might be attributed to intrinsic (soil-form-

Table 3. Correlation coefficient matrix for soil nutrients and locations (latitude and longitude)

Variable	OM	TN	EP	EK	LAT	LON
OM	1	**	ns	**	**	**
TN	0.503	1	ns	**	**	**
EP	–0.023	–0.032	1	**	ns	ns
EK	0.344	0.283	0.288	1	**	**
LAT	–0.339	–0.255	0.011	–0.407	1	**
LON	–0.306	–0.277	0.101	–0.163	0.625	1

For sake of brevity, the symbols are designated as follows: variables; organic matter (OM); total nitrogen (TN); extractable phosphorus (EP); extractable potassium (EK); latitude (LAT); longitude (LON); **denotes significance at the 0.01 level; ns means not significant. The number of observations for all variables was 352

ing processes) and extrinsic factors such as soil fertilization and cultivation practices. In contrast, OM had a weak spatial dependence with a nugget-to-sill ratio of 0.81.

Possible factors in relation to soil nutrients. The GIS software Arcview© was used to analyze the spatial distribution of soil nutrients from different elevations. The samples were assigned to three elevation groups: class 1 (140–180 m), class 2 (181–210 m), and class 3 (> 210 m), based on which contour line the sampling location was closest to. To determine whether the differences of soil nutrients among the elevation groups were significant, an analysis of variance (ANOVA) was applied. For log-transformed data of soil nutrients, the Levene's tests indicated that the variances between the groups of the data set are homogenous at the significance of 0.205, 0.299, and 0.300, respectively for LnOM, LnTN, and LnEP. Thus the Duncan's test could be applied. The ANOVA procedure showed that for LnOM, LnTN, and LnEP the differences between the groups were not significant at the 0.05 level of significance, with significance levels of 0.131, 0.669 and 0.555, respectively, indicating that elevation is not a main factor in relation to OM, TN, and EP. For the log-transformed data of EK, the Levene's test showed that the variances between the groups of the data set were not homogenous ($P = 0.000$), thus the Duncan's test could not be applied. The results of the Tamhane analysis showed that the differences between the three groups were not significant (with all significance levels > 0.05). This indicated that elevation was not a main factor affecting EK.

To explore the impacts of slope on soil nutrients, the differences of the values between samples with different slopes were conducted. To explore this, ArcView software was used to assign the samples to two slope groups: group 1 (0–3°) and group 2 (> 3°), and t-tests were performed to compare the mean values of the two groups for the four soil nutrients (Table 5). Results indicated that the variances between the two slope group data sets were homogenous for LnOM, LnTN, LnEP, and LnEK at the significance levels of 0.640, 0.875, 0.570 and 0.142, respectively, based on the Levene's test. Thus, the t-values with equal variance assumed were used. For LnOM, the significance level of 0.005 was found for the two-tailed test indicating that soil samples from a 0–3 slope degree (mean value 0.993) had significantly higher organic matter than those from a > 3 slope degree (mean value 0.786). For LnTN, the significance level of 0.016 showed a similar phenomenon. An explanation for this study area could be that the relatively steeper slope might result in more soil erosion, resulting

Table 4. Parameters for the variogram model for soil nutrients

	Model	Range a (km)	Effective range (km)	Nugget	Sill	Nugget/Sill (%)
LnOM	exponential	211.0	33.0	0.0385	0.204	0.811
LnTN	exponential	49.3	147.9	0.671	1.343	0.500
LnEP	exponential	2.9	8.7	0.265	1.035	0.744
LnEK	spherical	123.1	123.1	0.609	1.549	0.607

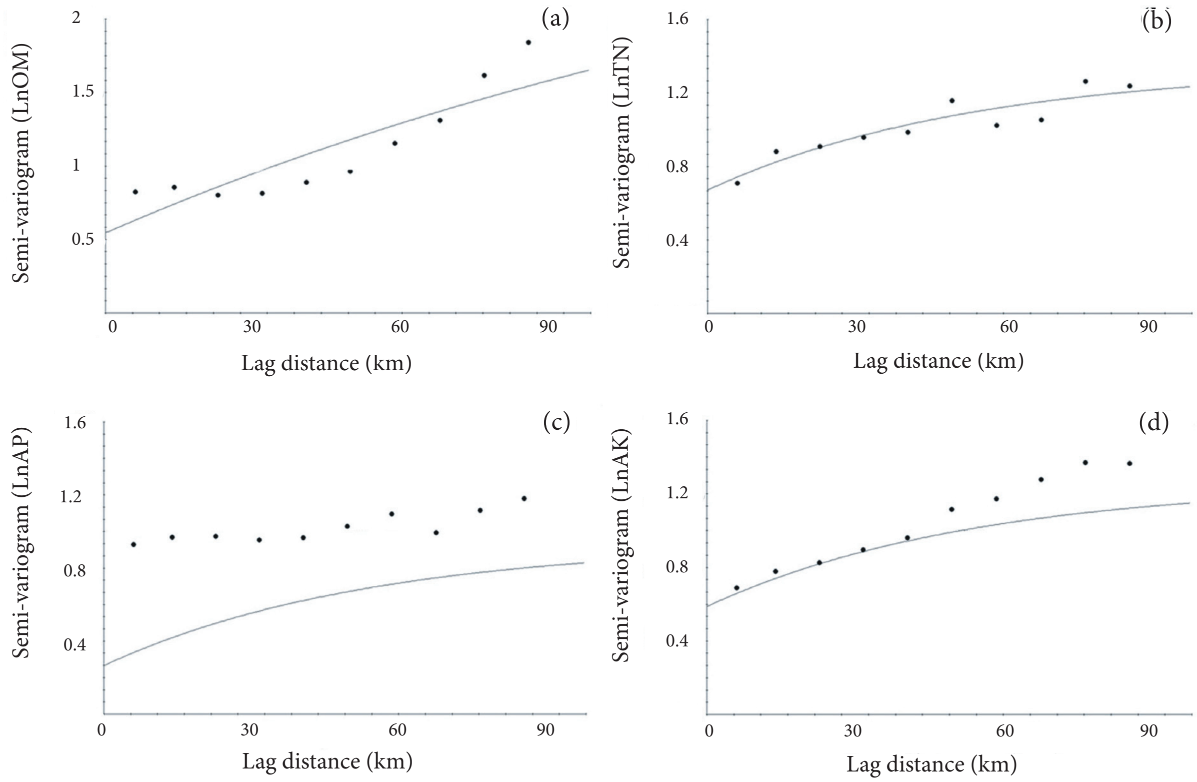

Figure 3. Omni-directional experimental variogram of soil nutrients

in soil nutrient loss, as has been previously reported by Tang (2004). For LnEP and LnEK, the differences between the two soil groups were not statistically significantly different (P = 0.271 and 0.525, respectively).

To find the effect of soil type on soil nutrients, comparisons of the data among soil samples from different soil types were conducted (Table 6). For LnOM, LnTN and LnAP, the Levene's test showed that the variances between the groups of the data set are homogenous at the significance level of 0.194, 0.462 and 0.174, thus the Duncan's test could be applied. For LnOM, the five soil type groups could be separated into two subsets. The differences within subsets were not significant at the 0.05 level of significance and were 0.079 and 0.397 for the two subsets. However, the difference between the subsets was significant at the level

Table 5. Results of Levene's test and t-tests between samples from a 0–3 slope degree and those from a > 3 slope degree

	Equal variances	Levene's test for equality of variances		t-test for equality of means	
		F	significance	t	significance (2-tailed)
LnOM	assumed	0.219	0.640	2.829	0.005**
	not assumed			2.819	0.016*
LnTN	assumed	0.025	0.875	2.767	0.006**
	not assumed			2.981	0.012
LnEP	assumed	0.323	0.570	1.102	0.271
	equal variances not assumed			1.342	0.204
LnEK	assumed	2.166	0.142	0.636	0.525
	not assumed			1.017	0.327

* and **denote significance at the 0.05 and 0.01 levels, respectively

Table 6. Results of ANOVA analysis for soil nutrients from different soil types

Soil nutrients	Test of homogeneity of variances	Between groups	
	significance	*F*	significance
LnOM	0.194	3.395	0.010*
LnTN	0.462	2.989	0.019*
LnEP	0.174	3.439	0.009**
LnEK	0.000	6.499	0.000**

* and **denote significance at the 0.05 and 0.01 levels, respectively

of 0.010 (with an *F*-value of 3.395). Statistically, soil samples from chernozem had the highest OM, and those under aeolian soil had the lowest OM. For LnTN, the same phenomenon was observed, and the significance level between the soil type groups was 0.019. For LnEP, the difference between the soil groups was significant at the level of 0.009 (with an *F*-value of 3.439). For LnEK, the Levene's test showed that the variances between the groups were not homogenous at the significance level of 0.000, thus the Duncan's test could not be applied and the Tamhane method was adopted. The results of this test showed that the difference between the soil type groups was significant at the level of 0.000. All of the above results reflected the effect of the soil parent materials on the soil nutrient status.

In this study, the soil samples were obtained from two land use types. The *t*-tests were done to compare mean values of soil nutrients from these groups. The results showed that for LnOM, LnTN and LnEP the variances between the two data sets were homogenous at the significance levels of 0.489, 0.727 and 0.082, respectively, based on the results of the Levene's test. Thus, the *t*-values, with equal variance assumed, were used. For LnOM, the significance level of 0.154 for the two-tailed test showed that there was no significant difference between the OM in soils from dry farming land and those from paddy fields. Soil samples from dry farming land had significantly higher TN than those from paddy fields ($P = 0.004$). In contrast, soil samples from dry farming land had significantly lower EP than those from paddy fields ($P = 0.041$). For LnEK, the variances for the two land use type groups were not homogenous because the significance level for the Levene's test was 0.000 (< 0.05). Thus, the *t*-test value of 3.591, with equal variances not assumed, was used. A significance level of 0.001 was found for the two-tailed test showing that soil samples from the dry farming land had statistically higher EK than those collected from paddy fields (Table 7). The land use map of the study area was illustrated in Figure 4.

In the study area, there is no significant difference between soil organic matter in soils from dry farming land and those from paddy fields. In general, paddy fields have a higher SOC concentration due to their greater dry matter production than dry farming lands. According to extensive household interviews, since the early 1990s, more attention has been paid to the importance of the protection of soil fertility, manure application, pulverization and the turnover of crop stubble post-harvest has been widely adopted. The average manure amount

Table 7. Results of Levene's test and the *t*-test for soil nutrients from different land use types

	Equal variances	Levene's test for equality of variances		*t*-test for equality of means	
		F	significance	*t*	significance (2-tailed)
LnOM	assumed	0.480	0.489	1.428	0.154
	not assumed			1.414	0.160
LnTN	assumed	0.122	0.727	2.916	0.004**
	not assumed			3.225	0.002
LnEP	assumed	3.043	0.082	–2.055	0.041*
	not assumed			–2.270	0.024
LnEK	assumed	52.274	0.000	4.678	0.000
	not assumed			3.591	0.001**

* and **denote significance at the 0.05 and 0.01 levels, respectively

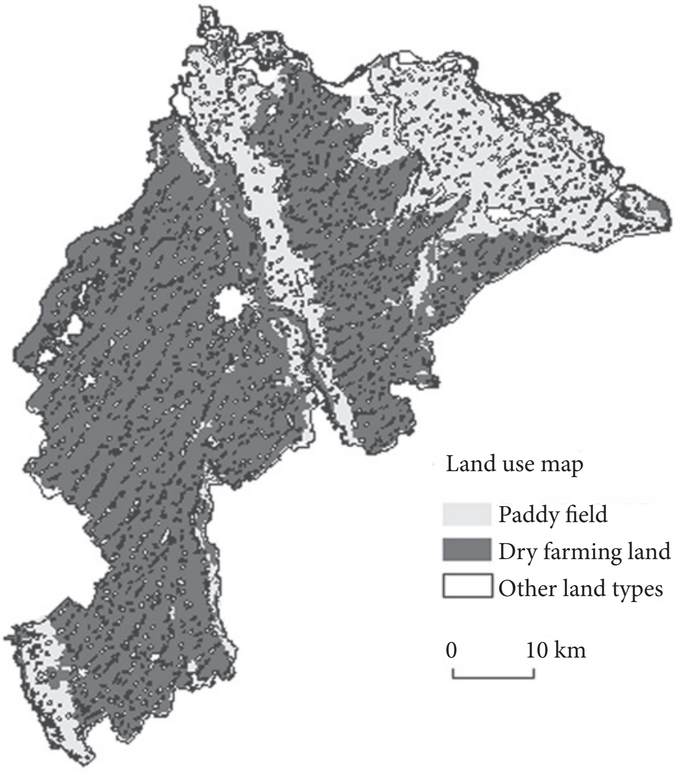

Figure 4. Land use map of Dehui County, Northeast China

applied is 4656 kg/ha, and the average nitrogen content of the manure is 0.7%. The average nitrogen (N) input is 180 and 156 kg/ha for dry farming land growing maize and paddy fields, respectively. The average phosphorus fertilizer (P) input is 69 and 92 kg/ha for dry farming land and paddy fields, respectively. The average potassium (K) input is 60 and 35 kg/ha, for dry farming land and paddy fields, respectively. We can conclude that chemical fertilizer inputs for different land use types impacted soil nutrient status.

Spatial distribution of the four soil nutrients. The parameters of geostatistics obtained above were used for Kriging to produce an interpolation map of the four soil nutrients, as shown in Figure 5. From the spatial distribution map of soil nutrients, we can see that for OM, TN and EK, the values in the western part were higher than those in the eastern part. However, for EP, there was no obvious visual trend. To explore the spatial differences of soil nutrients, we divided the study area into two parts: western and eastern, with a line along the Yinma River. The 352 soil samples were then further separated into two subsets, with sample sizes of 179 and 173, respectively. The mean values of OM, TN, EP and EK from the two areas are shown in Table 8. The results indicated that for OM, TN and EK the average values in the western part were noticeably higher than those from the eastern part, with a relative difference of 17.8%, 23.5%, and 18.8%, respectively. However, for EP, the average value of 17.73 m/kg in the western part was lower than the average value in the eastern part, 19.15 mg/kg, with a relative difference of –8.0%.

In order to compare the differences of the soil nutrients in the two parts of the study area, *t*-tests were conducted and the results are listed in Table 9. The results indicated that for OM, TN and EK, the variances between the two data sets were not homogenous and had significance levels of 0.003, 0.011 and 0.028, respectively. Thus, the *t*-test values of 6.442, 6.289 and 7.189, with equal variances not assumed, were used. The two-tailed test showed that the soil samples from the western part all had statistically higher OM, TN and EK values (P = 0.000 for all three nutrients) than those collected from the eastern part. For EP, the variances between the two soil groups were homogenous because the significance level was 0.954 (> 0.05). Thus, the *t*-test value of –1.166, with equal variances assumed, was used. The significance level of 0.244 for the two-tailed test showed that there was no significant difference between the EP in soils from the western part and those from the eastern part.

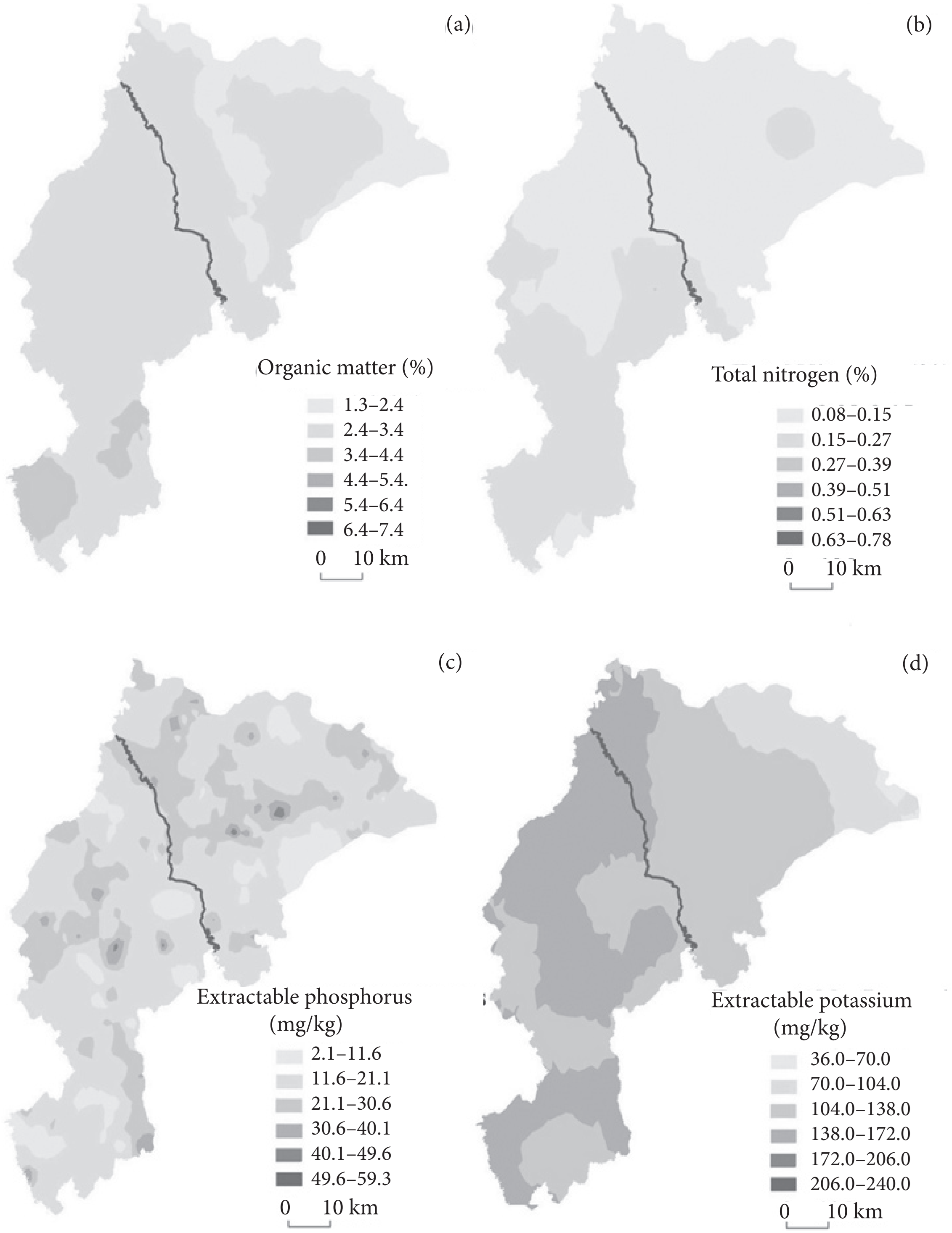

Figure 5. Spatial distribution map of OM (a), TN (b), EP (c) and EK (d) in Dehui County, Northeast China

The comparison between the spatial distribution map of soil nutrients (Figure 5), the slope gradient map (Figure 6) and the land use map (Figure 4) of the study area provided the information that the spatial distribution of OM, TN and EK was generally consistent with the topography and the different land use types. We argue that in the western part, the slope gradient is very small. However, in the eastern part, the slope gradient is relatively higher. For this reason, OM, TN and EK showed an increasing trend from northeast to southwest. In the eastern part, water and tillage erosion might be the main reason for the decline in soil nutrients due to relatively greater water and soil loss and little protection from tillage management. For EP, agricultural management and chemical fertilizer inputs could be the reason for not having obvious spatial variations.

Table 8. Mean values of soil nutrients in western and eastern part

	Part	*n*	Min	Max	Average	Median	Geometric mean	Standard deviation
OM (%)	western	179	1.85	7.63	3.04	2.77	2.89	0.92
	eastern	173	1.34	6.26	2.50	2.41	2.44	0.62
TN (%)	western	179	0.08	0.78	0.17	0.15	0.15	0.068
	eastern	173	0.08	0.28	0.13	0.13	0.13	0.026
EP (mg/kg)	western	179	2.11	48.44	17.73	14.94	13.43	11.23
	eastern	173	2.78	59.34	19.15	15.76	15.81	11.61
EK (mg/kg)	western	179	67.00	240.00	142.22	138.00	141.50	30.65
	eastern	173	36.00	237.00	115.53	112.00	104.92	38.43

Table 9. Results of Levene's test and *t*-test of soil nutrient values for the western and eastern part

	Equal variances	Levene's test for equality of variances		*t*-test for equality of means	
		F	significance	*t*	significance (2-tailed)
OM	assumed	9.192	0.003	6.401	0.000
	not assumed			6.442	0.000**
TN	assumed	6.564	0.011	6.209	0.000
	not assumed			6.289	0.000**
EP	assumed	0.003	0.954	–1.166	0.244
	not assumed			–1.165	0.245
EK	assumed	4.881	0.028	7.217	0.000
	not assumed			7.189	0.000**

* and **denote significance at the 0.05 and 0.01 levels, respectively

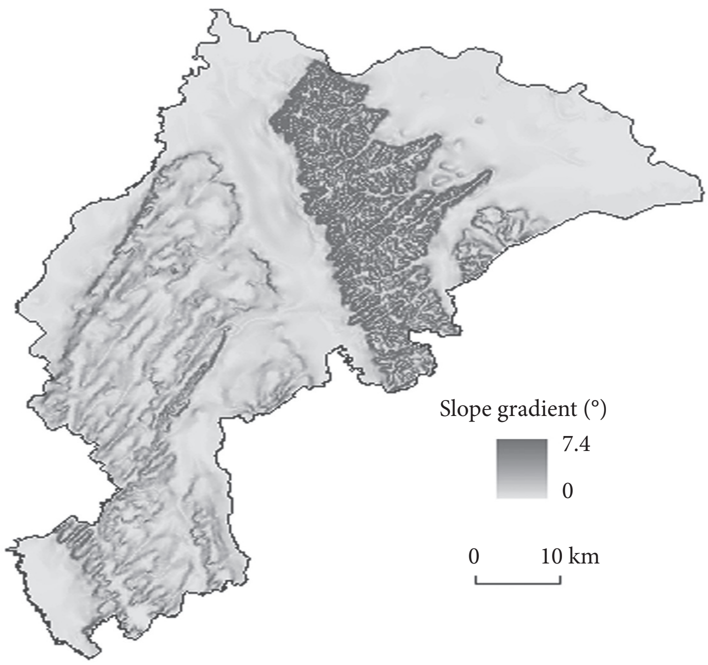

Figure 6. Slope gradient map of Dehui County, Northeast China

The spatial distribution characteristics and possible affecting factors of soil organic matter, total nitrogen, extractable phosphorus and extractable potassium in agricultural soils of Dehui County, Northeast China, were explored using geostatistics and geographic information systems (GIS). Total nitrogen, extractable phosphorus and extractable potassium showed moderate spatial dependence. Organic matter, however, had a weak spatial dependence. Slope gradient, soil type and land use type impacted the concentration of the soil nutrients and their spatial distribution significantly. A better understanding of the spatial variability of soil nutrients is useful for refining agricultural management practices and for improving sustainable agricultural land use in Northeastern China.

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