Journal of Agricultural Science and Technology A 4 (2014) 723-735
Earlier title: Journal of Agricultural Science and Technology, ISSN 1939-1250
doi: 10.17265/2161-6256/2014.09.002

Evaluation of Spatial Variability of Soil Properties in a Long-Term Experimental Tobacco Station in Southwest China

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Received: April 9, 2014 / Published: September 20, 2014.

Abstract: Analysis of the spatial variability of soil properties is important to arrange the experimental treatments in the experimental station. This paper aims to study the spatial structure of soil variables and their distribution in the Pengshui tobacco experiment station in Chongqing, China. Soil samples were taken from 289 soil points on 20 m grid in March 2012. Twenty-two soil chemical and physical properties were analyzed by classical statistical and geo-statistical methods. Soil pH, cation exchange capacity (CEC), total phosphorus (TP), available phosphorus (AP), zinc (Zn), magnesium (Mg) and sulphur (S) have the strong spatial dependence, with nugget/sill ratios of less than 25%. The others have the moderate dependence with nugget/sill ratios of 26.17% to 71.04%. Ranges of the spatial correlation varied from 51.30 m for chlorine (Cl) to 594.90 m for TP. The clearly patchy maps of the nutrients showed the spatial distributions of the soil variables, which can be used for better management of experimental treatments, achieving reliable experimental results in the tobacco experimental station.

Highlight: Scientific experimentation assumes the existence of random variability for soil attributes. This research was to evaluate the spatial variability of soil chemical and physical attributes and to interpolate the spatial distribution of soil properties in the tobacco experimental station in Chongqing. The result of this work can be used for the agricultural management of tobacco cultivation.

Key words: Geo-statistical analysis, soil property, spatial variability, tobacco experimental station.

1. Introduction

Soil properties are variable and this fact plays a crucial role on the yield and quality of crop. The knowledge of the soil properties is characterized by high spatial variability due to the combined effect of physical, chemical and biological processes, which act simultaneously with different intensities at different spatiotemporal scales [1]. The spatial variability of the nutrient concentration over a field can be very useful for the application of fertilizers, farming system and other agronomical measures. Due to the substantial spatial variability of soil nutrient levels at the macro-scale and micro-scale, the fertilizers' application often has results of its excessive use in areas with high nutrient levels and insufficient application in areas with low nutrient levels [2]. Ndiaye and Yost [3] emphasized that spatial variability in soil prosperity should be considered for the variable-rate application. Jiang et al. [4] have used the soil fertility as the basis of tobacco quality to delineate management zone (MZ). Ortega et al. [5] have found that the use of homogeneous MZ based on

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soil fertility and demonstrated the great potential for the site-specific management of traditional crops and vineyards. The variable rate fertilizers application can be achieved on the basis of the precisely defined spatial variability of soil nutrients. The spatial distribution of soil properties because of its extreme variability can be estimated by means of geo-statistics [6-9].

The most popular approach to assess the spatial variability of soil nutrients is the tool of geo-statistics [10], which uses point information for the interpolation [11]. Geostatistics provides a set of statistical tools for the description and modeling of spatial patterns, prediction at un-sampled locations and assessment of the uncertainty attached to these predictions [12]. The spatial information of the prediction can improve the estimation and enhance the map quality [13]. Sokouti and Mahdian [14] have determined the spatial distribution of N, P and K in soil and compared the effectiveness of various geo-statistical approaches in the estimation of nutrients and the preparation of spatial variability maps of these elements for the evaluation of soil nutrients levels and stocks. The geo-statistics has been used to prove the effectivel assess of the variability of soil nutrients. Shi et al. [15] examined the spatial variability of soil available micronutrients. Geo-statistical methods have also been used to estimate physical [16, 17], biological [18] and ecological properties of soils [19]. Other works have optimized sampling strategies for determination of management zones [4, 20-22].

Scientific experimentation assumes the existence of random variability for soil attributes. Nevertheless, several studies have demonstrated that the physical and chemical properties of soil are characterized by a high degree of spatial variability [23, 24]. It is a fact that experimental results are greatly affected by the soil spatial variability. In order to obtain the satisfactory test results, it is necessary to evaluate the spatial variability of soil properties, to prepare the distribution map of soil variables and to identify the management zone of experimental fields.

The aim of this research was to evaluate the spatial variability of soil chemical and physical attributes and to interpolate the spatial distribution of soil properties in the tobacco experimental station in Chongqing. The result of this work can be used for the distribution of experimental treatment and the agricultural management of tobacco cultivation.

2. Materials and Methods

2.1 Site Description

The studies were carried out in 2012 at the tobacco experimental station in Southeast Pengshui County (29.137352°N, 107.958557°E) of Chongqing City in Southwest China. The experimental land was surrounded by hills. The site is characterized by subtropical moist monsoon climate, the average annual temperature is 17.5 °C and the annual potential evapotranspiration is 950.4 mm. The annual precipitation is approximately 1,104.2 mm, more than the yearly precipitation of 30-year historical average values.

2.2 Soil Description

The soil texture in this site ranges from light clay (80.6%) to heavy loam (3.5%) and medium clay is 15.9%. The soil is slightly acidic, pH = 5.87.

2.3 Soil Sampling and Laboratory Analysis

The land with the area of ten hectares was selected for soil sampling; the overview of the boundaries of studed field is presented in Fig. 1. Soil samples were selected before sowing the tobacco from the layer of 20 cm on an approximate 16 m grid with using the GPS (global positioning system) unit and data were converted to coordinates (x, y) as presented in Fig. 1.

Soil samples were packed into plastic bags, then air-dried, divided, and ground to a size small enough to pass through a 2 mm sieve before analysis. The soil

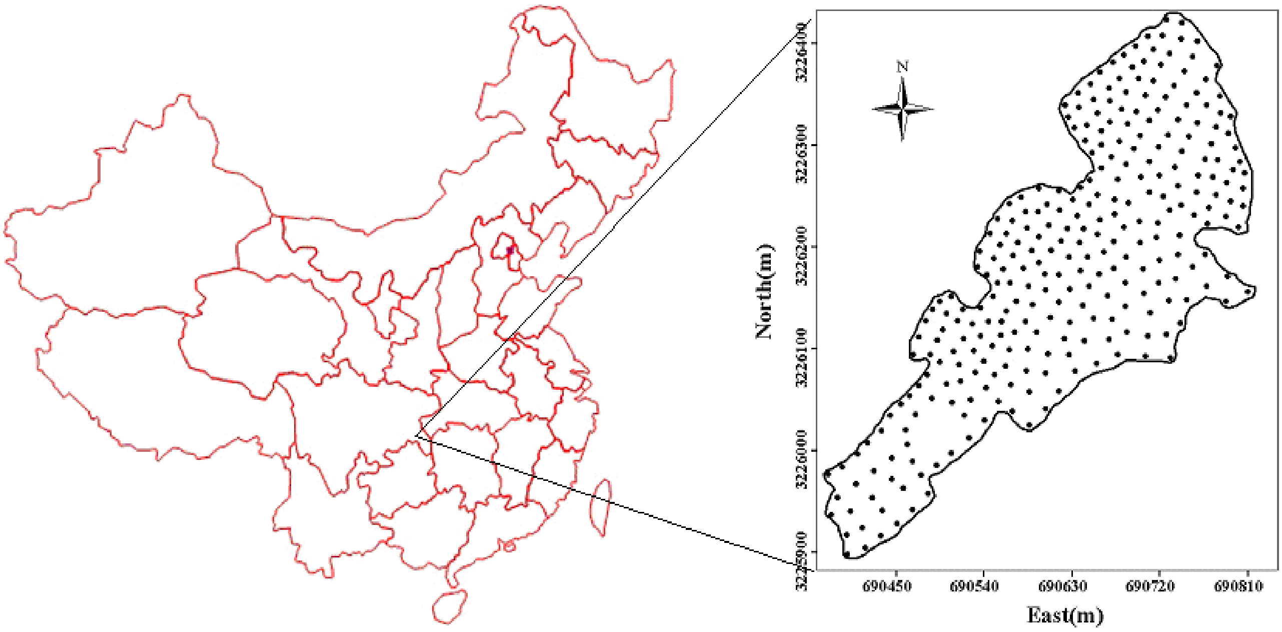


Fig. 1 Map of Southwest China with the location of the study field within the Chongqing and distribution of soil sampling sites within soil map unites in the study field.

texture (sand, silt and clay) was measured by the pipette method of Miller and Miller [25]. Soil pH was measured in soil:water = 1:2.5 using a glass electrode. The organic matter (OM) content was analyzed by the wet oxidation method of Walkley and Black [26]. The total nitrogen (TN) was determined by the Kjeldahl's method [27]. The alkaline nitrogen (AN) was measured using the alkaline hydrolysis diffusion method [28]. The ammonium nitrogen (NH_4-N) and the nitrate nitrogen (NO_3-N) were measured in fresh samples using the continuous flow analyzer [29]. The total phosphorus (TP) was measured by the sulfate-perchlorate acid heating digestion-MoSb colorimetric technique [30]. The available phosphorus (AP) was determined by the Olsen's extraction method, using the alkaline sodium bicarbonate as the extractant in a 20:1 ratio [31]. The total potassium (TK) was analyzed by the inductively coupled plasma-atomic emission spectroscopy. The available potassium (AK) was measured using the neutral ammonium acetate method [32]. The cation exchange capacity (CEC) was determined using the extraction with the neutral sodium acetate [33]. Available Fe, Cu, Mn, Zn, Ca, Mg, S and Cl were extracted with diethylenetriamine penta-acetic acid (DTPA) [34] and analyzed by the inductively coupled plasma-atomic emission spectroscopy.

2.4 Descriptive Statistics and Geo-statistical Analysis

The descriptive statistics, including mean values, standard deviation, minimum, median and maximum values, coefficient of variation (CV), skewness and kurtosis were calculated for each variable with SPSS13 software. Normality was tested using the Kolmogorov-Smirnov statistic.

Geo-statistical software, GS Version 3.1 for Windows (Gamma Design Software) was used for determining the semivariance analyses and the spatial distribution of soil properties [35]. Spatial patterns were usually described using the experimental semivariogram $\gamma(h)$, which measures the average dissimilarity between data separated by distance h [36]. The semivariogram $\gamma(h)$ can be calculated as follows [37]:

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

where, $N(h)$ represents the number of the observation pairs separated by distance h, $Z(x_i)$ and $Z(x_i + h)$ are the values of the observation at the i and $I + h$ positions, respectively, and the $\gamma(h)$ is the experimental semivariogram value at distance interval h. A semivariogram consists of three basic parameters that describe the spatial structure as: $\gamma(h) = C_0 + C$. $C_0 + C$ is the sill (total variance), which is the lag distance between measurements at which one value for a variable does not influence neighboring values. C_0 is the combination of random errors and sources of variation at distances smaller than the shortest sampling interval [12]. C is the structural variance, which is the constant semivariance value where the curve was stabilized. The range is the distance which the diameter of the zone of influence the average maximum distance over which soil property is spatially related [38].

The nugget ratio ($C_0/(C_0 + C)$; nugget-sill) represents the parameters that characterize the spatial structure of a property [39], and the ratio can be obtained by Kriging [40]. The classification proposed by Cambardella et al. [41], which considers the degree of spatial dependence as strong when values are ≤ 25%; moderate spatial dependence when values are between 25% and 75%; and weak spatial dependence when values are greater than 75%. The value of nugget ratio was used to classify the degree of spatial dependence of each one of the soil properties. If the value is 100% or the semivariogram slope is close to zero, the property is considered as non-spatially correlated (pure nugget).

3. Results

3.1 Descriptive Statistics

The statistical parameters for soil properties are presented in the Table 1. The parameters for soil chemical variables had indicated the high variation, with coefficients of variation ranging from almost 8.0% to approximately 42.0%. The highest variation was observed in the content of Mg and Mn (42.0%),

Table 1 Descriptive statistics of soil properties (n = 289) in the topsoil (0-20 cm) at different sampling dates.

Soil properties	Mean	S.D.	Min.	Median	Max.	$^{\#}$CV	Skewness	Kurtosis	$^{※}P_{K-S}$
pH	5.87	0.45	5	5.85	7	0.08	0.32	-0.25	0.59
OM, g/kg	25.24	5.01	14.26	25	39.34	0.2	0.32	-0.11	0.59
CEC, cmol/kg	17.65	5.34	6.23	17.19	31.09	0.3	0.35	-0.34	0.21
TN, g/kg	0.81	0.2	0.34	0.79	1.35	0.24	0.09	-0.4	0.63
AN, mg/kg	87.76	17.71	43.07	89.01	132.17	0.2	0.23	-0.08	0.01
NH_4-N, mg/kg	104.56	18.04	55.85	99.29	148.62	0.17	0.43	0.11	0.00
NO_3-N, mg/kg	177.33	16.79	137.3	174.3	221.3	0.09	0.52	-0.23	0.08
TP, g/kg	0.79	0.22	0.35	0.75	1.33	0.28	0.61	-0.12	0.01
AP, mg/kg	20.46	3.42	13.54	19.95	29.51	0.17	0.57	-0.48	0.01
TK, g/kg	17.22	2.93	10.85	17.26	24.57	0.17	0.27	-0.32	0.52
AK, mg/kg	199.78	65.76	62.41	202.31	374.11	0.33	0.22	0.56	0.16
Fe, mg/kg	30.88	6.1	14.99	31.11	44.3	0.2	-0.18	-0.41	0.95
Mn, mg/kg	10.77	4.52	3.52	9.95	22.95	0.42	0.63	-0.39	0.03
Cu, mg/kg	2.05	0.47	1.15	1.97	3.25	0.23	0.47	-0.4	0.02
Zn, mg/kg	1.81	0.37	0.94	1.79	2.63	0.2	0.21	-0.38	0.42
Ca, mg/kg	1.79	0.62	0.64	1.72	3.52	0.35	0.3	-0.47	0.42
Mg, mg/kg	0.55	0.23	0.09	0.56	0.96	0.42	-0.05	-1.21	0.04
S, mg/kg	50.04	18.45	3.17	51.4	86.54	0.37	-0.32	-0.54	0.13
Cl, mg/kg	1.89	0.19	1.43	1.88	2.42	0.1	0.12	-0.39	0.55
Sand, %	12.68	3.94	5	12	23	0.16	0.56	-0.38	
Silt, %	68.43	3.52	59.4	68.4	77.4	0.12	0.1	-0.33	
Clay, %	18.89	4.39	8	19	29.6	0.19	-0.18	-0.13	

$^{\#}$CV, coefficient of variation (%). $^{※}$K-S test, Kolmogorov-Smirnov test was used to test the significance level of normality and all variables were normally distributed ($P > 0.05$).

whereas the lowest variation was registered in values of pH (8.0%). This variability is the result of the irregular cropping system and non-uniform management practices with using different experimental treatments result in marked changes in the topsoil over a small distance and the big experimental error if this condition is ignored. According to the criterion established by Warrick [42], variation coefficient values are classified as low: < 15%, moderate: from 15% to 50%, and high: > 50%. Soil pH, NO_3-N, Cl and silt had a low variation, whereas all other properties were manifested a moderate variation according to guidelines.

The descriptive statistics of soil properties suggest that all variable distributions were only slightly skewed (skewness < 1) according to Webster and Oliver [43], and their medians values were close to their mean values, identifying a normal distribution of soil variables. The soil is slightly acidic; the maximum value of pH is 7.0 and the minimum value is 5.0 (Table 1).

Correlation measures the linear relationship between random variables. The Pearson's correlation coefficients and their significance levels ($P < 0.05$) among all the soil properties are present in the Table 2. For this study area, almost all the variables had reflected different degrees of correlation. Strong positive correlations ($P < 0.01$) were observed between pH and CEC, AN, TP, AP, Mn, Cu, Zn, Ca. Negative significant correlation ($P < 0.01$) was found between sand and pH, CEC, TP, AP, Fe, Mn, Cu, Zn, Mg, S. The correlation analysis also showed the significant correlation among OM, CEC and Fe, Mn, Cu, Zn, Ca, Me, S, Cl. It can be speculated that the content of eight microelements can be affected by the content of OM and CEC. Therefore, the study area demonstrated the complicated correlation among the OM, CEC, TN, AN, NH_4-N and NO_3-N.

3.2 Geo-statistics Analysis

Different spatial distribution models and spatial dependence levels for the 22 soil properties were determined by the geo-statistical analysis (Table 3). Soil OM, CEC, AN, NH_4-N, NO_3-N, Mn and Zn were defined by the spherical model, the soil clay was determined by the liner model and the rest of the soil variables were calculated by the exponential model. The coefficient of determination (R^2) of all the variables, except TK and Cl, were greater than 0.80, indicating that theoretical models of soil properties well reflect their spatial structural characteristics.

The nugget ratio (nugget-sill) can be used to classify the spatial dependence of soil properties. The values of < 0.25, 0.25-0.75, and > 0.75 mean the strong, moderate and slight spatial autocorrelation in soil properties, respectively [41]. The resulting semivariograms indicate the existence of different spatial dependence for the investigated soil properties (Table 3).

Soil pH, CEC, TP, AP, Zn, Mg and S were strongly spatially dependent, the nugget-sill ratios rangied from 11.95% to 23.71%, that indicates the soil properties may be affected by the internal factors. The rest of variables were in moderate spatial dependence with the nugget-sill, are between 25% and 75%, illustrating that the soil variables may be affected by internal and external factors, such as cultivation and fertilization.

The range can determine the maximum radius for which the neighboring samples are used for interpolation by Kriging [44]. The range of soil variable indices varied from 51.30 m to 594.90 m. The content of Cl had a smallest range (51.30 m), which implies that the sampling interval (16 m) is shorter than the length of the spatial autocorrelation. Therefore, the sampling design is reasonable for this research and reliable spatial structure will be reflected in the contour map.

3.3 Interpolation Maps

These research contour maps of soil variables were prepared by the conventional Kriging interpolation method. In order to describe the spatial distribution

Table 2 Correlations among measured soil properties on the basis of 289 soil samples of agricultural experiment station in Chongqing, China.

Variable	pH	OM	CEC	TN	AN	NH_4-N	NO_3-N	TP	AP	TK	AK	Fe	Mn	Cu	Zn	Ca	Mg	S	Cl	Sand	Silt	Clay
pH	1.00																					
OM	0.12^{*}	1.00																				
CEC	0.40^{**}	0.23^{**}	1.00																			
TN	0.09	0.89^{**}	0.22^{**}	1.00																		
AN	0.22^{**}	0.77^{**}	0.10	0.77^{**}	1.00																	
NH_4-N	0.15^{*}	0.28^{**}	0.10	0.21^{**}	0.23^{**}	1.00																
NO_3-N	-0.28^{**}	0.36^{**}	0.28^{**}	0.35^{**}	0.22^{**}	-0.02	1.00															
TP	0.40^{**}	0.19^{**}	0.10	0.18^{**}	0.29^{**}	0.11	-0.27^{**}	1.00														
AP	0.30^{**}	0.10	0.07	0.10	0.23^{**}	0.12^{*}	-0.28^{**}	0.80^{**}	1.00													
TK	-0.10	0.04	0.12^{*}	0.06	0.03	0.00	-0.01	0.13^{*}	0.09	1.00												
AK	-0.18^{**}	0.03	0.10	0.05	-0.02	0.02	0.00	0.10	0.06	0.78^{**}	1.00											
Fe	0.00	0.31^{**}	0.13^{*}	0.31^{**}	0.38^{**}	0.07	-0.09	0.54^{**}	0.41^{**}	0.08	0.03	1.00										
Mn	0.28^{**}	0.07	0.01	0.06	0.16^{**}	0.08	-0.25^{**}	0.50^{**}	0.39^{**}	0.00	-0.05	0.49^{**}	1.00									
Cu	0.45^{**}	0.33^{**}	0.15^{*}	0.32^{**}	0.44^{**}	0.22^{**}	-0.20^{**}	0.77^{**}	0.60^{**}	-0.03	-0.06	0.62^{**}	0.70^{**}	1.00								
Zn	0.19^{**}	0.16^{**}	0.22^{**}	0.19^{**}	0.32^{**}	0.21^{**}	-0.10	0.50^{**}	0.47^{**}	0.05	-0.01	0.43^{**}	0.39^{**}	0.54^{**}	1.00							
Ca	0.80^{**}	0.13^{*}	0.50^{**}	0.11	0.20^{**}	0.19^{**}	-0.17^{**}	0.35^{**}	0.27^{**}	-0.09	-0.13^{*}	-0.01	0.26^{**}	0.44^{**}	0.19^{**}	1.00						
Mg	0.14^{*}	0.15^{**}	0.34^{**}	-0.15^{*}	-0.01	0.32^{**}	-0.37^{**}	0.23^{**}	0.31^{**}	0.14^{*}	0.08	0.14^{*}	0.18^{**}	0.21^{**}	0.32^{**}	0.31^{**}	1.00					
S	0.00	0.16^{**}	0.25^{**}	-0.09	-0.08	0.29^{**}	-0.25^{**}	0.11	0.16^{**}	0.15^{*}	0.10	0.08	0.12^{*}	0.09	0.32^{**}	0.15^{*}	0.76^{**}	1.00				
Cl	0.12^{*}	0.87^{**}	0.23^{**}	0.97^{**}	0.73^{**}	0.22^{**}	0.32^{**}	0.19^{**}	0.11	0.04	0.06	0.32^{**}	0.08	0.34^{**}	0.19^{**}	0.14^{*}	-0.11	-0.07	1.00			
Sand	-0.16^{**}	-0.18^{**}	-0.32^{**}	0.18^{**}	0.05	-0.11	0.30^{**}	-0.26^{**}	-0.30^{**}	-0.05	-0.03	-0.18^{**}	-0.24^{**}	-0.24^{**}	-0.35^{**}	-0.07	-0.30^{**}	-0.23^{**}	0.16^{**}	1.00		
Silt	0.08	-0.02	0.08	0.01	0.04	0.06	-0.11	0.41^{**}	0.33^{**}	0.00	0.03	0.28^{**}	0.26^{**}	0.31^{**}	0.25^{**}	-0.07	-0.05	-0.04	0.03	-0.32^{**}	1.00	
Clay	0.08	-0.15^{*}	0.23^{**}	-0.17^{**}	-0.08	0.05	-0.18^{**}	-0.01	0.00	0.05	0.00	-0.06	0.01	-0.03	0.11	0.12^{*}	0.31^{**}	0.24^{**}	-0.16^{**}	-0.65^{**}	-0.52^{**}	1.00

*Signification at the 0.05 probability level. **Signification at the 0.01 probability level.

Table 3 Models and parameters of semivariograms for agricultural experiment station in topsoil (0-20 cm) at different sampling dates (n = 289).

Variable	Model[a]	$C_0 + C$[b]	$C_0 + C$	Nugget[c], %	Spatial class[d]	Range	R^2	RSS[e]	Lag[f]
pH	E	0.05	0.24	0.21	S	218.40	0.93	2.94E - 03	16.00
OM	S	12.89	25.79	0.50	M	62.00	0.85	1.36E + 01	17.00
CEC	S	7.33	30.92	0.24	S	137.50	0.97	1.97E + 01	17.00
TN	E	0.01	0.04	0.25	M	52.80	0.82	2.60E - 05	19.00
AN	S	155.30	310.70	0.50	M	68.80	0.82	2.57E + 03	18.00
NH_4-N	S	166.10	332.30	0.50	M	74.20	0.91	1.61E + 03	17.00
NO_3-N	S	119.00	446.50	0.27	M	454.70	0.98	2.52E - 03	15.00
TP	E	0.01	0.08	0.13	S	594.90	1.00	1.56E - 05	16.00
AP	E	3.20	14.12	0.23	S	331.80	0.99	2.08E + 00	16.00
TK	E	2.31	8.65	0.27	M	54.00	0.74	3.23E + 00	16.10
AK	E	1,200.00	4,362.00	0.28	M	95.40	0.87	6.52E + 05	19.00
Fe	E	10.33	37.11	0.28	M	94.80	0.88	4.25E + 01	19.00
Mn	S	8.94	21.14	0.42	M	137.20	0.98	3.60E + 00	16.00
Cu	E	0.08	0.26	0.31	M	288.90	0.96	1.38E - 03	16.00
Zn	S	0.03	0.15	0.20	S	117.10	0.94	1.17E - 03	16.00
Ca	E	0.11	0.41	0.27	M	116.70	0.92	5.15E - 03	16.00
Mg	E	0.01	0.08	0.13	S	472.80	0.98	1.02E - 04	17.00
S	E	43.00	359.70	0.12	S	97.20	0.97	2.06E + 03	17.00
Cl	E	0.01	0.04	0.25	M	51.30	0.78	3.28E - 05	18.00
Sand	E	9.38	20.13	0.47	M	477.00	0.98	1.98E + 00	16.00
Silt	E	6.88	13.77	0.50	M	210.30	0.94	2.94E + 00	17.00
Clay	L	15.21	21.41	0.71	M	289.71	0.81	1.01E + 01	20.00

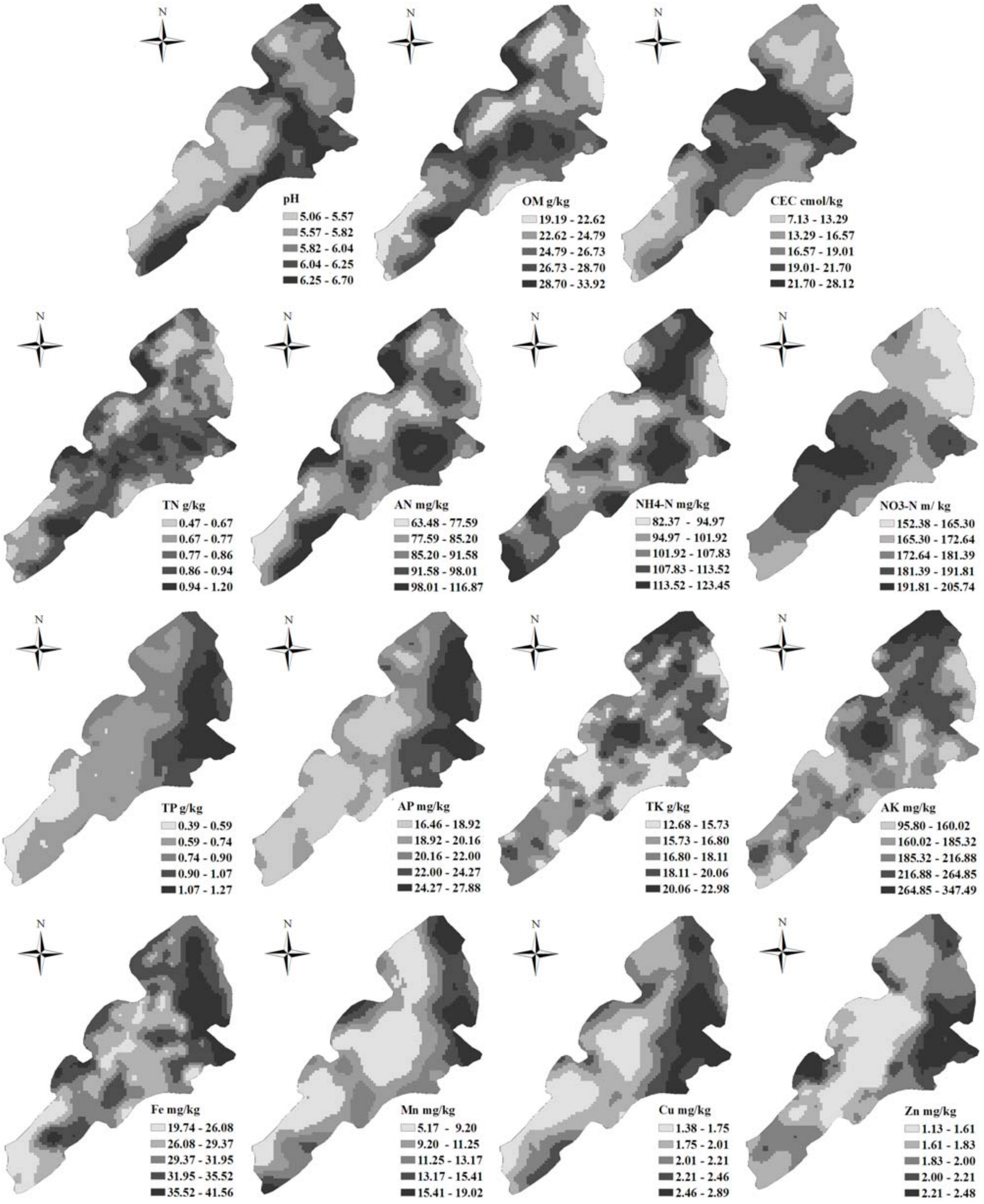
[a] E: Exponential model; S: spherical model; L: linear model. [b] C_0: nugget variance; C: structural variance. [c] Nugget %: $C_0/(C_0 + C) \times 100$. [d] S: strong spatial dependence (nugget < 25%); M: moderate spatial dependence (nugget between 25% and 75%). [e] RSS: reduced sums of squares. [f] Lag: lag interval.

differences during the soil properties, comparison analysis of the discrepancy results between the variables (Fig. 2). Spatial variables of pH, CEC, AN, Mn, Cu, Zn and Ca were similar on the investigated plot. Because the six variables had the strong positive correlation with pH (Table 2), their distribution (Fig. 2) was connected with pH. The content of TP and AP generally demonstrate the gradient from the Northeast to the Southwest. Deficiencies of soil CEC, TP, AP, Fe, Cu, Zn, Mn and Mg were observed in the Southwest primarily. Areas with higher TP, AP, Fe, Cu, Mg and S concentrations were mainly distributed in the Northeast. The content of AK had demonstrated a more localized pattern of enrichment according to the National Soil Survey Office [45].

4. Discussion

These studies have determined that the soil chemical and physical properties possessed the moderate variations according to the classification proposed by Webster and Oliver [43] with the exception of the soil pH, NO_3-N, Cl and silt. Coefficients of variation ranged from almost 7.67% to approximately 41.97% for pH (Table 1). The results demonstrated the heterogeneity of the soil continuum. The spatial distribution maps based on the geo-statistical analysis indicate the heterogeneity of soil properties. Therefore, the variable distribution maps are necessary for the preparation of the experimental treatment. According to Facchinelli et al. [46], the normality of the data is more important for geo-statistical analysis than the occurrence of a proportional effect in which the mean and the variance of the data and the result of descriptive statistics of soil properties suggest normal distribution.

It is very important that the spatial dependence and spatial patterns of soil variable need to be identified to develop agricultural experiment to create the consistent condition of the field experiment. Our results have indicated that all investigated properties demonstrated the strong or moderate spatial dependence within the scale of sampling (16 m sampling



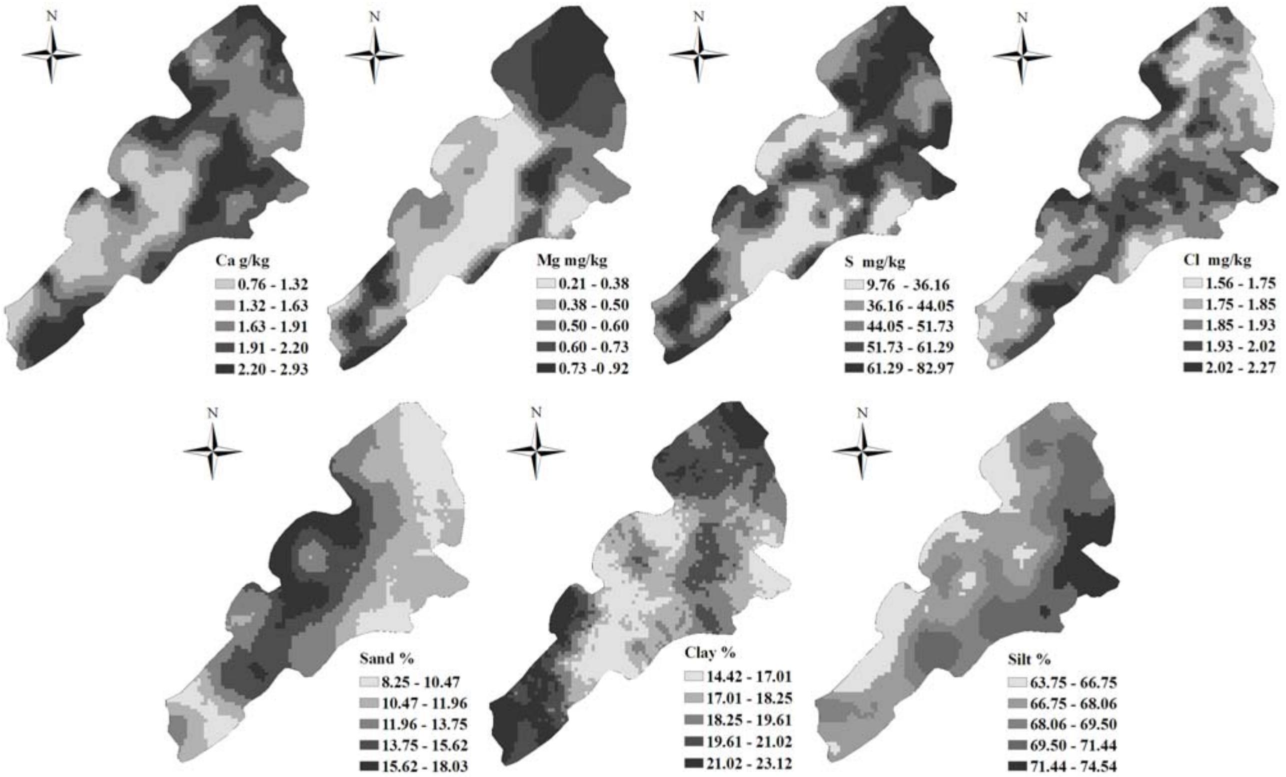


Fig. 2 Smoothed contour maps produced by Kriging for pH, OM, CEC, TN, AN, NH_4-N, NO_3-N, TP, AP, TK, AK, Fe, Cu, Mn, Zn, Ca, Mg, S, Cl, sand, silt and clay.

interval). If the soil indicators of pH, CEC, TP, AP, Zn, Mg and S showed the strong spatial dependence, then it means that internal factors (e.g., parent material and terrain) determined the spatial dependence of soil variables [41]. Data of pH variables are in accordance with the results of Vieira et al. [47], Liu et al. [48], Vieira and Gonzalez [49] and Jiang et al. [50], which have reported about the moderate spatial dependence for pH. Other studies [51] have found the slight spatial dependence for pH. Regarding to CEC, the slight, moderate and strong spatial dependence have been reported by Jung et al. [52], Alvares et al. [16] and Jiang et al. [24]. These researches have demonstrated that the spatial dependence level of identical soil variables can depend on the specific studied soil.

The spatial variability of TP and AP were mainly determined by internal factors. The clearly patchy distribution of TP and AP indicated that the development of the strategy of field experiments with P fertilizer is feasible in this area. Armindo et al. [53] have reported the similar spatial dependence for Zn and S in the soil, whereas the content of Mg showed the moderate spatial dependence. The geo-statistical analysis suggested that most soil variables showed the moderate spatial dependence in this study area, with the nugget/sill ratios ranging from 25% to 71%, because of random factors, as well as internal factors, which determine the spatial dependence of soil properties in general.

Nitrogen is the most important element for yield and quality of tobacco. The spatial distribution of soil nitrogen was influenced by the long-term application of chemical fertilizers and manure. Internal and external factors in conjunction determine the variability of OM, TN, AN, NH_4-N and NO_3-N in soil. Wei et al. [54] have found the similar spatial dependence for OM and NH_4-N. Our results differ from conclusions reported by López-Granados et al. [55], which showed that NH_4-N and NO_3-N in soil have no spatial dependence (pure nugget effect) and are mainly controlled by random factors.

Potassium fertilizers play an important role in the quality of tobacco [56]. The presented results have demonstrated that the TK and AK have the moderate spatial correlation, with nugget-sill ratios of 27% and 28%, respectively, because of the application of fertilizers on tobacco fields by farmers, especially in family-maintained small-scale operations. Mondo et al. [9], Brodský et al. [57] and Zhao et al. [58] have found out the similar spatial dependence for the content of K. Our results had differed from the findings reported by Ayoubi et al. [59]. They demonstrated that the content of K was mainly affected by internal factors.

The Fe, Mn, Cu, Ca and Cl are necessary micronutrients for tobacco growth. They are often applied on tobacco plantation in different doses. Therefore their spatial variability was determined by intrinsic and extrinsic factors simultaneously. The similar regularity has been reported by Wang et al. [60] for Fe and Mn.

The spatial variability of the soil granulometric composition is inherent in nature due to geologic and pedologic soil forming factors. Consequently, the spatial variability of soil granulometric composition was affected by internal factors. But soil sand, silt and clay had demonstrated the moderate spatial correlation, with nugget-sill ratios of 47%, 50%, 45.34% and 71%, respectively (Table 3) in the present research. The most probable reason could be the fact that the tillage and other management practices interact between themselves in spatial and temporal scales. Other researchers have concluded that sand [50], silt [48] and clay [61] were affected by both internal and external factors, suggesting that this phenomenon may be related to cultivation and soil tillage application.

A smaller range indicates that observed values of the soil variable are influenced by other values of this variable over lesser distances than soil variables which have larger ranges [62]. The range for TN, TK and Cl were 52.50 m, 54.00 m and 51.30 m, respectively, that were smaller than the others. This indicates that TN, TK and Cl values influenced neighboring values of TN, TK and Cl over lesser distances than other soil variable, e.g., TP, which had a range of more than 500 m. The smaller range suggests that smaller sampling intervals are needed for TN, TK and Cl.

The presented results suggested that the spatial variability of soil variables in selecting sites for the field experiment is mandatory to obtain coincident soil conditions and avoid the test errors from the inconsistent soil properties. These results can be used to facilitate the procedure of the preparation for field experiment in the tobacco experiment station. The spatial distribution maps of P, K, Cu, Fe, Mn and Zn can be used to design the experimental treatment and increase the reliability of test results.

5. Conclusions

Thus, descriptive statistics indicated the sizeable spatial variability for all soil variables. Further understanding of the spatial structures of soil variables can be helpful for revealing their spatial distribution and achieving the reasonable arrangement for experimental treatments. The geo-statistical analysis of soil variables suggested that the value nugget-sill ratio ranges from 8.97% (TP) to 49.98% (OM, AN, and NH_4-N), except for clay (71.04%), indicating that internal factors were dominant over external factors. Soil pH, CEC, TP, AP, Zn, Mg and S had the strong spatial dependence with a nugget-ill ratio of < 25%, primarily induced by structural factors, and the spatial variability of all other variables were mainly determined by internal and external factors. The spatial correlation distances of all variables varied from 51.30 m (Cl) to 594.90 m (TP), indicating that the sampling design is reasonable. The Kriging-interpolated maps of soil variables can be used to delineate homogenous zones for arrangement experimental treatments, which could avoid test errors derived from different soil conditions in the tobacco experiment station.

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