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Correlation Analysis Between Stand Structure Factors and Environmental Factors for Typical Forest Types in Beijing

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ABSTRACT

Studying the mechanisms between factors of stand structure and the environment is an important way to research and interpret the complex relationships between stand development and the environment. We investigated 113 sample plots of four typical forest types at Badaling forest farm in Beijing, and analysed stand soil structure, the correlations between stand structure and environmental factors, and the spatial distribution of soil nitrogen (TN) content and soil alkali-hydrolyzale (AN) content. The results showed that the typical forest types had significant differences in soil physical and chemical properties; the stand soil status of broad-leaved forest and scrubland was superior to that of the coniferous forest and the coniferous and broad-leaved mixed forest. The soil physical structure affected the stand structure more than the soil chemical structure, and stand structure variation caused by the soil factors was more important than the topographic factors in all the four typical forest types. Spatial heterogeneity in TN and AN was evidenced, and the overall N content was low.

INTRODUCTION

Stand composition, structure, function, origin, dynamic processes and distribution patterns are constrained by the surrounding abiotic and biotic environment (Sheng & Zhang 2000). Close and complex relationships exist between a stand and the environment, which are driven by environmental factors, resulting in variation in stand patterns as along an environmental gradient (Liu et al. 2005). Study of the complex environmental mechanisms driving stand structure is an important approach to researching and interpreting stand development (Zheng et al. 2007). The soil environment is not the only factor attributed to stand formation including stand structure, although soil does play a vital role in the development of stand patterns when considered among many environmental factors. Overall, the physical and chemical properties of a soil are considered to reflect the nutrient status of the soil, and these properties form over time as a function of the geology, terrain, biology, climatic factors, as well as anthropogenic disturbance (Birkeland 1984, Jenny 1994, Motavalli et al. 1995).

The spatial distributions of soil nutrients are correlated with many different environmental factors. Several studies have shown variability in soil nutrients in relation to topography, vegetation, cultivation, land use, moisture and parent materials (Swap et al. 2004, Tan & Lal 2005, Bai et al. 2009, Zhang et al. 2012). Numerous investigations also studied the spatial heterogeneity of soil properties using geostatistics analysis (Monokrousos et al. 2004, Gao et al. 2013, Baveye & Laba 2015) and have demonstrated geostatistics as a useful tool for estimating soil properties and for interpreting spatial variability (Long et al. 2014, Wang et al. 2015). Among soil properties, total nitrogen (TN) and alkali-hydrolyzale (AN) are often of particular interest to researchers because they are major determinants and indicators of soil fertility and quality and are closely related to soil productivity. In this paper, we present research whose purpose was to 1) describe and quantify the soil physical and chemical properties within four typical forest types in Beijing, 2) analyse the correlations between variables of forest structure and the environment, and 3) characterize the spatial heterogeneity of the soil TN and AN content using geostatistical semi-variogram analysis.

MATERIALS AND METHODS

Study area and field sampling: The study area was located at Badaling forest farm in Beijing (115°55’ E, 40°17’ N). The altitude ranges from 450 to 1238 m, and the slope is from 30° to 35°. The climate is continental monsoon, which is characterized as semi-humid to semi-arid and warm; the annual average temperature is 10.8°C. The average annual rainfall is 454 mm, falling mostly during the monsoon season in July and August at which time 59% of the annual precipitation is received.

We sampled 113 plots, including 25 in broad-leaved forest, 23 in coniferous and broad-leaved mixed forest, 25 in coniferous forest and 40 in scrubland. In every plot, we excavated one soil profile and measured the soil depth. Three 100 cm^3 soil cores were taken from the 0-20 cm soil layer at each site for analysis of the soil physical and chemical properties.

Analytical methods: The principal component analysis (PCA) is one of the multivariate statistical analysis techniques, and it can effectively summarize the independent variables contributing most of the variance (Kaiser 1960). Descriptive statistics of all data sets were generated (mean, standard deviation, coefficient of variation) and the Kolmogorov-Smirnov (KS) test was used (Massey 1951) at the 5% significance level to test the normality of each data distribution. The coefficient of variation (CV) of each data set was classified according to Wilding & Drees (1983) and is based on the variability of the data around the mean: $0 < CV \leq 0.15$ - low variability; $0.15 < CV \leq 0.35$ - moderate variability; and $CV > 0.35$ - high variability.

Geostatistical methods were used to study the spatial variability of the soil TN and AN. The geostatistics approach consists of two parts: 1) the calculation of an experimental variogram from the data and the fitting of a model and 2) a prediction of results for unsampled locations (Burgos et al. 2006). The semivariogram $\gamma(h)$ analysis method was used to establish the semivariogram theoretical model, which was constructed using the following calculation:

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

Where, $\gamma(h)$ is the semivariance for the lag interval h, $Z(x_i)$ and $Z(x_i+h)$ are variables at locations x_i and x_i+h, respectively, and $N(h)$ is the number of pairs separated by a distance h. The semivariogram is calculated and has three important statistics, namely the nugget (C_0), the sill (C_0+C), and the range (A_0). The sill value represents the maximum degree of variation and is a measure of the degree of spatial heterogeneity. The nugget value represents the discontinuous variation of regional variables on a small scale, mainly from random variation rather than the sampling scale and measurement errors. The range value is the maximum average distance of a variable for which spatial autocorrelation is relevant.

The degree of spatial autocorrelation $C_0/(C+C_0)$ (%) of each soil property was classified according to Cambardella et al. (1994): strong - $C_0/(C+C_0) \leq 25\%$, moderate - $25\% < C_0/(C+C_0) \leq 75\%$, and weak - $C_0/(C+C_0) > 75\%$. The spherical model, the exponential model, and the Gaussian model were used to fit the semivariance data, and the best fit among the semivariogram models was evaluated based on the coefficient of determination (R^2) and the sum of the squared residuals (SSR) (Webster & Oliver 2007).

RESULTS

Stand soil structure: The results of the analysis of the soil physical properties of the typical forest types are given in Table 1. There were significant differences in the soil physical properties among the typical forest types in the average soil depth and the soil bulk density; the trend for the values of these variables was broad-leaved forest > coniferous and broad-leaved mixed forest > coniferous forest > scrubland. The average soil depth of the broad-leaved forest reached a maximum of 0.84 m, indicating that this forest type possesses a large potential for water storage and soil conservation. The values of the soil porosity and capillary porosity indicated the following trend: scrubland > coniferous and broad-leaved mixed forest > broad-leaved forest > coniferous forest. The trend for non-capillary porosity was different than the trend for capillary porosity: broad-leaved forest > scrubland > coniferous and broad-leaved mixed forest > coniferous forest.

Table 1: Soil physical factors of typical forest types.

Forest types	SOID (m)	SOBD (g/cm^3)	TOPD (%)	CAPD (%)	UCAPD (%)
BF	0.84	1.22	49.90	31.00	18.80
CBMF	0.81	1.10	51.10	34.60	16.60
CF	0.71	1.03	37.40	25.20	12.30
SB	0.49	0.95	52.70	35.60	17.10

Note: BF: broad-leaved forest, CBMF: coniferous and broad-leaved mixed forest, CF: coniferous forest, SB: scrubland, SOID: soil depth, SOBD: soil bulk density, TOPD: soil total porosity, CAPD: soil capillary porosity, UCAPD: soil non-capillary porosity.

Table 2: Soil chemical factors of typical forest types.

Forest types	ORGS (g/kg)	TN (g/kg)	TP ((g/kg)	TK (g/kg)
BF	30.441	1.140	0.618	3.174
CBMF	28.327	1.009	0.583	2.986
CF	22.978	0.879	0.506	2.464
SB	30.790	1.194	0.690	3.192
Forest types	pH	AN (mg/kg)	AP (mg/kg)	AK (mg/kg)
BF	6.772	23.190	13.284	128.120
CBMF	6.912	25.945	12.017	119.087
CF	7.019	21.827	9.531	107.000
SB	6.770	24.625	10.792	117.625

Note: ORGS: soil organic matter, TP: total phosphorus, AP: available phosphorus, TK: total potassium, AK: available potassium.

Table 3: Vectors and root factors from PCA for the broad-leaved forest type.

Axis	Eigen value	CRAV (%)	SOID	SOBD	ORGS	TOPD	CAPD	UCAPD
AX1	0.80	61.6	0.59	0.42	0.25	0.26	0.21	-0.69
AX2	0.73	100	-0.15	-0.28	-0.14	0.33	-0.02	0.16
Axis	TN	TP	TK	AN	AP	AK	pH	
AX1	0.20	-0.18	0.27	-0.20	-0.31	-0.37	-0.05	
AX2	-0.42	0.34	0.03	0.17	-0.11	0.15	-0.27	

Note: CRAV: contribution rate of accumulated variance

Table 4: Relationships between stand structure factors and environmental factors with quantitative interpretation for the broad-leaved forest type.

Items	Eigen value	Interpretation ratio
The overall variation of stand structure	1.42	-
Terrain factors for stand structure	0.12	0.08
Soil factors for stand structure	0.65	0.46
Interaction of terrain factors and soil environmental factors for stand structure	0.20	0.14
Stand structure and environmental factors	0.97	0.68
Unexplained variation	0.45	0.32

The results of the analysis of the soil chemical properties for the typical forest types are presented in Table 2. There was variability of soil chemical properties among the typical forest types. For the values of soil organic matter content, the trend was as follows: scrubland > broad-leaved forest > coniferous and broad-leaved mixed forest > coniferous forest; the same trend was found for soil content of TN, TP and TK. These results revealed that the level of soil nutrition for plants was low across forest types, although soil nutrient content was slightly greater in the scrubland and broad-leaved forest types than the others, indicating a strong capacity for growth in stands of these two forest types. Most of the broad-leaved forest and scrubland stands originated from natural forest, with a stable stand structure and high growth rates. In contrast, most of the stands of the coniferous forest, coniferous and broad-leaved mixed forest originated from artificial forest.

The correlation analysis of broad-leaved forest stand structure factors and environmental factors: The results of the correlation analysis of broad-leaved forest stand structure factors and soil factors (Table 3) indicated that the first axis, which represents soil physical properties, contributed 61.6% of the variation, showing that the soil physical properties have a great effect on the broad-leaved forest stand structure. Moreover, the eigen values of the feature vectors indicated that soil non-capillary porosity (-0.69), soil depth (0.59), and soil bulk density (0.42) were the most important. The soil chemical factors of TN and TP had a large feature vectors with values of -0.42 and 0.34, respectively.

We analysed the topographic factors (i.e., terrain factors) of altitude, gradient and aspect. The quantitative relationships between the variables of stand structure and the environmental factors were analysed to investigate the importance of the different environmental factors on stand structure. The eigen value, attributed to the overall variation in the broad-leaved forest structure, was 1.42 (Table 4) and related to the soil environmental factors, the terrain factors, and the interaction of the terrain factors and the soil factors. These factors accounted for 46%, 8% and 14% of the variation, respectively. Overall, 68% of the variation of forest structure could be explained, leaving 32% of the variation unexplained, which illustrated the importance of other environmental factors.

The correlation analysis of coniferous and broad-leaved mixed forest stand structure factors and environmental factors: The correlation analysis of coniferous and broad-leaved mixed forest stand structure factors and soil factors (Table 5) showed that the soil physical structure had a great effect on the stand structure, contributing to 78.2% of the variation; based on the eigen values, soil depth (0.72), soil non-capillary porosity (-0.43), and soil total porosity (0.40) were the most important. The soil chemical factors of total phosphorus and total potassium had large feature vectors of 0.34 and -0.28, respectively.

The eigen value, indicating the overall variation in coniferous and broad-leaved mixed forest structure, was 1.56 (Table 6); the variation was attributed to terrain factors, soil factors, and the interaction of terrain factors and soil factors in which 30%, 39%, and 10% of the total variation could be explained, respectively. Nevertheless, 21% of the variation failed to be explained, illustrating that other environmental factors contributed to the variation.

The correlation analysis of coniferous forest stand structure factors and environmental factors: The correlation analysis of coniferous forest stand structure factors and soil factors (Table 7) showed that the soil physical factors had a great effect on stand structure in which (60.1%) of the variation in stand structure could be explained; based on the

Table 5: Vectors and root factors from the PCA for the coniferous and broad-leaved forest type.

Axis	Eigen value	CRAV (%)	SOID	SOBD	ORGS	TOPD	CAPD	UCAPD
AX1	0.91	78.2	0.72	0.36	-0.23	0.40	0.39	-0.43
AX2	0.68	100	0.21	0.38	-0.24	0.06	0.10	0.07
Axis	TN	TP	TK	AN	AP	AK	pH	
AX1	-0.28	-0.16	-0.05	-0.26	-0.08	-0.09	-0.13	
AX2	0.07	-0.34	-0.28	-0.18	-0.10	-0.20	-0.01	

Table 6: Relationships between stand structure factors and environmental factors with quantitative interpretation for the coniferous and broad-leaved mixed forest type.

Items	Eigen value	Interpretation ratio
The overall variability of stand structure	1.56	-
Terrain factors for stand structure	0.46	0.30
Soil factors for stand structure	0.61	0.39
Interaction of terrain and soil factors for stand structure	0.15	0.10
Stand structure and environmental factors	1.23	0.79
Unexplained variability	0.34	0.21

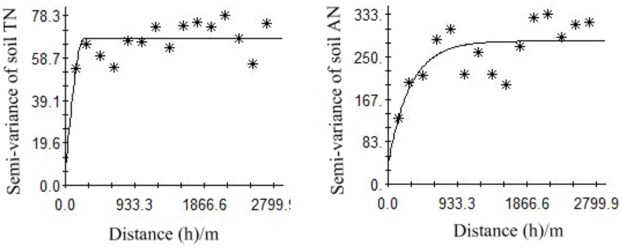

Fig. 1: Spatial heterogeneity of TN and AN content.

eigen values, soil non-capillary porosity (-0.51), soil depth (0.42), and soil total porosity (0.40) were the most important factors. Total nitrogen and total phosphorus had large feature vectors among the soil chemical factors, with eigen values of -0.48 and -0.40, respectively. Beijing has an arid climate where plant growth requires much water, and soil moisture is vital whereby the soil depth and the soil porosity are the most important factors affecting soil moisture.

The eigen value associated with the overall variation of coniferous forest structure was 1.22 (Table 8); the variation was attributed to terrain factors, soil factors, and the interaction of terrain factors and soil factors and accounted for 17%, 61%, 3% of the total variation, respectively. Nineteen percent of the variation could not be explained and was attributed to other environmental factors.

The correlation analysis of scrubland stand structure factors and environmental factors: The correlation analysis of scrubland stand structure factors and soil factors (Table 9) also showed that the soil physical structure had a great effect on the stand structure; based on the eigen values, the soil bulk density (0.76) and the soil total porosity (0.31) were the most important factors in the soil physical structure. Similarly, AN and AK had large feature vectors when considered among the soil chemical factors and had eigen values of 0.58 and 0.35, respectively.

The eigen value associated with the overall variation in broad-leaved forest structure was 6.40 (Table 10). The variation was attributed to terrain factors, soil factors, and the interaction of terrain factors and soil factors, accounting for 12%, 39%, and 3% of the variation, respectively; thus, 52% of the variation failed to be explained. The stand patterns for scrubland were complex and influenced by many environmental factors, in addition to the soil factors and the terrain factors.

The analysis of spatial heterogeneity of soil TN and AN: The coefficient of variation of soil TN and AN content was 0.477 and 0.710, respectively (Table 11); both TN and AN content had a high level of variability according to the criterion of Wilding & Drees (1983). The results of the spatial analysis of TN and AN soil content (Table 12) indicated a clear spatial heterogeneity for both (Fig. 1). The spherical model indicated the best fit for both soil factors. The TN content within a range of 246 m had a significant spatial structure, and the AN content within a range of 772 m also had a significant spatial structure. The spatial range of AN content was greater than the spatial range of TN content, indicating that there was similarity between neighbours and that the spatial distribution of AN content at the spatial scale under study was more homogeneous. The $C_0/(C_0+C)$ of TN content was 11.97%, indicating a distribution with a strong spatial autocorrelation. Similarly, the $C_0/(C_0+C)$ of AN content was 26.92%, indicating a moderate spatial autocorrelation. The great spatial variability in the study area of TN and AN content was mainly associated with soil structural factors, topographic factors and vegetation types.

The semivariogram model discussed above to determine the spatial variability of soil TN and AN content was derived utilizing the block kriging spatial interpolation

Table 7 Vectors and root factors from the PCA for the coniferous forest type.

Axis	Eigen value	CRAV (%)	SOID	SOBD	ORGS	TOPD	CAPD	UCAPD
AX1	0.92	60.1	0.42	0.39	0.25	0.40	0.35	-0.51
AX2	0.60	100	0.64	0.24	-0.37	-0.39	-0.37	0.12
Axis	TN	TP	TK	AN	AP	AK	pH	
AX1	-0.48	-0.40	-0.28	-0.20	-0.09	-0.30	-0.04	
AX2	0.28	0.05	-0.11	0.08	-0.33	-0.10	-0.05	

Table 8: Relationships between stand structure factors and environmental factors with quantitative interpretation for the coniferous forest type.

Items	Eigen value	Interpretation ratio
The overall variability of stand structure	1.22	-
Terrain factors for stand structure	0.21	0.17
Soil factors for stand structure	0.74	0.61
Interaction of terrain and soil factors for stand structure	0.04	0.03
Stand structure and environmental factors	0.99	0.81
Unexplained variability	0.23	0.19

Table 10: Relationships between stand structure factors and environmental factors with quantitative interpretation for the scrubland type.

Items	Eigen value	Interpretation ratio
The overall variability of stand structure	6.40	-
Terrain factors for stand structure	0.76	0.12
Soil factors for stand structure	2.52	0.39
Interaction of terrain and soil factors for stand structure	0.97	0.03
Stand structure and environmental factors	2.90	0.45
Unexplained variability	3.15	0.52

Table 9: Vectors and root factors from the PCA for the scrubland type.

Axis	Eigen value	CRAV (%)	SOID	SOBD	ORGS	TOPD	CAPD	UCAPD
AX1	0.90	77.1	-0.15	0.76	-0.26	0.21	0.31	-0.12
AX2	0.72	100	0.24	-0.06	-0.07	-0.17	-0.25	0.08
Axis	TN	TP	TK	AN	AP	AK	pH	
AX1	-0.01	-0.10	0.35	0.58	-0.09	0.15	-0.15	
AX2	-0.12	0.01	-0.34	0.06	-0.16	-0.07	-0.06	

Table 11: Analysis of TN and AN content using descriptive statistics.

Factors	Range	Mean ± SD	*CV*	Skewness	Kurtosis
TN	2590.00	1.075 ± 0.513	0.477	0.768	0.160
AN	84.26	24.92017.700	0.710	2.563	6.876

method. The results showed that the soil TN and AN content followed the typical spatial distribution pattern of mosaic patches (Fig. 2). The TN content within 1.043-1.212 g/kg had the maximum range of distribution, followed by the TN content of 0.874-1.043 g/kg when we divided the soil nitrogen content into 5 levels. Similarly, the maximum range of distribution for the soil AN content corresponded with an AN concentration level of 19.821-39.720 mg/kg. We also found that the overall N content was low, suggesting the soil was of poor nutritional quality for plants.

DISCUSSION

Numerous papers have discussed the effect of environmental factors on soil properties, including grazing intensity, which has been of particular interest to researchers (Pietola et al. 2005, Kurz et al. 2006, Arnholda et al. 2015). Livestock grazing causes considerable shifts in the physical and chemical properties of soils and has been found to increase the soil bulk density and negatively affect the soil hydraulic properties. In recent years, many researchers have

Table 12: Analysis of TN and AN content using geostatistical analysis.

Factors	Model	C_0	$C+C_0$	A_0 (m)	$C_0/(C+C_0)$ (%)	*FD*	*SSR*	R^2
TN	Spherical	8.10	67.65	246	11.97	1.957	709	0.204
AN	Spherical	74.60	277.10	772	26.92	1.882	25022	0.504

Note: *FD*: fractal dimension

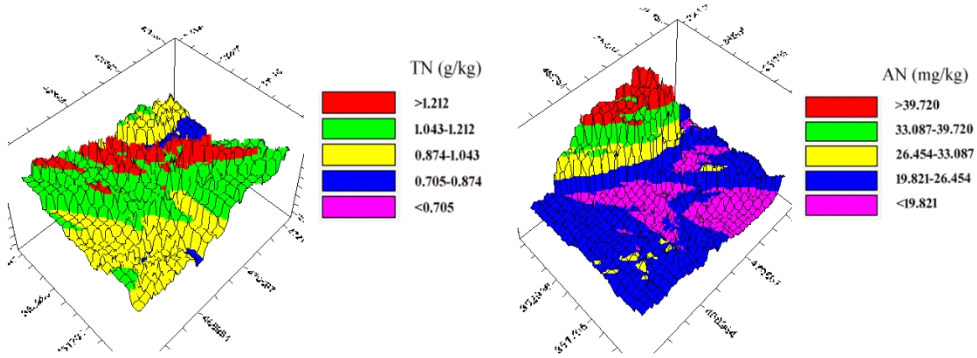

Fig. 2: Spatial distribution of (a) TN and (b) AN.

focussed on the spatial heterogeneity of soils, particularly in relation to organic matter and nitrogen, which are important because they reflect soil nutrition. The level of soil N depends on many factors, including the topography, land use, vegetation and soil moisture, all of which have been well covered in the literature (D'Odorico et al. 2003, Austin et al. 2004, Qiu et al. 2001, Wang et al. 2012). In addition, soil management has been reported as one of the main factors causing spatial and temporal variability of soil properties (Wang et al. 2009, Alletto et al. 2010, Arnholda et al. 2015). In our study, we found that the spatial distribution of soil properties varied among forest types, indicating that the difference in soil properties is related not only to the above-mentioned factors, but also to the spatial distribution of plant populations, which influence soil management to some extent.

The spatial variation of soil nitrogen strongly affects the circulation of soil N and can have an important impact on soil organic matter transformation and the litter decomposition rate, which affects the distribution patterns of loops and many other nutrients plant productivity. However, although spatial variation in nutrient content has often been observed (Grimm et al. 1981, Tate 1990, Valett et al. 1990), few studies have concentrated on long-term observations of changes in the spatial distribution of soil nutrient concentrations with time. Dent & Grimm (1999) measured the spatial heterogeneity of nutrient concentrations at three different times in plant succession: early, middle and late succession. The results demonstrated that nutrient concentrations are patchy in space and in time, and it is necessary to carry out long-term monitoring to discover the mechanisms driving the spatial heterogeneity of soil nutrients and other soil properties.

Scrubland in Badaling forest farm possesses a slightly smaller soil bulk density and a slightly larger soil porosity when compared with the other forest types (Table 1); soil TN, TP and organic matter content (Table 2) were also greater in scrubland than in the other forest types. The plant species making up the scrubland type are mostly native with cold- and drought-resistant characteristics, which are suitable for growth in the shallow, low nutrition soils in some areas of Beijing. This is important in relation to water and soil conservation in Beijing mountainous areas. Whereas, the beneficial ecological functions of scrubland have not drawn adequate attention, some scrubland that had adapted to the local soil was cut down to plant coniferous forest; however, a part of the coniferous forest did not grow well due the limiting water and soil conditions, resulting in an overall reduction of forest ecological functions. Therefore, we need to fully understand the ecological role of natural scrubland, enhance its protection and management, and effectively promote its ecological benefits.

CONCLUSION

Environmental factors have different effects on the stand structure of different forest types; based on the multivariate analysis, the percent variability and the trend for the forest types were as follows: coniferous forest (81%) > coniferous and broad-leaved mixed forest (79%) > broad-leaved forest (68%) > scrubland (48%). The principle conclusions related to the complexity and the stability characteristics of stand structure in Beijing are as follows: the stand structure of broad-leaved forest and scrubland (mostly originating from natural forest) was superior to that of the coniferous forest (mostly originating from artificial forest); the stand structure of the coniferous and broad-leaved mixed forest was superior to that of the pure coniferous forest. Meanwhile, among the soil environmental factors, the factors of soil depth, soil porosity and soil bulk density had a strong correlation with the stand structure factors.

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