

Spatial analysis of biodiversity soil macrofauna in *Populus deltoides* plantation of northern forests of Iran

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ABSTRACT

Information about the spatial patterns of soil biodiversity and understanding the effects of biodiversity on ecosystem processes are limited. This study was conducted to determine whether biodiversity of soil macrofauna features demonstrate spatial patterns in the *Populus deltoides* plantation in north of Iran. 150 soil samples were taken using a grid sample of 40 × 40 m. Soil macrofauna were sampled by digging and hand sorting two 50 × 50 cm areas into a depth of 20 cm in each treatment. Abundance (the number of macrofauna) diversity (Shannon-Weiner index), richness (Menhinick index) and evenness (Smith–Wilson index) were calculated using geostatistics (variogram) in order to describe and quantify the spatial continuity. Some soil chemical and physical properties were determined. The variograms of variable revealed the presence of spatial autocorrelation. The range of influence was 710.9 m for abundance, 650.3 m for diversity, 720.90 m for richness and 410.9 m for evenness. The kriging maps indicated that the soil macrofauna have spatial variability. Moreover, the spatial pattern of macrofauna biomass is similar to the pattern of clay and pH of soil.

Key words: Biodiversity, Geostatistic, Spatial pattern, Soil macrofauna biomass.

INTRODUCTION

The soil macrofauna community consists of invertebrates. They spend an important part of their life cycle in soil or inside the surface remnants. These invertebrates perform many ecological functions. Their functions such as primary decomposition and redistribution of organic residues in soil profiles and presence in nutrient cycle in soil have involved a lot of considerations about biodiversity and ecology of them (Ouedraogo *et al.* 2006).

Among the soil fauna communities, earthworms consist of the most biomass of soil invertebrates in most areas and affect the physical, chemical and biological characteristics of soil (Jostone *et al.* 2014). The soil invertebrates' distribution is restricted to under the influence of environmental factors. The mutability of soil physical and chemical properties is considered as the most important reason for soil macrofauna variation (Mathieu *et al.* 2004). Since the invertebrate's reduction in the soil can include negative effects on soil structure, decomposition process, and penetration process and gases exchange. Therefore, we need to determine the diversity, food and organism's abundance indicators in ecology, conservation programs, habitat management and ecosystem evaluation (Mathieu *et al.* 2004). These indicators are beneficial for making the biodiversity pattern of soil macrofauna quantitative (Gonglanski *et al.* 2008). Many authors have applied geostatistical methods to analyze the spatial pattern of soil macrofauna (Gonglanski *et al.* 2008; Golami *et al.* 2016). The soil characteristics usually have spatial variations, but these changes recognition especially in agricultural lands and natural resources is essential for accurate planning and management. We need to be aware about this issue to increase profits and attain the sustainable utilization (Ayoubi & Alizadeh 2007). Geostatistics is a branch of statistics which investigates the community data coordinates and studies their locative structure (Khosravi & Abasi 2018).

Geostatistics principles are based on the area variable theories which consider both structural and random changes of location variables. In addition to the quantity of a sample quantum, the sample location is also considered. Then, the samples can be analyzed together along the required quantity (Khosravi & Abasi 2018). The objective of this study was to analyze the spatial pattern of abundance, evenness, richness and diversity of soil macrofauna as well as to prepare the local distribution maps of these indicators by geostatistical approaches in order to manage and plan appropriately along with to preserve the ecosystem for *Populus deltoides* plantations in north of Iran.

MATERIALS AND METHODS

Study area

This study was conducted in Guilan Province, north of Iran. The province has covered by field crops, poplar plantations and natural forests. The study area is located at the Shafaroud forest lands (37° 34' N, 49° 50' E). Precipitation, relative humidity and mean annual temperature are 1242 mm, 83.5% and 16.0 °C respectively. The elevation of study area is between 0 - 20 m above sea level, located in plain areas. The soil was formed from alluvial fine-textured sediments with sandy loam texture, and with neutral to low acidic reaction.

Soil sampling

The samples were taken in a random-systematic grid from the upper 20 cm at 150 sampling points over 20 ha (40 × 40 m) on mid July 2015. The samples were air-dried and passed through a 2 mm sieve for analyzing chemical and physical properties. Organic carbon (OC) was determined according to Walkley & Black (1934), total nitrogen (N) by the Kjeldhal method, soil pH using a glass -electrode pH meter. Among soil physical properties, soil texture in hydrometric method was employed and saturation percentage (SP) was calculated.

Soil macrofauna

Soil macrofauna were sampled by digging and hand-sorting two- 50 × 50 cm -areas into a depth of 20 cm in each treatment. After detection, the organisms were placed in plastic bags and transported to the laboratory for biomass assessment. The number of individuals for each sample was determined on the day of collection. Soil macrofauna was defined according to Warren & Zou (2002), since invertebrates visible by the naked eye (macroscopic organisms).

Geostatistical analyses

Before application of geostatistical analysis, anisotropy of each variable was reviewed by drawing the procedural variograms. For the ideal variogram, three parameters can be stated as nugget effect, sill and range. The nugget effect is the variance of non-structural element (random), the range indicates an approximate of whole variance and the scope of influence determines the distance beyond which there is no place correlation among the observations. The degree of place dependency of variables is obtained by the division of nugget effect variance by the sill. Validation of variograms was attained by Jackknife method to determine the most suitable search radius and number of neighbor points in order to minimize the kriging estimation error through GEOEASE software. Regarding to the observed and estimated values, Mean Error (ME) and Root Mean Square Error (RMSE) were computed. After controlling the validity of kriging parameters and gaining the most appropriate parameters for interpolation of variables, the zoning and preparing the kriging maps were conducted. So that, interpolation was performed via kriging. Number of animals (abundance), evenness (Smith –Wilson index), richness (Menhinick index) and diversity (Shannon - Weiner index) were computed using Ecological Methodology software. These indices calculated by the following equations (1, 2 and 3), (Pourbabaei 2004):

$$\text{Minhinick} = \left(\frac{s}{\sqrt{n}} \right) \quad (1)$$

$$\text{Shannon } H' = \sum_{i=1}^s (p_i) (\log_2 p_i) \quad (2)$$

$$\text{Smith-Wilson} = \left[\frac{2}{\pi} \right] \left[\arctan \left\{ \frac{\sum_{i=1}^s \left[\log \sum_{e}^{(ni)} - \sum_{j=1}^s \log_e n_j / s \right]^2}{s} \right\} \right] \quad (3)$$

Geostatistical analysis was determined using the GS⁺ package program for the environmental sciences, version 10.

RESULTS

The Tables 1 and 2 indicate that data distribution did not exhibit normal distribution regarding some variables. By comparing variogram of variables in two moods of converted and non-converted (main data), it becomes obvious that the place structure of variograms was better once the converted data was used and it displayed more irregular shape. When the skewness is not much high, there is no need to convert data. Hence, regarding to low values of skewness, when the evenness, diversity and richness exhibited low deviation from normal distribution, all geostatistical analyses were performed on the basis of main data (Tables 1 - 2). The model with minimum Reduced Sums of Squares (RSS) and maximum R^2 were selected for fitness. The results indicated that most of variables displayed spatial structure together with sill model. Most of the indices were followed by spherical model (Fig. 1). The properties of variograms, the criteria to select model and control the validity for the characteristics of soil, and also biodiversity of macrofauna have been inserted in Table 3. The correlation coefficients of fitted model exhibited much proper values, displaying the appropriate number of sample in each step length to compute the variogram. Negative amount in evaluating the validity of some variables indicates the bigger estimated values than the real ones, while the positive amount exhibits smaller values compared to the real ones (Table 3).

Table 1. Summary of descriptive statistics for abundance and biodiversity of soil macrofauna

Attribute	MEAN	MIN	MAX	STDEV	CV (%)	SKEW	KURT
Abundance	7.61	2	31	4.97	65.30	0.26	-0.21
Evenness	0.95	0.03	3.53	0.94	98.94	0.6	0.79
Richness	2.54	0.01	4.15	0.85	33.46	0.58	0.51
Diversity	2.27	0.03	4.49	1.02	44.93	0.93	0.26

MEAN: mean, MIN: minimum, MAX: maximum, STDEV: standard deviation, CV: coefficient of variation, SKEW: skewness, KURT: kurtosis, abundance: Number of animals, diversity: Shannon-Weiner index, richness: Menhinick index, evenness: Smith–Wilson index.

Table 2. Statistics for some soil chemical and physical properties.

Attribute	MEAN	MIN	MAX	STDEV	CV (%)	SKEW	KURT
OC (%)	2.58	1.38	3.96	0.97	37.59	-0.98	-0.38
Log OC	0.22	0.21	0.59	0.17	77.27	0.37	-0.26
N (%)	0.42	0.80	1.07	0.12	30.76	-1.56	-0.86
Log N	0.84	0.2	0.47	0.17	20.23	1.00	0.76
pH	6.40	5.22	6.69	0.35	5.33	-0.85	-0.59
SP (%)	45.3	1.42	55.7	0.58	1.28	0.32	-0.46
Sand (%)	25.18	10.6	37.24	13.06	51.56	0.25	-0.65
Clay (%)	38.67	7.36	47.54	9.17	23.71	-0.44	-0.48
Silt (%)	24.41	5.35	35.59	10.01	41.00	0.19	0.84

OC: Organic Carbon content, N: Nitrogen content, pH: soil reaction, SP: saturation percentage.

Table 3. Parameters of semi-variograms for pairs of measured variable.

Variable	Model	C_0	C_0+C	A_0 (m)	C_0/C_0+C	correlation	ME	RMSE
Abundance	Exponential	0.20	1.18	710.9	16.94	strong	0.7	0.08
Diversity	Spherical	0.23	1.11	650.3	20.72	strong	0.2	0.53
Richness	Exponential	0.001	2.25	720.90	0.04	strong	0.12	0.25
Evenness	Spherical	0.38	1.91	401.9	19.89	strong	1.02	0.09
OC (%)	Spherical	0.156	1.05	620.20	14.85	strong	0.012	1.201
N (%)	Spherical	0.010	0.066	530.80	15.15	strong	0.025	0.301
pH	Spherical	6.06	5.22	410.67	5.77	strong	0.12	-0.55
SP (%)	Spherical	0.175	1.10	432.10	15.90	strong	0.23	0.06
Sand (%)	Linear	157.00	177.65	321.08	88.37	moderate	0.24	1.18
Silt (%)	Linear	97.86	100.82	322.08	97.06	moderate	0.236	0.057
Clay (%)	Exponential	97.50	135.01	320.00	49.99	weak	1.105	0.602

C_0 : nugget variance, $C_0 + C$: sill, A_0 : Range of parameter, ME: Mean Error, RMSE: Root Mean Square Error.

Kriging parameters were optimized by mutual validation method in order to minimize the estimation error. After statistical estimation and kriging, in relation to some data, the function was returned from logarithmic mood into initial one and the final maps were provided.

The spatial distribution maps relating to variables have been illustrated in Fig. 2. These maps demonstrate that the variables have not random pattern and have spatial disperse.

In the maps, the coordinates of X and Y have been given in UTM coordinate system vertically and horizontally. The map legend shows the estimated value for the non-sampled points (Fig. 2).

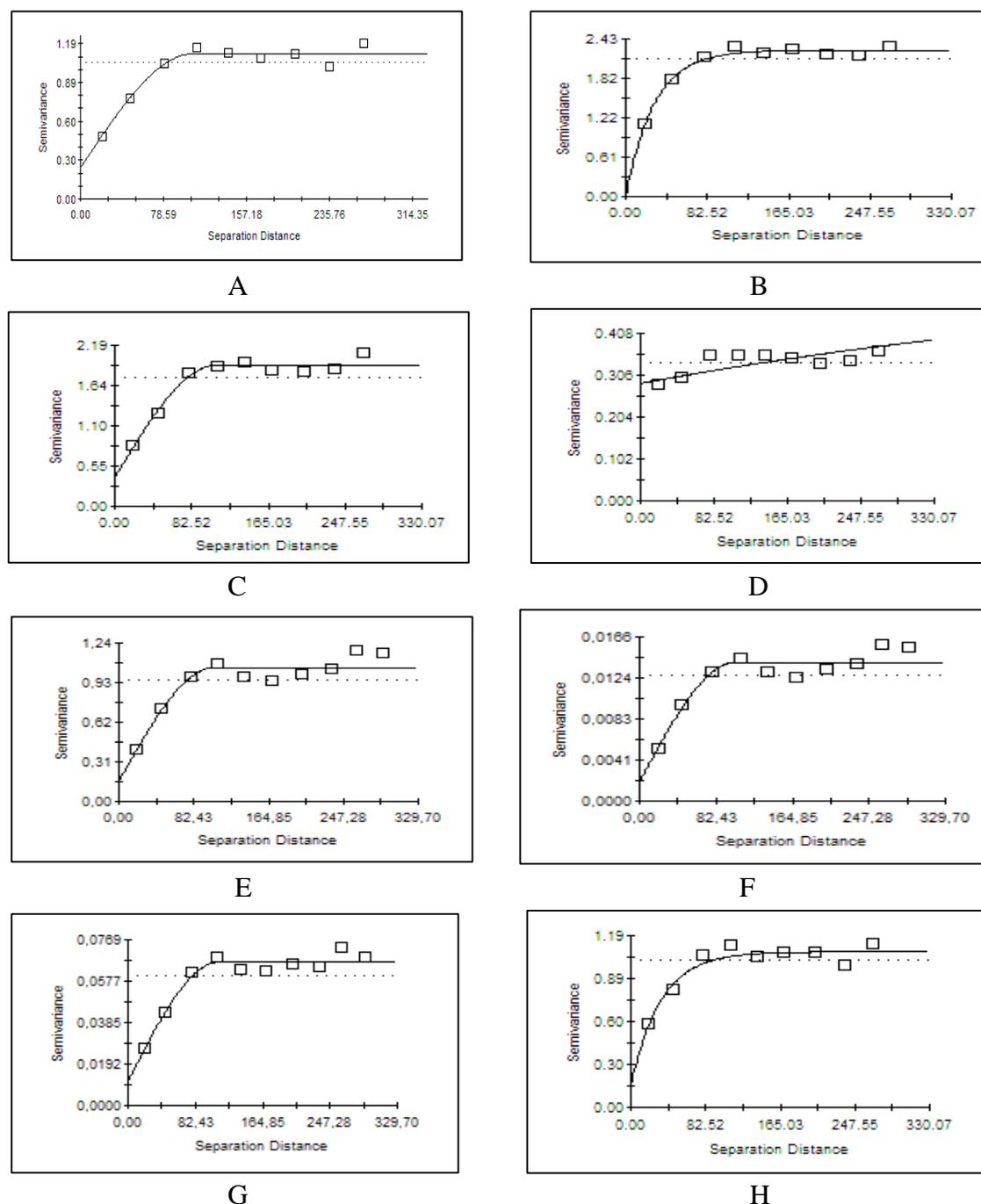


Fig. 1. Graphs of isotropic variograms and fitted models for the attributes of (A) diversity, (B) richness, (C) evenness, (D) abundance, (E) OC, (F) pH, (G) N, (H) SP.

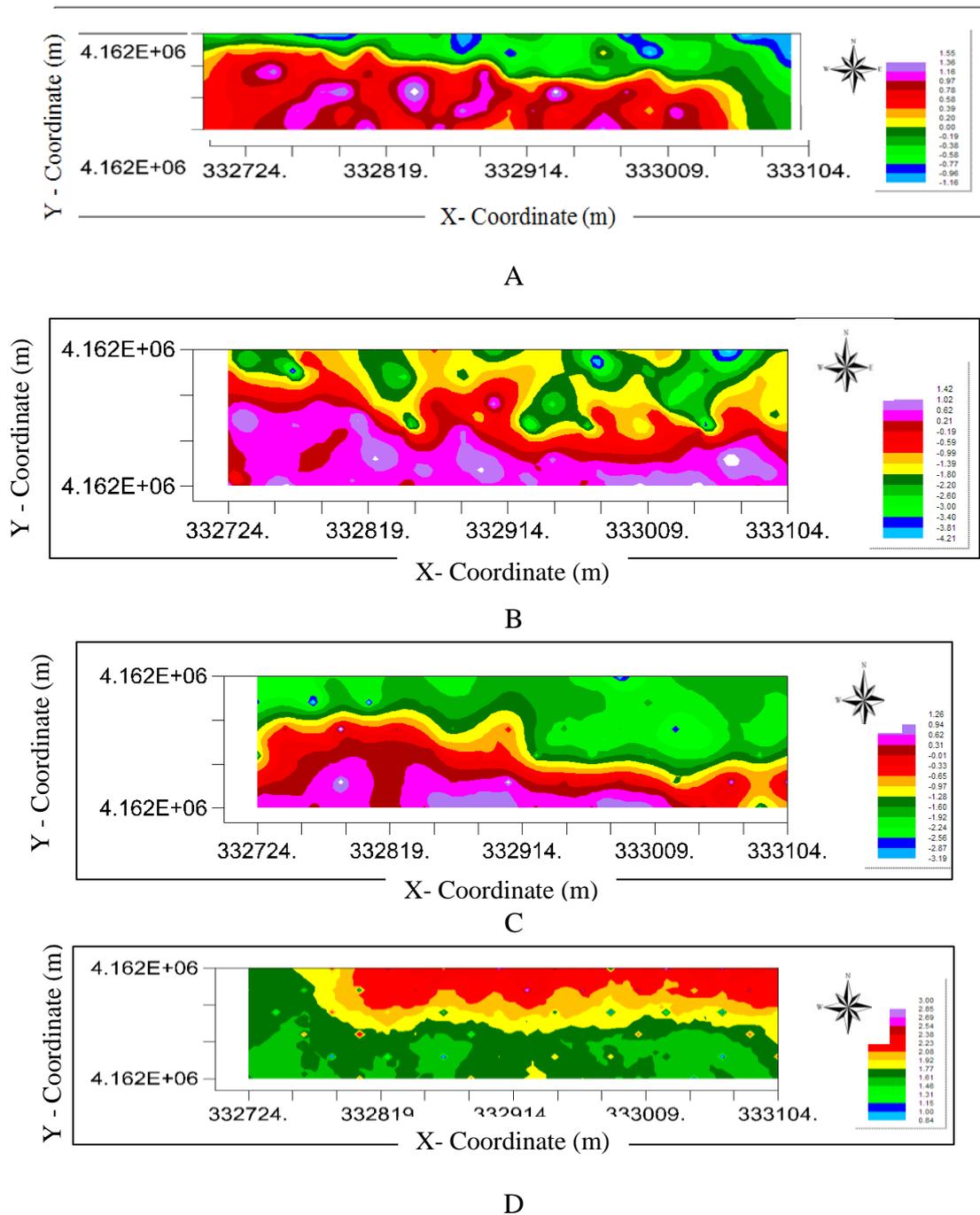


Fig. 2. Kriging map graphs of variograms and fitted models for (A) diversity, (B) richness, (C) evenness, (D) abundance.

DISCUSSION

The skewness of all abundance indicator, diversity index, richness and evenness tends to the right, exhibiting that the abundance, richness, diversity and evenness contain lower values. Some authors have reported similar right-tended skewness results concerning to the abundance and biodiversity of soil macrofauna (Rossi *et al.* 2006; Golami *et al.* 2016). The indices of variation coefficient were relatively high. This parameter of macrofauna was higher than the could be due to the mobility inherent characteristics of macrofauna.

No significant anisotropy was observed after measurement of the variability indicators, exhibiting that these variable alterations were the same in different directions, which may be due to the variability of soil characterization and those affecting the macrofauna population distribution in different directions (Gaston & Spice

2000). The study of these variograms indicated that the data distribution of all poplar stand factors did not indicate any trends in each indicator; and the variograms showed the spatial correlation. Notably, the considered characteristics of soil macrofauna mostly confirm the spherical model. The fitness model given to abundance and diversity variograms was also spherical. These patterns have been observed for earthworm species (Rossi *et al.* 2006).

The spatial correlation of abundance observations occurs at a greater distance, indicating that the condition of these indicators is the same. Therefore, we can increase the sampling distance in this case (Akhavan & Kelain 2009). The smaller influence range represents high variability. Generally, the variograms domain and their other parameters are relatively similar regarding the calculated indices, revealing that the distribution conditions and the biodiversity distribution pattern of soil macrofauna are identical in the study area. In other words, the processes leading to measure abundance, evenness, and richness as well as the diversity variations are the same.

The Kriging maps showed that the soil macrofauna diversity indices did not contain a random pattern and had spatial distribution. A similar distribution is nearly observed for considered indicators which imply the similarity of spatial distribution pattern in these variables. The Kriging maps illustrated the gradual and continuous changes in the indicators well. In this study, the spatial distribution pattern of soil macrofauna is nearly similar to the spatial distribution of silt and pH which also had a positive correlation with this feature, while negative correlation with the clay percentage. Areas exhibiting more abundance, diversity, richness and evenness, are located in regions with greater coverage and appropriate soil properties, which may be due to more humidity in these regions. Sometimes, cumulative macrofauna spots were observed which may also be the result of specific nutritional conditions and vegetation in these areas. Local distribution of soil macrofauna was under the influence of factors such as alterations in organic matter and soil texture (Ghorbanzadeh *et al.* 2017).

The value of Shannon-Weiner index was 2.27 which represented the high biodiversity in poplar. The variation range of Shannon-Weiner varies usually between 0.5 and 1.5 - 3.5 (Southwood & Henderson 2000). Lower values indicate stress and instability in the environment, whereas higher values exhibit the increased biodiversity in the region. The increasing amount of this index is due to the fact that the biological conditions such as humidity and food source were higher in that stand. Since the richness of soil organisms depends on several conditions and resources, the canopy variations affect the survival of soil organisms (Negrete-Yankelevich *et al.* 2008). The high richness in the stand can explain this matter. Noteworthy, in a forest or stand, the two factors, i.e. stability and diversity are interdependent to each other and have complementary effects. In fact, a stand should contain a relative stability (balance) to increase diversity. Despite the relative stability under these conditions, increased diversity leads to maintain stability (sustainability). Therefore, when Shannon-Weiner index is high in a stand, at first, it indicates the stability of the area that was found in poplar. The studied physical and chemical properties exhibited high correlation and their nugget effect in variograms was low. In general, the difference in the soil characteristics variability was due to the soil forming effects and land management processes. On the other hand, spatial correlation is severely under the influence of scale in each study. Therefore, in the present study, the features which display weak or fairly spatial correlation, may exhibit a stronger spatial correlation on smaller scales. The effective range of variograms in stand was large, representing a broader spatial structure, more uniform distribution and in fact, more spatial correlation in the variable values (Khosravi & Abasi 2016). The soil nitrogen range has been reported to be less than the other soil characteristics in the present study. In fact, a spatial correlation exists for this variable at a small distance. Probably, the smaller nitrogen effect range originates from higher nitrogen mobility in the soil and soil disturbance by the organisms. Based on the ME statistics, the prediction of physical and chemical soil properties contained the least skew. Based on the RSME statistics, Kriging's prediction is more accurate about these variables. Kriging maps indicated that some of the studied characteristics did not comprise a random pattern and included a spatial distribution.

These maps illustrated that the pattern of soil distribution properties can be found through spatial locality recognition. The results exhibited that spatial variations of soil characteristics including sand, silt, and clay percentages reflect the geological pattern and parent material of the region gradually and gently.

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تغییرات مکانی تنوع ماکروفون خاک در صنوبرکاری های دلتوئیدس *Populus deltoides* در جنگل های شمال ایران

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چکیده

اطلاعات در مورد الگوی مکانی تنوع زیستی خاک علیرغم اهمیت اثرات آن روی فرآیندهای اکوسیستم بسیار اندک است. این تحقیق جهت بررسی الگوی مکانی پارامترهای تنوع زیستی ماکروفون خاک در جنگلکاریهای صنوبر دلتوئیدس در شمال ایران انجام گرفت. ۱۵۰ نمونه خاک به وسیله شبکه منظم تصادفی جمع‌آوری شدند. نمونه‌برداری به روش دستی، در قطعات نمونه‌ای به ابعاد ۵۰×۵۰ سانتی‌متر و به عمق ۲۰ سانتی‌متر انجام شد. فراوانی (تعداد کل ماکروفون در هر قطعه نمونه) شاخص‌های تنوع (شانون-وینر) یکنواختی (اسمیت-ویلسون) و غنا (منهینیک) پس از محاسبه، با استفاده از روش‌های زمین‌آمار برای بررسی و کمی کردن همبستگی مکانی مورد تحلیل قرار گرفتند. برخی از خصوصیات فیزیکی و شیمیایی خاک تعیین شدند. نتایج بیانگر آن است که همه متغیرهای مورد بررسی دارای ساختار مکانی همراه با مدل‌های سقف‌دار بودند. دامنه تأثیر فراوانی ماکروفون ۷۱۰/۹ متر، ۶۵۰/۳ متر تنوع، ۷۲۰/۹۰ متر غنا و ۴۱۰/۹ متر برای یکنواختی بدست آمد. نقشه‌های کریجینگ نشان داد که بایومس ماکروفون و ویژگیهای خاک الگوی تصادفی نداشته و دارای الگوی مکانی می‌باشند. همچنین الگوی پراکنش مکانی بایومس ماکروفون، مشابه با الگوی پراکنش درصد رس و pH است.

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