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Assessment of Spatial Variability of Soil Characteristics and Plant Diversity in Semi-Arid Grasslands

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ABSTRACT

Research Article

Semi-arid areas comprise a considerable acreage in Turkey and the vegetation cover is very sensitive in those areas. This study was conducted in a typical semi-arid area at the Çankırı Karatekin University Campus for the purpose of analyzing spatial relationships between soil properties and the number of plant species (NPS) per square meter, which is an important indicator for desertification studies. Two transects (one normal and other parallel to the slope) were placed on north-east and another two transects on south-west aspect of a hill in the study area. Soil samples were taken from 0-5 and 5-20 cm soil depth from 5-m apart on each transect and the NPS per square meter was determined at each sampling point. The soil samples were analyzed for physical (sand, silt, clay, bulk density, field capacity, wilting point, plant available water content, aggregate stability) and chemical (pH, electrical conductivity, organic matter and $CaCO_3$ contents) properties. Descriptive statistics were calculated for all soil variables and the NPS. The results showed that the NPS was similar in mean and coefficient of variation on all the four transects. The correlation coefficients among the measured soil variables and the NPS changed between 0 and 0.82. The correlogram analysis of soil variables and cross-correlogram analysis between soil variables and the NPS were performed. The results of geostatistical analysis showed that sand content, bulk density, plant available water content, silt content, and EC spatially related to the NPS. The results have a potential for use in studies of grassland development.

Key Words: Correlogram analysis, desertification, geostatistics, plant diversity, semi-arid grasslands

Yarı-kurak Bir Merada Toprak Karakteristikleri ve Bitki Zenginliğinin Uzaysal Değişkenliğinin Değerlendirilmesi

ÖZ

Yarı-kurak alanlar Türkiye'de önemli bir yer kaplar ve bu alanlardaki vejetasyon dış etkenlere oldukça hassastır. Bu çalışma Çankırı koşullarında tipik-yarı kurak alanları temsilen seçilen bir merada bitki tür zenginliği ile toprak özellikleri arasındaki uzaysal ilişkilerin incelenmesi amacıyla yürütülmüştür. Birisi eğime dik ve diğeri eğime paralel olmak üzere iki örnekleme hattı tepenin kuzey-doğu ve güney-batı bakılarına yerleştirildi. Hatlar üzerinde 5 er m ara ile 0-5 ve 5-20 cm derinliklerden toprak örnekleri alınarak toprak fiziksel özellikleri (kum, silt, kil hacim ağırlığı, tarla kapasitesi, solma noktası ve agregat stabilite indeksi) ve kimyasal özellikler (pH, elektriksel iletkenlik, organik madde ve CaCO3 içeriği) için analiz edildi. Aynı zamanda örnekleme anında, her bir örnekleme noktasında 1 m^2'lik alanda bitki tür sayısı belirlendi. Her bir toprak değişkeni ve bitki tür sayısı için tanımsal istatistikler hesaplandı. Sonuçlar bitki tür sayısına ilişkin her dört hat için hesaplanan aritmetik ortalama ve değişkenlik katsayısı değerlerinin benzer olduğunu göstermiştir. Toprak özellikleri arasında hesaplanan korelasyon katsayıları 0 ve 0.82 arasında değişen değerler almıştır. Korelogram analizi kum içeriği, silt içeriği, hacim ağırlığı, bitkiye yarayışlı su içeriği ve EC ile bitki tür sayısı arasında uzaysal ilişkinin olduğunu göstermiştir. Sonuçların mera geliştirme çalışmalarında kullanım potansiyeli bulunmaktadır.

Anahtar Kelimeler: Korelogram analizi, Çölleşme, Jeoistatistik, Bitki çeşitliliği, Yarı-kurak meralar.

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1. Introduction

In Turkey, grassland management plans have been established to support herbal yield and quality of grasslands. In order to achieve an effective management plan, all components of grasslands quality must be considered in planning. However, these management plans have ignored effects of soil properties on plant species distribution. In this context, it is very important to know soil properties, which are important factors in determining grassland quality (Güsewell and Koerselman, 2002). The main factors affecting plant diversity are often related to abiotic factors such as soil properties (Wellstein et al., 2007). Many studies indicate that soil pH and organic matter content have important effects on the number of plant species (Cheng et al., 2016; Dingaan et al., 2017; Xue et al., 2019). Also, it is needed to know the temporal and spatial changes of soil properties that affect the number of plant species (Klaus et al., 2013).

Grasslands are very complex ecosystems because of interactions between vegetation and soil properties (Van der Putten et al., 2013). Geostatistical analysis is required to provide better understanding of these interactions than classical statistical methods (Isaaks and Srivastava, 1989). Quantification of soil spatial variability is important in grassland resource management (Wei et al., 2008). In arid and semi-arid grasslands, grazing can either increase or decrease the spatial heterogeneity of vegetation by modifying the structure and spatial arrangements of the vegetation patterns (Lin et al., 2010). An important limitation of analysis of spatial pattern in ecological systems that it requires spatially intensive data. Such information is difficult to obtain by field measurements. The spatial dependency is characterized and measured by geostatistical methods such as semivariogram analysis (Isaaks and Srivastava, 1989).

Correlograms are nonparametric statistical tools and used to quantify association among individual units across geographical scales (Stein et al., 1997; Zhao et al., 2010). Correlogram function provides correlation distance of a feature. For this, the mean correlation distance of the corresponding property must be calculated (Han et al., 1994). The range distance of the semivariogram is that the spatial dependence of the corresponding variable ends. However, it does not mean that spatial dependence in all of this distance is significant (statistically significant) (Nielsen and Wendroth, 2003). Similarly, spatial cross-correlograms estimate distance-based cross-correlations between units representing two different groups, and multivariate correlograms estimate compositional similarity or dissimilarity across space (Kendig et al., 2017). In this context, each soil characteristic studied is analyzed graphically by means of correlograms and the spatial structure of the variables is compared.

The aim of this study was to evaluate spatial cross-correlations between soil properties and plant diversity and compare them along vertical and horizontal transects of the northerly and southerly aspects of a semi-arid grassland hillslope.

2. Materials and Methods

2.1. Study area and soil sampling

The study area is located on a sloping landscape (height) nearby Çankırı city, in North Central Anatolia (between 400 30´ and 410 30´ North latitudes and 320 and 330 East longitudes). The climate is semi-arid continental, with annual mean total precipitation is 538 mm, of which 60-80% falls from April to June. Two transects, one parallel and the other normal to the slope were located at the north-east and south-west facing slopes of the hill. Disturbed and undisturbed soil samples were taken from 0-5 and 5-20 cm depths at each transect with 5-m intervals. Undisturbed soil samples were taken on the sampling points at the two layer (0-5 and 5-20) for bulk density. The number of plant species at 1-m2 surrounding each sampling point was determined at the sampling. In each sampling point, positioned by GPS with UTM system has been set up for the geostatistical analysis. Bulk density was determined on undisturbed soil samples which was taken by using a steel core sample of a 100 cm3 volume (Blake and Hartge, 1986), particle size distribution (Gee and Bauder, 1986) and aggregate stability (Kemper and Rosenau, 1986) were determined. The water contents at soil water pressures of −0.033 MPa (θ−0.033 MPa) and −1.50 MPa (θ−1.50 MPa) were measured using a pressure plate apparatus (Cassel and Nielsen, 1986). The plant species determined in the study area are given in the Table 1 and Table 2.

Table 1. Plants on the northeast slope.

Horizontal transect		Vertical transect	
Astragalus spp.	*Convolvulus spp.*	*Astragalus spp.*	*Cynodon dactylon*
Festuca ovina	*Crupina crupinastrum*	*Festuca ovina*	*Helianthemum nummularium*
Stipa spp.	*Bromus danthoniae*	*Stipa spp.*	*Onobrychis hypargyrea*
Onobrychis hypargyrea	*Allium spp*	*Origanum spp*	*Agropyron cristatum*
Helianthemum nummularium	*Origanum spp*	*Euphorbia spp.*	*Scabiosa spp*
Scabiosa spp	*Brachypodium spp.*	*Salvia spp.*	
Genista spp.	*Cynodon dactylon*		
Salvia spp.	*Euphorbia spp.*		

Table 2. Plants on the southwest slope.

Horizontal transect		Vertical transect	
Astragalus spp.	*Aegilops spp.*	*Astragalus spp.*	*Allium spp.*
Festuca ovina	*Centaurea virgata*	*Festuca ovina*	*Cynodon dactylon*
Stipa spp.	*Helianthemum nummularium*	*Stipa spp.*	*Medicago spp.*
Convolvulus spp.	*Eryngium spp.*	*Euphorbia spp.*	*Helianthemum nummularium*
Euphorbia spp.	*Bromus danthoniae*	*Pimpinella corymbosa*	*Salvia spp.*
Scabiosa spp	*Origanum spp*	*Origanum spp*	
Salvia spp.	*Pimpinella corymbosa*		

2.2. Statistical and geostatistical analyses

Descriptive statistics were calculated for soil physical properties and the number of plant species. The geostatistical software GS$^+$ was used to analyze the spatial structure of the data for each parameter. Cross-correlograms were calculated to evaluate spatial interactions between plant diversity and each of soil physical and chemical properties. Variable-lag distances were used to select correlograms, whereby at least ten lags were used, with a minimum of 30 data pairs ensured in each lag. Unlike the semivariogram, the correlogram filters out the effects of changes in both lag means and lag variances. Each point in a correlograms was calculated from following equation:

$$\rho^*(h)=\frac{1}{N\,(h)}\cdot\sum_{i=1}^{N\,(h)}\frac{\{[z(x_i)-m_{-h}][z(x_i+h)-m_{+h}]\}}{S_{-h}\,S_{+h}} \qquad (1)$$

Where $z(x_i)$ and $z(x_i + h)$ are two data points separated by a distance lag (h). Datum $z(x_i)$ is the tail and $z(x_i + h)$ is the head of the vector, $N(h)$ is the total number of data pairs separated by lag h, m_{-h} and m_{+h} are means of the points that correspond to tail and head of the lag, respectively, S_{-h} and S_{+h} are standard deviations of tail and head values of the lag (Halvorson et al., 1994). The correlogram was preferred because it removes the effects of lag means and standardizes by the lag variance (Rossi et al., 1992).

Cross–correlograms were calculated for between number of plant species and soil properties using the equation (2), where is $N(h)$ is the total number of data pairs separated by a vector h, I_A is plant data at some location (x_i), $m_{A_{-h}}$ and $S_{A_{-h}}$ are the mean and standard deviation, for the plant variable at those data locations that are –h away from a soil property data location.

$$\rho u(h)\times NPS(h)=\frac{1}{N\,(h)}\cdot\frac{\sum_{i=1}^{N(h)}\sum_{k=1}^{N(h)}\left[I_A-m_{A_{-h}}\right]\left[I_B-m_{B_{+h}}\right]}{S_{A_{-h}}S_{B_{+h}}} \qquad (2)$$

Similarly, I_B is soil variable data at location (x_k), $m_{B_{+h}}$ and $S_{B_{+h}}$ are the mean and standard deviation of soil variable's indicators calculated for those locations that are +h away from a number of plant species data location. When h is 0, equation 2 is equivalent to the Pearson correlation coefficient.

3. Results

3.1. Descriptive statistics

Descriptive statistics of soil variables and "number plant species" showed a complex interaction between soils and terrestrial attributes. The exploratory statistics for soil properties showed that data generally exhibited high variability (Tables 3 and 4) according to Mulla and McBratney (2002), who noted that a distribution with a coefficient of variation greater than 36% is deemed highly variable, between 16% and 36% is moderately variable, less than <16% is little variable. Statistical distribution for sand and clay content behaved similarly across transects and between the slope aspects, with the exception of horizontal transect on northwest aspect. Mean for silt content was relatively uniform across the transects. Clay content was generally highly variable, while sand and silt contents were moderately to slightly variable between the transects. In general, sand and silt contents were slightly skewed and clay content was moderately to highly skewed. Mean bulk density was highly consistent between transects and slope aspects (Tables 3 and 4).

Both of field capacity and wilting point were moderately variable across the subjects. The mean for organic matter (OM) content was highly uniform between transects and slope aspects, while it was generally highly variable. Similarly to OM content, $CaCO_3$ content was highly uniform between the transects and slope aspects in its mean, while its variability was always high and showed differences between the transects and slope aspects. Soil pH was highly consistent between the transects and slope aspects in its mean and variability. On the other hand, mean for EC behaved similarly to pH, while it showed medium to high variability, differing considerably between the transects and slope aspects. The mean for aggregate stability index (ASI) was considerably low for all the cases and it showed high variability.

Number of plant species (NPS) indicates vegetation diversity and it is an important indicator of grassland quality. Mean for NPS was highly consistent between transects and slope aspect. NPS was moderately variable at three of four transects and highly variable at one transect (Tables 3 and 4).

Coefficient of skewness is an important indicator of symmetricity of the distribution curve. Majority of soil variables are moderately and highly skewed according to Webster (2001), who noted that a distribution with a skewness greater than absolute 1.0 is deemed strongly skewed, between absolute 0.5 and absolute 1.0 moderately skewed, and less than absolute 0.5 is slightly skewed. EC was strongly skewed, and BD, sand content and OM content were slightly skewed in all the cases. The other soil properties showed differences in extent of their skewness across the cases. For example, CaCO3 content was strongly skewed on horizontal transect of northeast and vertical transect of southwest aspects, while it was slightly skewed on vertical transect of northeast and moderately skewed on the horizontal transect of southeast aspect. NPS was slightly skewed on three of four transects and moderately skewed on the rest (Tables 3 and 4).

Table 3. Descriptive statistics of soil properties and number of plant species in northeast aspect.

Variables	**Mean**	**SD**	**Max**	**Min**	**Skewness**	**Kurtosis**	**CV (%)**
Horizontal transect							
Clay (%)	37.5	20.02	76.0	8.00	0.12	-1.31	53.3
Sand (%)	34.1	16.56	76.0	3.00	0.31	-0.38	48.5
Silt (%)	28.2	10.80	53.0	10.0	0.69	-0.45	38.2
BD (g/cm^3)	1.20	0.11	1.60	1.00	0.68	0.79	9.10
FC (%)	26.6	6.64	43.0	11.0	0.15	-0.26	24.9
WP (%)	13.4	31.38	25.0	2.00	-0.08	-0.80	34.1
PAWC (%)	12.76	4.74	25.0	2.00	0.40	0.21	37.1
OM (%)	1.90	0.85	3.60	0.50	0.11	-1.28	44.7
$CaCO_3$ (%)	10.6	4.83	29.0	3.00	1.03	1.56	45.5
pH	7.97	0.18	8.50	7.60	0.24	-.0.38	2.20
EC (µS/cm)	1.60	10.8	2.32	0.27	-1.88	2.35	675.0
ASI (%)	3.90	13.64	13.07	0.50	0.77	-0.68	349.7
NPS	3.08	1.12	5.00	1.00	0.32	-1.02	36.3
Vertical transect							
Clay (%)	26.1	15.9	74.0	8.00	1.16	0.31	60.9
Sand (%)	48.2	16.9	83.0	12.0	-0.34	-0.64	35.0
Silt (%)	25.5	12.7	63.0	1.00	0.33	-0.03	49.8
BD (g/cm^3)	1.20	0.09	1.40	1.00	-0.15	-0.73	7.50
FC (%)	31.1	7.7	46.0	13.0	-0.18	-0.68	24.7
WP (%)	20.2	6.2	32.0	3.00	-0.44	-0.11	30.6
PAWC (%)	8.90	22.09	7.00	2.00	1.09	1.80	248.2
OM (%)	1.90	0.9	4.70	0.50	0.41	-0.66	47.03
$CaCO_3$ (%)	9.90	5.5	24.0	2.00	0.66	-0.51	55.5
pH	7.90	0.10	8.60	7.50	0.29	1.10	1.26
EC (µS/cm)	1.90	0.40	2.80	0.20	-2.16	3.90	21.0
ASI (%)	3.90	3.90	14.9	0.50	1.08	-0.20	105.4
NPS	3.10	1.00	7.00	0.00	-0.05	0.50	32.2

SD: Standard deviation, CV: Coefficient of variation, NPS: Number of plant species, BD: Bulk density, FC: field capacity, WP: Wilting point, PAWC: Plant available water content, Electrical conductivity, ASI: Aggregate stability index.

Table 4. Descriptive statistics of soil properties and number of plant species on southwest aspect.

Variables	Mean	SD	Max.	Min.	Skewness	Kurtosis	CV (%)
Horizontal transect							
Clay (%)	22.4	12.4	59.0	8.00	1.38	1.21	55.5
Sand (%)	49.7	14.3	78.0	8.00	-0.10	-0.35	28.9
Silt (%)	27.8	10.8	51.0	6.00	-0.05	-0.80	38.9
BD (g/cm^3)	1.20	0.09	1.50	1.00	0.04	-0.03	7.50
FC (%)	27.8	6.05	41.5	12.0	-0.09	-0.31	21.7
WP (%)	16.3	4.22	24.8	4.30	-0.56	-0.07	25.7
PAWC (%)	11.4	6.05	25.9	1.30	0.21	-0.89	52.7
OM (%)	1.79	0.90	3.80	0.30	0.33	-1.12	50.2
$CaCO_3$ (%)	8.90	3.11	17.0	3.00	0.42	-0.34	34.6
pH	7.90	0.12	8.20	7.40	-0.65	2.31	1.51
EC (µS/cm)	2.09	0.24	3.39	1.07	1.35	13.75	11.4
ASI (%)	4.15	3.93	14.9	0.53	0.85	-0.54	94.6
NPS	3.51	0.85	6.00	2.00	0.56	0.15	24.2
Vertical transect							
Clay (%)	30.0	12.8	52.0	4.00	0.00	-1.01	42.8
Sand (%)	46.6	13.3	86.0	22.0	0.21	0.82	28.5
Silt (%)	23.3	6.7	31.0	5.00	0.55	0.45	28.7
BD (g/cm^3)	1.19	0.10	1.40	1.00	1.00	-0.47	8.40
FC (%)	24.9	3.3	32.0	16.0	0.16	0.44	13.2
WP (%)	15.7	3.46	21.0	7.00	0.70	-0.36	21.9
PAWC (%)	8.70	4.56	21.0	0.00	0.00	0.28	51.9
OM (%)	1.50	0.89	3.40	0.30	0.30	-1.23	58.9
$CaCO_3$ (%)	8.50	3.04	15.0	3.00	3.00	-0.42	35.5
pH	7.80	0.18	8.20	7.20	0.70	3.04	2.28
EC (µS/cm)	1.90	0.45	3.53	1.03	1.00	3.09	23.0
ASI (%)	4.0	4.05	14.13	0.52	0.50	-0.49	101.2
NPS	2.3	0.94	4.00	0.00	0.00	0.54	39.8

SD: Standard deviation, CV: Coefficient of variation, NPS: Number of plant species, BD: Bulk density, FC: field capacity, WP: Wilting point, PAWC: Plant available water content, Electrical conductivity, ASI: Aggregate stability index.

3.2. Geostatistical Analysis of Spatial Variability of Soil Properties and Number of Plant Species

Table 5 depicts correlation distance values for correlograms for soil variables and cross-correlograms between soil variables and NPS. Autocorrelation (or simply correlation) distance obtained for correlograms and cross-correlograms are highly inconsistent between transects and slope aspects. The inconsistency was greater in horizontal transects compared to vertical ones on both of aspects. Clay and clay x NPS exhibited greatest inconsistency across the transects. Similarly to clay, soil pH and pH x NPS showed high inconsistency in correlation distance. In general, the correlation distance for both of correlograms and cross-correlograms are greater in horizontal directions than vertical directions on both of the aspects. Also, the cross-correlation distances were greater than correlations distances for corresponding soil variables. For example, correlations distance for clay at horizontal transect on southwest aspect was 5.00 m, while its cross-correlation distance was 175.0 m. Many of the soil properties showed no spatial structure as their correlation distance of 0.00 evidenced. However, their cross-correlograms had a spatial structure (Table 5). On the other hand, many cross-correlograms showed no spatial structure, while their corresponding correlograms showed a spatial structure (Table 5).

Table 5. Values for correlation distance for soil variables and cross-correlations distance for soil variable x number of plant species at vertical and horizontal transects on northeast and southwest aspect.

Variable	Northeast aspect				Southwest aspect			
	Horizontal transect		Vertical transect		Horizontal transect		Vertical transect	
	ρu(h)	ρu(h)×NPS (h)	ρu(h)	ρu(h)×NPS (h)	ρu(h)	ρu(h)×NPS (h)	ρu(h)	ρu(h)×NPS (h)
Clay	5.00	175.0	60.0	20.0	0.00	275.0	10.0	0.00
Sand	175.0	175.0	10.0	10.0	0.00	275.0	5.00	20.0
Silt	173.0	175.0	0.00	10.0	250.0	250.0	5.00	0.00
BD	0.00	0.00	0.00	30.0	5.00	250.0	20.0	5.00
FC	0.00	175.0	0.0	30.0	10.0	0.00	0.00	0.00
WP	0.00	20.0	0.00	60.0	275.0	275.0	0.00	20.0
PAWC	175.0	20.0	5.0	50.0	20.0	0.00	0.00	0.00
OM	0.00	10.0	0.00	0.00	5.00	0.00	5.00	0.00
$CaCO_3$	20.0	50.0	50.0	100.0	275.0	275.0	5.00	0.00
pH	0.00	175.0	0.00	50.0	5.00	275.0	0.00	5.00
EC	5.00	30.0	50.0	20.0	0.00	275.0	0.00	0.00
ASI	5.00	60.0	0.0	50.0	275	275.0	100.0	0.00
TSD	5.00	30.0	10.0	10.0	5.00	275.0	5.00	5.00
NPS	90.0	-	30.0	-	5.00	-	0.00	-

NPS: Number of plant species, BD: Bulk density; FC: Field capacity; WP: Wilting point, PAWC: Plant available water content; OM: Organic matter; EC: Electrical conductivity; ASI: Aggregate stability index, u: soil variable

4. Discussion

Our data evidenced a considerably complex spatial interaction among soil variables, topographic attributes and plant diversity in the study area. Data for some variables were spatially correlated along some transects, while no spatial correlation occurred on some other transects. For example, data for sand content spatially correlated over 175 m (Isaaks and Srivastava, 1989; Nielsen and Wendroth, 2003) on horizontal transect of northwest aspect, while data did not correlate at all on horizontal transect of southwest aspect. The data for soil variables were considerably inconsistent across the transects in their correlation distance. For example, data for PAWC spatially autocorrelated for 175.0 m on the horizontal transect on northwest aspect, for 5.5 m on vertical transect of northwest aspect, for 20 m on horizontal transect of southwest aspect, while no autocorrelation occurred for the same variable on vertical transect of southwest aspect.

Autocorrelation distances for cross-correlograms were generally greater than their corresponding correlograms (Table 5). In general, greater autocorrelation distances occurred for horizontal transects than vertical ones and this was attributed to greater variation in the soil properties resulted from local erosion and deposition processes in the study area (Schaetzl and Anderson, 2005). Data for many of the soil variables cross-correlated with NPS across 275 m, especially on the horizontal transect of southwest aspect, which may be attributed to that the spatial structure of cross-correlation would be controlled principally by NSP rather than corresponding soil properties. Data for some soil variables (e.g. OM and FC) showed very limited autocorrelation and cross-correlation. Changing sampling scheme and increasing the sample size may be needed to detect spatial autocorrelation of those variables as suggested elsewhere (Nielsen and Wendroth, 2003).

Autocorrelation distance for the data of NPS highly differs among the transects (Table 5). No autocorrelation occurred for NPS on vertical transect on southwest aspect. Similarly to correlogram for NPS, the cross-correlograms exhibited no spatial autocorrelation on the vertical transect of southwest aspect, suggesting that spatial structure of NPS is important determinant of structure of cross-correlograms on this transect as well as on the others in the study area.

Soil texture plays a significant role in regulating vegetation pattern, including vegetation composition, functional group, and structure (Burke et al., 1990). Spatial structure of sand and silt content dominated the spatial structure of cross-correlogram on the vertical transect of northeast aspect as indicated by similarity in autocorrelation distances as compared to ones for corresponding cross-correlograms.

The autocorrelation function or correlogram is a principal diagnostic measure that help interpreting the spatial nature of on-site sample data (Isaaks and Srivastava, 1989; Nielsen and Wendroth, 2003). Correlogram can aid to determine if the measurements are spatially correlated or independent of each other (Isaaks and Srivastava, 1989; Nielsen and Wendroth, 2003). Clearly, experimental studies are needed to test the relative importance of soils, plants and grazing pressure in regulating the spatial structure of semi-arid grasslands, particularly where livestock grazing pressure is intense. Understanding spatial relations between soil and vegetation structure can help sustainable management of grasslands. Information which is related to relationships between soil fertility and pasture-grass nutrient is a fundamental for regional sustainable development and planning. An important problem in the analysis of spatial pattern in ecological systems requires spatially intensive data.

5. Conclusions

Our data evidenced a complicated spatial interaction between soil and plant diversity in the study area. Some data spatially correlated over a distance 275.0 m, while others showed no spatial correlation. A considerable difference occurred between soil correlograms and their corresponding cross-correlograms with NPS across transects regarding to their autocorrelation distances. Spatial autocorrelation could not be detected for some correlograms and cross-correlograms, a greater sample size and/or a different sampling scheme or both would be needed to evaluate their spatial structure. Quality and extent of information gained on spatial variability of soil and NSP and spatial relationship between soil and NPS as affected by topography were far greater than those gained by classical statistics. Further research is needed to ensure spatial structure of soil properties, which exhibited no autocorrelation and to ensure if the measurements are temporarily stabile or they change over time.

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Conflict of Interest

The authors declare that they have no conflict of interest.

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