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Research article

SPATIAL VARIABILITY OF SOIL FERTILITY PARAMETERS FROM CUBAN VERTISOL SOILS

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ABSTRACT
This study was to evaluate the spatial variability of different soil fertility parameters from Cuban Vertisol soils at landscape level and within a field where sugarcane is cultivated. At landscape level, 144 soil samples from 144 different fields were taken from the plough layer (0 – 20 cm). At the field level, 29 soil samples were collected from one field of 1.96 ha at the same depth by using a stratified random sampling scheme. The collected soil samples were analysed for Cuban Vertisol (OM: *Walkley-Black method*), available potassium (K_2O- *Oniani method*) and available phosphorus (P- *Olsen and Oniani methods*). In order to compare the variability of the soil fertility parameters among themselves across the landscape and within a field, the coefficient of variation (CV) was used. The frequency distribution histograms of the average soil fertility parameters per field were calculated. Factor analysis was used to group the four soil fertility parameters into factors based on the correlation matrix of the variables using the principal component analysis method of factor extraction in SPSS software. A large spatial variability of the soil fertility parameters was obtained, mainly P and K_2O, for different fields within the province and even within a field. Also, similarities were found when comparing the values observed on the local maxima of each frequency distribution histogram at landscape level and within a field. In all cases, soil fertility parameters were assigned to the Factor 1 for which their eigenvalues were the highest.
Keywords: Cuban Vertisol; Soil Fertility; Component Analysis; Water-Resistant.

INTRODUCTION

Conventional agriculture treats an entire field uniformly with respect to the application of fertilisers. However, soil is spatially heterogeneous, with most soil fertility parameters varying significantly within just a meter. Thus, soil spatial variability is one of several factors that cause within-field variation in crop yield [1-4]. Characteristics and variability of different soil fertility parameters have been reported, analysed and detailed in several scientific sources [4-7]. Causes of spatial variability in soil fertility parameters include several factors. These factors occur as a result of the effect and interaction of various processes in the soil profile. Thus, the main consequences of spatial variability are related to the localized yield reduction, excessive fertiliser and water use, and nutrient losses [8-12].
The observed spatial variability in various soil fertility parameters that influence soil fertility will help farmers in making crop management decisions [3]. Therefore, knowledge of spatial variability in soil fertility is important for

site specific nutrient management [3,11,13]. Recognising the significance of quantifying and managing this variability that occurs in agricultural fields, could lead to different approaches for implementing a site-specific management in sugarcane production in the Villa Clara province.
The aim of this study was planned to evaluate the spatial variability of different soil fertility parameters from Cuban Vertisol soils at landscape level and within a field.

MATERIALS AND METHODS

Field experiments were performed at landscape level and within a field on Vertisol soil where sugarcane is cultivated. Landscape comprises the visible features of an area of land. In Cuba, Vertisols are most wide-spread in the eastern part of the island. When a Vertisol is used for agriculture the initial weakly water-resistant aggregates are destroyed and the clay fraction of the soil is peptized [14]. The studied fields are all located in the Villa Clara province at the central part of Cuba between the coordinates 22°16’, 23°09’ N and 80°02’, 80°25’ W.

The soil sampling was done before planting when the fields were ready to be furrowed. The 144 Vertisol soil samples from 144 different fields were taken from the plough layer (0 – 20 cm) by using a sampling auger with a footrest. At landscape level each soil sample consisted of 30 subsamples which were taken from subplots located across a diagonal line on the field, which starts and finishes 10 m from the field borders.

At the field level, the 29 soil samples were selected from one field of 1.96 ha. Also, the soil samples were collected at the same depth by using a stratified random sampling scheme. The fields were divided into several quadrants (strata) from which each soil core were selected separately and randomly. Each stratum was sampled in proportion to the total.

During the handling process the samples were bagged, labeled, air-dried at room temperature to constant weight, sieved with a 0.5 mm sieve, homogenized, and then measured with conventional chemical analyses. The collected soil samples were analysed for OM (*Walkley-Black method*), K_2O (*Oniani method*) and P (*Olsen and Oniani methods*). These soil fertility parameters are some of the most important for sugarcane growth. The chemical analyses were done in the analytical chemistry laboratories of the Territorial Station for Sugar Cane Research and in the Agricultural Research Centre belonging to the Central University “Marta Abreu” of Las Villas.

The levels of the selected soil fertility parameters reported by different authors are summarised in Table 1. These ranges and levels were used for interpreting the concentrations measured for the studied soils.

Table 1: Classification of levels of the selected soil fertility parameters.

Soil fertility parameter	Level						Source
	Very low	**low**	**Medium**	**Satisfactory**	**High**	**Very high**	
OM	<1.5	1.5 -3.0	3.1-5.0	-	>5.0	-	[15]
K_2O	<6.2	≥6.2<8.8	≥8.8<13.8	-	≥13.8<32	≥32	[16]
Olsen P	-	<1.14	1.14-2.29	2.29-4.12	>4.12	-	[17,18,19]
Oniani P	-	<6	6-11	-	11-15	>15	[16]

OM in %; K_2O in mg K_2O 100 g^{-1} d.s[1], Olsen P and Oniani P in mg P 100 g^{-1} d.s-dry soil

Basic descriptive statistics (range, mean, median, skewness, kurtosis, and coefficient of variation) were obtained by processing data with the statistical functions included in the Analyses Toolpack of Microsoft Excel 2007. The histograms of the average soil fertility parameters per field were calculated in MATLAB 7.9 (R2009b, The Mathworks, Nattick, MT). In order to compare the variability of the soil fertility parameters among themselves across the landscape and within a field, the coefficient of variation (CV) was used. The results were categorized into the three classes proposed by Aweto, where CV < 25% = low variability, 25 < CV < 50% = moderate variability, 50 < CV <100% = high variability. Factor analysis was used to group the four soil fertility parameters into factors based on the correlation matrix of the variables using the principal component analysis method of factor extraction in SPSS software.

RESULTS AND DISCUSSION

At Vertisol landscape, phosphorus was the soil fertility parameter with a higher variability than the others, independently of the chemical method used for its analysis. The higher value was observed in Oniani P with 57.17%, followed by Olsen P with 50.89%. Both values accounted for a high variability of these parameters. The high coefficients of variation observed in soil P levels are dependent on management practices. It seems that the applications of P fertilisers increased the variability of this nutrient in soil. Continued applications of P fertiliser are often required to maintain a given level of crop production. Then, the magnitude of P fertilisation has been constantly increased and applied in a uniform way across these fields. However, crops usually take up approximately 10 - 15% of the added P fertiliser, while the remainder is accumulated in the soil. Consequently, spatial variations of this soil fertility parameter can appear both horizontally and vertically. The lower CV corresponded to the OM (16.01%). This parameter showed a low variability across this area, while the variability of K_2O (39.28%) was classified as moderately variability. These results indicated a considerable variability in soil fertility parameters in Vertisol landscape, particularly for Olsen P and Oniani P. Fertiliser recommendations are commonly targeted for an average soil and management system, and then are applied for general soil types across a whole province. Thus, VR fertiliser application for different fields, hence, should be considered as an important method for making soil fertility distribution more uniform.

Within a field the CV results confirmed a low variability for OM (14.41%) and a moderate variability for K_2O (32.57%), Olsen P (43.95%) and Oniani P (47.02%). In comparison, across the Vertisol landscape, the CV values were higher for all the soil fertility parameters. However, for OM and K_2O there was no difference as to the variability classification. In both cases, landscape level and field scale, the variability was classified as low (OM) and moderate (K_2O). Similar reports are presented by Weindorf and Zhu [20], which found CV values of 49.73% for phosphorus and 29.72% for potassium.

The results of the frequency distribution of soil fertility parameters measured for Vertisols at the landscape level are presented in Figure 1. The distribution for OM content showed a histogram with one local maximum at the interval 2.55 – 2.71%. The values comprised at this interval corresponded to a frequency distribution of 26 soil samples. This number of samples was equivalent to 18.05% of the total soil samples analysed in this set, and the values were classified as low, according to the scale used. This histogram showed a positively skewed distribution with a skewness coefficient of 0.12 and a negative kurtosis coefficient (-0.64).

The bimodal distribution for K_2O content showed two local maxima at the intervals 6.62 – 9.15 mg 100 g^{-1} d.s and 11.60 – 13.95 mg 100 g^{-1} d.s. These intervals were represented by 22 and 26 soil samples, which were equivalent to 15.27 and 18.05% respectively of the total soil samples analysed. In the first interval these values were classified between low and medium and in the second interval were classified between medium and high. Potassium does not move readily in most soils; however it is more mobile than phosphorus [21]. For Olsen P a right-skewed histogram was obtained with a positive skewness coefficient of 1.06 and a relatively peaked distribution where the kurtosis coefficient was positive (0.01).

The interval of the local maximum was 1.32 – 1.77 mg 100 g^{-1} d.s. In this interval a frequency of 47 samples was observed, which represented 32.64% of the analysed soil samples. These values were classified as medium according to the classification scale used for Olsen P in this research.

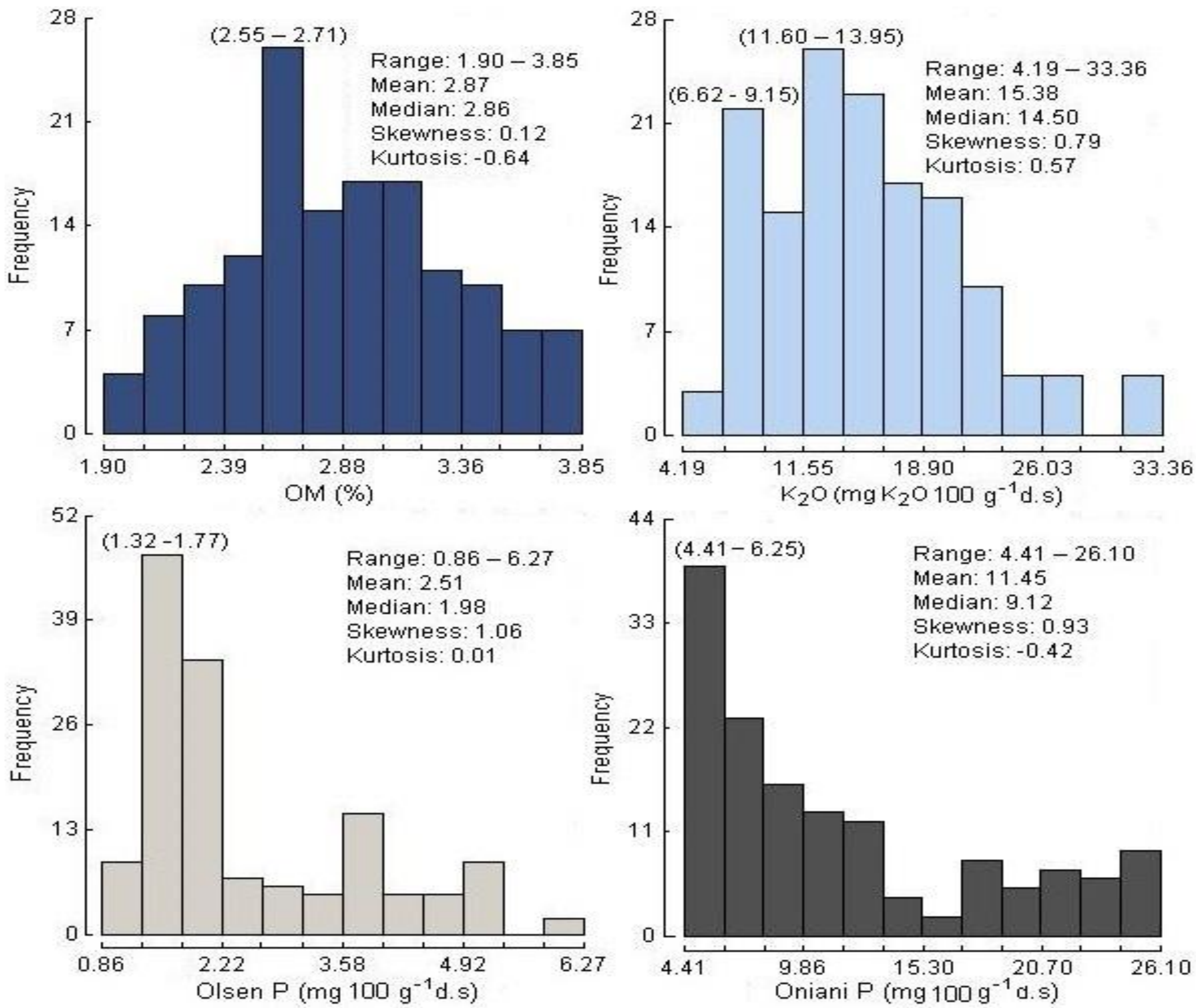

Figure 1: Frequency distribution of soil fertility parameters in Vertisol landscape.

The frequency distribution of the P content analysed by the Oniani method showed a histogram with one local maximum at the interval 4.41 – 6.25 mg 100 g^{-1} d.s. This interval corresponded to a frequency distribution of 39 soil samples equivalent to 27.08% of the analysed soil samples. These values were classified between low and medium, according to the scale used. Also, the histogram showed a positive skewness coefficient of 0.93, while the kurtosis coefficient was negative (-0.42).

The frequency distribution histograms for the subsamples taken from the same Vertisol field are given in Figure 2. In this sense a local maximum obtained for OM corresponded to a frequency distribution of 8 samples which represented 27.59% in the interval 2.99 – 3.23%. These values were classified between low and medium. The higher number of samples was towards the left side of this local maximum, and included a total of 17 or 58.62% of all those analysed in this set. Also, two intervals with the same frequency of 5 soil samples were observed. These two intervals comprised values between 2.50 to 2.75% and 2.75 to 2.99%, which were evaluated as low in both cases. The skewness and kurtosis coefficients were negative with values of -0.29 and -0.65 respectively.

For K_2O two local maxima with 8 soil samples in each one were observed at the intervals 11.47 – 14.50 mg 100 g^{-1} d.s and 14.50 – 17.57 mg 100 g^{-1} d.s. These 8 soil samples represented 27.59% of the total analysed in this set. In the first interval these values were classified among medium and high and in the second interval were high. The skewness coefficient was positive (0.03) while the kurtosis coefficient was negative (-0.35). The frequency distribution histogram for Olsen P shows a local maximum at the interval of 1.45 – 2.07 mg 100 g^{-1} d.s. The local maximum obtained corresponds to a frequency distribution of 13 soil samples which represent the 44.83% of the total soil samples analysed in this set.

These values were classified as medium. Also, two intervals with the same number of soil samples (5) were observed at both sides (right and left) of the local maximum. These two intervals comprised values between 0.83 to 1.45 mg 100 g^{-1} d.s and 2.07 to 2.69 mg 100 g^{-1} d.s respectively. The skewness and the kurtosis coefficients were positive with values of 1.10 and 0.18 respectively. In the histogram with the frequency distribution of Oniani P content, two local maxima can be observed at the intervals 4.46 – 7.25 mg 100 g^{-1} d.s and 9.95 – 12.80 mg 100 g^{-1} d.s. In the first interval 12 soil samples (41.38%) are included while in the second interval 6 soil samples (20.69%) are included.

These values in the first interval were classified between low and medium and in the second interval between medium and high. The skewness and the kurtosis coefficients were positive with values of 1.06 and 0.51 respectively.

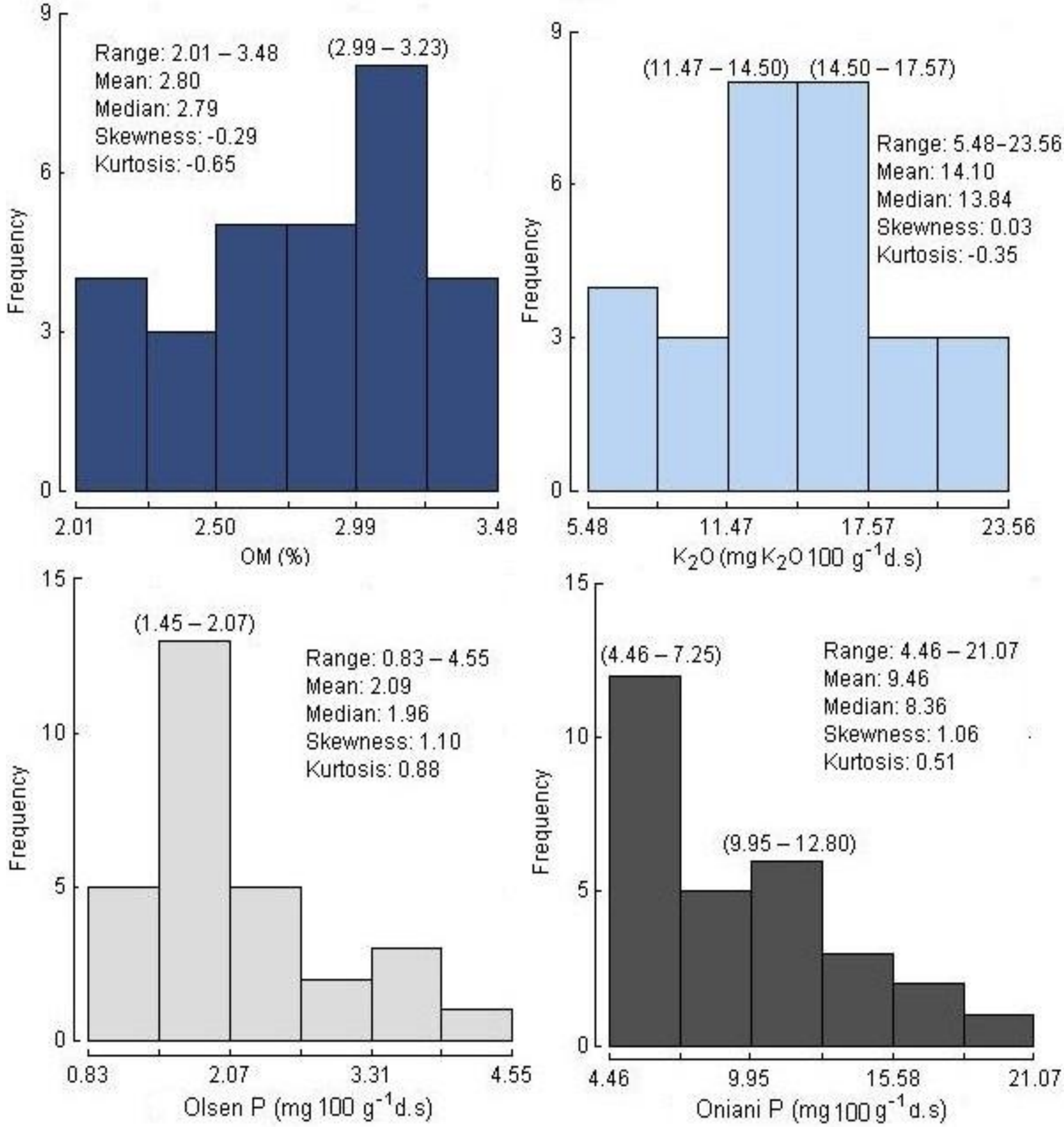

Figure 2: Frequency distribution of soil fertility parameters within a field on Vertisol soil.

For the four soil fertility parameters measured, a maximum of four factors explain the total variance of each factor. An eigenvalue analysis allows the identification of the significant factors that collectively represent the major proportions of the total variability. When an eigenvalue is less than 1 the factor explains less variance than the individual attribute. This is in line with the findings of Shukla et al. [22] and Ayoubi et al. [23].

In Vertisol landscape only the Factor 1 shows an eigenvalue >1, and then it is the most significant factor for explaining the system variance (Table 2).

Table 2: Initial eigenvalues, proportion of variance and cumulative variance in Vertisol landscape.

Factor	Eigenvalue	Proportion of variance (%)	Cumulative variance (%)
1	3.47	86.64	86.64
2	0.33	8.12	94.76
3	0.18	4.42	99.18
4	0.03	0.82	100

The Factor 1 accounted for an 86.64% of the total variance with high positive loadings from all the soil fertility parameters. This factor accounted for 49.17% of the total variance when rotated, also with positive loadings from all the soil fertility parameters. According to the factor loadings all the soil fertility parameters contributed quite equally to the same factor that produces the variability. The communality estimates explained 89% of variance in OM and more than 90% in the remaining factors (Table 3).

Table 3: Varimax rotation and comunalities for soil fertility parameters in Vertisol landscape.

Soil fertility parameter	Factor matrix	Rotated factor matrix	Comunality estimates
OM	0.921	0.522	0.89
K_2O	0.897	0.399	0.94
Olsen P	0.963	0.856	0.98
Oniani P	0.940	0.896	0.98
Eigenvalue	3.47	1.97	-
Variance %	86.64	49.17	-
Cumulative variance %	86.64	49.17	-

The Factor 1 shows an eigenvalue >1 within a field on Vertisol soil, and then it is retained as the most important factor for explaining the system variance. This factor accounted for an 84.74% of the total variance (Table 4).

Table 4: Initial eigenvalues, proportion of variance and cumulative variance within a field on Vertisol soil.

Factor	Eigenvalue	Proportion of variance (%)	Cumulative variance (%)
1	3.39	84.74	84.74
2	0.35	8.66	93.40
3	0.22	5.44	98.84
4	0.05	1.16	100

This factor accounted for 47.81% of the total variance when rotated, with positive loadings. The loadings for OM and K_2O were lower than those from the remaining soil fertility parameters. According to the factor loadings all the soil fertility parameters contributed in the same way to the same factor that produces the variability. The communality estimates explained 89% of variance in OM and more than 90% in the remaining factors (Table 5).

Table 5: Varimax rotation and comunalities for soil fertility parameters within a field on Vertisol soil.

Soil fertility parameter	Factor matrix	Rotated factor matrix	Comunality estimates
OM	0.899	0.447	0.89
K_2O	0.893	0.419	0.90
Olsen P	0. 950	0.866	0.97
Oniani P	0.938	0.887	0.97
Eigenvalue	3.39	1.91	-
Variance %	84.74	47.81	-
Cumulative variance %	84.74	47.81	-

CONCLUSIONS

The high coefficients of variation obtained in this research might indicate a large spatial variability of the soil fertility parameters, mainly P and K_2O, for different fields within the province and even within a field. It means that soil analyses prior to fertilization are needed to allow efficient fertilization. In terms of measured nutrients, similarities were found when comparing the values observed on the local maxima of each frequency distribution histogram at landscape level and within a field. These results indicated that in several locations the soil fertility parameters analysed do not specify P or K_2O as a limiting soil nutrient, according to the classification scale used. In factor analysis the significance of the eigenvalues was used as a criterion for understanding the relationship between soil fertility parameters and factors. In all cases, soil fertility parameters were assigned to the Factor 1 for which their eigenvalues were the highest.

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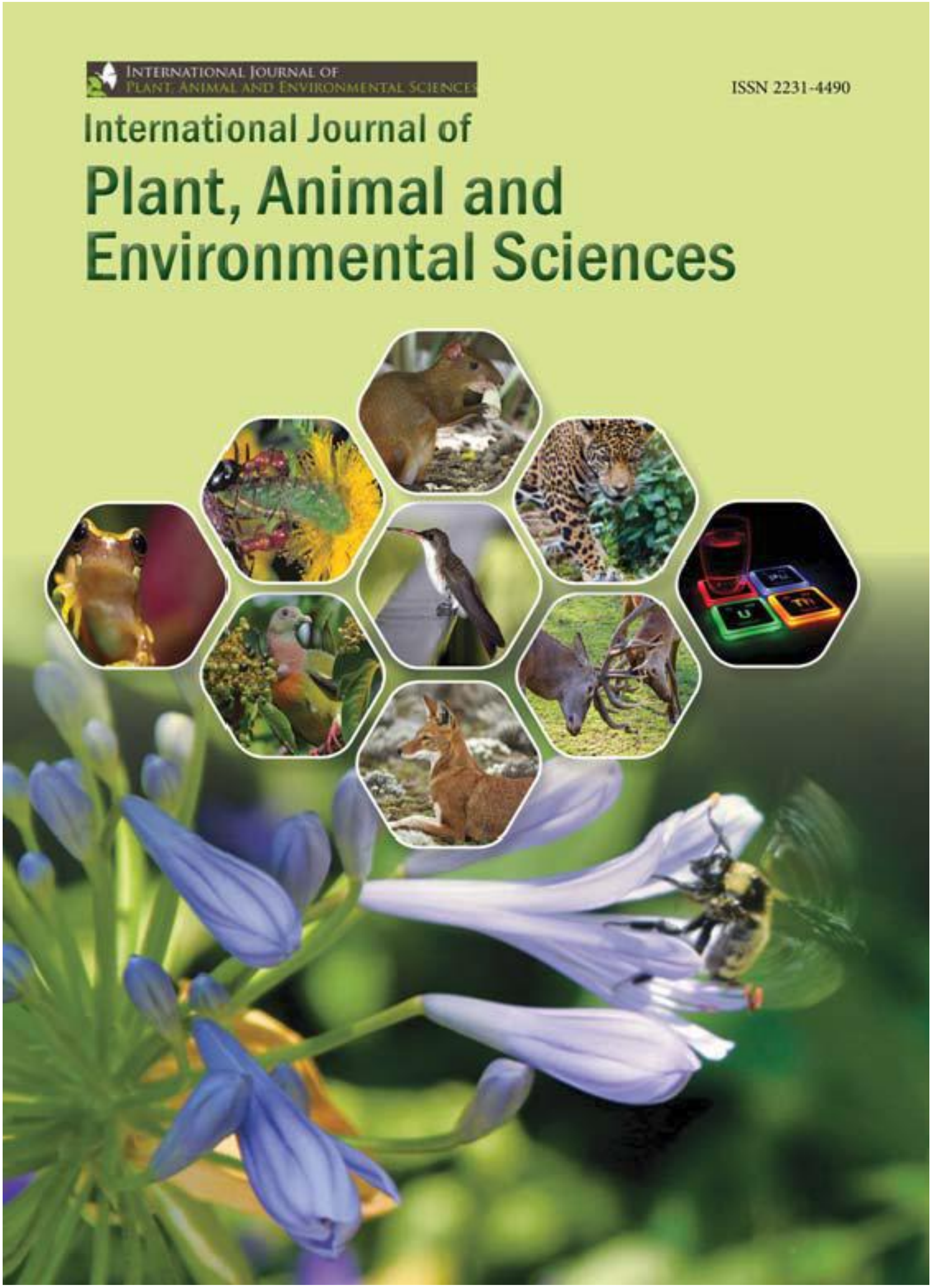
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