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Spatial variability of weeds in an Oxisol under no-tillage system

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In the global agribusiness, the herbicide use is a major problem for sustainable production, in this sense, it is necessary to better understand the interaction of weed species and floristic composition such as biodiversity indicators. The objective of this study was to analyze the spatial variability of weeds in an Oxisol under no-tillage system. Samples were taken in an area of 0.5 ha, in 50 sampling points with spacing of 5 m x 10 m. Data were analyzed by means of classical statistics, geostatistics, and spatial variability of the constructed maps by the interpolation by kriging technique. All the species of weeds presented in the study area showed spatial variability with the exception of *Ipomoea triloba* (L.) and *Heliotropium indicum* (L.), which showed pure nugget effect. The range values (a) shows that the spacing between samples can be extended to all species of weeds. The study was unable to determine specifics areas of management in the local since the different species of weed infested different plots of the area.

Key words: Precision agriculture, semivariograms, site-specific management.

INTRODUCTION

The weeds have acquired along the evolutionary process the capacity to establish themselves in areas where the natural vegetation has been eliminated, mainly for agricultural cultivation. Among the developed features by the weeds, there are high reproductive capacity, rapfastid dispersal, and genetic adaptations. These associated characteristics are responsible for a significant part in the reduction of agricultural production (Rodrigues et al., 2010). Once uncontrolled, weeds host several pest insects, nematodes, and pathogens in the crops.

Furthermore, the weeds even compete for water, nutrients which reduce the availability in the crop in the area.

The knowledge of how the populations of weeds develop allows adding to the agricultural production system a lot of information that were previously ignored in most of the cases which herbicide application is made considering an average infestation for all growing area. In

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this sense, the use of precision farming tools allows space and temporal monitoring of weeds variability, mapping the infestation areas, specific areas of management determination (Goel et al., 2003), and herbicides localized application, which reduces the applied amount and costs.

According to Mortensen et al. (1998), the weed species presented temporal stability which favors the management of cropping areas. However, in Brazil, little is known about the spatial variability of weeds. The first works were Shiratsuchi et al. (2004, 2005), Schaffrath et al. (2007) and Monquero et al. (2008) whose studied the spatial distribution of weed in order to determine specific zones of management. Other studies emphasized the importance of studying the weeds distribution and specific management sites. Domingos and Laca-Buendia (2010) studied weeds in the preharvest of the sorghum crop. Calado et al. (2013) studied weed control in winter wheat influenced by different farming systems. Bressan et al. (2006) used geostatistics techniques to classify the risk of weed infestation, and made the decision on the best management for each field area.

Shiratsuchi et al. (2005) also reported that most studies that focused on weeds mapping had as a primary concern mapping the emerging flora during the critical cycle of interference, being the only few studies on spatial variability of weeds in the course of the crop cycle. Allied to this, studies focusing on weed parameters analysis of species diversities of the communities try to determine the degree of infestation, being one of the first steps in studying the weeds dynamics and the choice of strategies control (Lacerda et al., 2005).

Thus, this study aimed to determine the spatial variability of weeds in an Oxisol managed under the no-tillage system in Urutaí (Goiás, Brazil).

MATERIALS AND METHODS

The study area has 0.5 ha (50 m x 100 m), and is located at the Goiano Federal Institute - Campus Urutaí (17°27'50'' South and 48°12'10'' West). The soil of the area is Rhodic Hapludox (USDA, 1999), managed under no-tillage since 2001, and the sampling time was cultivated with sunflower (*Helianthus annuus* L.) cultivate M-734. The climate, according to Köppen is Aw, with two well-defined seasons, dry in winter and humid in the summer, with average temperatures higher than 18°C during all months of the year.

The study area was divided into a sampling grid with 50 points with spacing of 5 m x 10 m. At each sampling point was randomly placed a circle of 0.5 m diameter (0.196 m^2) for identifying the number of individuals per point, the number of species per point and the incidence of each type in each sampling point, by manual identification technique (Lutman and Perry, 1999).

The identification of the presented weeds in the area of study was performed using the Identification Manual and Weed Control (Lorenzi, 2000). The following weed species were identified: *Cenchrus echinatus* L.; *Chamaesyce* sp. (L.) Mill; *Heliotropium indicum* L.; *Ipomoea triloba* L.; *Eleusine indica* (L.) Gaertn and *Bidens pilosa* L. They were evaluated for their quantitative values for density, relative density, frequency, relative frequency, abundance, relative abundance and relative importance index values, according to Mueller-Dombois and Ellenberg (1974).

$$Density = \frac{Total\ number\ of\ individuals\ per\ species}{Total\ number\ of\ circles\ obtained\ (total\ area)} \quad (1)$$

$$Relative\ density = \frac{100\ x\ density\ of\ the\ species}{Total\ density\ of\ all\ species} \quad (2)$$

$$Frequency = \frac{Number\ of\ squares\ containing\ the\ species}{Total\ number\ of\ circles\ obtained\ (total\ area)} \quad (3)$$

$$Relative\ frequency = \frac{100\ \text{x frequency of the species}}{\text{overall frequency of all kinds}} \quad (4)$$

$$Abundance = \frac{Total\ number\ of\ individuals\ per\ species}{total\ number\ of\ circles\ containing\ the\ species} \quad (5)$$

$$Relative\ abundance\ = \frac{100\ x\ abundance\ of\ species}{total\ abundance\ of\ all\ species} \quad (6)$$

$$Relative\ Importance\ Value\ Index = rel.freq + rel.abund. + rel.density \quad (7)$$

Where: *rel. freq*= relative frequency, *rel. abund*=relative abundance and *rel. density*=relative density. Biodiversity indexes were obtained by Species Diversity program (DivEs 3.0.7) (Rodrigues, 2015). The Shannon-Wiener Index is suitable for random samples of species of an interested community or sub-community.

$$H' = \sum_{i=0}^{n} Pi\ x\ logb\ Pi \quad (8)$$

Where: *pi* is the proportion of species in relation to the total number of found species in the conducted surveys logb = logarithm to the basis b (2 or 10). Simpson index takes into consideration the number of species (*S*), the total numbers of individuals (*N*), and the total proportion of occurrence of each species.

$$Ds = 1 - \frac{\sum_{i=0}^{n} ni\ x\ (ni-1)}{N(N-1)} \quad (9)$$

Where: *n* is the number of individuals of each species; *N* is the number of subjects. Simpson Diversity D is determined by the Simpson diversity index.

$$Ds = 1 - \left(\frac{\sum_{i=1}^{n} n_{i\ x\ (n_i-1)}}{N(N-1)}\right) \quad (10)$$

Where: *ni* is the number of each species individuals; *N* is the number of subjects. Menhinick diversity is a simple diversity index, taking into account only the species number (s) and the square root of the individuals total number. The diversity index of Menhinick (Db) is:

$$Db = \frac{s}{\sqrt{N}} \quad (11)$$

Where: s is the number of sampled specie, N is the total number of individuals in all species and Logb = logarithm base b (2 or 10).

Table 1. Descriptive statistics of weeds populations in an Oxisol under the no-tillage system, Instituto Federal Goiano - Campus Urutaí.

Atributs	*C. echinatus*	*Chamaesyce sp.*	*H. indicum*	*I. triloba.*	*E. indica*	*B. pilosa*
N	41	10	13	5	20	25
Min	1	1	1	1	1	1
Max	40	3	7	2	10	4
Mean	8.9	1.5	2.5	1.2	4	2.6
Variance	57.3	0.72	3.9	0.2	11	1.4
Standard deviation	7.57	0.85	2	0.45	3.3	1.2
Coefficient of variation	85.06	56.65	80.59	37.26	81.88	46.6
Skew	2.014	1.358	1.202	2.236	0.865	-0.154
Kurtosis	6.357	0.107	0.604	5	-0.836	-1.507
D	0.149Ln	0.422Ln	0.308Ln	0.473Ln	0.274Ln	0.204Ln

N = number of measurement; Min = minimum value; Max = maximum value; D=Kolmogorov-Smirnov test with 1% of probability of error.

McIntosh is a simple index more complex since it considers the total number of individuals (N) and the U-value, which is the square root of the sum of squared individuals of each species. The diversity index McIntosh (D) is:

$$D = \frac{N - U}{N - \sqrt{N}} \quad (12)$$

Where: N is the total number of individuals (s) or sample (s); and U is calculated as follows:

$$U = \sqrt{\sum_{i=1}^{n} n_i^2} \quad (13)$$

Where i is the number of individuals belonging to the each species. Gleason diversity is a simple index of diversity considering only the species number (s) and the logarithm (base 10 or natural) of the individuals total number.

$$Dg = \frac{s}{Log_b N} \quad (14)$$

Where: s is the number of sampled species, N is the total number of individuals in all species and Logb = logarithm base b (2 or 10). Total diversity estimates a region diversity as:

$$TD = \sum_{i=1}^{n} w_{i[pi\,(1-pi)]} \quad (15)$$

Where: i is the weight given to the function, which expresses the importance that wants to give the species i in the global quantification of the regional diversity; pi is the relative frequency. The spatial variability was analyzed by constructing semivariograms according to Vieira (2000). The semivariogram, γ (h), a spatially distributed z variable (xi) is:

$$y(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2 \quad (16)$$

Where: N (h) is the number of observations separated by a distance h. The semivariograms were adjusted to a mathematical model according to the following parameters: nugget effect (C_0), level ($C_0 + C_1$), and range (a).

The equation 16 was determined by considering the intrinsic possibility of geostatistics, in which there is no requirement for the existence of a finite variance Var (z). It requires only the stationarity of averages and a second order stationarity for the differences [(Z (x) -Z (x + h)] (Journel and Huijbregts, 1978). The semivariogram behavior for small h values reveals important aspects of the spatial variability of the properties under which it can be used for comparison.

The semivariograms weeds were staggered, according to Vieira et al. (1997):

$$y^{sc} = (h) = \frac{y(h)}{Var(z)} \quad (17)$$

Where: y^{sc} (h) is the phased semivariogram, γ (h) is the original semivariogram, and Var (z) is the data variance.

Theoretically, this equation requires the existence of a finite variance, which can be ensured if the second order stationarity exists. However, the greatness that is used in this calculation is only the conveniently calculated number for the data variance, but not exactly the statistical magnitude of variance. The scale is used for designing various semivariograms on the same graph when otherwise have different scales on the axis of semivariances. When phased the semivariograms for clusters, it can be said that the properties involved have similar spatial variability (Vieira et al., 1997). The adjustment of the experimental semivariograms of weed was performed by adjusting the spherical models, exponential and gaussian, being chosen the best setting in the technical function of "*jack-knifing*", as presented by Carvalho et al. (2002). The spatial dependence ratio was calculated according to the equation below:

$$RD = \left(\frac{C_0}{C_0 + C_1}\right) x100 \quad (18)$$

As proposed by Cambardella et al. (1994), being 0.00 to 25% strong, 25 to 75% moderate and 75 to 100% weak.

RESULTS AND DISCUSSION

All the studied weeds species presented frequency distribution of lognormal type (Table 1). According to

Table 2. Density values, frequency, abundance and index values of relative importance found in the no-tillage system located at the Instituto Federal Goiano - Campus Urutaí.

Variable	Frequency		Density		Abundance		
	Absolute	Relative	Absolute	Relative	Absolute	Relative	I.V.I (%)*
C. echinatus	0.82	35.34	37.24	64.38	8.90	39.26	138.99
Chamaesyce sp	0.2	8.62	1.53	2.64	1.5	6.61	17.88
H. indicum	0.26	11.20	3.26	5.64	2.46	10.85	27.70
I. triloba	0.1	4.31	0.61	1.05	1.2	5.29	10.66
E. indica	0.4	17.24	8.26	14.28	4.05	17.86	49.39
B. pilosa	0.5	21.55	6.53	11.28	2.56	11.29	44.13
Total	2.28	98.27	57.44	100	20.672	91.17	300

*I.V.I=Importance Value Index.

Carvalho et al. (2002), skewness and kurtosis values near to 0 and 3 are indicative of a normal frequency distribution. In this case, the elevated values of skewness and kurtosis confirm the presence of log-normal distribution. However, *B. pilosa* and *E. indica* obtained skewness and kurtosis respectively below zero, in which case these two species probably have no log-normal distribution. According to Johnson et al. (1996) and Wiles et al. (1992), negative distributions as well as the aggregate behavior variables are typical weeds.

According to Warrick and Nielsen (1980), the number of rating individuals, *C. echinatus*, *H. indicum* and *E. indica* indicates a high coefficient of variation values (CV ≥ 60%), the other variables had moderate CV values. The species, *C. echinatus* was the most common weed in the area of study, occurring in 41 of the 50 sampling points, and *I. triloba* was the lower frequency species found only in 5 sampling points (Table 1).

It was found that three species of plants presented greater frequency, density, abundance and relative importance value. *C. echinatus* presented relative frequency (35.34), specific gravity (64.38), relative abundance (39.26) and relative importance index (138.99). *B. pilosa* was obtained for relative frequency (21.55), relative density (11.28), relative abundance (11:29) and relative importance index (44.13). Also, the grass *E. indica* indicated relative frequency (17.24), relative density (14.28), relative abundance (17.86) and relative importance index (49.39) (Table 2).

The coefficients of variation (CV%) for the diversity indexes are considered low, ranging from 0.293 to Menhinick index to 0.670 for McIntosh. The asymmetry parameter for the contents of D. Simpson, Simpson, Shannon, Menhinick, McIntosh and Margalef showed values lower than 0.5 which, according to Webster and Olivier (1990) who indicates normal distribution.

In this case, only the total diversity and Gleason index had values that did not follow a normal distribution (-0.851 and 1.592 respectively) (Table 3).

The linear correlation matrix (Table 4) demonstrate that among *H. indicum* x *E*. *indica* (*r* = 0.816), *H. indicum* x Shannon index (*r* = 0.797), Simpson index x Shannon index (*r*= 0.873), Simpson index x Menhinick index (*r* = 0.765), Simpson index x McIntosh index (*r*= 0.985), Simpson index x Margalef index (*r* = 0.827), Simpson index x Gleason index (*r*= 0.684), Shannon index x McIntosh index (*r* = 0.793), Shannon index x Margalef index (*r*= 0.824), index Menhinick x McIntosh index (*r* = 0.814), Menhinick index x Margalef index (*r*= 0.838), Menhinick index x Gleason index (*r* = 0.941), McIntosh index x Margalef index (*r*= 0.809), McIntosh index x Gleason index (*r* = 0.764) and index Margalef x Gleason index (*r*= 0.758) there is a high linear correlation according to Santos (2007) classification. The other correlations are considered low (| *r* | = 0.1-0.5) or zero (| *r* | = <0.1).

The presence of negative linear correlation for the vast majority of species with C*. echinatus* (*C. echinatus* x *Chamaesyce sp* = -0.162; *C. echinatus* x *I. triloba* = -0.783; *C. echinatus* x *E. indica* = -0.170; *C. echinatus* x *B. pilosa* = -0,371) indicating the superiority of the grass, *C. echinatus* in the colonization process of the area of study in relation to another weed species, this is confirmed when we analyze the occurrence of each weed species in 50 sampling points (Table 1).

The geostatistical analysis presented that the species, *H. indicum* and *I. triloba* showed pure nugget effect, as well as the Shannon diversity indexes, Menhinick, Margalef and Gleason (Table 5). According to Vieira (2000), the presence of nugget effect is mainly because of the spacing used, which was not enough to detect the spatial variability between the samples.

However, the presence of pure nugget effect for *H. indicum* and *I. triloba* is mainly because these two weed species are not common in the area of study, as evidenced by the number of sampled individuals (Table 1).

The spherical model was the most adjusted one to the weed plants data, corroborating to other studies that describe this model as the most adjusted one with soil and plant data (Cambardella et al., 1994; Vieira, 2000; Chiba et al., 2010; Siqueira et al., 2015), excepting the

Table 4. Linear correlation between species and levels of diversity of the weed plants presented in the area of study.

Variable	*C. echinatus*	*Chamaesyce sp*	*H. indicum*	*I. Triloba*	*E. indica*	*B. pilosa*	Div. total*	D. Si*	Si*	Sha*	Men*	Mc*	Mar*	Gleason
C. echinatus	1.000	-	-	-	-	-	-	-	-	-	-	-	-	-
Chamaesyce sp	-0.162	1.000	-	-	-	-	-	-	-	-	-	-		-
H. indicum	0.123	**	1.000	-	-	-	-	-	-	-	-	-	-	-
I. triloba	-0.783	**	**	1.000	-	-	-	-	-	-	-	-	-	-
E. indica	-0.170	0.478	0.816	**	1.000	-	-	-	-	-	-	-	-	-
B. pilosa	-0.371	0.522	0.168	**	-0.041	1.000	-	-	-	-	-	-	-	-
Div. Total	0.255	0.247	0.121	-0.848	-0.047	-0.511	1.000	-	-	-	-	-	-	-
D. Simpson	0.478	-0.475	-0.404	-0.339	-0.155	-0.230	-0.181	1.000	-	-	-	-	-	-
Simpson	-0.478	0.475	0.404	0.339	0.155	0.230	0.181	-1.000	1.000	-	-	-	-	-
Shannon	-0.259	0.452	0.797	-0.309	0.349	0.158	0.408	-0.873	0.873	1.000	-	-	-	-
Menhinick	-0.519	0.241	0.086	0.597	-0.400	-0.122	0.019	-0.765	0.765	0.581	1.000	--	-	-
McIntosh	-0.521	0.451	0.263	0.515	0.024	0.237	0.085	-0.985	0.985	0.793	0.814	1.000	-	-
Margalef	-0.235	0.286	0.387	-0.045	-0.225	-0.192	0.463	-0.827	0.827	0.824	0.838	0.809	1.000	-
Gleason	-0.491	0.260	0.051	0.617	-0.353	-0.234	-0.007	-0.684	0.684	0.441	0.941	0.764	0.758	1.000

Div. Total*= total diversity; D. Si*= D Simpson; Si*= Simpson; Sha*=Shannon; Men*=Menhinick; Mc*=McIntosh; Mar*= Margalef.

Table 3. Descriptive statistics of weeds diversity indexes in an Oxisol under the no-tillage system, Instituto Federal Goiano - Campus Urutaí.

Variable	Total diversity	D. Simpson	Simpson	Shannon	Menhinick	McIntosh	Margalef	Gleason
Numbers	48	48	48	48	48	48	48	48
Minimum	0	0	0	0	0.436	0	0	1,430.7
Maximum	0.965	1	1	0.626	1.414	1	3.419	6,643.9
Mean	0.631	0.575	0.424	0.258	0.794	0.337	1.452	2,712.0
Median	0.679	0.507	0.492	0.276	0.816	0.356	1.627	2,631.0
Variance	0.098	0.064	0.064	0.022	0.054	0.051	0.649	0.920
Standard deviation	0.314	0.253	0.253	0.150	0.232	0.226	0.805	0.959
Coefficient of variation	0.498	0.440	0.596	0.582	0.293	0.670	0.554	0.353
Skew	-0.851	0.218	-0.218	0.09	0.361	0.284	-0.086	1,592.0
Kurtosis	-0.377	-0.761	-0.761	0.06	-0.434	-0.042	0.128	4,714.0
Kolmogorov-Smirnov	0.157	0.117	0.117	0.142	0.115	0.08	0.11	0.138
Critical K-S stat, alpha=.05	0.192	0.192	0.192	0.192	0.192	0.192	0.192	0.192

grass, *C. echinatus* that set the gaussian model. In biodiversity, indexes were the exponential model (D Simpson, Simpson Diversity, McIntosh

Table 5. Adjustment parameters of the semivariogram for the studied weed species.

Variable		Model	C_0	C_1	A	RD
Species	*C. echinatus*	Gaussian	25.00	60.00	38.00	29.41
	Chamaesyce sp.	Spherical	0.00	0.60	28.00	0.00
	H. indicum	Pure nugget effect				
	I. triloba	Pure nugget effect				
	E. indica	Spherical	0.00	15.0	40.00	0.00
	B. pilosa	Spherical	0.10	1.30	20.00	7.14
Biodiversity indexes	Total diversity	Spherical	0.04	0.05	30.70	44.44
	Simpson (D)	Exponential	0.00	0.06	7.20	0.00
	Simpson diversity	Exponential	0.00	0.06	7.30	0.00
	Shannon diversity	Pure nugget effect				
	Menhinick diversity	Pure nugeet effect				
	McIntosh diversity	Exponential	0.00	0.05	7.70	0.00
	Margalef diversity	Pure nugget effect				
	Gleason diversity	Pure nugget effect				

diversity), with the exception of the total diversity that adjusted to the spherical model (Table 5).

Several studies have reported that some weed species are aggregated or occur in reboilers, so the infestation mapping of the agricultural area enables located management application. That's because when the areas are mapped with the occurrences, they also know other aspects of weeds, such as the degree of infestation, contagiousness, species present and edaphoclimatic relations (Wiles et al., 1992; Jonhnson et al., 1996; Schaffrath et al., 2007). *C. echinatus* had high values of nugget effect (C_0, Table 5). Siqueira et al. (2008) pointed out that the nugget effect values represent the spatial variation not detected in the sampling process, indicating that if the spacing was shorter it would be possible to detect other patterns of variability thanks to this attribute. The grass, *C. echinatus* had the higher range value (a = 38.00 m) and *B. pilosa* had the lowest range value (a = 20.00 m).

For the biodiversity reach indexes, the highest value was the total diversity (30.70 m). Siqueira et al. (2015) studying the variability of weed found a range between 40 and 210 m. The spatial dependence reason was calculated according to Cambardella et al. (1994), was high for *Chamaesyce sp*., *E. indica*, *B. pilosa*, Simpson (D), Simpson diversity and McIntosh Diversity (RD = 0.0 to 25%), medium for *C. echinatus* and Total diversity (RD = 25-75%).

Figure depicted the phased semivariogram. In Figure 1 A, the total diversity, as well as the Margalef index exhibit greater dispersion when compared to the other indexes. Similarly, *Chamaesyce sp, H. indicum* and *I. triloba* presents great dispersion in the semivariance pairs in a short distance and upon the increasing of the distance (Figure 1B). The other variables that presented spatial variability had the same spatial behavior.

The spatial variability map for the diversity of Simpson and Shannon full diversity which weeds species are present throughout the study area occurred with greater intensity on the left side of the sampled area (Figure 1 C). In general, all kinds of weeds present in the area showed spatial variability, with the exception of *I. triloba* and *H. indicum*.

The weed species presented distribution in “reboilers”. The range of values (a) showed that the space between the samples can be extended to all weed species. It was not possible to determine specific areas of management in the studied area since different species of weed infested plots of the area.

Conflict of Interests

The author has not declared any conflict of interest.

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Figure A

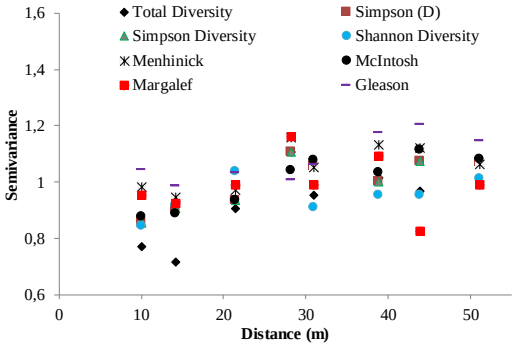


Figure B

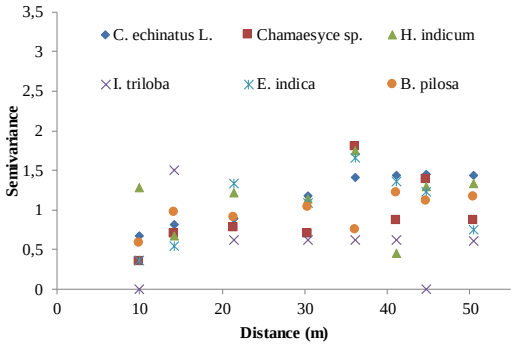
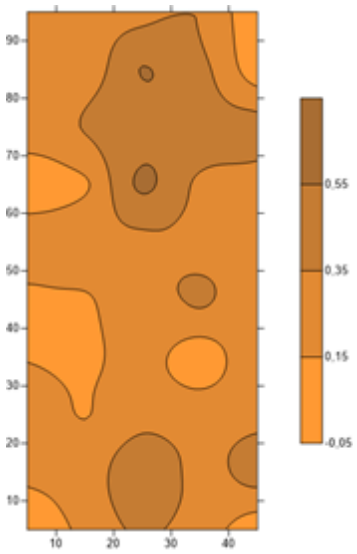
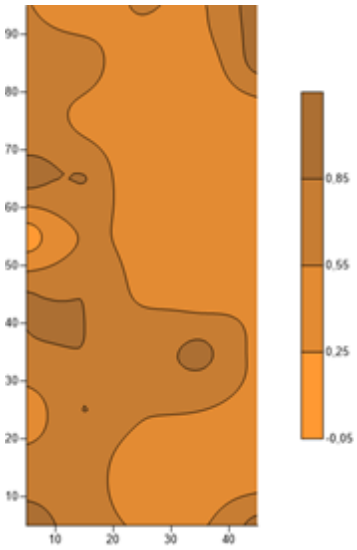


Figure C

Shannon Diversity



Simpson Diversity



Total Diversity

Diversity D Simpson

Figure 1. Semivariogram phased for the biodiversity indexes (Figure A), for the weed species (Figure B), and variability maps (Figure C) in the studied area.

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