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Spatial variability of sunn hemp under residual effect of nitrogen and water salinity

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ABSTRACT. This work had as objectives to use the Sunn Hemp (*Crotalaria juncea* L.) to evaluate the residual effect in the soil of levels of water salinity and nitrogen doses, and the occurrence of spatial dependence within the experimental area. In previous years, the experimental area received six consecutive trials, which tested different levels of nitrogen and water salinity on different crops. The same experimental design was applied to this trial, that is, a randomized block design with split-plots (5 x 3), corresponding to the residual effect of water salinity and nitrogen, and four replications. The variables determined were: the plant height on six dates after the sowing, and the dry mass of the shoot, root and the whole plant. The data were firstly subjected to the variance analysis of the residual effects and to the study of spatial variability through geostatistics. The variance analysis did not show significant residual effects of the levels of salinity and nitrogen doses in the soil on the height and dry mass of Sunn Hemp. It was observed a spatial dependence, from moderate to high, in all dates, for height and dry mass of Sunn Hemp.

Keywords: green manuring, spatial dependence, geostatistics, sustainability.

Variabilidade espacial de crotalaria juncea sob efeito residual de níveis de nitrogênio e salinidade da água

RESUMO. O trabalho teve como objetivo cultivar Crotalária juncea L. para avaliar o efeito residual no solo de níveis de salinidade da água e doses de nitrogênio e a existência de dependência espacial dentro da área experimental. Em anos anteriores, a área experimental recebeu seis experimentos consecutivos para testar níveis de nitrogênio e de salinidade da água sobre diferentes culturas. O mesmo delineamento foi usado neste experimento, ou seja, blocos ao acaso com parcelas subdivididas 5 x 3, correspondentes ao efeito residual de salinidade da água e nitrogênio, com quatro repetições. As variáveis estudadas foram: altura de plantas em seis datas após semeadura e as massas secas de parte aérea, de raízes e total. Os resultados foram submetidos à análise de variância do efeito residual e ao estudo da variabilidade espacial por meio da geoestatística. A análise da variância não indicou efeito residual significativo dos níveis de salinidade e doses de nitrogênio no solo sobre as variáveis de crescimento e massa seca da crotalária. Observou-se dependência espacial de moderada a forte de todas as variáveis de crescimento e massa seca dentro da área experimental.

Palavras-chave: adubação verde, dependência espacial, geoestatística, sustentabilidade.

Introduction

The green manuring is used since antiquity, and consists of the use of plant species, especially legumes, in order to recycle the soil nutrients and to fix nitrogen (AMADO et al., 2001). Such species, also known as cover crops can be used for pre-planting, consortium or post-planting of annual or perennial crops, either incorporated into the soil or not.

Green manures and their residues hold a variety of organic substances to soil and release nutrients in labile forms that may become available for subsequent crops, particularly nitrogen (AMADO et al., 2002). Furthermore, their profound and branched root systems extract nutrients from the deepest soil layers (ALCÂNTARA et al., 2000).

Among the legumes used as green manure, *Crotalaria juncea* L. (Sun Hemp) is a shrubby tropical plant of annual cycle, erect and with determinate growth, widely used due to its rapid growth, large biomass production, easy decomposition, nutrient cycling and efficiency in the biological nitrogen fixation from the atmosphere (KAPPES, 2011). It yields between 6-8 tons of dry mass per cycle, being able to add from 180 to 300 kg ha^{-1} of N, 60% of which remain in the soil, 30% are used by the plant in succession and 10% are lost in the environment (LOPES et al., 2005).

Although irrigation has been practiced for millennia, the importance of the water quality only began to be recognized in the early years of the last century. This was due to the abundance of water sources of good quality. However, it is important to determine the feasibility in using specific irrigation water, considering its chemical composition, species cropped and its tolerance to salts, physical and chemical properties of the soil, soil management practices, weather conditions, irrigation method and drainage conditions (FIGUEIRÊDO et al., 2009).

One concern about the increased demand of water for irrigation is that this leads to the overuse of the good quality sources available, leading to the use of water with higher salinity levels. This is evident in arid and semiarid regions. Although most water sources in the Northeast region of Brazil presents good quality, there is water of lower quality with a very high volume that can be used to increase the irrigated areas (MEDEIROS et al., 2003).

Studies involving aspects of the soil and crops are usually analyzed by classical statistics, which assumes that the implementation of the random variables are mutually independent, i.e., there is no relationship between the variation and the distance among the sampling points. The random variable is that which can have different values at different locations of observation, thus showing a certain independence between one point and another (GUERRA, 1988).

However, studies employing classical statistical techniques, such as variance analysis, are inadequate for understanding some soil-water-plant interactions. In such cases, an option is to use geostatistics, which considers the existence of variation dependence within the sampling space. The geostatistical tools are sensitive to spatial correlations among properties and can better describe these interactions. Actually, classical statistics and geostatistics are complementary, and one of them can answer questions not answered by the other.

Sunn Hemp is cropped to recover the soil quality of agricultural areas, degraded over time. In semiarid conditions, this crop needs irrigation and may have its growth affected by the use of saline water and the cultivation in saline soils, in the same way as other plants. Thus, besides the soil recovery, the growth of Sunn Hemp may indicate a soil variability after years of application of the experimental treatments. In this context, this work aimed at, through the cultivation of Sunn Hemp, evaluating the residual effect in the soil of levels of water salinity and nitrogen doses and the existence of spatial dependence within an experimental area.

Material and methods

The experiments were conducted at the Experimental Farm of the Federal Rural University of Semiarid (5º 03' 37"S, 37º 23' 50"W), in Mossoró, RN, Brazil, whose soil is a loamy sand argisolic Oxisol (EMBRAPA, 2006). The local climate is classified as Bswh', according to the Köppen Classification, with annual averages of 27.4ºC for temperature, 674 mm for rainfall and relative humidity of 68.9% (CARMO FILHO; OLIVEIRA, 1995).

The experimental area received five experiments (Table 1), in which the crops received, through fertirrigation, water with different levels of salinity and nitrogen doses (FIGUEIRÊDO et al., 2009; CARMO et al., 2011; MELO et al., 2011; COSTA et al., 2013).

In the last trial, the hybrid maize was cultivated to evaluating the residual effect of the previous experiments (SANTOS et al., 2013). For this purpose, the soil was irrigated with water of good quality from the Açu Sandstone aquifer, whose electrical conductivity (EC) was of 0.57 dS m^{-1} (S1). The calcium nitrate and urea were used as nitrogen sources.

Table 1. History of crops, nitrogen and salinity levels used in the experimental area before the sowing of Sunn Hemp in Mossoró, RN, 2015.

	Doses of nitrogen (kg ha^{-1})			Water salinity levels (dS m^{-1})					Period
Crop	N1	N2	N3	S1	S2	S3	S4	S5	
Watermelon	-	-	-	0.55	1.65	2.35	3.45	4.5	February to April (2006)
Watermelon	55	106	156	0.66	1.69	2.36	3.46	3.98	Nov. (2007) to Jan. (2008)
Pumpkin	26	51	76	0.66	2.21	3.29	4.11	4.39	February to April (2008)
Melon	42.5	85	127,5	0.65	1.65	2.83	3.06	4.73	October (2008)
Watermelon	48	96	144	0.57	1.36	2.77	3.86	4.91	August to November (2009)
Corn	-	-	-	0.57	-	-	-	-	November (2011)

Source: Data obtained from experiments previously installed in the experimental area.

The experimental design was a completely randomized block design with split-plots (5 x 3) and four replications. The main plots, with dimensions of 22.5 x 7.5 m, received five levels of water salinity in the previous years, while the subplots received three nitrogen doses. Each plots consisted of three subplots with three double plant rows with distances of 0.2 m and 2.0 m between the single and the double rows, and 0.05 m of distance between the plants. Only the central double row was sampled for evaluations.

The soil tillage was done by plowing and harrowing. As for the sowing, performed in June 2012, three seeds per hill were used. The thinning was performed eight days after the sowing, leaving one plant per hill, resulting in a population of approximately 200,000 plants per ha^{-1}.

The weed control was done with hand hoes in the period of 20-60 days after the emergence (DAE). The daily irrigation was performed by a drip system consisting of 30 pipes with a length of 45 m, one for each double plant row. Emitters with a spacing of 0.3 m and a flow rate of 1.5 L h^{-1} at a pressure of 100 kPa were used. The irrigation water presented an electrical conductivity of 0.57 dS m^{-1}

The plant height was measured in 10 plants per subplot, randomly selected from the central double row. Measurements were taken at 21, 28, 35, 42, 49 and 56 DAS, until the crop reached full bloom and was incorporated into the soil.

The determination of the fresh mass of roots and shoots consisted of collecting 40 plants of the central double row, in a space of 1 long and 2 m wide, within a floor area of 15 m^2 in each subplot. Among these plants, two were selected randomly, in which after separating shoot and root, they were placed into an oven at 70°C for 48 hours in order to determine the water content and thus calculating the dry weight of the shoot, root and the total dry weight through a precision scale. The material was collected at the flowering, the time in which the plants were incorporated into the soil. The results were subjected to the analysis of variance for the residual effect of previous experiments, using a randomized complete block design, with split plots (5 x 3) and four replications, as already defined. The descriptive statistics was performed through the software Assistat, and included the minimum and maximum values, mean, median, standard deviation, coefficient of variation, skewness and kurtosis. The data were tested for normality through the W test of Shapiro-Wilk and the homogeneity hypothesis of independence of mean and variance were also tested. The data that did not fit to normality after eliminating the outliers underwent a logarithmic transformation.

As for the assessment of the spatial variability of the variables, through geostatistical techniques, the data of each subplot were used as a sample, totaling 60 samples georeferenced according to the Cartesian coordinates, corresponding to the center of each subplot. Thus, the sampling grid had a spacing of 6 m in the Y direction and 7.5 m in the direction X (Figure 1).

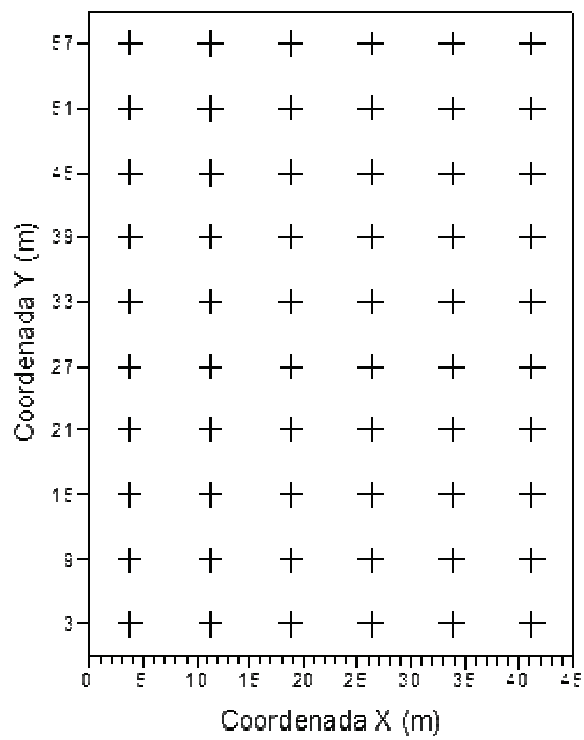


Figure 1. Sampling grid of the experimental area cropped with Sunn Hemp, in Mossoró, 2015.

The spatial dependence was assessed based on the assumptions of stationarity of intrinsic hypothesis (VIEIRA, 2000) by semivariogram analysis adjusted through the demo version of the GS + 9 software (GAMMA DESIGN SOFTWARE, 2004). The semivariogram was estimated by:

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

where:
$\gamma(h)$ is the estimated experimental semi-variance, obtained by the sampled values [Z(xi), Z(xi + h)];
h is the distance among sampling points;
N(h) is the total number of possible pairs of points, within the sampling area, separated by a distance h.

The degree of variability of the properties analyzed was classified by the coefficient of variation (CV), according to Warrick (1998), who considered low the CV below 15%, intermediate the CV between 15 and 50% and high the CV above 50%. In order to choose the models that best fit the semivariograms, it was considered the highest coefficient of determination (R^2) and the residual sum of squares (RSS). The RSS is a more robust parameter than the R^2 and provides an accurate measurement, according to which model the data best fit.

Based on the sampling points, we analyzed the structure and the spatial dependence from the experimental semivariogram, which is a plot of semivariance γ (h) versus the distance h. When the semivariance increases with distance, the sill ($C + C_0$) rises to a constant value. The distance at which γ (h) reaches the sill is called range (A), that is, the distance beyond which the samples are not spatially dependent. When the variable presents a nonzero semivariance, that is, when the distance tends to zero, the semivariance is called nugget effect (C_0), and represents an unexplained or random variance, caused by measurement errors or due to a large spacing of sampling (VIEIRA, 2000).

The degree of spatial dependence (DSD) was taken as the ratio between the nugget effect and the sill [$C_0/(C + C_0)$], and classified as strong if the ratio is $\leq$ 0.25, moderate if the ratio is between 0.26 and 0.74 and weak if the ratio is $\geq$ 0.75 (CAMBARDELLA et al., 1994).

The spatial estimation was performed by the interpolation of values of the unsampled locations, through the kriging method, in order to define the spatial pattern of the variables studied, allowing the drawing of the contour maps.

Results and discussion

The height of *Crotalaria juncea*, in the evaluated weeks, did not suffer significant residual effect of the factors studied (Table 2). Likewise, it was not observed any significant interaction between the factors salinity and nitrogen in any of the weeks. They are corroborated by Bezerra et al. (2010), who did not find residual effect of salinity, which can be assigned to the moderate resistance of the crop regarding salinity, leaching of N out of the surface layer and / or the nutrient extraction by maize, although it has been fertilized with the same doses of N.

The water salinity, nitrogen dose and their interaction did also not present significant residual effect on the Shoot Dry Mass (MSPA), Root Dry Mass (MSR) and total Dry Mass (MST) of Sunn Hemp (Table 2). It was also observed no residual effect in other studies, such as the findings of Nunes et al. (2009), regarding the dry mass of Sunn Hemp by testing sources and levels of salinity on the seed germination; or the findings of Lima et al. (2011) for the shoot dry mass of castor bean by evaluating the interaction between salinity and nitrogen levels, observing similar response to the levels of N independent on the water salinity; and the findings of Nobre et al. (2010), on the variables of sunflower, by observing similar behavior of N rates at different levels of salinity in the irrigation water. According to the general average of dry mass produced by the Sunn Hemp (Table 2), the crop production reached 13.33 tons per hectare for the dry weight of shoots, 2.43 for the root dry mass and 15.76 tons for the total dry mass.

We identified five outliers for the variable Height at 42 DAS and only one value out of the distribution at 49 DAS. Therefore, the descriptive statistics was calculated after those values have been removed (Table 3). The mean and median values had a slight weekly increase, presenting a symmetric distribution, which was subsequently evidenced by the asymmetry values near zero for all dates, and by their adjustment to the normal distribution according to the Shapiro-Wilk test. The use of symmetry and kurtosis parameters can indicate adjustment to the normal distribution when their values are near zero and three, respectively, according to Vieira et al. (2010). Additionally, the normality of the data benefits the adjustment of the semivariograms (MACHADO et al., 2007), leading to the estimation of values for the unsampled points by the kriging method. The close relationship between the mean and median can also be observed in Table 3 for the variables MSPA, MSR and MST, after data processing. The results showed adjustment to the normal distribution, also confirmed by the Shapiro-Wilk test (SW). By analyzing the variability of the data, according to Warrick (1998), the coefficients of variation observed in Table 3 are low for the plant height at 42, 49 and 56 DAS, and intermediate for the other dates.

The CV of the variable plant height is classified as low, while the variables MSPA, MSR and MST (Table 3) presented CV classified as intermediate, with values of 30.44, 48.75 and 31.45%, respectively. Salviano et al. (1998) also observed the coefficients of variation similar to the values found in our study, by studying the spatial variability of sun hemp in a field.

The adjustment of the semivariogram models and the analysis of their parameters (Table 4) showed that the height of the Sunn Hemp plants assessed weekly presented spatial dependence and was adjusted to the Gaussian model, except at 56 DAS, when it was best fitted to the exponential model. The graphical models of the semivariogram can be observed in Figure 2.

The spatial dependence observed may be associated with the intrinsic variations in the soil properties, overlapping the residual effect of the salinity levels and nitrogen fertilizer rates. According to Salviano et al. (1998) the plant development results from the combination of the soil variables and Miranda et al. (2005) state that the variability in the crop stand is due to the physical, chemical and biological soil properties, climatic factors such as rainfall and due to management practices such as the uneven application of the agricultural inputs.

The small differences among the range values (from 22.9 m to 29.95 m) for the models of semivariogram of the plant height (Table 4) indicate that for all dates the same phenomenon is acting and causing the spatial and temporal variability. Our values differ slightly from those found by Salviano et al. (1998), when assessing the sun hemp height until the flowering period. It is important to highlight that the range value has practical application in conducting experiments, because it defines the distance at which the sampling points are spatially correlated and can be used to estimate values at any point among them (MACHADO et al., 2007). Furthermore, in order to ensure the spatial dependence, the sampling points should be collected at a distance equivalent to half of the range (SOUZA et al., 2006).

Table 1. Analysis of variance for plant Height assessed in consecutive weeks, Shoot Dry Mass (MSPA), Root Dry Mass (MSR) and Total Dry Mass (MST) of Sunn Hemp under residual effect of the factors water salinity and nitrogen in Mossoró, 2015.

DF	CV	Plant height								
		21 DAS	28 DAS	35 DAS	42 DAS	49 DAS	56 DAS	MSPA	MSR	MSPA
		Medium Square								
Block	3	141.8*	407.3^{ns}	1433.3*	1657.9*	2616*	401.5^{ns}	253.2^{ns}	32^{ns}	435.9^{ns}
Sal	4	20.6^{ns}	186.7^{ns}	300.4^{ns}	325.3^{ns}	161.8^{ns}	90.4^{ns}	84.6^{ns}	5.4^{ns}	100.1^{ns}
Error 1	12	28.7	141.9	239.3	264.0	174.7	207.1	209.2	14.4	312.9
Nit	2	1.1^{ns}	7.9^{ns}	98.7^{ns}	12.6^{ns}	9.8^{ns}	30.5^{ns}	18.5^{ns}	8.4^{ns}	11.9^{ns}
Sal x Nit	8	17.9^{ns}	58.6^{ns}	184.3^{ns}	172^{ns}	102.1^{ns}	66.2^{ns}	116^{ns}	4.9^{ns}	159.1^{ns}
Error 2	30	12.4	30.5	92.7	109.2	77.9	59.1	83.6	8.5	132.6
CV(%)	1	20.1	27.9	20.0	13.8	9.8	8.9	40.2	57.9	41.6
CV(%)	1	13. 2	12.9	12.5	8.9	6.6	4.8	25.4	44.6	27.1

DF = Degrees of Freedom; Sal = Salinity; Nit = Nitrogen; ^{ns}not significant; *significant by the F test (p < 0,01); CV = coefficient of variation; SV = source of variation; DAS = days after the sowing.

Table 3. Descriptive statistics of the weekly evolution of the plant height, and of the Shoot Dry Mass (MSPA), Root Dry Mass (MSR) and Total Dry Mass (MST) of the Sunn Hemp from the 21 to the 56 DAS in Mossoró-RN. 2015.

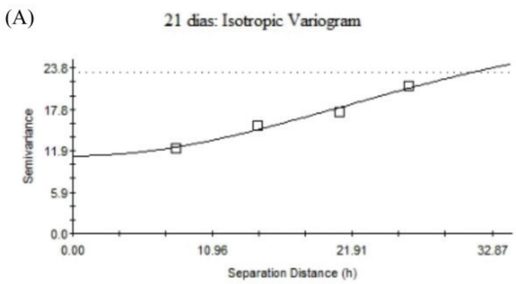
	Plant height								
	21 DAS	28 DAS	35 DAS	42 DAS*	49 DAS*	56 DAS	MSPA	MSR**	MSPA
Mean	26.66	42.74	77.32	120.81	134.25	160.13	35.99	6.56	42.55
Median	26.38	41.63	76.50	120.00	136.25	159.5	35.65	6.00	41.64
Min	14.00	19.00	39.00	92.00	96.05	138.50	18.30	2.25	22.55
Max	39.50	62.75	108.00	145.00	157.50	186.50	67.94	16.70	84.64
St. dev	4.82	9.27	14.75	11.60	15.28	10.43	10.96	3.20	13.38
Asym	-0.06	-0.00	-0.24	-0.11	-0.69	0.06	0.64	1.19	0.73
Kurt	0.63	-0.04	0.10	0.17	0.29	-0.25	0.39	1.16	0.78
CV%	18.08	21.70	19.07	9.60	11.38	6.51	30.44	48.75	31.45
W	0.98	0.99	0.98	0.98	0.96	0.99	0.96	0.98	0.96
Pr	0.48	0.68	0.65	0.62	0.08	0.87	0.08	0.62	0.07

*Values after removing the outliers; **Values transformed into Log; DAS = days after the sowing; CV = Coefficient of Variation; Min = minimum value; Max = maximum value; St. dev = standard deviation; Asym = asymmetry; Kurt = kurtosis; W = value of the W test; Pr = probability level of the W test.

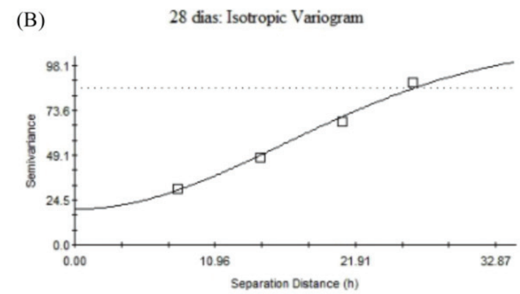
Table 4. Parameters of the models fitted to the isotropic semivariograms for the plant height of Sunn Hemp weekly from the 21 to the 56 DAS in Mossoró-RN. 2015.

Variable	Model	Nugget Efect	Sill	Range	R^2	DSD	SSR
		(C_0)	(C_0+C)	A			
21 DAS	Gaussian	11.14	29.19	29.95	0.98	0.38	1.05
28 DAS	Gaussian	19.50	110.00	23.06	0.99	0.18	21.70
35 DAS	Gaussian	55.00	310.90	26.45	0.99	0.18	28.30
42 DAS	Gaussian	53.00	174.00	23.13	0.99	0.30	14.80
49 DAS	Gaussian	39.20	241.40	22.29	0.99	0.16	3.33
56 DAS	Exponential	13.40	195.30	25.57	0.99	0.07	25.00

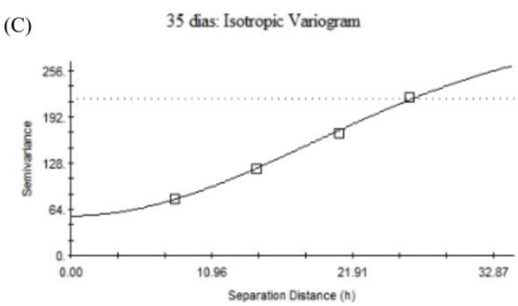
DAS = days after the sowing; R^2: coefficient of determination; DSD: degree of spatial dependence; SSR: Sum of squared residuals.



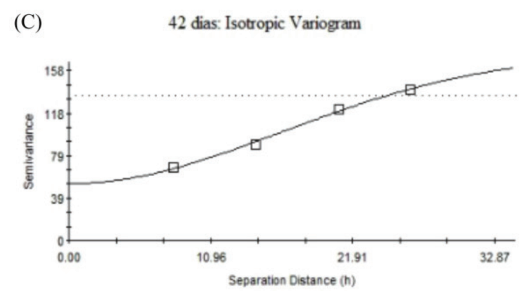
Gaussian model (Co = 11.14000; Co + C = 29.19000; Ao = 29.95; r2 = 0.975; RSS = 1.05)



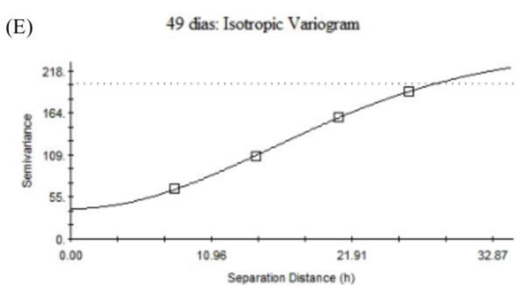
Gaussian model (Co = 19.50000; Co + C = 110.00000; Ao = 23.06; r2 = 0.990; RSS = 21.7)



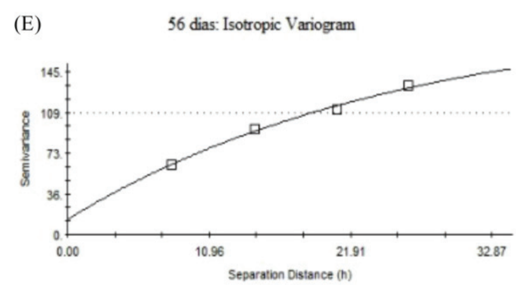
Gaussian model (Co = 55.00000; Co + C = 310.90000; Ao = 26.45; r2 = 0.998; RSS = 28.3)



Gaussian model (Co = 53.00000; Co + C = 174.00000; Ao = 23.13; r2 = 0.995; RSS = 14.8)



Gaussian model (Co = 39.20000; Co + C = 241.40000; Ao = 22.29; r2 = 1.000; RSS = 3.33)



Exponential model (Co = 13.40000; Co + C = 195.30000; Ao = 25.57; r2 = 0.991; RSS = 25.0)

Figure 2. Graphical models of the semivaiogram for the plant height of Sunn Hemp weekly from the 21 to the 56 DAS in Mossoró-RN. 2015.

The assessment of the DSD showed strong spatial dependence of the plant height at 28, 35, 49 and 56 DAS, while at 21 and 42 DAS the spatial dependence was moderate (Table 4). Strong spatial dependence was also observed by Salviano et al. (1998) for the plant height and dry mass of sun hemp in eroded soil. According to Cambardella et al. (1994), the nugget effect represents the field experimental variability that is undetectable at the scale of sampling. When expressed as percentage of total semivariance, the intensity of spatial dependence can be defined. A strong spatial dependence may be due to intrinsic variations in the soil characteristics, such as texture and mineralogy, while a weak spatial dependence may be due to the extrinsic variations, such as those resulting from management practices. In the present study, such information is useful to understand the behavior of the Sunn Hemp variables and to make management decisions for future studies in the area.

The variables of Sunn Hemp dry mass (Table 5) also showed spatial dependence and were adjusted to the exponential (MSPA and MST) and spherical models (MSR). The graphical models of the semivariogram can be observed in Figure 3. The range of spatial dependence observed for the MSR is the lowest obtained in this study, indicating that for this variable the samples were independent at a distance of 11.04 m. The other range values, 35.02 m for the MSPA and 33.38 m for the MST are close to those obtained by Salviano et al. (1998) (32 m) for the Dry Mass of the Sunn Hemp. There was moderate spatial dependence for the variables MSPA and MST, while the spatial dependence of the MSR was classified as strong.

Table 5. Parameters of the models fitted to the isotropic semivariograms for the Shoot Dry Mass (MSPA), Root Dry Mass (MSR) and Total Dry Mass (MST) of the Sunn Hemp in Mossoró-RN. 2015.

Variable	Model	Nugget Efect (C_0)	Sill (C_0+C)	Range A	R^2	DSD	SSR
MSPA	Exponential	70.6000	177.40	35.02	0.67	0.40	340
MSR*	Spherical	0.0027	0.2034	11.04	0.67	0.01	1.461×10^{-4}
MST	Exponential	170.7000	250.20	33.38	0.69	0.43	577

*Log-transformed values; R^2: coefficient of determination; DSD: Degree of spatial dependence; SSR: Sum of Squared Residuals.

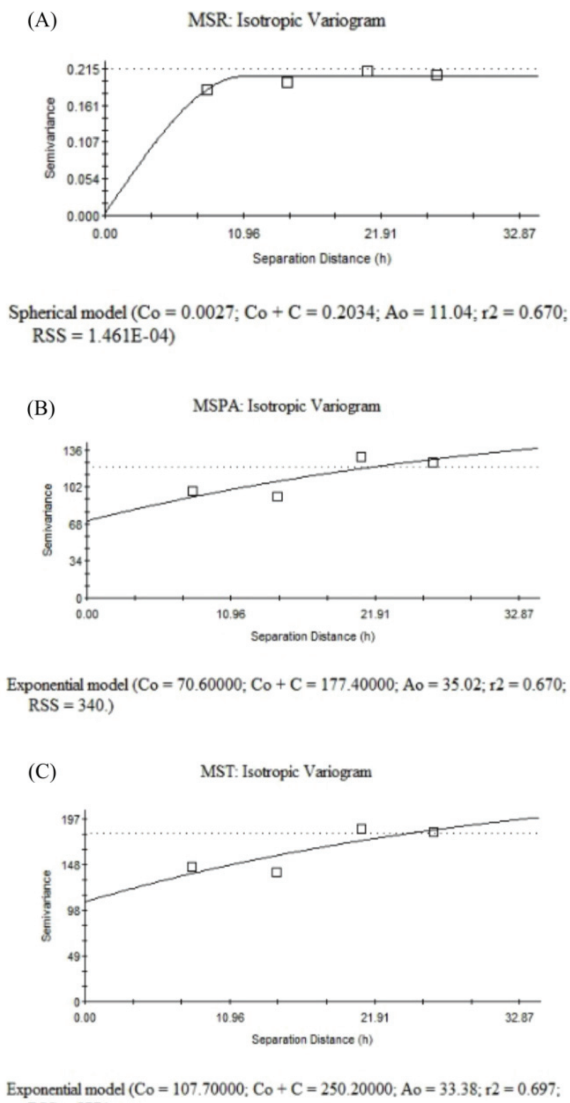


Figure 3. Graphical models of the semivariogram for the Shoot Dry Mass (MSPA), Root Dry Mass (MSR) and Total Dry Mass (MST) of the Sunn Hemp in Mossoró-RN. 2015.

The analyses of the weekly means of the plant height showed steady growth of the crop (Table 3). However, the contour maps (Figure 4) showed a clear trend of spatial evolution, which consists of forming a central area with lower and higher values on the sides of the area. The gradual formation of this region with low values may indicate problems with irrigation or fertilization, being the response more intense as the flowering period approached, with increased mobilization of nutrients by the plant. Another possibility is the occurrence of localized soil factors, whose prejudicial effect would be more intense than the residual effect of salinity and nitrogen, explaining the lack of significant effect on the plant height.

The contour maps illustrate the temporal and spatial evolution of the plant height: at 21 DAS (Figure 4A) there is a greater proportion of regions with lower values on the left side of the map, increasing progressively to the right side; at 28 DAS (Figure 4B) a region with lower values is evident in the lower left part of the map, extending to the center and upwards, highlighting the central region with intermediate values; at 35 DAS (Figure 4C) the lower region with low values was remained but the central band of intermediate values became wider, emphasizing the highest values on the right side; at 42 DAS (Figure 4D) it is more evident the predominance of the greatest values in the bottom center of the map, extending upwards as a central band, with higher values on the right side; at 49 DAS (Figure 4E) the lower values are in the lower left side of the map and are growing progressively upwards and to the right, with the highest values at the right upper side of the map; at 56 DAS (Figure 4F) it is notable a vertical central band with low values occupying a large proportion of the area in relation to the other values. We also observed that the values were rising to the sides, with highest values restricted to small regions on each side of the area.

The contour map of the Shoot Dry Mass (Figure 5A), which ranged between 27 and 49 g plant^{-1}, presents a distinct region of low values in the lower left side, expanding upwards. It was also observed predominance of intermediate values of the MSPA on the right side of the map, with lower values in the lower right side. The concentration of low values of dry mass in this region indicates the occurrence of localized problems of soil or management. The contour map of the Total Dry Mass (Figure 5C) closely resembled that of the MSPA. This is explained because the MSPA contributed with 85% of the MST.

The contour map of the MSR (Figure 5B) shows well-defined small regions, in which higher or lower values are located. Each of these regions with specific values may express the residual effect of treatments of previous experiments, as the value of the range (11.04 m) is slightly larger than the size of the plot. In this case, regions with greater root development correspond to the subplots that had residual effect of higher doses of nitrogen applied to the soil and lower salinity levels. This is confirmed by Bosco et al. (2009) who argue that plants grown under salinity tend to absorb less nitrogen; also confirmed by Nobre et al. (2010) who found that salinity impairs the absorption of N due to the ion competition in the adsorption sites.

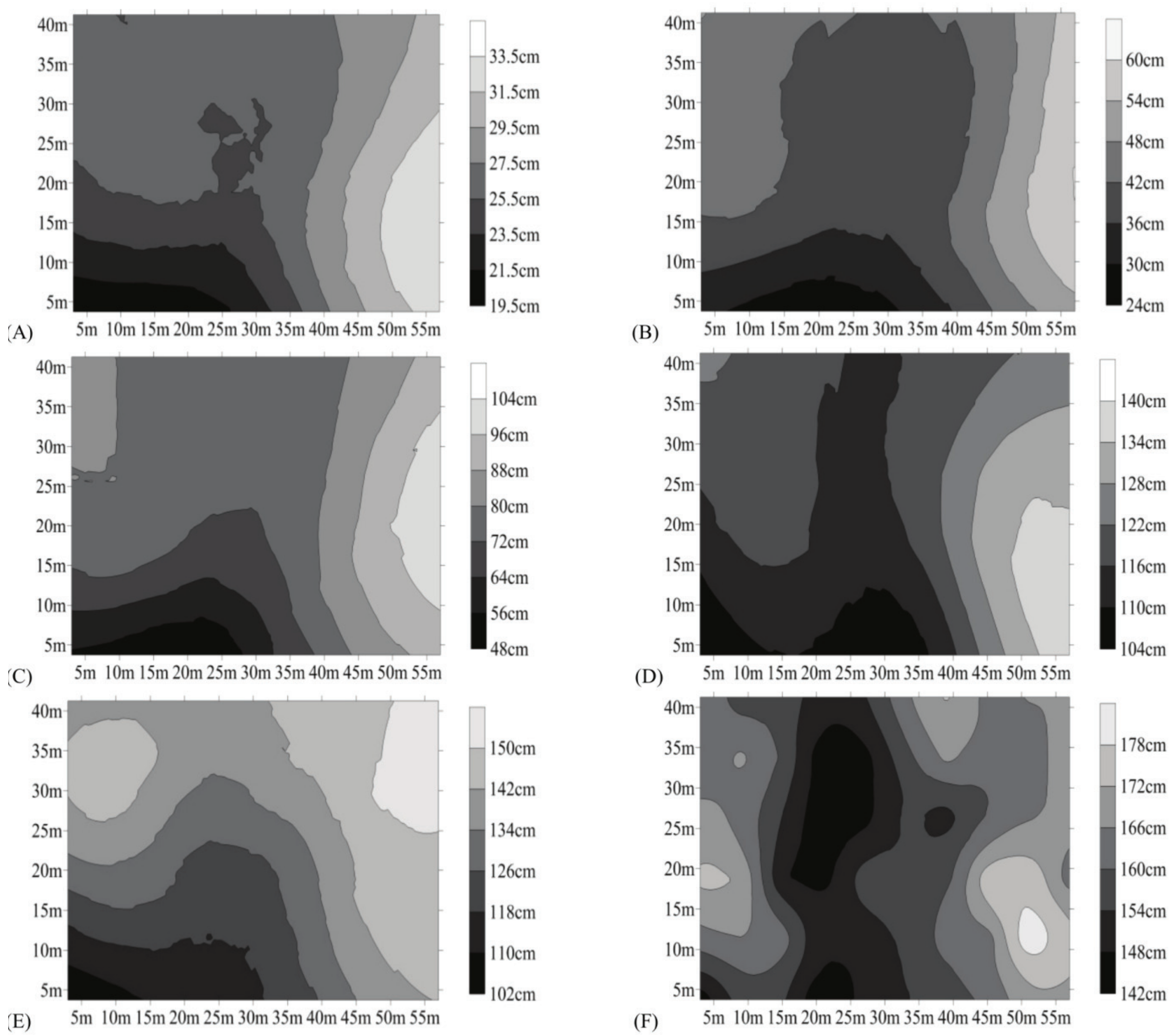


Figure 4. Contour maps of the height of Sunn Hemp at (A) 21 DAS, (B) 28 DAS, (C) 35 DAS, (D) 42 DAS, (E) 49 DAS and (F) 56 DAS in Mossoró, 2015.

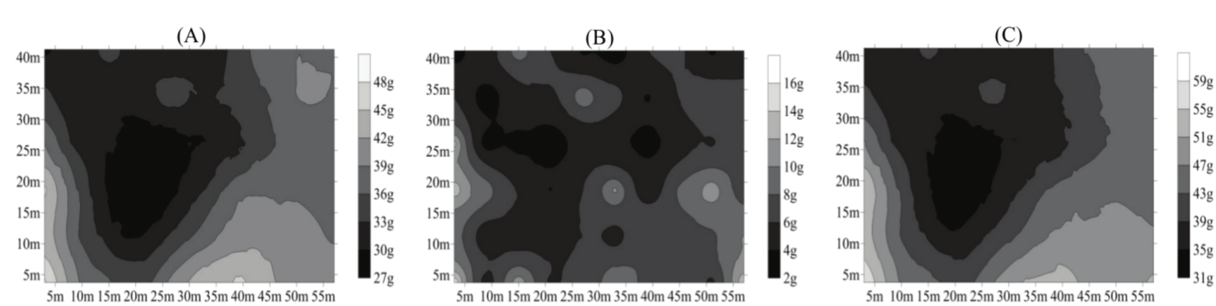


Figure 5. Contour maps showing the variable (A) MSPA. (B) MSR. (C) MST in the sampling area. Mossoró, 2015.

Conclusion

The variables Height and Dry mass of *Crotalaria juncea* did not show residual effect of levels of water salinity and nitrogen doses;

Strong and moderate spatial dependence were observed for the plant height and dry mass of *Crotalaria juncea*;

The contour maps of the variables allowed to locate the regions in the field where the *Crotalaria juncea* growth was hampered by possible soil problems or mismanagement;

The Semivariogram ranges obtained indicate that, for the conventional experiments in the same area, the sampling distances should be greater than 30 or 35 m.

References

ALCÂNTARA, F. A.; FURTINI NETO, A. E.; PAULA, M. B.; MESQUITA, H. A.; MUNIZ, J. A. Adubação verde na recuperação da fertilidade de um Latossolo Vermelho-Escuro degradado. **Pesquisa Agropecuária Brasileira**, v. 35, n. 2, p. 277-288, 2000.

AMADO, T. J. C.; BAYER, C.; ELTZ, F. L. F.; BRUM, A. C. R. Potencial de culturas de cobertura em acumular carbono e nitrogênio no solo no plantio direto e a melhoria da qualidade ambiental. **Revista Brasileira de Ciência do Solo**, v. 25, n. 1, p. 189-197, 2001.

AMADO, T. J. C.; MIELNICZUK, J.; AITA, C. Recomendação de adubação nitrogenada para o milho no RS e SC adaptada ao uso de culturas de cobertura do solo, sob sistema plantio direto. **Revista Brasileira de Ciência do Solo**, v. 26, n. 1, p. 241-248, 2002.

BEZERRA, A. K. P.; LACERDA, C. F.; HERNADEZ, F. F. F.; SILVA, F. B.; GHEYI, H. R. Rotação cultural feijão caupi/milho utilizando-se águas de salinidades diferentes. **Ciência Rural**, v. 40, n. 5, p. 1075-1082, 2010.

BOSCO, M. R. O.; OLIVEIRA, A. B.; HERNANDEZ, F. F. F.; LACERDA, C. F. Influência do estresse salino na composição mineral da berinjela. **Revista Ciência Agronômica**, v. 40, n. 2, p. 157-164, 2009.

CAMBARDELLA, C. A.; MOORMAN, T. B.; NOVAK, J. M.; PARKIN, T. B.; KARLEN, D. L.; TURCO, R. F.; KONOPKA, A. E. Field-scale variability of soil properties in Central Iowa Soils. **Soil Science Society of America Journal**, v. 58, n. 5, p. 1501-1511, 1994.

CARMO, G. A.; OLIVEIRA, F. R. A.; MEDEIROS, J. F.; OLIVEIRA, F. A.; CAMPOS, M. S.; FREITAS, D. C. Teores foliares, acúmulo e partição de macronutrientes na cultura da abóbora irrigada com água salina. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 15, n. 5, p. 512-518, 2011.

CARMO FILHO, F.; OLIVEIRA, O. F. **Mossoró**: um município do semi-árido nordestino. caracterização climática e aspecto florístico. Mossoró: Esam, 1995.

COSTA, A. R. F. C.; MEDEIROS, J. F.; PORTO FILHO, F. Q.; SILVA, J. S.; COSTA, F. G. B.; FREITAS, D. C. Produção e qualidade de melancia cultivada com água de diferentes salinidades e doses de nitrogênio. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 17, n. 9, p. 947-954, 2013.

EMBRAPA-Empresa Brasileira de Pesquisa Agropecuária. **Sistema Brasileiro de classificação de solos**. 2. Ed. Rio de Janeiro: Embrapa, 2006.

FIGUEIRÊDO, V. B.; MEDEIROS, J. F.; ZOCOLER, J. L.; ESPINOLA SOBRINHO, J. Evapotranspiração da cultura da melancia irrigada com água de diferentes salinidades. **Engenharia Agrícola**, v. 29, n. 2, p. 172-338, 2009.

GAMMA DESIGN SOFTWARE. **GS+® - Geostatistics for the environmental sciences**. Version 7.0. Michigan: Gamma Design Software, 2004.

GUERRA, P. A. G. **Geoestatística operacional**. Brasília: Ministério das Minas e Energia, Departamento de Produção Mineral, 1988.

KAPPES, C. Utilizações e benefícios da crotalária na agricultura. **Revista Panorama Rural**, v. 147, n. 1, p. 16-17, 2011.

LIMA, G. S.; SOARES, L. A. A.; NOBRE, R. G.; GHEYI, H. R.; SILVA, S. S. Influência do estresse salino e da adubação nitrogenada no crescimento da mamoneira cv. BRS energia. **Revista Verde**, v. 6, n. 3, p. 213-221, 2011.

LOPES, H. M.; QUEIROZ, O. A.; MOREIRA, L. B. Características agronômicas e qualidade de sementes de crotalária (*Crotalaria juncea* L.) na maturação. **Revista Universidade Rural**, v. 25, n. 2, p. 24-30, 2005.

MACHADO, L. O.; LANA, A. M. Q.; LANA, R. M. Q.; GUIMARÃES, E. C.; FERREIRA, C. V. Variabilidade espacial de atributos químicos do solo em áreas sob sistema plantio convencional. **Revista Brasileira de Ciência do Solo**, v. 31, n. 3, p. 591-599, 2007.

MEDEIROS, J. F.; LISBOA, R. A.; OLIVEIRA, M.; SILVA JÚNIOR, M. J.; ALVES, L. P. Caracterização das águas subterrâneas usadas para irrigação na área produtora de melão da Chapada do Apodi. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 7, n. 3, p. 469-472, 2003.

MELO, T. K.; MEDEIROS, J. F.; ESPÍNOLA SOBRINHO, J.; FIGUEIRÊDO, V. B.; PEREIRA, V. C.; CAMPOS, M. S. Evapotranspiração e produção do melão Gália irrigado com água de diferentes salinidades e adubação nitrogenada. **Revista Brasileira de Engenharia Agrícola e Ambiental**, v. 15, n. 12, p. 1235-1242, 2011.

MIRANDA, N. O.; OLIVEIRA, T. S.; MEDEIROS, J. F.; SILVA, C. A. Variabilidade espacial da produtividade do meloeiro em áreas de cultivo fertirrigado. **Horticultura Brasileira**, v. 23, n. 2, p. 260-265, 2005.

NOBRE, R. G.; GHEYI, H. R.; CORREIA, K. G.; SOARES, F. E. L.; ANDRADE, L. O. Crescimento e floração do girassol sob estresse salino e adubação nitrogenada. **Revista Ciência Agronômica**, v. 41, n. 3, p. 358-365, 2010.

NUNES, A. S.; LOURENÇÃO, A. L. F.; PEZARICO, C. R.; SCALON, S. P. Q.; GONÇALVES, M. C. Fontes e níveis de salinidade na germinação de sementes de *Crotalaria juncea* L. **Ciência e Agrotecnologia**, v. 33, n. 3, p. 753-757, 2009.

SALVIANO, A. A. C.; VIEIRA, S. R.; SPAROVEK, G. Variabilidade espacial de atributos de solo e de Crotalaria juncea L. em área severamente erodida. **Revista Brasileira de Ciência do Solo**, v. 22, n. 1, p. 115-122, 1998.

SANTOS, W. O.; NUNES, R. L. C.; GALVÃO, D. C.; PEREIRA, G. C.; MANIÇOBA, R. M.; LIMA, J. G. A.; VIANA, P. C. Evapotranspiração da cultura do milho verde, análise estatística. **Agropecuária Científica no Semiárido**, v. 9, n. 1, p. 75-81, 2013.

SOUZA, Z. M.; MARQUES JÚNIOR, J.; PERREIRA, G. T.; MONTANARI, R. Otimização amostral de atributos de Latossolos considerando aspectos solo-relevo. **Ciência Rural**, v. 36, n. 3, p. 829-836, 2006.

VIEIRA, S. R. Geoestatística em estudos de variabilidade espacial do solo. In: NOVAIS, R. F.; ALVAREZ, V. V. H.; SCHAEFER, C. E. G. R. (Ed.). **Tópicos em ciência do solo**. Viçosa: Sociedade Brasileira de Ciência do Solo, 2000. p. 1-54.

VIEIRA, S. R.; BRANCALIÃO, S. R.; GREGO, C. R.; MARTINS, A. L. M. Variabilidade espacial de atributos físicos de um argissolo vermelho-amarelo cultivado com leguminosas consorciada com a seringueira. **Bragantia**, v. 69, n. 2, p. 423-432, 2010.

WARRICK, A. W. Spatial variability. In: HILLEL, D. (Ed.). **Environmental soil physics**. San Diego: Academic Press, 1998. p. 655-675.

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