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REGULAR ARTICLE

Spatial variability of physical attributes of a Oxisol related to garlic productivity

Job Teixeira de Oliveira[1*], Rubens Alves de Oliveira[2], Gloria Milena Rojas Plazas[3], Cassiano Garcia Roque[1]

[1]Professor UFMS, Department Agronomy, Universidade Federal de Mato Grosso do Sul (UFMS), CPCS, Chapadão do Sul – MS, Brazil.
[2]Professor UFV, Departament Agricultural Engineering UFV, Universidade Federal de Viçosa (UFV), Viçosa-MG, Brazil.
[3]Postgraduate UFV, Departament Agricultural Engineering UFV, Universidade Federal de Viçosa (UFV), Viçosa-MG, Brazil.

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All data will be shared if requested.

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Autor contribution
JTO: conceptualization, supervision, experimental data collection, data custody, data analysis, literature review, writing the manuscript, manuscript review; RAO: conceptualization, manuscript review, responsible for funding; GMRP: literature review, writing the manuscript, manuscript review, FCSS and CG: literature review, writing the manuscript, manuscript review.

Abstract

Garlic is a product with high demand in Brazil and worldwide, being highly valued in the cuisine of several countries and is a culture with high added economic value. In 2018, this work was carried out in the irrigation and drainage area of the Federal University of Viçosa, in Viçosa, Minas Gerais State, Brazil, in a Oxisol. The objective was to characterize the structure and magnitude of the spatial distribution of physical attributes of a Oxisol, perform the mapping, and evaluate the spatial correlation between garlic bulb yield, lateral shoot growing and soil characteristics. The attributes studied were garlic bulb yield, lateral shoot growing, soil moisture on a dry basis, soil moisture on a humid basis, volumetric soil moisture, particle density, free soil porosity, sampled in a 90-georeferenced grid. Data analysis using statistical techniques and geostatistics made it possible to verify that the garlic yield and other soil physical attributes studied showed spatial dependence. There was an emphasis on the spatial correlation between garlic bulb yield and free-soil porosity. The lateral shoot growing of garlic has a direct and positive relationship with free soil porosity, soil moisture on a dry basis and soil moisture on a humid basis.

Keywords

Precision agriculture. Geostatistics. Plant attribute. Plant production. *Allium sativum* L.

Introduction

Garlic (*Allium sativum* L.) is cultivated and recognized as an excellent source of proteins, vitamins, minerals and fibers that nourish and reduce the incidence of diseases, in addition to being a component of the Brazilian diet. Considering the year 2017, the total area cultivated with garlic was 11,130 hectares and production reached around 79,721 thousand megagrams, obtaining a national average productivity of 7 Mg ha^{-1} (IBGE, 2018). Garlic is a product with high demand in Brazil and worldwide, being highly valued in the cuisine of several countries and is an aggregate culture with high economic value.

With the increase in the use of precision agriculture in Brazil, the geostatistical study of soil attributes related to crop productivity has been intensified (Oliveira et al., 2018). Research can provide harvest status and essential information about the activities carried out, especially in the context of attention to crop management (Oliveira et al., 2020a).

In the field of geostatistics, the study of the technique helps the computer programs used in precision agriculture; that is, the data generated and adjusted for simple data interpolation (kriging) and cross interpolation (cokriging) between plant attributes versus another attribute. Serving as a basis to estimate the spatial variability of a given variable by means of another with ease of determination (Montanari et al., 2015).

The present work was carried out with the objective of characterizing the structure and magnitude of the spatial distribution of physical attributes of an Oxisol, performing the mapping, and evaluating the spatial correlation between garlic yield and overgrowth and soil characteristics.

Materials and methods

The study was developed in the irrigation and drainage area of the Federal University of Viçosa, in Viçosa, Minas Gerais State, Brazil, under the geographic coordinates: 23 K, 722569.09 m E; 7701897.59 m S (UTM). According to Köppen and Geiger (1936), the climate is classified as Cwa, with an average annual temperature of 20.6 °C. The summers have a high rainfall rate, and the average annual rainfall is 1,230 mm.

The present work was conducted on a Oxisol with sandy clay texture (dos Santos et al., 2018). Before starting the experiment, the soil was sampled at the 0.0–0.20 m layer, and

* Corresponding author
E-mail address: job.oliveira@hotmail.com (J. T. Oliveira).

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the results of the chemical analysis showed the following values: pH in H2O of 6.0; 21.2 mg dm^{-3} of P (Mehlich^{-1}); 0.35 cmolc dm^{-3} of K+; 2.3 cmolc dm^{-3} of Ca2+; 1.0 cmolc dm^{-3} of Mg2+; 2.48 cmolc dm^{-3} of H+Al; base sum of 3.7 cmolc dm^{-3}; cation exchange capacity of 6.1 cmolc dm^{-3}; soil base saturation of 70%; organic matter of 2.18 dag kg^{-1}; and 24.4 mg L^{-1} of P remaining.

In the area of conduction of the crop, with a conventional planting system in an irrigated area, plowing, harrowing and rotary hoe were carried out to make the beds for planting garlic. The area was prepared between 01 and 05/05/2018 and on 05/07/2018 the purple garlic cultivar was sown.

Each sampling point consisted of a bed with an area of 2.56 m², with three double lines of garlic and the useful area composed of the central line, where the adjacent ones were used as a border. The x and y directions of the cartesian coordinate system were defined and, at the end of the garlic phenological cycle (September 15th, 2018), the experimental grid was staked in plots spaced at 1.6 m between them. Each experimental grid was constituted of three transects of 48 × 1.6 m. Therefore, the transects were spaced 1.6 m, with sample points squared in 1.6 × 1.6 m, containing 90 of them (Figure 1).

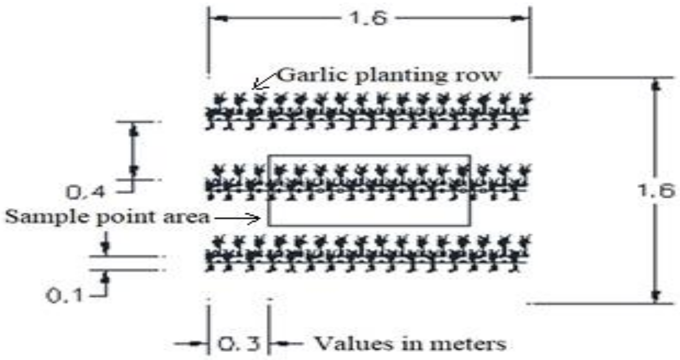


Figure 1: Detail of the garlic planting plot and representation of a sampling point (useful area).

The physical attributes of the soil were determined individually and collected in the useful area of the sampling point, which was composed of one double line 1.00 meters long, totaling 20 plants. The laboratory stage of the analyzes were carried out between the months of October and November 2018.

Garlic bulb yield (BY) was determined by weighing the bulb mass, expressed in kg ha^{-1}. The lateral shoot growing (LSG) was obtained by the percentage of plants with secondary bulb growth at each sampling point. The methodology for determining the physical attributes of the soil followed the recommendations proposed by Teixeira et al. (2017). Attributes were determined: soil moisture on a dry basis from 0 to 0.10 m (DS1), (%); soil moisture on a humid basis from 0 to 0.10 m (HS1), (%); volumetric soil moisture from 0 to 0.10 m (VS1), (%); particle density from 0 to 0.10 m (PD1), (g cm^{-1}); free soil porosity from 0 to 0.10 m (FS1), (%); soil moisture on a dry basis from 0.10 to 0.20 m (DS2), (%); soil moisture on a humid basis from 0.10 to 0.20 m (HS2), (%); volumetric soil moisture from 0.10 to 0.20 m (VS2), (%); particle density from 0.10 to 0.20 m (PD2), (g cm^{-1}); free soil porosity from 0.10 to 0.20 m (FS2), (%).

For each physical attribute of the studied soil, in addition to the Garlic bulb yield and lateral shoot growing, the classic descriptive analysis was performed, with the aid of the statistical program Rbio (biometrics in R) version 17, Bhering, (2017), in which the average was calculated, median, minimum and maximum values, standard deviation, coefficient of variation, kurtosis, asymmetry and an analysis of the frequency distribution of the data was performed. Thus, to test the hypothesis of normality, or lognormality of the productive components (x), the Shapiro and Wilk test (1965) at 5% was used. In it, the statistic tests the null hypothesis, which it judges to be the sample from a population with normal distribution.

In order to characterize the structure and magnitude of the spatial dependence of the attributes, the semivariogram adjustments were made, and the semivariate estimate was made by estimating the coefficients of the theoretical model for the semivariogram called the nugget (C0), sill (C0 + C) and the range (A0). After adjusting the semivariograms, the data were interpolated by kriging in order to allow visualization of the spatial distribution patterns of the attributes, using maps. Standard error maps of kriging prediction were generated.

Results and discussion

The data for the descriptive analysis of the attributes under study are shown in Table 1.

Table 1: Descriptive statistics for studied attributes.

Attribute [a]	Average	Minimum	Maximum	Standard deviation	Coefficient of variation	Pr > F	FD
BY	10351.02	8370.36	12518.51	840,39	8.12	0.6587	NO
LSG	9.34	0.00	46.87	9.36	100.25	3.0×10^{-8}	ID
DS1	23.57	15.60	32.10	4.02	17.03	0.1100	NO
HS1	18.99	13.50	24.30	2.64	13.92	0.0678	NO
VS1	27.19	17.80	38.30	4.81	17.67	0.0101	ID
PD1	2.20	1.70	2.50	0.13	5.85	1.9×10^{-10}	ID
FS1	20.23	10.80	39.00	6.01	29.74	0.0054	ID
DS2	25.53	18.40	30.80	3.53	7.05	8.3×10^{-5}	ID
HS2	20.28	15.50	23.60	2.27	6.80	5.0×10^{-5}	ID
VS2	28.61	17.50	36.60	4.71	8.38	0.0171	ID
PD2	2.23	1.80	3.50	0.26	6.13	2.2×10^{-16}	ID
FS2	20.68	10.00	51.50	7.90	38.18	5.6×10^{-5}	ID

(a) garlic bulb yield (BY), (kg ha^{-1}); lateral shoot growing (LSG), (%); soil moisture on a dry basis from 0 to 0.10 m (DS1), (%); soil moisture on a humid basis from 0 to 0.10 m (HS1), (%); volumetric soil moisture from 0 to 0.10 m (VS1), (%); particle density from 0 to 0.10 m (PD1), (g cm^{-1}); free soil porosity from 0 to 0.10 m (FS1), (%); soil moisture on a dry basis from 0.10 to 0.20 m (DS2), (%); soil moisture on a humid basis from 0.10 to 0.20 m (HS2), (%); volumetric soil moisture from 0.10 to 0.20 m (VS2), (%); particle density from 0.10 to 0.20 m (PD2), (g cm^{-1}); free soil porosity from 0.10 to 0.20 m (FS2), (%). FD: frequency distribution, where, NO: normal type, and, ID, indeterminate.

From the analysis of the minimum and maximum values, the average and also the variance of the values of the soil attributes, it is possible to notice a considerable variation in the data. However, the knowledge of this variation alone is not sufficient to identify the places where the high values of an attribute are found, nor the places where the lowest values are found. In this case, the use of geostatistics is necessary to identify whether there is spatial variability and how this variability occurs in the area under study, with the consequent making of maps, in order to allow more precise management of the necessary field interventions.

According to Pimentel-Gomes and Garcia (2002), the variability of a characteristic can be classified according to the magnitude of its coefficient of variation (CV). Their classes were determined as low (CV < 10%), medium (10% < CV < 20%), high (20% < CV < 30%) and very high (CV > 30%). BY, PD1, DS2, HS2, VS2 and PD2, presented low variability. The attributes, DS1, HS1 e VS1, presented a medium coefficient of variation. Viana et al. 2015 studying garlic, they found coefficients of variation for the BY (15.82%) was classified as average. Da Silva et al. (2020a), found a low coefficient of variation of 6.3% for soil porosity in a study with geostatistics in the semiarid region of northeastern Brazil.

BY, DS1 e HS1 were significant at 5% probability by the normality test of Shapiro and Wilk (1965), since their respective probabilities were 0.6587; 0.1100 and 0.0678. Barbieri et al., 2017 studying the humidity in an Argisol, he found no significant result in the normality test, for the humidity with value 0.0079, undetermined.

The average garlic bulb yield was 10,351.02 kg ha^{-1}, being within the values found in high-tech irrigated garlic. Similar results were found by Macedo et al. (2006), who found average garlic yields of 9,760 kg ha^{-1} and Prato-Sarmiento 2016 which estimated productivity of 9,500 kg ha^{-1}. Average productivity among the largest producing states in Brazil is highly variable. While Goiás and Minas Gerais reach between 12,000 to 16,000 kg ha^{-1}, in the states of the southern region the yield ranges from 5,000 to 9,000 kg ha^{-1} (IBGE, 2018).

The geostatistical analysis (Table 2) showed that there was spatial dependence for all attributes studied with adjustment models ranging from exponential to Gaussian spherical.

Table 2: Estimated parameters for the simple semivariogram of the studied attributes.

Attribute [a]	Model [b]	Nugget C_o	Sill C_o+C	Range A_o (m)	r^2	SRS [c]	SDE [d]	
							%	Class
Simple Semivariogram								
BY	exp	$3.86x10^6$	$7.72x10^6$	12.6	0.714	$1.63x10^{10}$	0.500	Moderate
LSG	gau	4.40	$1.46x10^1$	35.0	0.787	$4.53x10^1$	0.699	Moderate
DS1	gau	2.42	6.00	37.0	0.956	0.76	0.597	Moderate
HS1	exp	1.00	2.50	5.0	0.369	0.60	0.600	Moderate
VS1	gau	4.40	$1.15x10^1$	38.0	0.922	5.26	0.617	Moderate
PD1	exp	0.01	0.02	5.0	0.586	$1.22x10^{-5}$	0.571	Moderate
FS1	gau	$1.37x10^1$	$3.75x10^1$	3.5	0.762	$4.27x10^1$	0.635	Moderate
DS2	gau	2.76	6.07	40.0	0.907	1.84	0.546	Moderate
HS2	gau	1.48	4.15	47.0	0.928	0.81	0.643	Moderate
VS2	gau	5.59	8.80	33.0	0.765	4.42	0.365	Moderate
PD2	gau	0.05	0.09	12.4	0.758	$7.32x10^{-4}$	0.505	Moderate
FS2	sph	$3.74x10^1$	$7.48x10^1$	15.8	0.877	$1.40x10^2$	0.500	Moderate
Cross Semivariogram								
BY=f(FS2)	gau	$1.30x10^3$	$2.76x10^3$	18.0	0.800	$6.67x10^5$	0.529	Moderate
LSG=f(FS1)	gau	0.87	$1.40x10^1$	31.0	0.771	$5.63x10^1$	0.938	Strong
LSG=f(DS2)	gau	0.28	5.70	27.0	0.900	4.06	0.951	Strong
LSG=f(HS2)	gau	0.23	3.70	28.0	0.897	1.69	0.938	Strong

(a) Simple Semivariogram: garlic bulb yield (BY), (kg ha^{-1}); lateral shoot growing (LSG), (%); soil moisture on a dry basis from 0 to 0.10 m (DS1), (%); soil moisture on a humid basis from 0 to 0.10 m (HS1), (%); volumetric soil moisture from 0 to 0.10 m (VS1), (%); particle density from 0 to 0.10 m (PD1), (g cm^{-1}); free soil porosity from 0 to 0.10 m (FS1), (%); soil moisture on a dry basis from 0.10 to 0.20 m (DS2), (%); soil moisture on a humid basis from 0.10 to 0.20 m (HS2), (%); volumetric soil moisture from 0.10 to 0.20 m (VS2), (%); particle density from 0.10 to 0.20 m (PD2), (g cm^{-1}); free soil porosity from 0.10 to 0.20 m (FS2), (%). Cross Semivariogram: garlic bulb yield in function free soil porosity from 0.10 to 0.20 m, BY=f(FS2); lateral shoot growing in function free soil porosity from 0 to 0.10 m, LSG=f(FS1); lateral shoot growing in function soil moisture on a dry basis from 0.10 to 0.20 m, LSG=f(DS2); lateral shoot growing in function soil moisture on a humid basis from 0.10 to 0.20 m, LSG=f(HS2). (b) sph: spherical, exp: exponential, and gau: gaussian. (c) SRS = sum of the residue square. (d) SDE = spatial dependence evaluation.

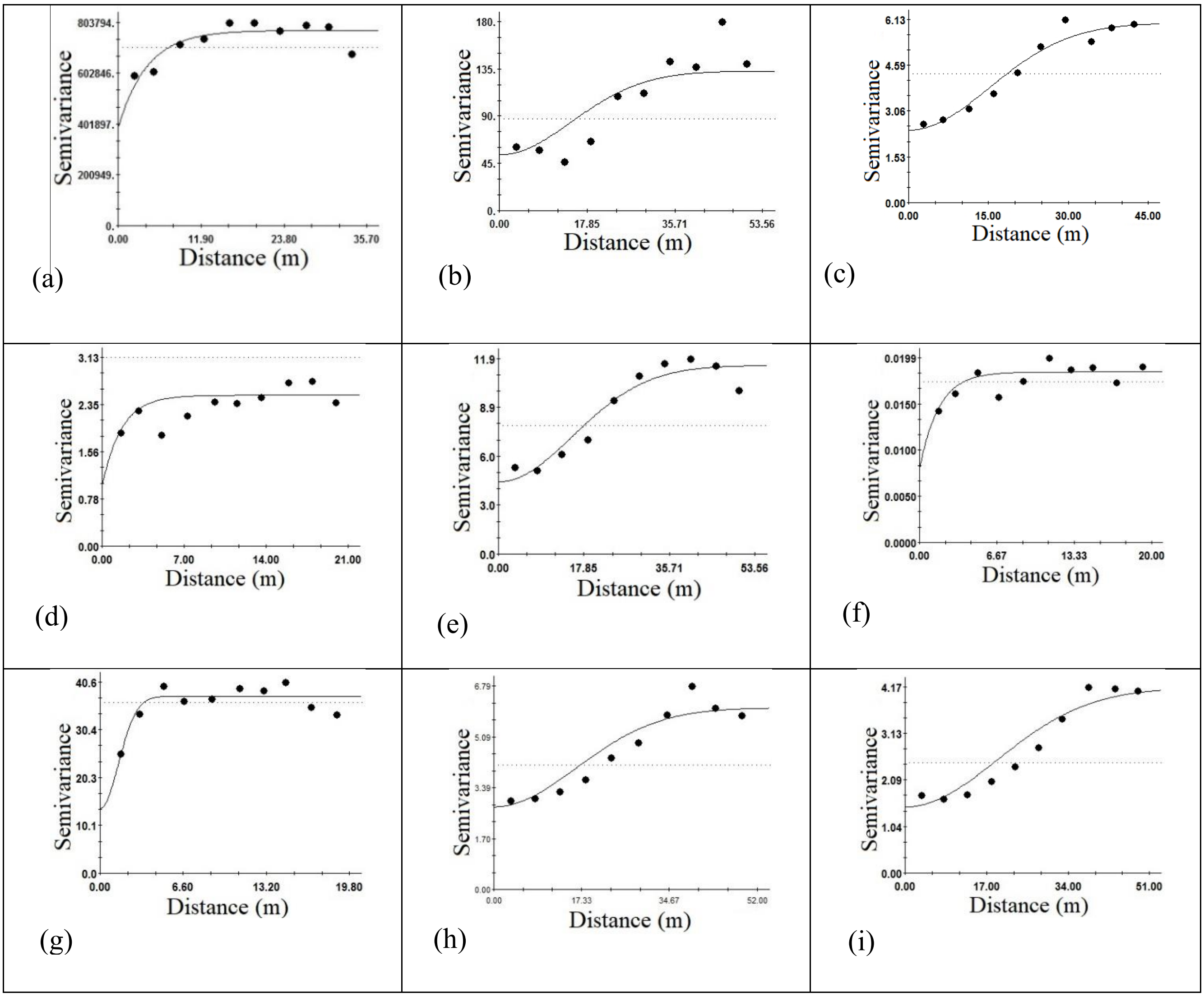
According to the classification of Cambardella et al. (1994), semivariograms that have a nugget effect of <25% of the sill are considered as an evaluation of the strong spatial dependence, while the semivariograms with effects between 25 and 75%, and >75% are moderate and weak dependence, respectively.

The reach values for the semivariograms found by the variables ranged from 3.5 m (free soil porosity from 0 to 0.10 m (FS1)) to 47.0 m (soil moisture on a humid basis from 0.10 to 0.20 m (HS2)). Barbieri et al., 2017, cites the importance of the reach value, aiming to assist future research, in which soil attributes are involved, which will feed the computational packages used in precision agriculture. Da Silva et al. (2020b), found range values ranging from 11.92 m to 55.00 m for soil moisture and porosity respectively, with a study of geostatistics on black soil in the Amazon Region of Brazil. In the present study, the range values should not be less than 3.5 m.

When the cross semivariogram between the productive components of the plant and the soil attributes was performed, we found positive spatial correlations (Table 2). For BY=f(FS2), a moderate spatial dependence (SDE = 52.9%), and an adjusted Gaussian model were observed. These results show a direct relationship between productivity and free-soil porosity. Regarding the lateral shoot growing of garlic, we observed that there is a close positive relationship with free soil porosity, soil moisture on a dry basis and soil moisture on a humid basis.

The spatial determination coefficient (r2) was all greater than 0.771 for the adjustment of crossed semivariograms. Thus, there was a significant linear correlation between BY and LSG with soil attributes. Therefore, analyzing Table 2, it can be inferred, as an example, that the free porosity of the soil presented itself as a good indicator of garlic productivity, when used to estimate productivity, in Oxisol.

After semivariogram adjustments (Figures 2a, 2b, 2c, 2d, 2e, 2f, 2g, 2h, 2i, 2j, 2k e 2l) for each attribute, values were estimated using ordinary kriging. In this way, it was possible to build maps of spatial distribution for all variables of this study (Figures 3a, 3b, 3c, 3d, 3e, 3f, 3g, 3h, 3i, 3j, 3k e 3l), that allowed visualizing the spatial variability in the area.



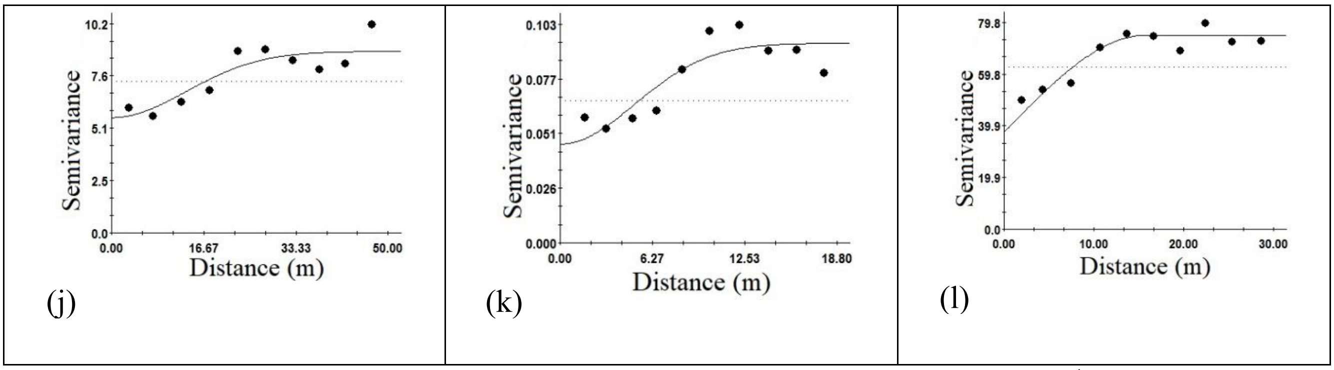
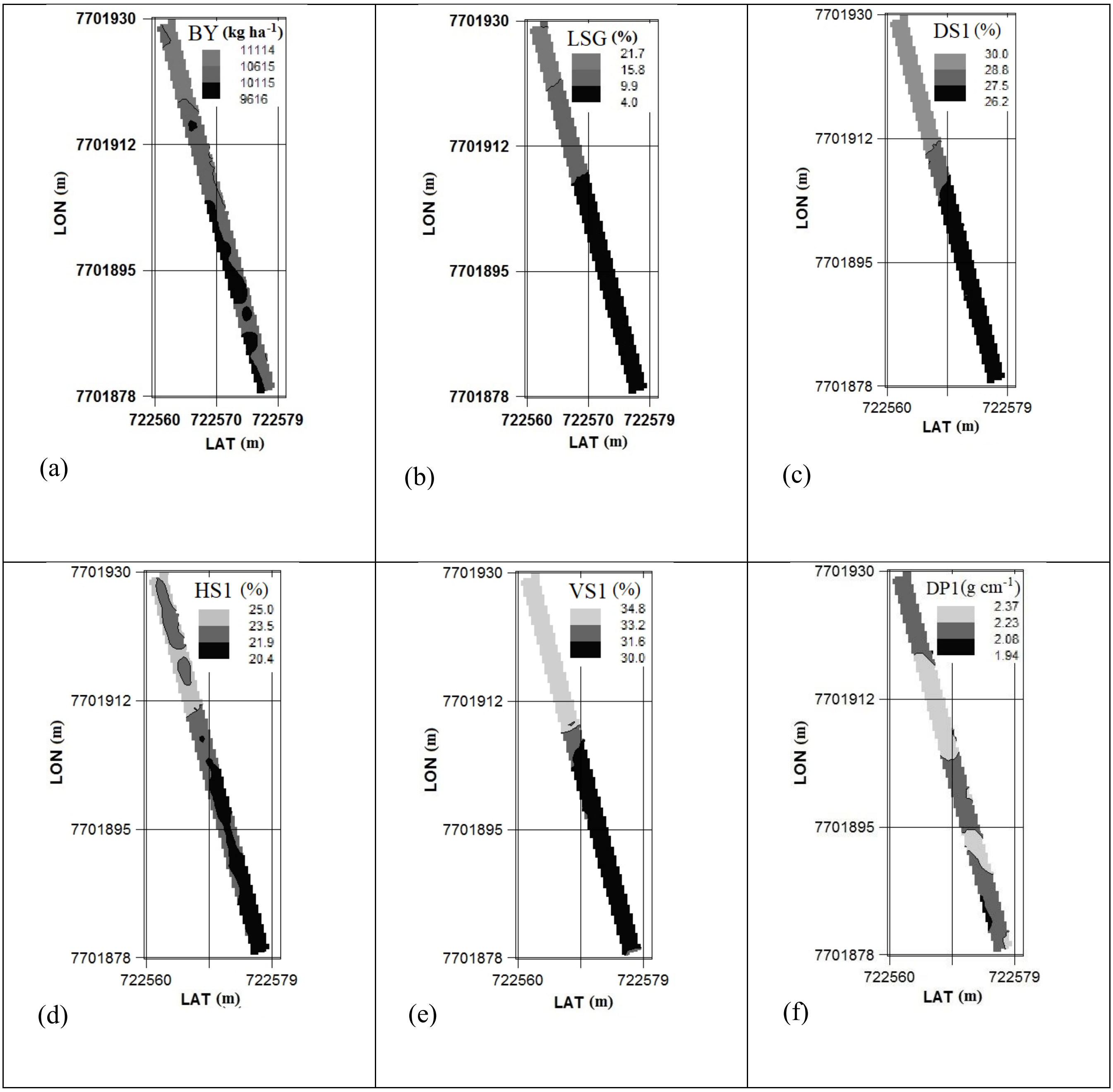


Figure 2: Semivariograms of the garlic production components, where (a) garlic bulb yield (BY), (kg ha^{-1}); (b) lateral shoot growing (LSG), (%); (c) soil moisture on a dry basis from 0 to 0.10 m (DS1), (%); (d) soil moisture on a humid basis from 0 to 0.10 m (HS1), (%); (e) volumetric soil moisture from 0 to 0.10 m (VS1), (%); (f) particle density from 0 to 0.10 m (PD1), (g cm^{-1}); (g) free soil porosity from 0 to 0.10 m (FS1), (%); (h) soil moisture on a dry basis from 0.10 to 0.20 m (DS2), (%); (i) soil moisture on a humid basis from 0.10 to 0.20 m (HS2), (%); (j) volumetric soil moisture from 0.10 to 0.20 m (VS2), (%); (k) particle density from 0.10 to 0.20 m (PD2), (g cm^{-1}); (l) free soil porosity from 0.10 to 0.20 m (FS2), (%).



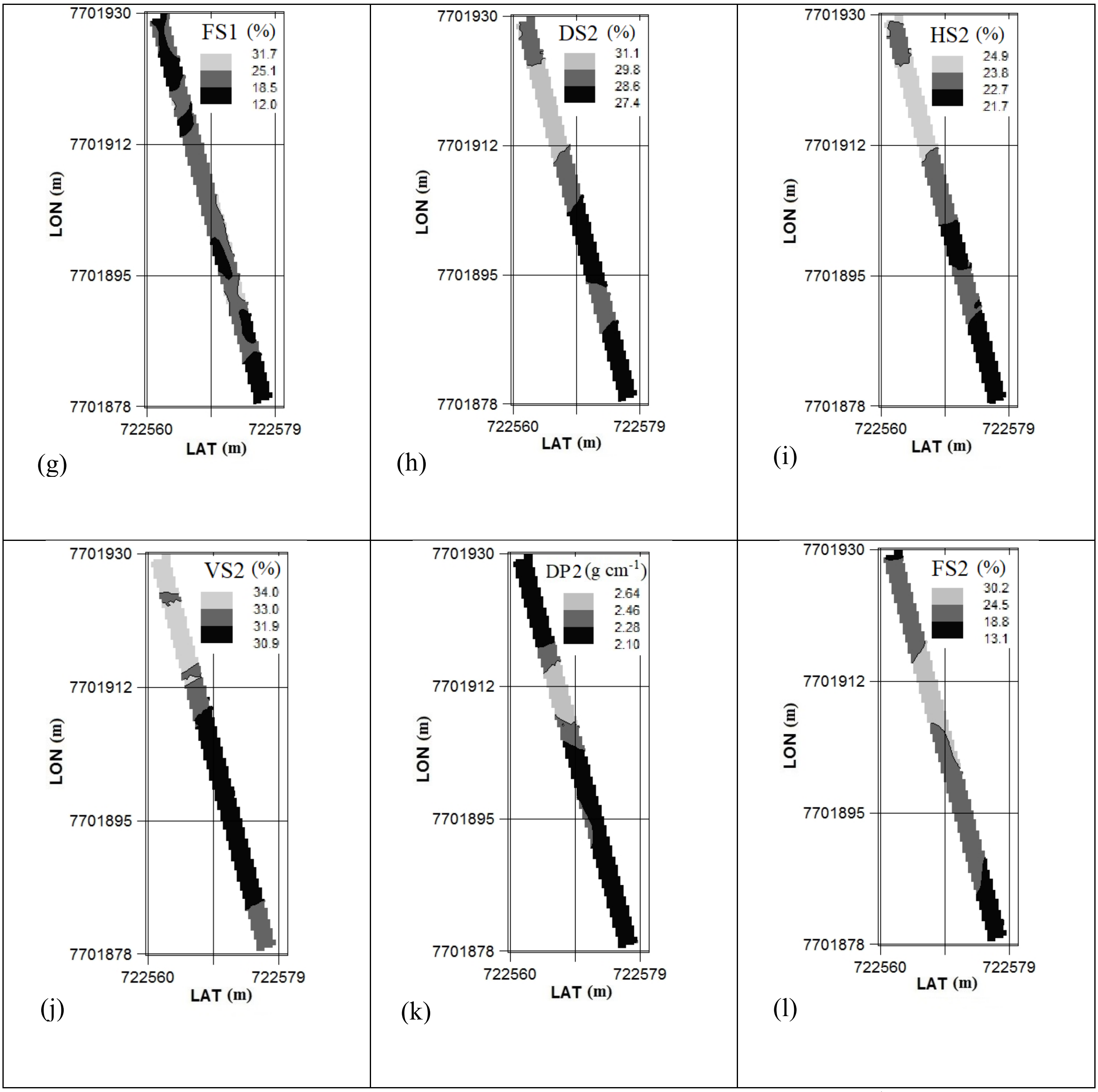


Figure 3: Simple kriging maps of the garlic production components: (a) garlic bulb yield (BY), (kg ha^{-1}); (b) lateral shoot growing (LSG), (%); (c) soil moisture on a dry basis from 0 to 0.10 m (DS1), (%); (d) soil moisture on a humid basis from 0 to 0.10 m (HS1), (%); (e) volumetric soil moisture from 0 to 0.10 m (VS1), (%); (f) particle density from 0 to 0.10 m (PD1), (g cm^{-1}); (g) free soil porosity from 0 to 0.10 m (FS1), (%); (h) soil moisture on a dry basis from 0.10 to 0.20 m (DS2), (%); (i) soil moisture on a humid basis from 0.10 to 0.20 m (HS2), (%); (j) volumetric soil moisture from 0.10 to 0.20 m (VS2), (%); (k) particle density from 0.10 to 0.20 m (PD2), (g cm^{-1}); (l) free soil porosity from 0.10 to 0.20 m (FS2), (%).

When analyzing the spatial variability map of productivity, it can be seen that the southern regions of the experimental area had the lowest crop yields. The highest productivity values were observed in the northern region of the area. The observation of a productivity map (Figure 3a), together with the observation of other types of maps, such as the physical attributes of the soil, can contribute to find the reasons for the occurrence of productivity variability. This identification allows the correction of possible failures, allowing that in the next harvest the problems can be minimized. In this way, the farmer can take advantage of the historical information of the area from previous mappings to make the necessary decisions for a correct management of the crop, identifying regions where there is a greater or lesser need for intervention, either in the soil or in the plant (Oliveira et al 2018).

According to dos Santos et al. (2020), the resistance to penetration increases exponentially with the decrease of humidity, due to the increase of the cohesion forces between the soil particles, resulting from the concentration of cementing agents (iron and aluminum associated with degraded humic materials, exudation of the soil microorganisms, etc.) and reducing the lubricating effect of water. The maps in Figures 3c, 3d, 3e, 3h, 3i and 3j, show the behavior of soil moisture, demonstrating its spatial variability, which can serve as parameters for other interpretations such as soil compaction.

Observing the map of spatial distribution lateral shoot growing (Figure 3b), it can be seen that the upper (northern) regions of the map are those that showed the highest incidence of the anomaly. This same verification is observed in the maps of Figures 3c and 3e, where the north of the figure presents the highest soil moisture on a dry basis from 0 to 0.10 m and volumetric soil moisture from 0 to 0.10 m, respectively. The lateral shoot growing of garlic is a genetic-physiological anomaly characterized by the atypical appearance of leaves of lateral buds before they form the normal leaves constituting bulbils (cloves). This abnormality, in addition to reducing the yield of commercial bulbs, depreciates the product, causing its market value to be compromised (Souza & Casali, 1986). Oliveira et al., 2020b studying spatial variability in garlic crops, found a close relationship between productivity and overgrowing.

Conclusions

The garlic bulb yield and other soil physical attributes studied showed spatial dependence.

There was an emphasis on the spatial correlation between garlic bulb yield and free-soil porosity.

The lateral shoot growing of garlic has a direct and positive relationship with free soil porosity, soil moisture on a dry basis and soil moisture on a humid basis.

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