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SPATIAL VARIABILITY OF ECOPHYSIOLOGICAL AND PRODUCTION COMPONENTS IN IRRIGATED NOBLE GARLIC

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KEYWORDS

Allium sativum L., geostatistics, plant ecophysiology, precision agriculture.

ABSTRACT

Among agricultural components, crop ecophysiological parameters play an essential role in garlic growth and yield. This study aimed to characterize the structure and spatialization of garlic crop parameters, evaluating spatial correlations among yield, lateral shoot growth, and plant ecophysiological components. These consisted of intercellular CO_2 concentration, stomatal conductance, transpiration, water-use efficiency, carboxylation efficiency, photosynthetically active radiation, relative humidity around leaves, relative humidity in leaves, air temperature, leaf temperature, vapor pressure deficit, and water content in the air and leaves. Our results showed that irrigated purple garlic yield, lateral shoot growth, and ecophysiological components are spatially dependent. A cross-semivariogram between plant ecophysiological parameters showed negative spatial correlations and spatial dependence, with a coefficient of determination (r^2) above 0.730. These findings indicate a close correlation between garlic yield and lateral shoot growth with the ecophysiological parameters studied. In short, purple garlic production had a high inter-spatial correlation with plant transpiration and water contents in the air and leaves.

INTRODUCTION

Horticultural activity in Brazil occupies an area of 2.7 million hectares. The average yield is 40.6 tons per hectare, generating 7 million direct jobs and around 20 million indirect jobs. Due to increases in population and purchasing power, national consumption of vegetables has increased over the last decade, mainly due to higher social awareness about balanced and healthy food habits (Ceccato & Basso, 2016; Costa et al., 2015).

Garlic (*Allium sativum* L.) is a vegetable widely used as a condiment and in traditional medicine for hundreds of years. Several studies in the literature have shown its remarkable biological benefits, with antioxidant, cardiovascular, anti-cancer, anti-inflammatory, anti-diabetic, anti-obesity, and antibacterial functions. Such properties often result from bioactive compounds, such as organic sulfides, saponins, phenolics, and polysaccharides in their constitution (Shang et al., 2019; Tao et al., 2018).

The total area cultivated with garlic in Brazil in 2018 was 10,657 hectares, and production reached about 118.84 thousand megagrams, with a national average yield of 11.26 Mg ha-1 (IBGE, 2018). Among the factors that interfere with garlic management, irrigation stands out as essential to obtaining good yields, given its high sensitivity to water deficit (Resende et al., 2013).

Due to the increase in the use of precision agriculture in Brazil, geostatistical studies on agronomic attributes related to productivity have been intensified. Precision agriculture is composed of a set of techniques that help farmers manage their crops, increasing production and income, as well as fertilization, harvesting, and spraying efficiencies, thus improving the final quality of the product (Oliveira et al., 2020).

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Georeferencing, spatial distribution, and thematic mapping of production fields are tools of great importance for crop management risk analysis. The spatial distribution of indicators can contribute to understanding the processes involved in each phenomenon to be studied. Such analysis allows the study of characteristics and differences of each territorial space beyond a simple geographical view, encompassing purpose-built production space (Oliveira et al., 2021).

Among agronomic components, ecophysiological ones play a role in garlic growth and productive output. Based on this, studies integrating the current knowledge on garlic physiology can improve its yield and final product quality, optimizing its management decisions and developing adaptation to reduce climate change impacts (Kim et al., 2013).

Given the above, this study was to characterize the structure and spatialization of garlic attributes and evaluate the spatial correlation between garlic yield and ecophysiological parameters.

MATERIAL AND METHODS

The experiment was carried out on the premises of the Federal University of Viçosa (UFV), in Minas Gerais (Brazil) (722569.09 m E; 7701897.59 m S UTM) between May and August 2018 (Figure 1). Figure 2 shows the meteorological data during the experimental period.

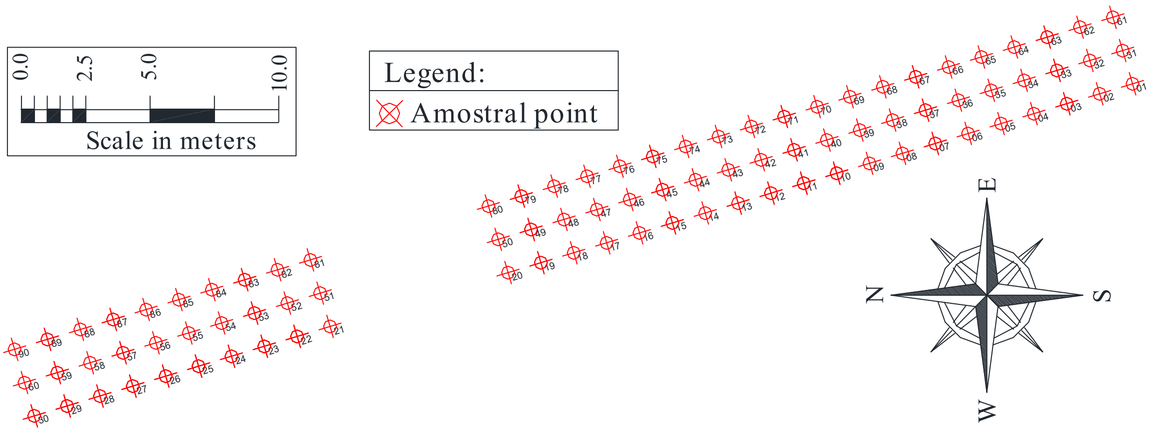

FIGURE 1. Sampling grid and details in the irrigation and drainage area of the Federal University of Viçosa, Viçosa, Minas Gerais, Brazil. Adapted from Oliveira et al. (2021).

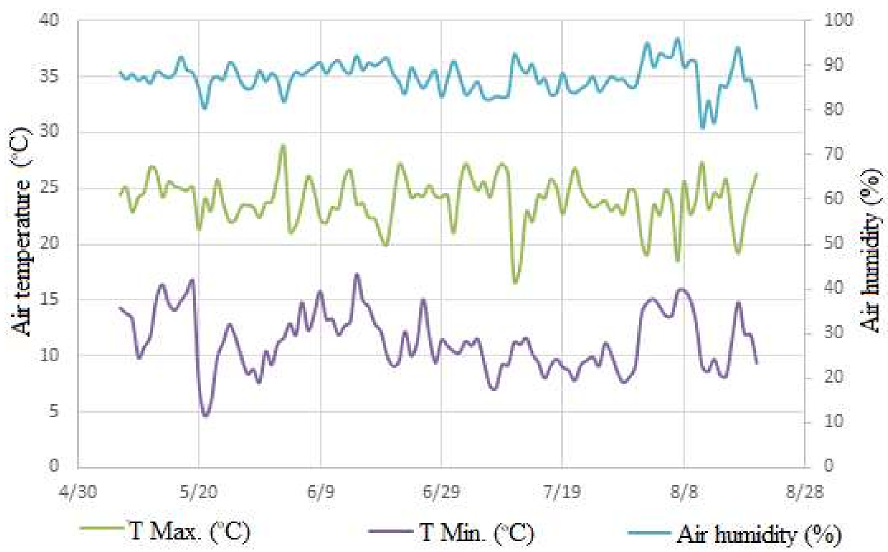

FIGURE 2. Minimum temperature (°C), maximum temperature (°C), and air humidity (%) recorded in the experiment site between May and August 2018. Source: INMET (2019).

The local soil was classified as *Latossolo Vermelho Amarelo* (Red Yellow Latosol) (EMBRAPA, 2018), with a sandy-clay textural class. Soil samples from the 0-20 cm depth layer were composed of 460 g kg^{-1} sand, 150 g kg^{-1} silt, and 390 g kg^{-1} clay. Soil chemical characteristics were as follows: pH (H_2O): 6.0; organic matter content: 2.18 dag kg^{-1}; and 21.2 and 135.0 mg dm^{-3} of phosphorus and potassium, respectively. Cation exchange capacity (CEC) and the sum of bases were 6.1 and 3.7 cmol$_c$ dm^{-3}, respectively.

The soil was plowed and harrowed, then seedbeds were prepared with a rotary hoe for planting. The tillage was made between May 01 to 05, 2018. On May 7, 2018, plants of purple garlic cultivar were planted. Each sampling point consisted of 1.60 m wide and 1.60 m long seedbeds, totaling 2.56 m^2, with three double planting rows. The useful area consisted of the middle row, discarding 0.30 m from its ends and the side rows. Double rows were spaced 0.40 m apart and 0.10 m between rows within double rows.

Garlic plants were drip irrigated through a line placed between a double row, with drippers spaced 0.20 m apart and with a flow rate of 2.4 L h^{-1}. The application uniformity coefficient was 97%. The water application rate of drippers was determined following the method of Bernardo et al. (2019). The water application need of garlic plants was monitored using Irrigâmetro® equipment (Oliveira & Ramos, 2018), which was installed in the experimental area. The total irrigation depth applied throughout the garlic cycle was 194.9 mm.

Garlic ecophysiological data were collected individually within the useful sample area 104 days after planting (DAP), between 10 am and 4 pm, using the IRGA LI-6400XT Portable Photosynthesis System. The following ecophysiological components were evaluated: intercellular CO_2 concentration (C_i), in µmol mol^{-1}; stomatal conductance (g_s), in mol m^{-2} s^{-1}; transpiration (E), in mmol m^{-2} s^{-1}; water-use efficiency (WUE), in %; carboxylation efficiency (CE), in decimal; photosynthetically active radiation (PAR), in µmol m^{-2} s^{-1}; relative air humidity around leaf (RHA), in %; relative humidity in leaves (RHL), in %; air temperature (T_{air}), in °C; leaf temperature (T_{leaf}), in °C; vapor pressure deficit (V*pdL*), in KPa; water content in the air (WA); and water content in leaves (WL).

At 130 DAP, garlic yield (GY) was measured by weighing 20-plant bulbs within the sampling point and expressed as kg ha^{-1}. The incidence of anomalies was assessed through lateral shoot growth (LSG), counting affected plants within the useful area. The results were expressed in percentages (%).

Each variable was analyzed descriptively using the statistical software Rbio (biometrics in R), version 17, (Bhering, 2017). Average, median, minimum and maximum values, standard deviation, and coefficient of variation were calculated. Frequency distribution analysis was also performed. Thus, Shapiro and Wilk's test at 5% significance was used to evaluate the normality or lognormality hypothesis of production components (x). The null hypothesis was also tested on a sample from a population with normal distribution.

Semivariogram adjustments and semivariance estimation were performed, estimating theoretical model coefficients for semivariogram, known as nugget effect (C_0), sill (C_0+C), and range (A_0) to characterize spatial dependence structure and magnitude for the studied garlic ecophysiological components. After semivariogram adjustment, data were interpolated by kriging to allow visualization of the spatial distribution patterns of garlic ecophysiological components, using maps. Standard error maps of kriging prediction were generated.

RESULTS AND DISCUSSION

Table 1 shows the statistical analysis results for garlic agronomic components. By Shapiro and Wilk's normality test, the parameters GY, *Ci*, WUE, PAR, RHA, RHL, T_{air}, T_{leaf}, WA, and WL showed low variability (CV <10%), whereas GY, g_s, and WL were high (CVs of 0.6587, 0.1970, and 0.0970, respectively). Similar results were found by Oliveira et al. (2020) for GY in a study with beans, with a frequency distribution of the normal type.

TABLE 1. Descriptive statistics for the garlic crop parameters studied.

Parameter	Average	Minimum	Maximum	Standard deviation	CF*	Pr<w	FD**
GY	10351.02	8370.36	12518.51	840.39	8.12	0.6587	NO
LSG	9.34	0.00	46.88	9.36	10.22	3.4×10^{-8}	ID
Ci	308.81	261.48	359.03	18.98	6.14	0.0020	ID
g_s	0.49	0.12	1.01	0.17	34.44	0.1970	NO
WUE	28.95	8.57	54.34	10.05	34.73	0.0001	ID
CE	0.84	0.73	0.94	0.05	5.61	5.9×10^{-5}	ID
PAR	999.10	981.60	1000.70	2.36	0.24	2.2×10^{-16}	ID
RHA	50.58	40.33	55.97	4.54	8.99	2.3×10^{-9}	ID
RHL	64.93	50.90	70.93	4.31	6.64	8.0×10^{-6}	ID
T_{air}	26.03	23.64	31.00	2.16	8.29	9.3×10^{-8}	ID
T_{leaf}	25.08	22.64	29.91	1.93	7.68	4.1×10^{-7}	ID
E	4.45	2.27	7.28	1.08	24.29	0.0064	ID
V*pdL*	1.03	0.68	2.27	0.24	23.63	5.2×10^{-10}	ID
WA	18.05	16.14	19.82	0.86	4.76	0.0160	TN
WL	23.27	19.42	27.27	1.84	7.89	0.0970	NO

Garlic yield (GY), in kg ha^{-1}; lateral shoot growing (LSG); intercellular CO_2 concentration (C_i), in µmol mol^{-1}; stomatal conductance (g_s), in mol m^{-2} s^{-1}; water use efficiency (WUE), in %; carboxylation efficiency (CE), in decimal; photosynthetically active radiation (PAR), in µmol m^{-2} s^{-1}; relative air humidity around leaf (RHA), in %; relative humidity of leaf (RHL), in %; air temperature (T_{air}), in °C; leaf temperature (T_{leaf}), in °C; transpiration (E), in mmol m^{-2} s^{-1}; vapor pressure deficit (V*pdL*), in KPa; water in the air (WA); water in the leaf (WL). CF*: Coefficient of variation, in %. FD**: frequency distribution, - NO: normal type, TN: tending to normal, and ID, indeterminate.

The average garlic yield was 10,351.02 kg ha^{-1}. This value is within the those found for high-tech irrigated garlic and published by IBGE (2018). Similar results were found by Prato-Sarmiento (2016), who estimated a garlic yield of 9,500 kg ha^{-1} and lower than the maximum production estimated by Domínguez et al. (2013) in central Spain under different regulated water regimes.

Table 2 shows that the attributes g_s, T_{air}, *E,* and V*pdL* fitted to a spherical model, while GY*, Ci,* WUE, CE*,* and RHL to an exponential one. On the other hand, the attributes LSG, RHA, T_{leaf}, WA, and WL fitted to a Gaussian model, and PAR had a pure nugget effect.

TABLE 2. Semivariogram of the garlic crop parameters studied.

Parameter [(a)]	Model [(b)]	Nugget C_0	Sill C_0+C	Range A_0 (m)	r^2	SRS [(c)]	SDE [(d)]	
							%	Class
GY	exp	$3.86x10^6$	$7.72x10^6$	12.6	0.714	$1.63x10^{10}$	50.0	Moderate
LSG	gau	4.40	14.60	35.0	0.787	45.30	69.9	Moderate
Ci	exp	179.00	358.00	5.0	0.341	5063.00	50.0	Moderate
g_s	sph	0.01	0.03	3.5	0.538	$7.94x10^{-5}$	67.9	Moderate
WUE	exp	25.00	100.90	4.5	0.572	277.00	75.2	Strong
CE	exp	0.00	0.00	6.3	0.524	$2.03x10^{-7}$	50.6	Moderate
PAR	pnf	-	-	-	-	-	-	-
RHA	gau	5.10	20.60	4.2	0.430	71.50	75.2	Strong
RHL	exp	4.79	19.30	7.2	0.424	15.60	75.1	Strong
T_{air}	sph	1.13	4.80	5.4	0.700	2.12	76.5	Strong
T_{leaf}	gau	1.00	4.00	5.0	0.786	0.75	75.0	Strong
E	sph	0.30	1.20	5.2	0.376	0.21	75.0	Strong
V*pdL*	sph	0.04	0.08	18.5	0.740	$4.28x10^{-4}$	50.1	Moderate
WA	gau	0.18	0.85	5.5	0.844	0.03	78.5	Strong
WL	gau	1.52	3.70	4.5	0.707	1.19	59.0	Moderate

[(a)]Garlic yield (GY), in kg ha^{-1}; lateral shoot growing (LSG); intercellular CO_2 concentration (C_i), in µmol mol^{-1}; stomatal conductance (g_s), in mol m^{-2} s^{-1}; water use efficiency (WUE), in %; carboxylation efficiency (CE), in decimal; photosynthetically active radiation (PAR), in µmol m^{-2} s^{-1}; relative air humidity around leaf (RHA), in %; relative humidity of leaf (RHL), in %; air temperature (T_{air}), in °C; leaf temperature (T_{leaf}), in °C; transpiration (E), in mmol m^{-2} s^{-1}; vapor pressure deficit (V*pdL*), in KPa; water in the air (WA); water in the leaf (WL). [(b)] sph: spherical, exp: exponential, pne: pure nugget effect, and gau: gaussian. [(c)]SRS = sum of the residue square. [(d)]SDE = spatial dependence evaluation.

After semivariogram fitting (Figure 3), each garlic crop parameter was estimated by ordinary kriging. Thus, spatial distribution maps could be built for all parameters studied (Figure 4), allowing us to visualize spatial variability in the area, except PAR, which had a pure nugget effect.

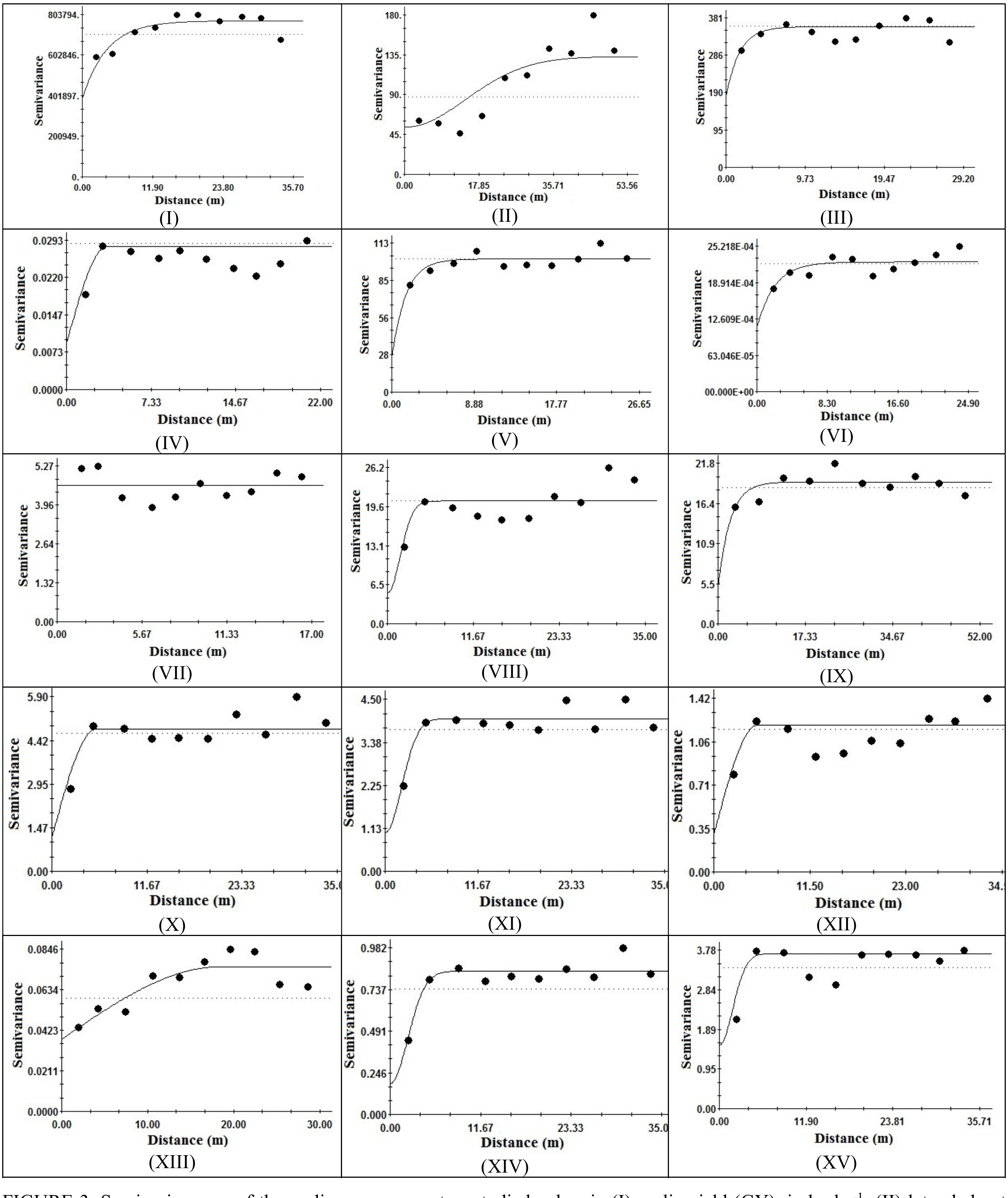

FIGURE 3. Semivariograms of the garlic crop parameters studied, wherein (I) garlic yield (GY), in kg ha^{-1}; (II) lateral shoot growing (LSG); (III) intercellular CO_2 concentration (C_i), in µmol mol^{-1}; (IV) stomatal conductance (g_s), in mol m^{-2} s^{-1}; (V) water use efficiency (WUE), in %; (VI) carboxylation efficiency (CE), in decimal; (VII) photosynthetically active radiation (PAR), in µmol m^{-2} s^{-1}; (VIII) relative air humidity around leaf (RHA), in %; (IX) relative humidity of leaf (RHL), in %; (X) air temperature (T_{air}), in °C; (XI) leaf temperature (T_{leaf}), in °C; (XII) transpiration (E), in mmol m^{-2} s^{-1}; (XIII) vapor pressure deficit (V*pdL*), in KPa; (XIV) water in the air (WA); (XV) water in the leaf (WL).

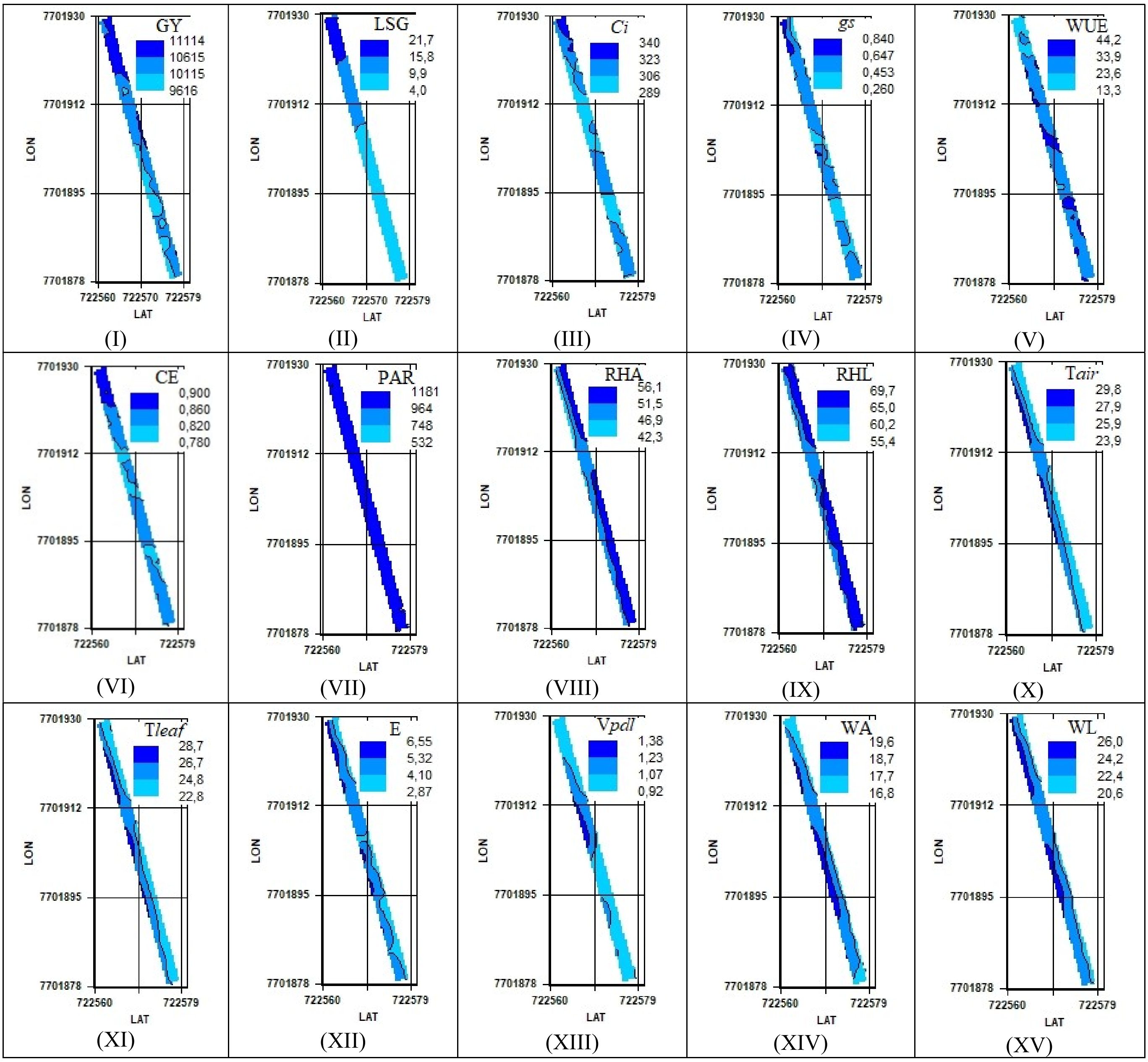

FIGURE 4. Simple kriging maps of the garlic crop parameters studied: (I) garlic yield (GY), in kg ha^{-1}; (II) lateral shoot growing (LSG); (III) intercellular CO_2 concentration (C_i), in μmol mol^{-1}; (IV) stomatal conductance (g_s), in mol m^{-2} s^{-1}; (V) water use efficiency (WUE), in %; (VI) carboxylation efficiency (CE), in decimal; (VII) photosynthetically active radiation (PAR), in μmol m^{-2} s^{-1}; (VIII) relative air humidity around leaf (RHA), in %; (IX) relative humidity of leaf (RHL), in %; (X) air temperature (T_{air}), in °C; (XI) leaf temperature (T*leaf*), in °C; (XII) transpiration (E), in mmol m^{-2} s^{-1}; (XIII) vapor pressure deficit (V*pdL*), in KPa; (XIV) water in the air (WA); (XV) water in the leaf (WL).

The spatial variability map shows that regions south of the experimental area had the lowest yields, while the highest garlic yields were observed to the north. Crossing yield maps (Figure 4 I) with other map types, such as plant traits, can help to find reasons for yield variability (Oliveira et al., 2020).

The spatial distribution map of incidence of garlic lateral shoot growing revealed that the areas to the north and center stood out. These higher incidences often coincided with points of higher garlic yields (Figure 4 II). Therefore, high-yield areas may have an increased incidence of lateral shoots. Lateral shoot growth is an anomaly of genetic-physiological causes, which is characterized by an atypical appearance of lateral bud leaves before the normal leaves that form a bulb. Such an abnormality, besides reducing commercial bulb yields, depreciates the product, compromising its market value (Puiatti, 2017). Accordingly, producers must adopt techniques to avoid the onset of these lateral shoots and increase crop yield. In this respect, Resende et al. (2013) pointed out that noble garlic cultivars are highly sensitive to overgrowth, which may be indicative of the low adaptability of a cultivar to a particular growing region, due to photoperiod, temperature, nitrogen fertilization, and irrigation adversities.

Regarding irrigation, Lopes et al. (2016) reinforced that excess moisture favors overgrowth and recommended a water deficit of 8 to 20 days during the bulbing stage. In our study, the water deficit period was of 30 days due to irrigation control; however, water accumulation during bulbing phase was 105.40 mm. According to Lopes et al.

(2016) and Resende et al. (2013), high water accumulations during bulbing can favor overgrowth. Unfortunately, it is a common meteorological event in the Center-South of Brazil despite the efforts from producers to avoid excess moisture at this phenological phase.

In that matter, despite the irrigation homogeneity and 30-day water deficit induction at bulbing, some points in the sampled area may have retained more moisture, causing overgrowth in high-yield areas (northern range of the map) (Figure 4). Moreover, the noble garlic cultivar "Ito" may have poorly adapted to the region. Seifu et al. (2017) and Soares et al. (2015) related decreases in garlic yields with cultivar sensitivity to climatic factors, such as excess moisture during bulbing.

The study of ecophysiological traits revealed that points with the highest garlic yields were associated with medium/high carboxylation efficiency (CE) and intercellular CO_2 concentration (C_i). Such a trend was already observed in the north of the map, wherein water-use efficiency (WUE), stomatal conductance (g_s), and transpiration (E) were medium/low (Figure 4). These results are because the efficiency of plants in using abiotic resources may vary across the area, even if it is considered homogeneous. Therefore, identifying such variations can assist producers in adopting precision agriculture techniques to enhance yield and hence income in commercial areas, detecting and repairing failures.

Regarding abiotic factors interfering with crop ecophysiology, photosynthetically active radiation (PAR) was homogeneous throughout the experimental area, ranging from 964 to 1181 μmol m^{-2} s^{-1} in areas of higher yield. These results emphasize that gas exchange studies of photosynthesis and transpiration are useful approaches, as they mechanically interact with carbon, water, and energy balances, thus controlling physical, biochemical, and physiological processes of gas exchange (Kim et al., 2013).

However, variations were observed in relative humidity surrounding leaves, relative humidity in leaves, air temperature, leaf temperature, vapor pressure deficit, and water contents in air and leaves. These changes can interfere with crop productivity. VpdL is a relevant ecophysiological component, as it can portray crop water stress in a cultivation environment. Among these, vapor pressure deficit is the most relevant. According to Almeida et al. (2015), vapor pressure deficit can portray crop water stress, as well as plasticity in water use. In this sense, points with higher garlic yields coincided with those with lower VpdL, whose greatest trends were to the north of the map (Figure 4).

Table 3 displays the semivariogram parameters from the kriging of garlic yield and agronomic components.

TABLE 3. Cross-semivariogram of the garlic crop parameters studied.

Parameter [(a)]	Model [(b)]	Nugget C_0	Sill C_0+C	Range A_0 (m)	r^2	SRS [(c)]	SDE	
							%	Class
GY = f(g_s)	gau	-18.47	-33.0	15.0	0.752	101.0	50.0	Moderate
GY = f(E)	exp	-9.00	-233.0	12.0	0.853	5541.0	96.1	Strong
GY = f(WA)	sph	-65.20	-283.2	10.3	0.809	4983.0	77.0	Strong
GY = f(WL)	sph	-84.00	-530.0	10.0	0.786	32628.0	84.2	Strong
LSG = f(RHA)	gau	-0.01	-9.0	4.0	0.730	10.7	99.9	Strong
LSG = f(RHL)	gau	-2.30	-14.0	35.0	0.803	37.0	83.6	Strong

[(a)]GY = garlic yield, in function of f(g_s), f(E), f(WA), f(WL) and lateral shoot growing, in function of f(RHA), f(RHL). [(b)]sph: spherical, exp: exponential, and gau: gaussian. [(c)]SRS: sum of the residue square. [(d)]SDE: spatial dependence evaluation.

A cross-semivariogram between plant ecophysiological parameters showed negative spatial correlations (Table 3) and a moderate spatial dependence for GY = f(g_s). By contrast, another cross-semivariogram showed a high spatial dependence with a coefficient of determination (r^2) above 0.730. These results indicate a close relationship among yield, lateral shoot growing, and ecophysiological parameters studied.

Based on Table 3, water contents in the air and leaves and plant transpiration were good indicators of garlic yield for sandy-clay soil. In other words, abiotic factors, such as water, can directly interfere with crop yields since they can increase CO_2 capture, with a consequent increase in C net assimilation.

CONCLUSIONS

Yield, lateral shoot growing, and ecophysiological components of irrigated purple garlic are spatially dependent. Cross-semivariograms showed high spatial dependence with a coefficient of determination (r^2) above 0.730. Garlic yield shows a strong cross-spatial correlation with plant transpiration, water contents in the air, and leaves.

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REFERENCES

Almeida EIB, Celin EF, Freire AG, Lacerda CF, Bezerra MA, Mesquita RO (2015) Ecofisiologia de mangueiras ‘Tommy Atkins’ submetidas a diferentes regimes hídricos e disponibilidade de luz. Revista Agro@mbiente On-line 9:251-260. DOI: http://dx.doi.org/10.18227/1982-8470ragro.v9i3.2336.

Bernardo S, Soares AA, Mantovani EC (2019) Manual de irrigação. 9 ed. Viçosa (MG): Ed. UFV, 545 p.

Bhering LL (2017) Rbio: A tool for biometric and statistical analysis using the R Platform.Crop Breeding and Applied Biotechnology 17: 187-190. DOI: https://doi.org/10.1590/1984-70332017v17n2s29.

Ceccato C, Basso C (2016) Avaliação das perdas de frutas, legumes e verduras em supermercado de Santa Maria (RS). Disciplinarum Scientia Saúde 12: 127-137. Available: https://www.periodicos.ufn.edu.br/index.php/disciplinarumS/article/view/983

Costa CCD, Guilhoto JJM, Burnquist HL (2015) Impactos socioeconômicos de reduções nas perdas pós-colheita de produtos agrícolas no Brasil. Revista de Economia e Sociologia Rural 53: 395-408. DOI: https://doi.org/10.1590/1234-56781806-9479005303002.

Domínguez A, Martínez-Romero A, Leite KN, Tarjuelo JM, Juan JA, López-Urrea R (2013) Combination of typical meteorological year with regulated deficit irrigation to improve the profitability of garlic growing in central spain. Agricultural Water Management 130: 154-167. DOI: https://doi.org/10.1016/j.agwat.2013.08.024.

EMBRAPA - Empresa Brasileira de Pesquisa Agropecuária (2018). Sistema brasileiro de classificação de solos. 5 ed. Brasília, DF, Embrapa.

IBGE – Instituto Brasileiro de Geografia e Estatística (2018) Levantamento sistemático da produção agrícola - LSPA. Brasília, DF. Available: https://www.ibge.gov.br/

Kim SH, Jeong JH, Nackley LL (2013) Photosynthetic and transpiration responses to light, CO2, temperature, and leaf senescence in garlic: Analysis and modeling. Journal of the American Society for Horticultural Science 138(2): 149-156. DOI: https://doi.org/10.21273/JASHS.138.2.149.

Lopes WA, Negreiros MZ, Resende FV, Lucena RR, Soares AM, Silva OM, Medeiros JF (2016) Produção de alho submetido a períodos de vernalização e épocas de plantio em região de clima semiárido. Horticultura Brasileira 34(2): 249-256. DOI: https://doi.org/10.1590/S0102-053620160000200016.

Oliveira RA, Ramos MM (2018) Manual do irrigâmetro. Viçosa, UFV, 144p. https://www.editoraufv.com.br/produto/manual-do-irrigametro/1109336.

Oliveira JT, Oliveira RA, Oliveira LAA, Teodoro PE, Montanari R (2020) Spatial variability of irrigated Garlic (*Allium sativum* L.) production components. Horticultural Science 55(3): 300. DOI: https://doi.org/10.21273/HORTSCI14409-19.

Oliveira JT, Oliveira RA, Cunha FF, Santos ES (2021) Spatial autocorrelation of physical attributes of an Oxisol. Engenharia Agrícola 41(2): 255-262. DOI: http://dx.doi.org/10.1590/1809-4430-Eng.Agric.v41n2p255-262/2021.

Prato Sarmiento AI (2016) Avaliação financeira do alho (*Allium sativum* L.) roxo Nacional e Peruano no planalto Cundiboyacense, Colômbia. Corpoica Ciencia y Tecnología Agropecuaria 17(1): 43-53. DOI: https://doi.org/10.21930/rcta.vol17_num1_art:460.

Resende JTV, Morales RGF, Zanin DS, Resende FV, Paula JT, Dias DM, Galvão AG (2013) Caracterização morfológica, produtividade e rendimento comercial de cultivares de alho. Horticultura Brasileira 31(1): 157-162. DOI: https://doi.org/10.1590/S0102-05362013000100025.

Seifu W, Yemane T, Bedada S, Alemu T, Boshoftu E (2017) Evaluation of Different Mulching Practices on Garlic (*Allium sativum* L.) Growth Parameters under Irrigated Condition in Fiche, North Shoa Ethiopia. Journal of Biology, Agriculture and Healthcare 7: 25-31. DOI: https://doi.org/10.1590/S0102-05362013000100025.

Shang A, Cao SY, Xu XY, Gan RY, Tang GY, Corke H, Li HB (2019) Bioactive Compounds and Biological Functions of Garlic (*Allium sativum* L.). Foods 8(246): 1-31. DOI: https://doi.org/10.3390/foods8070246.

Soares AM, Negreiros MZ, Resende FV, Lopes W, Medeiros JF, Grangeiro LC (2015) Avaliação de cultivares de alho no município de Governador Dix-sept Rosado-RN, Brasil. Revista Agro@mbiente 9: 423-430. DOI: https://doi.org/10.18227/1982-8470ragro.v9i4.2553.

Tao J, Li Y, Li S, Li HB (2018) Plant foods for the prevention and management of colon cancer. Foods 42: 95–110. DOI: https://doi.org/10.1016/j.jff.2017.12.064.

Puiatti M (2017) Exigências climáticas e ecofisiologia do alho. In: Nick C, Borém A (ed.). Alho: do plantio à colheita: Viçosa, Editora UFV.