Comunicata Scientiae
Horticultural Journal

ORIGINAL ARTICLE
published: 06 August 2022
https://doi.org/10.14295/CS.v13.3771

Plant growth and yield of garlic (*Allium sativum* L.) under applications of liquid biofertilizers

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Abstract

Garlic is a highly relevant vegetable crop from the food and medicinal point of view in the culture of different peoples around the world. The new discoveries of the active components present in the bulbs increase the demand and require that garlic's production system meets the demands of the market in quantity and quality. The nutrition in vegetables is crucial for the production and protection of crops, and in the garlic crop it is usual practice to apply minerals via leaf application during the cycle. The use and benefits of organic sources associated with minerals in the garlic crop raise questions about the viability of the leaf application method in this crop. The objective of this study was to evaluate the effectiveness of biofertilizers containing humic acids applied via leaf application in the crop of garlic (*Allium sativum*) in relation to the control (absence of humic acid). There was no significant variation for the foliar application of biofertilizers for the development parameters (aerial part, root system and bulb formation) and garlic production classes. Biofertilizer 4 at the dose of 30 L ha^{-1} stood out compared to the Biofertilizers 2 and 3 for total productivity. The use of foliar biofertilizers with organic components associated with minerals can be considered an interesting alternative for the cultivation of garlic, especially if evaluated in the long term and considering the global benefits to the cultivation system.

Keywords: *Allium sativum*, biostimulants, growth promoters, humic acids

Introduction

Garlic (*Allium sativum* L.) is one of the most cultivated and consumed vegetable species in the world. It is mainly used as a condiment, but it is also consumed for its health benefits, in the prevention and treatment of cardiovascular diseases, including antiplatelet, antihypertensive and antioxidant activity (Barboza et al., 2020).

Garlic production is of great economic and social importance in Brazil, with cultivation being mostly carried out by small producers and which requires a lot of labor during the crop cycle (Luís et al., 2020). The annual global production of garlic in 2015 and 2016 was around 27 million tons in approximately 1.5 million hectares (Faostat, 2018). Despite the importance of garlic crop in Brazil, the country is the largest importer in the world, with China and Argentina as its main suppliers (Lucena et al., 2016).

In order to strengthen national production, measures are needed to reduce imports and increase average productivity, which, despite having increased notably with the adoption of noble cultivars vernalized with "seeds" from the meristem culture, still presents some relevant potential expansion. Research efforts in the crucial aspects of management can be decisive in providing improved leverage to the garlic production chain.

Garlic plants require large amounts of nutrients. The ideal application of fertilizers in the cultivation of garlic is important to improve the growth, yield and marketable proportions of the bulbs, as well as the quality of the bulbs. Mineral fertilizers in adequate doses promote increases in leaf area and productivity (Kenea & Gedamu, 2019).

Due to the limited availability of chemical fertilizers , biofertilizers are considered environmentally friendly, provide an economical and sustainable alternative to synthetic fertilizers, and increases agricultural production

Received: 03 July 2021
Accepted: 24 January 2022

and decreases environmental pollution (Sattar et al., 2018; Mounir et al., 2020). This aspect, in addition to meeting the growing demand for quality and quantity products, has short and long-term advantages in the nutritional management of plants and the ecosystem.

The benefits of these fertilizers for the soil-plant system include: increased mineralization rate and cation exchange capacity (CEC) due to nutrient retention and release, as well as causing reduced losses by leaching (N and K), volatilization (NH_3) and adsorption (P); promotion of the buffer effect, which contributes to the stability of the soil pH; increased aggregate stability, which improves structure, aeration and water retention of the system; and causing an increased proliferation of microorganisms (Virgolino et al., 2017).

The objective of this study was to evaluate the effectiveness of biofertilizers containing humic acids, provided via the leaf application method in the crop of garlic (*Allium sativum*), in relation to its control (absence of humic acid).

Material and Methods

Location and general characteristics of the experimental area

The experiment was carried out at Fazenda Barro Preto, in the municipality of Uberaba-MG, Latitude 19° 45'27" S, Longitude 47° 55'36" W and altitude approximately 752 m, where the climate is classified as Aw according to Köppen and Geiger, that is, tropical climate with dry winter season. The average annual rainfall in Uberaba is 1571 mm and average temperature of 22.3° C. The cultivar used was « Ito », planted on May 22, 2020.

Experimental design

The experiment was conducted in a randomized block design, with 8 treatments with four replications. Each plot consisted of 3 double lines of 6 meters long, spaced 0.35 meters apart, totaling 10.8 m² each plot.

The useful plot destined for the evaluations along the cycle was the area referring to the double lines of the border where samples of the inner line of each pair of each plot were collected. At harvest, the central double line of each plot of 5 meters was taken for sampling, totaling 8 linear meters of harvested area.

The 8 treatments were applied as described in Table 1 with the aid of a CO_2 sprayer. The control treatment consisted of the absence of biofertilizer application. Four biofertilizers with different composition were evaluated, the last one (Biof. 4) being evaluated in 4 doses (10, 20, 30 and 40 L ha^{-1}) that were determined based on the response of the crop already observed with the dose of 20 L ha^{-1} with this product. Thus, levels below and above 20 L ha^{-1} were established to determine the crop response curve as a function of different doses.

The compounds of the products applied in the present study are shown in Table 2.

Table 1. Rates of the Biofertilizers applied during sowing and plant growth of garlic.

	Applications (Dose)					
	1	2	3	4	5	Total
Treatments	(Sowing)	Vegetative phase	Vegetative phase	Phases V9 and R1	Reproductive phase	
	L ha^{-1}					
Control (absence application)	-	-	-	-	-	0
T2 Biof. 1	5	-	-	-	-	5
T3 Biof. 2	5	-	-	-	-	5
T4 Biof. 4	2	2	2	2	2	10
T5 Biof. 4	4	4	4	4	4	20
T6 Biof. 4	6	6	6	6	6	30
T7 Biof. 4	8	8	8	8	8	40
T8 Biof. 3	1	1	1	1	1	5

Table 2. Chemical composition (%) of biofertilizers.

Biof. 1	Organic Carbon	Humic Acid	Fulvic Acid	K_2O				
	12	18	3	4.8				
Biof. 2	Organic Carbon	N	P_2O_5	K_2O				
	7.89	2	1.5	3.0				
Biof. 3	Organic Carbon	N	K_2O					
	14.0	1.4	8.0					
Biof. 4	Humic Acid	N	Phosphoric Acid	K	Mg	Ca	B	Fe
	5.5	0.1	0.03	1.5	0.02	0.17	0.01	0.02

Conducting the experiment

All cultural treatments, such as phytosanitary control, were carried out as practiced by the producer through monitoring of pests and diseases. Upon reaching the level of control, pesticides were applied according to the standards and instructions of the manufacturers in all treatments. Irrigation management was carried out through a center pivot from planting to 5 days before harvest. The crop fertilization recommendation was based on soil analysis and the CFSEMG recommendation bulletin (1999).

Soil mineral analysis was performed according to the method described by EMBRAPA (2013). The physical and chemical components of 0-20 cm soil layer were as follows: pH H_2O = 5.3; P = 50.3 mg dm^{-3}; K = 1.04 $mmol_c$ dm^{-3}; Ca = 17.7 $mmol_c$ dm^{-3}; Mg = 3.5 $mmol_c$ dm^{-3}; Al = 0.0 $mmol_c$ dm^{-3}, CTC= 48.28 $mmol_c$ dm^{-3}; V= 46.1%.

Variables determined in the experiment.
Growth analysis

Six plants were collected from each experimental plot for the composition of a sample for the following evaluations: height of the aerial part (measuring the length of the main stem with a tape measure), fresh mass of the aerial part, root and bulbs (weighing in analytical balance), dry mass of the aerial part, root and bulbs (the plants were dried in an oven with forced air circulation (60°C) until reaching constant mass).

Root volume was also evaluated (determination carried out by measuring the displacement of the water column in a graduated cylinder, that is, placing the roots in a beaker containing a known volume of water - 100 mL. By the difference, the direct response of the root volume was obtained by the equivalence of units (1 mL = 1 cm^3),and the transverse bulb diameters were measured with the aid of a caliper.

Leaf analysis

At 70 days after planting (DAP) leaf samples were collected for leaf chemical analysis of macro and micronutrients from each experimental plot. Young and fully developed leaves were collected from 10 plants. The leaves were collected within 3 meters of the inner line of the two doubles lines of the extremities (that is, outside the useful area).

Spad Index

At 50 and 85 DAP, the critical level of the SPAD index (Soil Plant Analysis Development) on garlic leaves was determined using the portable SPAD-502 Plus meter, in order to identify the nutritional condition of the plants in relation to nitrogen.

The evaluations were carried out in the upper third sections of fully developed (adult) leaves. Ten plants chosen at random in the double lines of the extremities were evaluated.

Harvest classification

The garlic harvest was carried out at the end of the crop cycle, in the central double line of the plot, which corresponded to 10 linear meters harvested (useful area). The bulbs were classified according to diameter and weighed.

The classification of garlic was carried out according to the diameter: class 2/3 (less than 40 mm); class 4 (40 to 45 mm); class 5 (45 to 50 mm); class 6 (50 to 55 mm); class 7 (55 to 60 mm). For each class there was a subdivision: extra, special and commercial. Total productivity refers to the sum of all classes.

Statistical analysis

The evaluated characteristics were submitted to the F test of the analysis of variance. The Scott-Knott test was performed to compare all treatments with each other, indicating which ones obtained positive results. To evaluate the proper rate of Biofertilizer 4 the regression analysis was performed with the different rates tested. These tests were performed using the SISVAR program.

Results

Aerial part development

In the evaluation at 50 DAP, no statistically significant differences were observed between the four biofertilizers, the control and the doses of Biof. 4 (Table 3). The SPAD index varied between 56.9 (T6) to 60.1 (T3), the plant height between 68.9 (T8) to 71.7 cm (T4), the total number of leaves varied between 9 and 10, with number of dead leaves varying from 1 to 2. The fresh mass of the aerial part of garlic varied between 30.5 (T7) to 34.2 (T6) g $plant^{-1}$, while the dry mass of the aerial part varied between 3, 7 (T3) to 4.3 (T6) g $plant^{-1}$.

Root and bulb development

The development, both of roots and the garlic bulbs, were also not affected by the biofertilizers applied via leaf in the evaluations at 50 and 84 DAP (Table 4). The fresh mass of garlic root varied between 3.5 to 3.8 and 5.1 (T5) to 5.8 (T1 and T4) g $plant^{-1}$ at 50 DAP and 84 DAP, respectively. The dry root mass varied from 0.6 to 0.7 and 1.1 to 1.2 g $plant^{-1}$ at 50 DAP and 84 DAP. The fresh mass of garlic bulbs ranged from 7.9 (T1 to T3) to 8.9 (T7) and 38.1 (T8) to 41.9 (T5) g $plant^{-1}$ at 50 DAP and 84 DAP, respectively . The dry mass of bulb varied between 1.3 to 1.5 g plant^{-1} at 50 DAP and 8.9 (T3) to 10.4 (T7) g plant^{-1} at 84 DAP. The diameter varied between 21.9 (T3) to 23.3 (T7) mm at 50 DAP and 45.3 (T8) to 47.1 (T5) mm at 84 DAP.

Macro and micronutrient contents in garlic plants at 70 DAP

For nutrient contents, only N, S and B showed a significant difference ($p < 0.05$). The control had the lowest N content among all treatments evaluated (38.7 g kg^{-1}), not differing from Biof. 2 (38.5 g kg^{-1}). The highest levels of N referred to the doses of 20, 30 and 40 L ha^{-1} of Biof. 4, with no difference between them and also with no difference for Biof. 3 (Table 5).

For the S content, Biof. 4 was highlighted in the dose of 20 L ha^{-1} (16.1 g kg^{-1}), and the other treatments did not differ among themselves, including with regard to control. Regarding B, Biof.2 and Biof. 4 stood out at doses of 20 and 30 L ha^{-1} (Table 5).

Table 3. Aerial part of garlic plants subjected to different treatments at 50 and 84 days after planting (DAP).

		Spad		Plant height (cm)		Fresh mass (g plant^{-1})		Dry mass (g plant^{-1})	
Treatments		50	84	50	84	50	84	50	84
		DAP							
T1	Control	58.5 a	62.0 b	70.6 a	81.5 a	31.9 a	60.3 a	4.0 a	9.5 a
T2	Biof. 1	58.2 a	62.1 b	70.4 a	80.8 a	31.3 a	60.7 a	3.9 a	9.4 a
T3	Biof. 2	60.1 a	63.7 b	69.4 a	80.7 a	30.6 a	56.7 a	3.7 a	8.9 a
T4	Biof. 3	59.4 a	65.6 a	68.9 a	81.1 a	30.6 a	60.7 a	3.9 a	9.3 a
T5	Biof. 4 (10L ha^{-1})	58.6 a	65.6 a	71.7 a	80.6 a	32.1 a	57.2 a	3.9 a	8.8 a
T6	Biof. 4 (20L ha^{-1})	58.5 a	64.5 a	69.3 a	80.2 a	30.8 a	58.2 a	3.7 a	8.9 a
T7	Biof. 4 (30L ha^{-1})	56.9 a	65.4 a	71.9 a	83.1 a	34.2 a	60.7 a	4.3 a	9.6 a
T8	Biof. 4 (40L ha^{-1})	59.3 a	64.9 a	69.5 a	80.9 a	30.5 a	57.7 a	3.9 a	9.1 a
	CV (%)	4.5	2.6	3.5	2.4	8.6	11.7	9.0	12.4
	Average	58.7	64.2	70.2	81.1	31.5	59.0	3.9	9.1
	Fc	0.8^{ns}	0.02*	0.6^{ns}	0.5^{ns}	0.6^{ns}	0.9^{ns}	0.5^{ns}	0.9^{ns}

Means followed by equal letters in the column do not differ by Scott-Knott test at 5% probability. *Significant and ^{ns} not significant by F test at 5% probability.

Table 4. Roots and bulbs of garlic subjected to different treatments at 50 and 84 days after planting (DAP).

		Root				Bulb					
		Fresh mass		Dry mass		Fresh mass		Dry mass		Diameter	
		(g plant^{-1})				(g plant^{-1})				(mm)	
Treatments		50	84	50	84	50	84	50	84	50	84
		DAP									
T1	Control	3.5 a	5.8 a	0.6 a	1.2 a	7.9 a	40.9 a	1.3 a	9.7 a	22.1 a	45.8 a
T2	Biof. 1	3.7 a	5.6 a	0.6 a	1.1 a	7.9 a	41.6 a	1.3 a	9.8 a	22.3 a	46.5 a
T3	Biof. 2	3.8 a	5.7 a	0.6 a	1.1 a	7.9 a	38.2 a	1.3 a	8.9 a	21.9 a	45.9 a
T4	Biof. 3	3.8 a	5.8 a	0.6 a	1.2 a	8.2 a	40.0 a	1.4 a	9.5 a	22.3 a	46.0 a
T5	Biof. 4 (10L ha^{-1})	3.7 a	5.1 a	0.6 a	1.1 a	8.4 a	41.9 a	1.4 a	10.2 a	22.8 a	47.1 a
T6	Biof. 4 (20L ha^{-1})	3.5 a	5.5 a	0.6 a	1.2 a	8.2 a	40.7 a	1.4 a	10.1 a	22.5 a	46.5 a
T7	Biof. 4 (30L ha^{-1})	3.7 a	5.4 a	0.7 a	1.2 a	8.9 a	41.0 a	1.5 a	10.4 a	23.3 a	46.8 a
T8	Biof. 4 (40L ha^{-1})	3.8 a	5.2 a	0.6 a	1.2 a	8.4 a	38.1 a	1.5 a	9.6 a	22.9 a	45.3 a
	CV (%)	8.4	10.2	9.4	14.3	6.4	11.5	7.3	11.9	3.2	3.9
	Average	3.7	5.5	0.6	1.2	8.2	40.3	1.4	9.8	22.5	46.3
	Fc	0.5^{ns}	0.5^{ns}	0.6^{ns}	0.9^{ns}	0.2^{ns}	0.9^{ns}	0.1^{ns}	0.8^{ns}	0.2^{ns}	0.9^{ns}

Means followed by equal letters in the column do not differ by Scott-Knott test at 5% probability. *Significant and ^{ns} not significant by F test at 5% probability.

Table 5. Aerial part of garlic plants subjected to different treatments at 70 DAP.

	Treatments	N	P	K	S	Ca	Mg
				g kg-1			
T1	Control	38.7 c	3.5 a	29.3 a	12.3 b	8.4 a	3.0 a
T2	Biof. 1	41.3 b	3.9 a	29.8 a	12.9 b	7.9 a	2.9 a
T3	Biof. 2	38.5 c	3.9 a	28.6 a	11.7 b	7.9 a	2.9 a
T4	Biof. 3	44.3 a	3.7 a	29.8 a	12.6 b	8.2 a	2.9 a
T5	Biof. 4 (10L ha-1)	40.6 b	3.8 a	29.4 a	13.9 b	7.2 a	2.8 a
T6	Biof. 4 (20L ha-1)	44.1 a	4.2 a	29.6 a	16.1 a	8.1 a	2.9 a
T7	Biof. 4 (30L ha-1)	43.9 a	3.9 a	30.8 a	12.2 b	9.0 a	3.2 a
T8	Biof. 4 (40L ha-1)	43.1 a	3.9 a	30.0 a	13.1 b	8.5 a	3.1 a
	CV (%)	2.5	8.4	4.3	11.3	9.9	6.8
	Average	41.8	3.8	29.6	13.1	8.2	2.9
	Fc	0.0*	0.2 ns	0.5 ns	0.01*	0.1 ns	0.3 ns
	Treatments	Cu	Fe	Mn	Zn	B	
				mg kg-1			
T1	Control	6.9 a	146.8 a	23.3 a	23.5 a	20.4 b	
T2	Biof. 1	6.1 a	105.8 a	21.5 a	23.7 a	20.1 b	
T3	Biof. 2	6.3 a	161.0 a	24.5 a	22.9 a	21.9 a	
T4	Biof. 3	7.5 a	113.0 a	22.3 a	23.1 a	19.3 b	
T5	Biof. 4 (10L ha-1)	6.4 a	224.3 a	24.3 a	23.3 a	19.1 b	
T6	Biof. 4 (20L ha-1)	6.9 a	157.3 a	20.3 a	23.5 a	20.8 a	
T7	Biof. 4 (30L ha-1)	6.9 a	138.3 a	25.8 a	22.6 a	22.3 a	
T8	Biof. 4 (40L ha-1)	6.9 a	177.8 a	24.3 a	22.4 a	20.7 b	
	CV (%)	20.7	50.5	11.9	8.6	6.3	
	Average	6.8	153.0	23.3	23.1	20.6	
	Fc	0.9 ns	0.5 ns	0.2 ns	0.9 ns	0.02*	

As for the evaluation of significant nutrients for Biof.4 doses, B and S did not fit any model, whereas N fit the quadratic polynomial model. The maximum values of N (43.9 g kg^{-1}) was related to the doses of 29.2 L ha^{-1}, respectively (Figure 1).

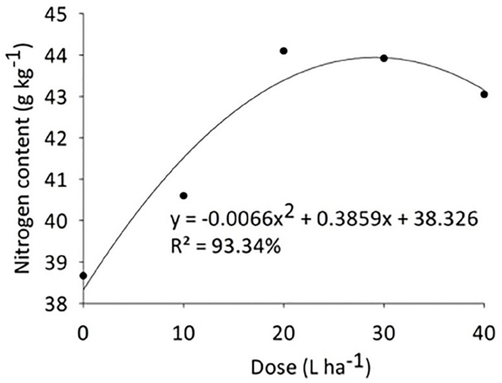

Figure 1. Nitrogen (N) content (g kg^{-1}) in the garlic leaves as a function of Biof.4 doses.

Productivity

There was no statistical difference between the biofertilizers for the garlic bulb classes, in their subdivisions (Industry, class 4, class 5, class 6, class 7, class 2 to 4 - lowest commercial value, class 5 to 7 - highest commercial value) (Table 6). For total productivity, Biof. 4 at the dose of 30 L ha^{-1} stood out compared to Biof. 2 and Biof. 3, however without difference with the control (absence of foliar application with humic acids) (Table 6).

Table 6. Productivity of garlic bulbs in the classes industry and 3 to 7 (total) under application of organic fertilizers.

	Treatments	Industry	4	5	6	7	2 a 4	5 a 7	Total
T1	Control	0.6 a	4.0 a	4.7 a	3.8 a	1.1 a	6.6 a	9.7 a	16.8 ab
T2	Biof. 1	0.7 a	3.8 a	4.8 a	3.9 a	1.6 a	6.1 a	10.4 a	17.2 ab
T3	Biof. 2	0.8 a	3.9 a	3.6 a	3.2 a	0.5 a	6.5 a	7.4 a	14.6 c
T4	Biof. 3	1.0 a	3.5 a	4.9 a	3.2 a	1.0 a	6.1 a	9.2 a	16.3 b
T5	Biof. 4 (10L ha-1)	0.5 a	3.8 a	5.0 a	3.8 a	1.4 a	6.5 a	10.2 a	17.2 ab
T6	Biof. 4 (20L ha-1)	0.9 a	3.9 a	5.1 a	2.9 a	1.8 a	6.4 a	9.9 a	17.2 ab
T7	Biof. 4 (30L ha-1)	0.6 a	3.7 a	4.9 a	4.9 a	1.4 a	6.7 a	11.3 a	18.6 a
T8	Biof. 4 (40L ha-1)	0.5 a	3.8 a	4.9 a	4.2 a	1.2 a	6.6 a	10.4 a	17.5 ab
	CV	58.3	26.1	25.2	31.4	79.5	15.9	15.7	8.2
	Average	0.7	3.8	4.7	3.8	1.3	6.4	9.8	16.9
	Fc	0.6ns	0.9ns	0.7ns	0.3ns	0.8ns	0.9ns	0.06ns	0.04*

Means followed by equal letters in the column do not differ by Scott-Knott test at 5% probability. *Significant and ns not significant by F test at 5% probability.

Discussion

Humic substances contained in biofertilizers are the most abundant components of soil organic matter (they can reach up to 80%). Due to the wide diversity of composition, they can attribute to the agricultural system benefits for physical, chemical and biological processes in the soil (Zanin et al., 2019). The use of these compounds has been raised in the literature as an innovative practice due to the positive impacts on physiology, biochemical characteristics and soil fertility, and which are favorable aspects for the production of garlic (Boutasknit et al., 2020).

In the present work, it was observed that humic acids applied to the crop of garlic showed a small increase for the development of the aerial part, not being enough to generate a significant difference between the four biofertilizers evaluated and the control. It is worth mentioning that the continuous application of the components present in biofertilizers can bring benefits in the long-term in continued use, since the structural benefits in the system may not be immediate and visible in short periods of evaluation.

Foliar applications, such as those carried out in this study, require less amounts of biostimulants and allows nutrients to be absorbed quickly and directly by the leaf (Popescu & Popescu, 2018). In terms of growth, it was observed that the dose of 10 L ha^{-1} was as efficient as 40 L ha^{-1},and was necessary to validate this indication with the other evaluated parameters.

The increase in chlorophyll, measured indirectly by SPAD, also proved to be favorable for garlic. Wilczewski et al. (2018) in application of HA in sugar beet obtained an increase in SPAD index, which was significantly correlated with sugar yield.

The beneficial effects of HA go beyond the growth-promoting effect of plants and include an endogenous biological response to stress effects promoted by the environment through the combination of properties of the constituents of the mixture that form humic acids and commercial products (Yakhin et al., 2017; Rouphael & Colla, 2018; Pizzeghello et al., 2020). Positive responses from the application of HA, with greater plant growth, development, production and the quality of commercial organs, have been reported in the literature (Souri et al., 2017, Ibrahim et al., 2019), including in the garlic crop by Balmori et al . (2019).

In onion, AH promoted greater number of leaves, height, leaf diameter, stem diameter, fresh leaf weight, length and root number, bulb length and diameter and fresh weight of the plants, in comparison with untreated plants (control) (Al-Fraihat et al., 2018). Zaki et al. (2014) concluded that HA can result in an increase and improvement in the yield and quality of garlic bulbs, attributing to the incremental improvement that the compounds promote in the absorption of nutrients and structure of the soil, and which consequently generate a positive influence on the growth of the plants (Badawy et al., 2019).

Mohsen et al. (2017) reported that the supply of HA promoted greater absorption of nutrients and that this influenced the development of the root system, followed by an increase in some growth parameters, for example plant height and number of leaves, and culminated in an increase in total yield.

To estimate the dose response function, Badawy et al. (2019) observed that the linear regression model described the behavior of HA as being positive at low doses of HA, while negative at high doses of HA. Higher doses of HA have less or no effect.

It is worth mentioning that the effect caused by the leaf application of HA seems to be less consistent and relevant than that observed when HA are applied at the root (De Hita et al., 2019). Novais & Novais (2017) commented that the use of HA contributes to better management of the physical aspects of the soil through its action on the formation of more stable aggregates, and consequently on the maintenance of more balanced soils for the development of crops.

Not all plant species respond to foliar application, as most of the classes presented in the present work. However, as raised by Aslani & Souri (2018), the application can be considered as a complementary nutrition to a dosage applied to the soil.

Despite the remarkable results with the use of HA in the literature, the relationship between functional structures and bioactivity in plants is still confusing and there is little information from basic science explaining the interactions, especially considering the enormous potential of this category of inputs (Olivares et al., 2017).

The biological activity of HA is also dependent on their origin, chemical structure and concentrations. Leonardite, for example, is the commercial humic substance most commonly used in manufacturing (Bulgari et al., 2019; Dziugiel & Wada, 2020). Sarıyıldız (2020) observed a significantly positive effect on soil properties, vegetative growth and garlic yield using HA (of Leonardite origin) compared to conventional NPK fertilization only.

Due to the consistent change in the compositions of HA offered on the market, it is observed that the choice of the commercial product can have a significant effect on the responses of the plants (Van Oosten et al., 2017). Its use will grow even more as it gains credibility among the main farmers (Olk et al., 2018), in particular due to the growing look towards a more balanced agriculture. This suggests that a combination of high technology and organic techniques (biofertilizers and organominerals), especially in the long term, can provide more realistic and sustainable solutions (Timsina, 2018).

It is important to note that HAs contribute to the development of plants that can be expressed under stress conditions, which did not occur in this study, as the conditions under which the experiment was conducted were considered optimal for the crop (water and phytosanitary supply) . It is also interesting to evaluate from an ecological point of view whether it is beneficial to consider the application of organic sources only for the purpose of soil structures, especially the physical and biological aspects attributed to humic components applied both via soil and foliar applications, since that what is not absorbed by plants, the destination is the soil.

The diversity of components present in biofertilizers is also an interesting aspect from the point of view of the ecosystem, as it provides a wide range of carbon chains and dynamically stimulates the microbiota present in soils, which can generate a greater biodiversity of life in the soil and in consequence makes the activity more balanced and sustainable.

Conclusions

There was no significant variation for the foliar application of biofertilizers for the development parameters (aerial part, root system and bulb formation) and garlic production classes.

Biofertilizer 4 at the dose of 30 L ha^{-1} stood out compared to Biofertilizers 2 and 3 for total productivity.

The use of foliar biofertilizers with organic components associated with minerals can be considered an interesting alternative, especially if evaluated in the long term and considering the global benefits to the cultivation system.

References

Al-Fraihat, A.H., Al-tabbal, J.A., Abu-Darwish, M.S., Alhrout, H.H., Hasan, H.S. 2018. Response of onion (Allium cepa) crop to foliar application of humic acid under rain-fed conditions. *International Journal of Agriculture and Biology* 20: 1235-1241.

Aslani, M., Souri, M.K. 2018. Growth and quality of green bean (Phaseolus vulgaris L.) under foliar application of organic Chelate. *Fertilizers Open Agriculture* 3: 146–154.

Badawy, A.S., Zahran, M.M.A., Hefzy, M.M. 2019. *Effect of irrigation level and bio-stimulants on productivity and quality of garlic (Allium sativum l) in calcareous soils. Fayoum Journal of Agricultre Research & Development*. 33: 90-101.

Balmori, D.M., Domínguez, C.Y.A., Carreras, C.R., Rebatos, S.M., Farías, L.B.P., Izquierdo, F.G., Berbara, R.L.L., García, A.C. 2019. Foliar application of humic liquid extract from vermicompost improves garlic (Allium sativum L.) production and fruit quality. *International Journal of Recycling of Organic Waste in Agriculture* 8 : 103–112.

Barboza, K., Salinas, M.C., Acuña, C.V., Bannoud, V., Beretta, V., García-Lampason, S., Burb, J.L., Galmarini, C.R. Cavagnaro, P.F. 2020. Assessment of genetic diversity and population structure in a garlic (Allium sativum L.) germplasm collection varying in bulb content of pyruvate, phenolics, and solids. *Scientia Horticulturae* 261: 108900.

Boutasknit, A., Ait-Rahou Y., Anli, M., Ait-El-Mokhtar, M., Ben-Laouane, R., Meddich, A. 2020. Improvement of garlic growth, physiology, biochemical traits, and soil fertility by Rhizophagus Irregularis and Compost. *Gesunde Pflanzen 73:149-160*.

Bulgari, R., Franzoni, G., Ferrante, A. 2019. Biostimulants application in horticultural crops under abiotic stress conditions. *Agronomy* 9: 306.

Dziugieł, T., Wada, W. 2020. Effect of Plant Biostimulants on Macronutrient Content in Early Crop Potato Tubers. *Agronomy*. 10: 1202.

EMBRAPA, Empresa Brasileira de Pesquisa Agropecuária. 2013. Sistema Brasileiro de Classificação de Solos. Embrapa, Brasilia, Brasil. 353 p.

FAOSTAT, Harvested area, yield and production in the main garlic producing countries. 2018 . http://www.fao.org/faostat/en/#home<Accessed in 22 Nov. 2018>

Hita, D. De, Fuentes, M., García, A.C. Olaetxea, M., Baigorri, R., Zamarreño, A.M., Berbara R., Garcia-Mina, J.M. 2019. Humic substances: a valuable agronomic tool for improving crop adaptation to saline water irrigation. *Water Supply* 19: 1-6.

Kenea, F.T., Gedamu, F. 2019. Response of Garlic (Allium sativum L.) Growth and Bulb Yield to Application of Vermicompost and Mineral Nitrogen Fertilizers in Haramaya District, Eastern Ethiopia. *East African Journal of Sciences* 13: 159-168.

Ibrahim, A., Abdel-Razzak, H., Wahb-Allah, M., Alenazi, M., Alsadon, A., Dewir, Y.A. 2019. Improvement in Growth, Yield, and Fruit Quality of Three Red Sweet Pepper Cultivars by Foliar Application of Humic and Salicylic Acids. *Hortechonoly* 29: 170-178.

Lucena, R.R.M., Negreiros, M.Z., Resende, F.V., Lopes, W.A.R., Silva, O.M.P. 2016. Productive performance of vernalizated semi-noble garlic cultivars in western Rio Grande do Norte state, Brazil. *Revista Caatinga* 29: 327-337.

Luís, M.A.S., Negreiros, M.Z., Resende, F.V., Paulino, R.C., Lopes, W.A.R., Paiva, L.G. 2020. Organic mulch on early garlic cultivars grown under semiarid conditions. *Revista Caatinga* 33: 412-421.

Mohsen, A.A.M., Sabreen K., Ibraheim, H.A., Abdel-Fattah, M.K. 2017. Effect of potassium humate, nitrogen bio fertilizer and molybdenum on growth and productivity of Garlic (Allium sativum L.). *Current Science International* 6: 75-85.

Mounir, A.M., Osman, Y.M.M., Khalil, O.A.A. 2020. Impact of potassium solubilizing bacteria on growth and yield of garlic. *Plant Archives* 20: 8374-8388.

Novais, R. F.; NOVAIS, S. V. 2016. Manejo de adubação fosfatada em solos de cerrado. Simpósio Brasileiro de Agropecuária Sustentável, Sinop, Brasil. p. 141-154,

Olivares, F.L., Busato, J.G., Paula, A.M., Lima, L.S., Aguiar, N.O., Canellas, L.P. 2017. Plant growth promoting bactéria and humic substances: crop promotion and mechanisms of action. *Chemical and Biological Technologies in Agriculture* 4: 1-13.

Olk, D.C., Dinnes, D.L., Scoresby, J.R., Callaway, C.R., Darlington, J.W. 2018. Humic products in agriculture: potential benefits and research challenges—a review. *Journal of Soils and Sediments* 18:1-11.

Pizzeghello, D., Schiavon, M., Francioso, O., Vecchia, F.D., Ertani, A., Nardi, S. 2020. Bioactivity of size-fractionated and unfractionated Humic substances from two forest soils and comparative effects on N and S metabolism, nutrition, and root anatomy of Allium sativum L. *Frontiers in Plant Science* 11: 1203.

Popescu, G.C., Popescu, M. 2018. Yield, berry quality and physiological response of grapevine to foliar humic acid application. *Bragantia* 77: 273-282.

Rouphael, Y., Colla, G. 2018. Synergistic biostimulatory action: designing the next generation of plant biostimulants for sustainable agriculture. *Frontiers in Plant Science* 9: 1655.

Sariyildiz, T. 2020. Effects of Leonardite and Mineral Fertilizer Applications on Plant Growth and Soil Quality of Garlic (Allium sativum L.). *Turkish Journal of Agriculture - Food Science and Technology* 8: 1763-1772.

Sattar, A., Naveed, M., ALI, M., Zahr, Z.A., Nadeem, S.M., Yaseen, M., Meena, V.S., Farooq, M., Singh, R., Rahman, M., Meena, H.N. 2018. Perspectives of potassium solubilizing microbes in sustainable food production system: A review. *Applied Soil Ecology* 13: 146-159.

Souri, M.K., Sooraki, F.Y., Moghadamyar, M. 2017. Growth and quality of cucumber, tomato, and green bean under foliar and soil applications of an aminochelate fertilizer. *Horticulture, Environment, and Biotechnology* 58: 530-536.

Souza, R.J., Paula, M.B., Cecílio Filho, A.B. 1999. Sugestões de adubação para as diferentes culturas em Minas Gerais. In: Ribeiro, A.C., Guimarães, P.T.G., Alvarez V, V.H. (eds.) *Recomendações para o uso de corretivos e fertilizantes em Minas Gerais: 5ª Aproximação*. Embrapa Gado de Corte, Viçosa, Brazil. p. 178.

Timsina, J. 2018. Can Organic Sources of Nutrients Increase Crop Yields to Meet Global Food Demand? *Agronomy* 8: 214.

Van Oosten, M. J., Pepe, O., De Pascale, S., Silletti, S., Maggio, A. 2017. The role of biostimulants and bioeffectors as alleviators of abiotic stress in crop plants. *Chemical and Biological Technologies in Agriculture* 4: 1-12.

Virgolino Filho, A.S., Silva, M.I.V. 2017. Importância das Substâncias Húmicas para a Agricultura.https://www.researchgate.net/publication/268049508_Importancia_das_Substancias_Humicas_para_a_Agricultura<Accessed in 22 nov. 2020.

Zaki, H.E.M., Toney, H. S.H., Abd El-Raouf, R.M. 2014. Response of two garlic cultivars (Allium sativum L.) to inorganic and organic fertilization. *Nature and Science* 12: 52-60.

Zanin, L., Tomasi, N., Cesco, S., Varanini, Z., Pinton, R. 2019. Humic substances contribute to plant iron nutrition acting as chelators and biostimulants. *Frontiers in Plant Science* 10: 675.

Wilczewski, E., Szczepanek, M., Wenda-Piesik, A. 2018. Response of sugar beet to humic substances and foliar fertilization with potassium. *Journal of Central European Agriculture* 19: 153-165.

Yakhin, O.I., Lubyanov, A.A., Yakhin, I.A., Brown, P.H. 2017. Biostimulants in plant science: a global perspective. *Frontiers in Plant Science* 7: 2049.

Conflict of Interest Statement: The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.