PESQUISA AGROPECUÁRIA GAÚCHA

doi: https://doi.org/10.36812/pag.2022281139-155

ORIGINAL ARTICLE

Effect of irrigation, planting position, and application of calcium silicate on garlic development in 'Serra Gaúcha' region, South Brazil

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Abstract - Garlic crop is widely distributed in the Serra Gaúcha region, South Brazil. However, there is little information relative to irrigation in garlic, and on the influence of bulbil planting position in the development of the crop. Silicon is being used in garlic as an auxiliary fertilizer, but it is necessary to study further its effects in the crop. This study aimed to verify the effect of different irrigation regimes based on the evapotranspiration and empirically, evaluate the development of the plants that germinated under different planting positions, and observe the physiology of the plants according to the different doses of calcium silicate applied to the soil. Experiments were carried out in the municipality of São Marcos, using a design of randomized blocks, with four repetitions in each treatment. Plant height, stalk height and diameter, germination percentage of the bulbils, and average bulb mass were evaluated. The observed results indicated that irrigation induced higher plant heights when it was carried out based on evapotranspiration; planting with the bulbils face up have had the smaller germination time and the highest average bulb mass; the application of silicon at the highest dose (800 kg·ha^{-1}) increased the average bulb mass by approximately 18 %.

Keywords: *Allium sativum*. 'San Valentin'. Micronutrients. Evapotranspiration.

Efeito da irrigação, posição de plantio e aplicação de silicato de cálcio sobre o desenvolvimento da cultura de alho na região da Serra Gaúcha, Sul do Brasil

Resumo - A cultura do alho é amplamente distribuída na região da Serra Gaúcha, Sul do Brasil. Todavia, há poucas informações sobre a irrigação em alho e sobre a influência da posição de plantio do bulbilho no desenvolvimento da cultura. O silício está sendo utilizado no alho como fertilizante auxiliar, mas é necessário estudar mais seus efeitos na cultura. Este trabalho visou verificar o efeito de diferentes regimes de irrigação com base na evapotranspiração e empiricamente, avaliar o desenvolvimento das plantas que germinaram em diferentes posições de plantio e observar a fisiologia das plantas de acordo com as diferentes doses de silicato de cálcio aplicadas ao solo. Os experimentos foram realizados no município de São Marcos, seguindo um delineamento de blocos casualizados, com quatro repetições em cada tratamento. Avaliaram-se a altura das plantas, altura e diâmetro do colmo, porcentagem de germinação dos bulbilhos e massa média dos bulbos. Os resultados indicaram que a irrigação induziu maiores alturas de plantas quando realizada com base na evapotranspiração; o plantio com os bulbilhos voltados para cima teve o menor tempo de germinação e a maior massa média dos bulbos; a aplicação de silício na maior dose (800 kg·ha^{-1}) aumentou a massa média do bulbo em aproximadamente 18 %.

Palavras chave: *Allium sativum*. 'San Valentin'. Micronutrientes. Evapotranspiração

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ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received on March 16 2022. Accepted on May 30 2022.

Introduction

Garlic (*Allium sativum* L.) is a crop widely cultivated in South Brazil due to its flavor and aroma characteristics, being one of the main culinary condiments used in Brazil. Original from Central Asia, garlic is an herbaceous plant, belonging to Amaryllidaceae family and subfamily Allioideae. Brazil is one of the greatest world producers of garlic, but despite having edaphoclimatic conditions that favor this crop, the Brazilian production does not meet the national demand, being necessary to import this condiment (LANDAU; BARTOLOMEU; SILVA, 2020). According to 2019 data from IBGE, the national production was 131,523 t, with average productivity of 11.73 t ha^{-1}, an increase of 9.6 % regarding the 2018 harvest (IBGE, 2020).

Garlic planting is carried out by vegetative propagation with bulbils since the seeds are non-viable in field conditions. The plant growth is affected by the position in which the bulbils are put in the soil. Planting the bulbils in positions that may hinder plant growth may cause losses in crop productivity since plants with smaller heights, delay in bulbil germination, and bulbs with smaller mass and diameter are less valuable commercially and generate heterogeneity in the crop (LUCINI, 2004).

Garlic is very susceptible to drought and excess water; its water requirement (as rainfall) throughout the cycle varies between 400 and 800 mm. Thus, proper irrigation management is essential to attain higher productivity and good bulb conditions in post-harvest. Currently, most farmers do not carry out a standardized irrigation procedure, running the risk of jeopardizing the crop due to lack or excess water in critical stages of the plant cycle (BRAGA, 2014; MAROUELLI, 2017).

According to the traditional management of garlic crops, it is preferable that the bulbils be planted in a way where the side from which the roots will develop be downwards, and the side where the vegetative part be upwards, facilitating the germination. However, there are few studies that evaluated a possible influence of bulbil position at planting on germination and crop productivity. Burba (2003) concluded that bulbils, when planted in an inverted position, caused a 47 % reduction in crop productivity, a common problem especially regarding the mechanized planting of this crop (CHENGQIAN *et al.*, 2008). Castellanos *et al.* (2004) described that, when garlic bulbil is planted in an inverted position, seedling emergence is delayed, and it tends to be uneven. Aquino *et al.* (2017) observed that, when bulbils are planted sideways, productivity may not be negatively affected but the bulbs tend to become deformed.

Silicon (Si) is an element that is abundant in the soil since it constitutes the mineral fraction of it, such as quartz, kaolinite, feldspar, among others (REIS *et al.*, 2007). This element is not regarded as essential, and the decree n°. 4,954 have classified it as a micronutrient (BRASIL, 2004). However, there is no consensus relative to its classification because silicon is present in considerable amounts in the soil but at the same time is classified as a micronutrient according to Brazilian law (BRASIL, 2004; SENA; CASTRO, 2010).

The addition of Si may help to improve the natural plant defenses against pathogens by increasing the resistance of cell walls. This increase in cell was resistance also has effect in increasing the tolerance to drought in some species, such as rice, wheat, soybean, sunflower, and pepper, among others. This effect is important once hydric stress is the main abiotic stress that affects crop plants. On the other hand, crop yields

PESQ. AGROP. GAÚCHA, V.28, N.1, P. 139-155, 2022.
ISSN: 0104-907. ISSN ONLINE: 2595-7686.
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and productivities are often reduced because of drought and the lack of sufficient water in critical development periods. In garlic, these periods are vegetative growth and bulbil differentiation (PETRAZZINI; SOUZA; CARVALHO, 2011; HAYNES, 2017; AVILA *et al.*, 2020).

This work aimed to evaluate the water requirement for garlic crops, aiming to observe an equilibrium point between the lack of and excess water; to verify whether the bulbil planting position had any effect on plant growth and crop productivity; and to observe whether the addition of increasing doses of silicon generate some effect on crop productivity and biometric parameters of the plants.

Materials and methods

Field conditions and crop management

The study was carried out in field conditions, in a rural property located in the municipality of São Marcos, South Brazil, between May and October 2020. This region has a Cfb climate according to Köppen classification. The property, whose soil was classified as cambisol (EMBRAPA, 2018), is located at the geographical coordinates 28º 54’ 21’’ S and 51º 09’ 00’’ W, with an altitude of 687 m above sea level.

Table 1. Fertility parameters of the soil used in the experiments, sampled in the depth of 0-10 cm.

Parameter	Unit	Result
pH	-	6.7
pH-SMP	-	6.7
Clay	% w/v	44.0
P	$mg{\cdot}dm^{-3}$	71.0
K	$mg{\cdot}dm^{-3}$	> 300.0
Ca	$cmol_c{\cdot}dm^{-3}$	10.6
Mg	$cmol_c{\cdot}dm^{-3}$	4.6
Organic matter	% w/v	3.2
S	$mg{\cdot}dm^{-3}$	8.7
Mn	$mg{\cdot}dm^{-3}$	12.1
B	$mg{\cdot}dm^{-3}$	1.8
Cu	$mg{\cdot}dm^{-3}$	10.4
Zn	$mg{\cdot}dm^{-3}$	21.0
Al	$cmol_c{\cdot}dm^{-3}$	0.1
H+Al	$cmol_c{\cdot}dm^{-3}$	2.0
CEC at pH 7	$cmol_c{\cdot}dm^{-3}$	18.1
Effective CEC	$cmol_c{\cdot}dm^{-3}$	16.3
Base saturation	%	89.2
Al saturation	%	0.5
Ca/Mg	molar ratio	2.3
Ca/K	molar ratio	10.9
Mg/K	molar ratio	4.8
Clay	wt.%	53.0
Silt	wt.%	28.0
Sand	wt.%	20.0

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The crop management was carried out following the nutritional state of the soil and crop recommendations, according to Embrapa (2015). Liming and fertilization were carried out following the official recommendations for garlic (CQFS, 2016). The same management was applied to all treatments, aiming to standardize it throughout the experiment. The fertility parameters of the area used in the study are presented in Table 1.

The bulbils were kept in a cold chamber for 50 days at 3 ± 1 ºC and 65 % RH in order to reduce the need for chilling hours, allowing for the plantation of the crop in areas that do not have the optimum climatic conditions for garlic cultivation (RESENDE *et al.*, 2011).

Experiment evaluating the irrigation regime

This experiment tested three irrigation regimes: control (no irrigation), irrigation based on farmer experience (empiric), and irrigation based on the calculated potential evapotranspiration (PET) of the crop.

PET was calculated using equation 1, proposed by Hargraives and Samani (SAMANI, 2000), which uses average, maximum, and minimum temperature data measured *in situ* and the extraterrestrial radiation (R_a), a tabulated value (IAPAR, 2019).

$$ET_0 = 0.0135 \times K \times R_a \times (T_{max} - T_{min}) \times (T_{med} + 17.8) \quad (1)$$

With the determination of ET_0, the PET_c (evapotranspiration of the crop) was calculated using equation 2. Based on it, the irrigation volumes were determined.

$$PET_c = ET_0 \times K_c \quad (2)$$

The following crop coefficient (K_c) values for garlic were considered: 0.80 to 0.85 in the vegetative stage, 1.00 to 1.05 during bulb growth, and 0.70 to 0.75 in bulb ripening (ALLEN *et al.*, 1998; MAROUELLI; LUCINI, 2013). The irrigation layer (L) was calculated daily; irrigation was carried out when the difference between PET_c and rainfall (P) was equal or greater than 15 mm, according to equation 3.

$$L = PET_c - P \quad (3)$$

Irrigation based on PET_c was carried out using a watering can to control strictly the amount of water supplied to the parcels.

Empiric irrigation was the one carried out based on farmer's experience, using mid-sized impact sprinklers. The calculated irrigation layer indicated that about 15 mm·m^{-2} were needed, considered that each parcel had 3.6 m^2; 54 L of water were applied in each parcel of this treatment throughout the experiment.

PESQ. AGROP. GAÚCHA, V.28, N.1, P. 139-155, 2022.
ISSN: 0104-907. ISSN ONLINE: 2595-7686.
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Experiment evaluating bulbil planting position

In this experiment, garlic bulbils were planted in three different positions. In the upward position, the bulbil apex was pointed upwards (recommended position), and the root developing side was downwards. In the sideways position, bulbils were placed laterally, with both the vegetative and root parts in the soil-air interface. In the inverted position, the bulbils were planted with the vegetative part downwards and the root part upwards.

Experiment evaluating the effect of silicon application to the crop

Silicon was supplied as calcium silicate (Ca_2SiO_4) in powder form (Silifértil Ambiental®, Itatiaia, Brazil), containing 16.3 wt. % Si, 36 – 40 wt. % Ca, and relative total neutralizing power (RTNP) of 63 %. The doses of zero, 200, 400, 600, and 800 $kg{\cdot}ha^{-1}$ Ca_2SiO_4 (corresponding to the doses of zero, 32.6, 65.2, 97.9, and 130.5 $kg{\cdot}ha^{-1}$ of pure silicon) were tested, with manual incorporation to a depth of 10-20 cm.

Evaluation of crop productivity and garlic biometric parameters

The following parameters were evaluated in all experiments: crop productivity, plant height, stalk diameter, bulb diameter, and average bulb mass. Germination percentage was only evaluated in the experiment of bulbil planting position because preliminary tests showed that both silicon application and irrigation regime had no effect on this parameter. Plant tissue analysis was only carried out in the silicon application experiment.

The biometric parameters were determined following the procedures described by Petrazzini, Souza, and Carvalho (2011). Plant height was measured using a measuring tape, starting in soil surface up to the topmost completely developed leaf. Stalk and bulb diameters were measured with a digital caliper. For these measurements, ten plants were randomly chosen from each parcel. Average bulb mass was determined immediately after harvest, in which all bulbs from each parcel were weighed and the arithmetic mean was calculated. The productivity was calculated by weighing all bulbs of each parcel and dividing by parcel area (3.6 m^2); the results were converted into tonnes per hectare ($t\ ha^{-1}$). Germination percentage was calculated by counting the number of seedlings that emerged in each parcel in 10, 15, 25, and 55 days after the planting of the bulbils. Ca determination in plant tissue was carried out following the procedures described by Malavolta, Vitti and Oliveira (1997).

Experimental design and statistical analysis

The study was composed by three independent experiments, one evaluating bulbil planting position, one evaluating the irrigation regime, and one evaluating the application of increasing doses of Ca_2SiO_4. The experiments were carried out following a randomized blocks design, with four replicates for each treatment. Spacing between plants was 12 cm between plants and 20 cm between lines, with a 10 cm border in each side of the parcel area; this spacing was used in all experiments, regardless of the treatment. Each parcel was composed of an area with 1.2 x 3.0 m, totaling 3.6 m^2 and 55 plants per parcel and 220 plants per treatment.

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
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The obtained results underwent Levene's test (homoscedasticity) and Shapiro-Wilk test (normality of residuals), followed by Analysis of Variance (ANOVA) and Tukey's multiple range test at 5 % probability ($\alpha = 0.05$). All statistical analyses were carried out using the AgroEstat® software.

Results and discussion

Effect of irrigation on garlic crop development

The 2020 cycle for garlic started with high rainfall volumes, about 400 mm in the period between May and June 2020, with and accumulated rainfall of 1,174 mm in the 180 days of the cycle (INMET, 2020). As can be seen in Figure 1, rainfall was high but poorly distributed throughout the crop cycle, considering that the average accumulated rainfall for garlic ranged between 400 and 850 mm, varying in accordance with the development stage. This crop requires more water in the vegetative stage and with variations in the temperature, being necessary temperatures below 15 °C for bud differentiation and 10 – 20 °C in the rest of the cycle (MAROUELLI, 2017).

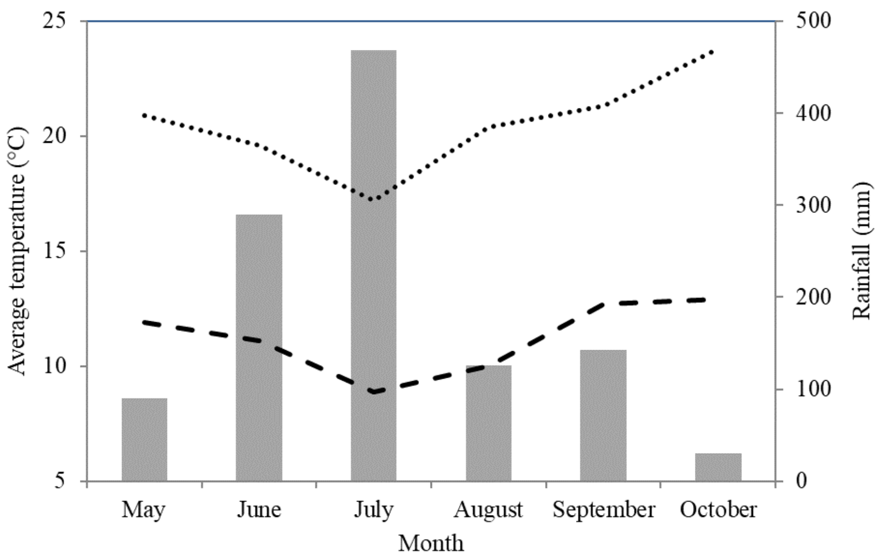

Figure 1. Rainfall (bars) and average maximum (dotted line) and minimum (dashed line) temperatures registered from May to October 2020, when the study was carried out. Source: INMET (2020).

In the germinative stage (10 – 30 days), the bulbils rely only on their own energetic reserves, not depending on external water supply. Even so, rainfall occurred in a balanced way in the starting phase (90 mm) an even in excess in June (287 mm).

In July, August, and September occurred the periods of vegetative growth and bulb differentiation (85 – 90 days), which are critical regarding hydric deficit. The rainfall supplied the crop demand (more than 700 mm between July and September 2020) since the plant demands more water as the roots and aerial parts grow. In this phase evapotranspiration tends to increase due to plant growth and because of temperature increase in August and September, in the transition between winter and spring, rendering the plants more susceptible to water stress (NICK; BORÉM, 2017).

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
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Considering that the rainfall volumes supplied more than enough the water requirements of the crop, the farmer had not irrigated the plants. Based on the PET equation used in the work, in this phase five irrigation events were carried out, in the following dates: June 02, June 22, August 06, August 21, and September 20, 2020.

The ripening stage (30 – 35 days) has lower water requirements (50 – 80 mm) because in this phase soluble solids accumulate, and the plant dries (ABYANEH *et al.*, 2011). However, as can be observed, from the beginning of October there was a drought period (30 mm), and the farmer had to irrigate the parcels on October 10 and 15, adding 30 mm of water in each irrigation event. PET calculation required more frequent irrigation events. Between October 1st and 30th, six irrigation events were carried out, on October 3rd, 11th, 16th, 21st, 25th, and 30th.

According to the observed results (Table 2), irrigation had no influence on bulb and stalk diameters and average bulb mass, only plant height was influenced.

Table 2. Results of the evaluation of garlic crop development parameters as a function of the irrigation regime.

Treatment	Productivity ($t \cdot ha^{-1}$)	Plant height (cm)	Stalk diameter (mm)	Bulb diameter (mm)	Average bulb mass (g)
Control	7.42 a	41.45 c	12.35 a	47.13 a	48.6 a
Empiric	8.48 a	45.13 b	12.46 a	49.63 a	55.5 a
Evapotranspiration	8.45 a	49.40 a	13.61 a	49.46 a	55.3 a
F-value	2.50 ^{NS}	312.70**	3.78 ^{NS}	1.82 ^{NS}	2.50 ^{NS}
MSD[1]	1.65	0.98	1.56	4.48	10.77
CV[2] (%)	9.34	0.99	5.61	4.24	9.35

Means in column followed by the same letter do not differ statistically by Tukey's multiple range test at 5 % (*) or 1 % (**) probability. [1] – Minimum significant difference. [2] – Coefficient of variation. ^{NS} – Not significant.

The plants irrigated based on PET calculation had higher plant height (49.4 cm) than the ones irrigated based on farmer experience (45.1 cm), which was also higher than the control (41.5 cm). On the other hand, all other parameters were not influenced by the irrigation regime. This may be attributed to the fact that there was enough rainfall to supply the water demand for most of the crop cycle, including the most critical periods.

As observed by Ahmad and Choi (2021), even if the crop cycle has high rainfall volumes, it is necessary to carry out irrigation events. This is due to the uneven distribution throughout the cycle since excessive rainfall in one stage does not compensate for water deficits in other stages of crop development. Considering that irrigation depends on the climatic conditions, which are specific and variable for each productive cycle, and there are years in which irrigation may be unnecessary and others it may be needed. Marouelli, Silva, and Moretti (2002) commented that vegetative growth is negatively affected when there is water deficit in the soil, as observed in the present work, in which the control had the smallest plant height.

Oliveira (2019) observed that crop productivity was directly related to plant height and bulb diameter in irrigated areas. In the present work, it was possible to observe that the greater heights occurred in the treatment with most irrigation (PET), however, crop productivity had not differed statistically between treatments; this behavior was different from the one reported by Oliveira (2019). This lack of difference in crop productivity in treatments under different irrigation regimes may be attributed to a more than enough rainfall in the most water demanding stage of the crop (MAROUELLI, 2017). However, it would be necessary to carry out further evaluations to establish a definitive relationship regarding the observed results.

Effect of bulbil planting direction on garlic crop development

The results of the biometric parameters of garlic crop relative to bulbil planting positions are presented in Table 3.

Table 3. Results of development parameters for garlic crop as function of different bulbil planting positions.

Treatment	Productivity ($t \cdot ha^{-1}$)	Plant height (cm)	Stalk diameter (mm)	Bulb diameter (mm)	Average bulb mass (g)
Face up	7.97 a	51.32 a	11.75 a	48.90 a	52.2 a
Sideways	7.46 a	48.40 a	10.76 a	47.79 a	48.8 a
Inverted	4.77 b	34.95 b	8.09 b	40.48 b	31.2 b
F-value	12.98**	53.35**	59.81**	50.09**	12.98**
MSD[1]	2.07	5.18	1.06	2.80	13.54
CV[2] (%)	14.16	5.32	4.79	2.82	14.16

Means in column followed by the same letter do not differ statistically by Tukey's multiple range test at 5 % (*) or 1 % (**) probability. [1] – Minimum significant difference. [2] – Coefficient of variation.

According to Table 3, crop productivity and plant height differed statistically, in which the plants whose bulbils were planted inverted had smaller height 73 days after planting. The plants whose bulbils were planted in the inverted position had productivity 40 % smaller than the parcels in face up position. Stalk diameter was also smaller in the inverted bulbils (8.09 mm), whereas both face up and sideways positions had similar performance (11.75 and 10.76 mm, respectively).

Bulb diameter in harvest was also smaller in the plants whose bulbils were planted inverted. Based on Brazilian classification, these bulbs were classified as class 4 (37 – 42 mm), whereas the bulbs of the other two treatments (face up and sideways) were classified as class 6 (47 – 56 mm). It is important to stress out that this classification is the base used for marketing and pricing, in which higher classes have better pricing than the lower ones (BRASIL, 1992).

The evaluation of average bulb mass had statistical differences, in which the plants whose bulbils were planted in the inverted position had average mass of 31.3 g, whereas the planting position face up and sideways had average bulb masses of 55.2 and 48.8 g, respectively, not differing statistically. Comparing the masses, the plants whose bulbils were planted in the inverted position had an average mass 40 % smaller than the other two treatments.

According to Resende, Haber and Pinheiro (2014), average productivities for garlic cultivated in South Brazil ranged between 8.25 and 13.71 $t \cdot ha^{-1}$, whereas average productivities in specific regions with optimum conditions may achieve up to 15 t·ha^{-1}, such as in Cerrado biome, in Southeast Brazil (LANDAU; BARTOLOMEU; SILVA, 2020). It can be considered that crop productivity was low (the highest productivity observed was 7.97 t·ha^{-1}), but with the spacing used in this work, the number of plants per hectare was approx. 152,800, whereas some works comment on plant densities up to 600,000 plants per hectare (CASTELLANOS *et al.*, 2004). This may explain the lower yield relative to other crop productivities reported in the literature.

Moreover, in the treatment where the bulbils were planted in the inverted position, it was possible to observed irregularities and deformations in plant stalks (Figure 2).

(a) (b) (c)

Figure 2. Comparison of plant growth according to bulbil planting position: face up (a), sideways (b), and inverted (c).

Figure 3. Stalk softening in the plants whose bulbils were planted in the inverted position.

In Figure 2 is possible to observe that the bulbils planted face up (a) had an almost straight stalk, whereas the ones planted sideways (b) and inverted (c) had stalk deformations. The bulbils planted inverted presented the greatest deformations. Alves (1997) reported a similar phenomenon when testing the inverted bulbil planting position. On the other hand, no important irregularities were observed in the plants whose bulbils were planted in the upwards and sideways positions.

PESQ. AGROP. GAÚCHA, V.28, N.1, P. 139-155, 2022.
ISSN: 0104-907. ISSN ONLINE: 2595-7686.
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It is also important to point out that the plants whose bulbils were planted inverted had stalk softening (Figure 3). This may be a physiological response to bulbil position or a symptom of a bacterial disease, factors that may cause great damage to the crop and render the garlic unmarketable. This phenomenon was not observed in the plants whose bulbils were planted in the upwards and sideways positions.

The plants whose bulbils were planted sideways have not differed from the upward position regarding the biometric parameters and productivity. However, it was possible to observe that there were stalk deformations similar to the ones observed for the inverted planting position; this phenomenon may cause loss of commercial value of the product (AQUINO *et al.*, 2017).

Regarding bulbil germination, there were significant differences between the three planting positions, with a behavior similar to the one observed by Castellanos *et al.* (2004). The bulbils planted in the upward position had a quicker and even germination than the ones planted sideways. The germination pattern relative to the days after planting is presented in Figure 4.

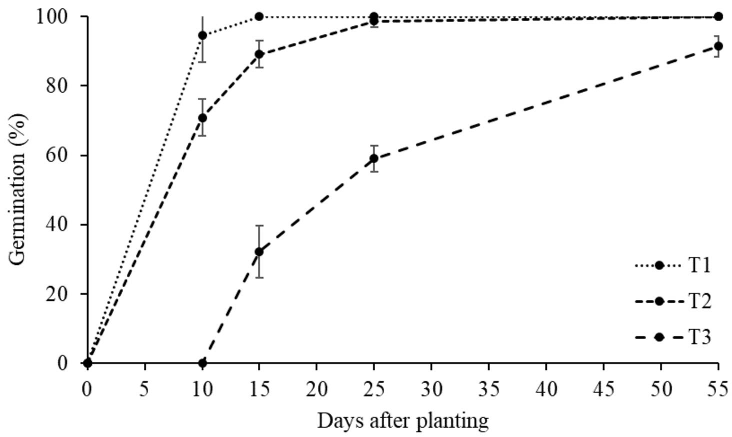

Figure 4. Germination of garlic bulbils planted face up (T1), sideways (T2), and inverted (T3). Evaluation carried out 10 days after planting: MSD (5 %): 12.451; F-value: 293.97**; CV: 10.41 %. Evaluation 15 days after planting: MSD (5 %): 11.814; F-value: 178.42**; CV: 7.37 %. Evaluation 25 days after plating: MSD (5 %): 4.960; F-value: 412.49*; CV: 2.66 %. Evaluation 55 days after planting: MSD (5 %) = 3.888; F-value: 31.01**; CV: 1.85 %. ** - Significant at 1 % probability level.

It is possible to observe that all plants whose bulbils were planted face up emerged within 10 days after planting, whereas no bulbils planted inverted had germinated in the same period. The bulbils planted sideways germinated unevenly and there were plants with deformed bulbs in harvest.

There are few studies in the literature that address bulbil planting position and its effect on garlic germination and development. Couto (1958) observed that bulbils planted sideways and inverted had germination difficulties, with germination delays up to 25 days relative to bulbils planted face up. Chen, Keong, and Chiu (1976) also observed a similar behavior and commented the occurrence of high levels of

Received on March 16 2022. Accepted on May 30 2022.

heterogeneity in the crop, which was also observed in this work. Lucini (2004) recommended that the bulbils be planted upwards, aiming to obtain a crop with germination and growth as uniform as possible. On the other hand, Resende *et al.* (2011) reported that the planting position of the bulbil had no effect on the biometric parameters of the plants, causing only difficulties and delays in germination. However, as seen in this work, the inverted planting position affected negatively both crop productivity and plant biometric parameters.

Fifty-five days after planting, all plants should have germinated, indicating the loss of viable bulbils that were planted inverted, considering that 8.64 % of the plants of this treatment have not emerged. Regarding the bulbils planted sideways, there was 98 % germination after 55 days and all plants emerged (100 % germination) when the bulbils were planted upwards. These results show that the planting position of the bulbil is critical since all parcels whose bulbils were planted inverted had poorer performance, as observed by Burba (2003) and Lopez, Burba, and Lanzavechia (2012).

Planting is one the most important stages in the productive chain and cycle of garlic, and bulbil positioning are limiting when considering the mechanization of this crop. Schimidt (1997) concluded that most of the mechanization equipment already designed for garlic planting does not meet the requirement of bulbil positioning at planting, indicating that mechanization can bring losses until a system is developed capable of ensuring the right bulbil planting position. Beltrame and Schmidt (2013) observed when developing a prototype of mechanization machine for garlic that 56.4 % of the bulbils released form the machine in the upward position effectively remained planted in this position, a percentage still too low to carry out an efficient mechanization of this crop.

Influence of silicon application on crop productivity and garlic biometric parameters

The results of crop productivity and the biometric parameters of the plants regarding the application of increasing silicon doses are presented in Table 4.

According to Table 4, there were no statistical differences regarding plant height, stalk diameter, and bulb diameter. For crop productivity and average bulb mass, the plants supplied with the highest Ca_2SiO_4 dose (800 kg·ha^{-1}) had higher productivity (5.99 t ha^{-1}) and average bulb mass (39.2 g) when compared to the control (5.09 t ha^{-1} and 33.3 g, respectively). The other Ca_2SiO_4 doses have not differed statistically from the control.

The application of Ca_2SiO_4 at a dose of 800 kg·ha^{-1} caused an increase of about 18 % in productivity. Petrazzini, Souza and Carvalho (2011), who tested the application of the same doses of Ca_2SiO_4 tested in this work, commented that greater Ca_2SiO_4 doses tend to increase the average productivity of garlic and bulb quality for marketing.

However, as commented by Reis *et al.* (2007), garlic is classified as a species that does not accumulate silicon. Considering that Ca_2SiO_4 also has about 40 wt % calcium in its composition, it is possible that calcium is also playing a role in increasing crop productivity, or even a synergistic effect may be occurring with the joint supply of silicon and calcium. This dual supply of silicon and calcium may be promoting vegetative growth and bulb development, increasing crop productivity (MA; MIYAKE; TAKAHASHI, 2001).

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received on March 16 2022. Accepted on May 30 2022.

The results of Ca content in plant tissue are presented in Table 4. The application of Ca_2SiO_4 had no effect on the Ca content in the plant tissue of garlic. Moreover, when analyzing Table 1, it is possible to observe that Ca content in the soil prior to the application of Ca_2SiO_4 was already considered as high (values above 4.0 $cmol_c \cdot dm^{-3}$ are regarded as high). The soil pH was also adequate since the recommended pH value for garlic is 6.0 (CQFS, 2016).

Table 4. Results of development parameters for garlic with increasing calcium silicate doses.

Ca_2SiO_4 dose ($kg \cdot ha^{-1}$)	Productivity ($t \cdot ha^{-1}$)	Plant height (cm)	Stalk diameter (mm)	Bulb diameter (mm)	Average bulb mass (g)	Ca content in plant tissue ($g \cdot kg^{-1}$)
zero	5.09 b	44.70 a	9.82 a	40.57 a	33.3 b	4.7 a
200	5.71 ab	43.60 a	10.15 a	42.49 a	37.4 ab	4.5 a
400	5.53 ab	44.65 a	9.61 a	41.61 a	36.2 ab	4.4 a
600	5.97 ab	44.50 a	9.77 a	43.14 a	39.1 ab	4.7 a
800	5.99 a	46.30 a	10.16 a	43.59 a	39.2 a	4.3 a
F-value	3.49*	1.43 ^{NS}	0.85 ^{NS}	1.85 ^{NS}	3.49*	2.25 ^{NS}
MSD[1]	0.89	3.67	1.19	4.01	5.85	0.7
CV[2] (%)	7.01	3.64	5.30	4.21	7.01	8.1

Means in column followed by the same letter do not differ statistically by Tukey's multiple range test at 5 % (*) or 1 % (**) probability. [1] – Minimum significant difference. [2] – Coefficient of variation. ^{NS} – Not significant.

Thus, considering that Ca contents in soil before the application of Ca_2SiO_4 were already quite high, the addition of more Ca had no effect in the crop. In this sense, the increase in the production was probably due to the presence of greater amounts of available silicon as silicate (SiO_4^{-4}) for absorption by the garlic plants.

The treatment with irrigation based on PET_c calculations resulted in plants with greater height, but with no effect on the other parameters evaluated, probably because the rainfall that occurred was sufficient to meet the water requirements of the crop. Based on the results obtained during the experiment, it can be considered that the planting position directly influenced several productive aspects. Bulbils planted in the vertical position had better germination, biometric parameters, and productivity relative to the other planting positions, which explains the difficulties in mechanizing garlic crops. The application of calcium silicate increased the average bulb mass and productivity, where the highest dose used (800 $kg \cdot ha^{-1}$) had a higher average bulb mass and productivity 17.7 % higher relative to the control, with no significant effect on the other parameters analyzed.

Conflict of interest

The authors declare that the research was conducted in the absence of any potential conflicts of interest.

Received on March 16 2022. Accepted on May 30 2022.

Ethical statements

The authors confirm that the ethical guidelines adopted by the journal were followed by this work, and all authors agree with the submission, content and transfer of the publication rights of the article to the journal. They also declare that the work has not been previously published nor is it being considered for publication in another journal.

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ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received on March 16 2022. Accepted on May 30 2022.

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ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received on March 16 2022. Accepted on May 30 2022.