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Tomato growth submitted to different soil water conditions using biostimulants

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Abstract

Stress caused by water deficit is the main factor that decreases the productivity and quality of agricultural products. The objective of this study was to describe the morphological components of tomato plants subjected to different soil water conditions, as well as elucidate the use of the Seed+ and Crop+ biostimulants as an alternative to mitigate the effects of water deficit. The experiment was conducted in a completely randomized design with 12 treatments: control; Seed$^+$; Seed$^+$ + Crop$^+$ 1x; Seed$^+$ + Crop$^+$ 2x; Crop$^+$ 1x; Crop$^+$ 2x, in soil water conditions at 50% and 100% soil water retention capacity (WRC). The plant height, leaf width and length, and stem diameter variables referring to the plants were assessed under both soil water conditions and by applying biostimulants. Data were organized and adjusted to the non-linear logistic regression model in order to describe the growth of tomato plants of the Santa Cruz Kada cultivar, which proved to be adequate to describe the growth and showed the best fit; in addition, the use of the Seed+ and Crop+ biostimulants helped in the morphology of tomato plants in both water conditions and reduced the damages caused by water deficit.

Keywords: logistic model, *Solanum lycopersicum*, water deficit

Introduction

Tomato (*Solanum lycopersicum* L.) is the main vegetable produced in Brazil and an important global commodity (Boteon et al., 2020). According to the IBGE (2021), the planted area amounts to approximately 52.12 thousand hectares, with a production of 3.7 million tons. However, yield is directly related to water conditions, as the crop is extremely sensitive, requiring high water demand throughout the cycle (Melo, 2014).

When subjected to stress, plants express different reactions to adapt, synthesizing adaptive molecules within organized structures (Chanamé, 2016). Thus, under water deficit conditions, they may present responses such as decreased stomatal conductance (Nascimento et al., 2011), reduced photosynthesis (Lopes et al., 2011), lower leaf water potential, reduced plant and leaf size, leaf abscission, larger root system, and reduced fresh and dry matter, etc. (Morales et al., 2015). However, all these characteristics directly interfere in the productivity and final quality of the product.

In an attempt to mitigate the damages caused by water deficit, the use of biostimulants based on natural or synthetic substances and seaweed, mainly *Ascophyllum nodosum* (L.), has been chosen. They can regulate or modify the physiological processes of plants, stimulating plant growth and mitigating the effects of abiotic stresses, consequently increasing their productivity (Yakhin et al., 2017). These products can be applied to seeds, plants, or directly to the soil over the sowing or planting furrow (Yakhin et al., 2017), favoring signaling in plants for the production of elicitors or osmoprotective substances, producing changes in cell metabolism, as well as favoring the structuring of the cell wall and cuticle in leaves and stems.

Research has shown that the use of biostimulants improves the initial establishment of plants, increasing

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resistance to stresses caused by drought, temperature, salinity, diseases and insects, and promotes greater root development and greater intensity of the green color due to the higher chlorophyll content (Rodrigues et al., 2015). The Seed+ and Crop+ biostimulants consist of a formulated mixture of macronutrients and micronutrients and fermented extracts of the *Ascophyllum nodosum* (L.) seaweed (Wozniak and Martineau, 2007). This seaweed is made up of phenolic compounds, alginic acid, mannitol, laminarin, betaines, proteins, lipids, among other carbohydrates (Shukla et al., 2018).

Growth analysis describes plant development as a function of time and said development can be evaluated in several ways. One alternative is to adjust growth curves, which provide information about the growth of the plant and its phenological stages (Leite et al., 2017). Thus, the adjustment of nonlinear regression models can be used to facilitate the interpretation of plant development. Among them, the logistic model is widely used because it provides information based on the estimates of its parameters and presents a biological interpretation (Prado et al., 2013). These models were used to describe the fruit production behavior of *C. annuum* and *C. pepo* (Lúcio et al., 2015), zucchini, pepper and cherry tomato (Lúcio et al., 2015; Lúcio et al., 2016), strawberry (Diel et al., 2020a, 2019), tomato (Sari et al., 2019), pout pepper (Diel et al., 2020b), among others.

In this context, the objective of this study was to model the growth of tomato plants of the Santa Cruz Kada cultivar, fitting it to the nonlinear logistic regression model, in order to describe the plant height, stem diameter, leaf width and length variables referring to tomato plants subjected to different soil water conditions, with a view to elucidating the responses of the Seed+ and Crop+ biostimulants as an alternative to mitigate the effects of water deficit.

Material and Methods

The experiment was carried out in a 50 m x 12 m greenhouse, at the Experimental Station in the Boca do Monte District (29°39,059' S and 53°57,413' W), located in the municipality of Santa Maria, Rio Grande do Sul, RS. According to the Köppen classification, the climate of the region is Cfa Subtropical humid, with hot summers, with no defined dry season (Alvares et al., 2013). The soil is classified as sandy Red Dystrophic Ultisol. According to the soil physical analysis report from the Soil Physics Laboratory – UFSM, it is considered to be type 2, belonging to the following textural class (SBCS): Sandy loam, with base saturation < 50%, 60.6% sand, 22.8% silt and 16.6% clay.

The experimental design used was completely randomized, and its treatments are described in **Table 1**. The cultivar used was Santa Cruz Kada. Sowing was performed in Styrofoam trays with 200 cells filled with Mecplant® substrate, which were divided into two floating systems, with the Seed+ biostimulant being applied to one, at a dose of 100 mL.100L^{-1} of water, and the other receiving just water. The seedlings remained in this system for approximately 30 days, and then they were transplanted into 9-liter black polypropylene pots filled with 8.5 kg of soil, which had been sieved, homogenized and had its acidity corrected in accordance with the soil analysis.

Table 1. Description of the treatments assessed in the experiment. Santa Maria - RS, 2019.

Treatments	Soil water condition
T1 - Control	50% WRC
T2 - Seed$^+$	50% WRC
T3 - Seed$^+$ + Crop$^+$ 1x	50% WRC
T4 - Seed$^+$ + Crop$^+$ 2x	50% WRC
T5 - Crop$^+$ 1x	50% WRC
T6 - Crop$^+$ 2x	50% WRC
T7 - No treatment	100% WRC
T8 - Seed$^+$	100% WRC
T9 - Seed$^+$ + Crop$^+$ 1x	100% WRC
T10 - Seed$^+$ + Crop$^+$ 2x	100% WRC
T11 - Crop$^+$ 1x	100% WRC
T12 - Crop$^+$ 2x	100% WRC

The WRC of the soil was determined by drying until constant mass was reached (oven at 70° C). Subsequently, the dry soil was irrigated until saturation and then weighed; by subtracting the mass of the pot with dry soil from that of the pot with wet soil, the volume of water necessary to reach 100% WRC was obtained.

Water was supplied regularly through the weighing method, using an ACS System electronic scale with a precision of 5 g, with water being added until the predetermined total mass was reached (pot + dry soil + volume of water to reach 100 or 50% soil WRC). To determine the soil water conditions (50% and 100% soil WRC), the following adapted formulas were used:

$$PM50\% = (PMWRC - PMdry) \times 0.5 + PMdry \quad (1)$$

$$PM100\% = (PMWRC - PMdry) \times 1.0 + PMdry \quad (2)$$

Where: PM% - pot mass for each of the treatments; PMWRC - pot mass at water retention capacity; and PMdry - mass of the pot filled with dry soil.

The Crop+ biostimulant was applied at doses of 100 mL 100L^{-1} (Crop+ 1x) and 200 mL 100L^{-1} (Crop+ 2x), in the flowering development stages, 69 609 BBCH scale (Meier, 2001); afterwards, water deficit in the soil was induced. The evaluations were carried out weekly based on plant height (cm), measured from the stem to the longest leaf, with the aid of a millimeter ruler; leaf length (cm) and width (cm), assessed on the same leaf with the aid of a millimeter ruler; and stem diameter (mm), measured at 3 cm from the base, with the aid of a 150 mm professional manual caliper.

The data obtained were adjusted by the nonlinear logistic model, using this formula: $Yi=\beta_1/(1+\exp(\beta_2-\beta_3*xi))+\varepsilon$, with Yi being the measured variable; xi being time (in days after transplant (DAT)); β_1 being the horizontal asymptote; β_2 reflecting the distance between the initial value (observation) and the asymptote; β3 being the growth rate; ε being the experimental error. The critical point estimates were obtained by equating to zero the second order derivative (inflection point - IP), third order derivative (maximum acceleration point - MAP and maximum deceleration point - MDP) and fourth order derivative (asymptotic deceleration point - ADP) (Mischan et al., 2011; Mischan & Pinho, 2014). IP represents the maximum growth rate; MAP provides the time the plant took to obtain maximum increment; MDP is the moment when the increments start to decrease; ADP is the moment when the increments become insignificant (Mischan & Pinho, 2014), and concentration (difference between MAP and MDP) is the period in which the plant had the longest growth time (Sari et al. 2018).

The estimates of the model parameters were obtained by the least squares method, using the Gauss-Newton iterative method, performed using the nls () function, in the R software. Subsequently, the normality, homogeneity and independence of the residuals were tested by the Shapiro-Wilk, Breusch-Pagan and Durbin Watson tests, respectively. The lmtest and car packages of the R software were used to test the homogeneity of the variances and the independence of the residuals, respectively. However, due to the violation of the assumptions, the bootstrap estimate resampling was used through the nlsboot function of the nlstools package in the R software. The goodness of fit of the nonlinear model was evaluated by the curve method suggested by Bates & Watts (1988) and must take into account the measures of intrinsic (c^{ι}) and parametric (c^{θ}) nonlinearity, whose values must remain below 0.3 and 1.0, respectively (Fernandes et al. 2015). The intrinsic and parametric nonlinearity test used the rms.curv function in the MASS package of the R software. It was also based on the adjusted coefficient of determination (R^2aj), the Akaike information criterion (AIC), and the Schwarz-Bayesian information criterion (BIC). All analyses adopted a level of 5% error probability and were run in the R software .

Results and Discussion

For the plant height, stem diameter, and leaf width and length variables, the estimated residuals showed normal and homoscedastic distributions (p-value<0.05). However, the assumption of independence of errors was not met, that is, the residuals are autocorrelated, a condition explained by the evaluations having occurred on a weekly basis (data not shown). Nonetheless, when the model's assumptions are not fully met, the confidence intervals for the parameters can be estimated using bootstrap resampling to circumvent problems with the model's assumptions (Diel et al., 2020a, 2019).

The model will represent growth when it is close to linear, that is, when intrinsic (c^{ι}) and parametric (c^{θ}) nonlinearity are obtained with lower values, which are below 0.3 and 1.0, respectively (Fernandes et al., 2015). According to Sari et al. (2019), these measures are important to assess the goodness-of-fit of models to describe plant growth. In general, the intrinsic and parametric nonlinearity measures presented values within the normal range, with only a few treatments not meeting the assumptions, and only at values above 1.0 for parametric nonlinearity, as found in treatments T3, T9 and 10 for plant height, and T4 and T11 for leaf width (**Table 2).** In the four variables analyzed, the R^2aj values were high, close to 1, indicating that the data provided good fit.

Table 2. Values of goodness-of-fit measures for the nonlinear logistic model, for intrinsic (c^{ι}) and parametric (c^{θ}) nonlinearity, and adjusted coefficient of determination (R^2_{aj}) referring to the plant height, stem diameter, and leaf length and width variables, in the Santa Cruz Kada cultivar, Santa Maria, 2019.

	Height			Diameter			Length			Width		
Treat	c^{ι}	c^{θ}	R^2_{aj}	c^{ι}	c^{θ}	R^2_{aj}	c^{ι}	c^{θ}	R^2_{aj}	c^{ι}	c^{θ}	R^2_{aj}
T1	0.0614	0.9993	0.9974	0.0479	0.6412	0.9978	0.0593	0.8308	0.9969	0.0566	0.8284	0.9971
T2	0.0614	0.9993	0.9975	0.0640	0.6831	0.9964	0.0593	0.8308	0.9972	0.0643	0.6690	0.9966
T3	0.0675	1.1770	0.9967	0.0657	0.7810	0.9959	0.0676	0.9858	0.9953	0.1484	0.9143	0.9816
T4	0.0648	0.8684	0.9972	0.0627	0.7165	0.9965	0.0555	0.8098	0.9971	0.0321	1.1239	0.9983
T5	0.0646	0.9494	0.9973	0.0556	0.6015	0.9973	0.0939	0.8605	0.9933	0.0616	0.7826	0.9963
T6	0.0551	0.9648	0.9981	0.0838	0.7260	0.9936	0.2081	0.80124	0.9528	0.0489	0.6190	0.9978
T7	0.0932	0.8268	0.9945	0.0498	0.6557	0.9976	0.0548	0.6182	0.9975	0.0479	0.5252	0.9980
T8	0.0609	0.9071	0.9976	0.1243	0.3823	0.9929	0.0557	0.7269	0.9974	0.1168	0.8035	0.9926
T9	0.1147	2.8128	0.9914	0.0939	0.7052	0.9922	0.0541	0.6446	0.9976	0.0556	0.6637	0.9972
T10	0.0701	1.0854	0.9958	0.0562	0.6084	0.9976	0.0500	0.5960	0.9979	0.0627	0.6736	0.9965
T11	0.1330	0.9667	0.9912	0.0534	0.7638	0.9972	0.0567	0.6852	0.9970	0.1512	1.4069	0.9729
T12	0.0595	0.9114	0.9972	0.1490	0.7320	0.9815	0.0574	0.6765	0.9971	0.0555	0.6983	0.9972

In this study, it was observed that the description curves of the plant height, leaf length and width, and stem diameter variables of tomato plants, adjusted to the nonlinear logistic regression models, showed good model fit. The use of a nonlinear logistic regression model had a high descriptive capacity for numerous crops, such as zucchini, pepper and cherry tomato (Lúcio et al., 2016; Lúcio et al., 2015), strawberry (Diel et al., 2020a, 2019), tomato (Sari et al., 2019), and pout pepper (Diel et al., 2020b).

For the plant height variable, treatment T9 was the one that presented the greatest data variability and the greatest results, since the values of parameter β_1 (asymptote) were significantly higher than those of the other treatments, followed by T11 and T12, which did not differ statistically in height, under the 100% soil WRC condition, that is, the highest dose of the Crop+ biostimulant did not generate an increase for the plant height variable (**Figure 1**). In a study carried out by Lima et al. (2017), in which the authors assessed the effect of different irrigation depths on tomato development, they observed an increase in plant height at the 100% depth. These results corroborate those verified in this study, in which the use of biostimulants did not favor the height of plants under water deficit conditions.

The shortest plant heights were found in treatments T1 (control, 50% soil WRC) and T7 (control, 100% soil WRC), showing that the biostimulant influenced the height of plants, regardless of the soil water condition (Figure 1). Plant height is directly affected by water scarcity, which promotes changes in morphological characteristics and causes a decrease in cell turgor and a reduction in growth by elongation (Taiz et al., 2017).

The use of the Seed+ and Crop+ biostimulants, alone or in combination, presented similar results in the 50% soil WRC condition, in treatments T2, T3, T4, T5 and T6, contributing to mitigating the effects of water deficit on plant height (Figure 1). Biostimulants alter the physiology of plants, increasing the efficiency of water and nutrient use, resistance to stress, and consequently improving agronomic characteristics (Luz et al., 2018).

Also, it is observed that even in the 100% soil WRC condition, the application of biostimulants obtained positive results, with treatments T10 and T12 needing less time to reach the greatest plant heights (Figure 1). On the other hand, treatments T11 and T9 had taller tomato plants grown in a longer period of time. According to Battacharyya et al. (2015), biostimulants provide physiological changes and contribute to growth. Said changes include improving cell division, differentiation and cell elongation, providing greater absorption of water and nutrients (Silva et al., 2013).

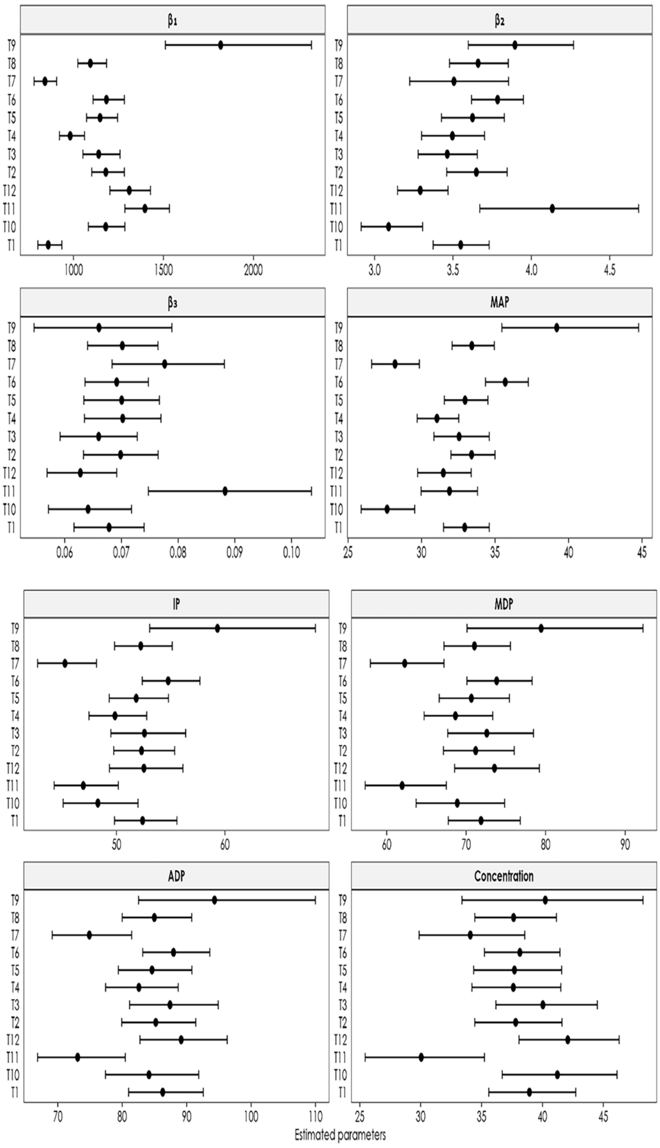

Figure 1. Confidence intervals of the parameters and critical points of the logistic model, estimated via bootstrap for the plant height (cm) variable, in the Santa Cruz Kada cultivar, Santa Maria, 2019. β_1 (represents height), β_2 (represents growth time), β_3 (represents growth rate), XMAP (maximum acceleration point), XIP (inflection point), XMDP (maximum deceleration point), XADP (asymptotic deceleration point) and Concentration (XMDP-XMAP)

The leaf area of a plant depends on the number and size of leaves and how long they remain on the plant. The results for the leaf width (cm) and length (cm) variables were similar, so it will only be represented by leaf length, as shown in **Figure 2**. Treatment T6 showed greater leaf length and width, longer growth time and higher growth rate, that is, even under water deficit condition, the Crop+ 2x biostimulant reversed the damage caused, promoting less impact even in the event of water deficit in the crop (Rodrigues et al., 2015). The increase in the leaf area promotes an increase in the plant's ability to

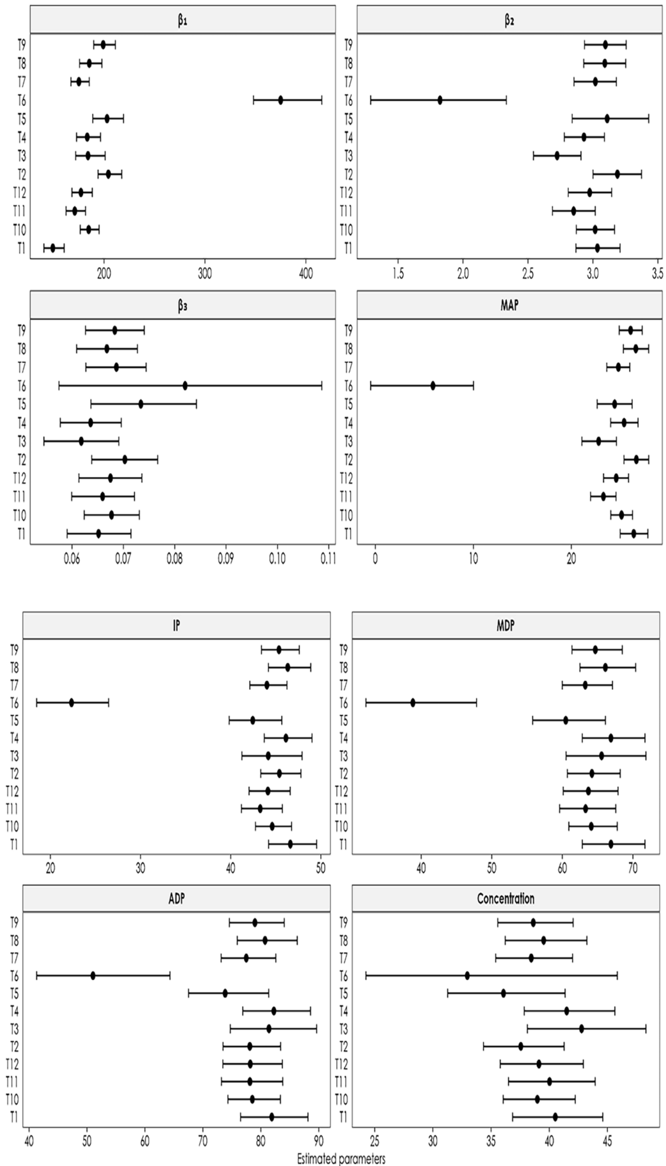

Figure 2. Confidence intervals of the parameters and critical points of the logistic model, estimated via bootstrap for the leaf length (cm) variable, in the Santa Cruz Kada cultivar, Santa Maria, 2019. β_1 (represents height), β_2 (represents growth time), β_3 (represents growth rate), XMAP (maximum acceleration point), XIP (inflection point), XMDP (maximum deceleration point), XADP (asymptotic deceleration point) and Concentration (XMDP-XMAP)

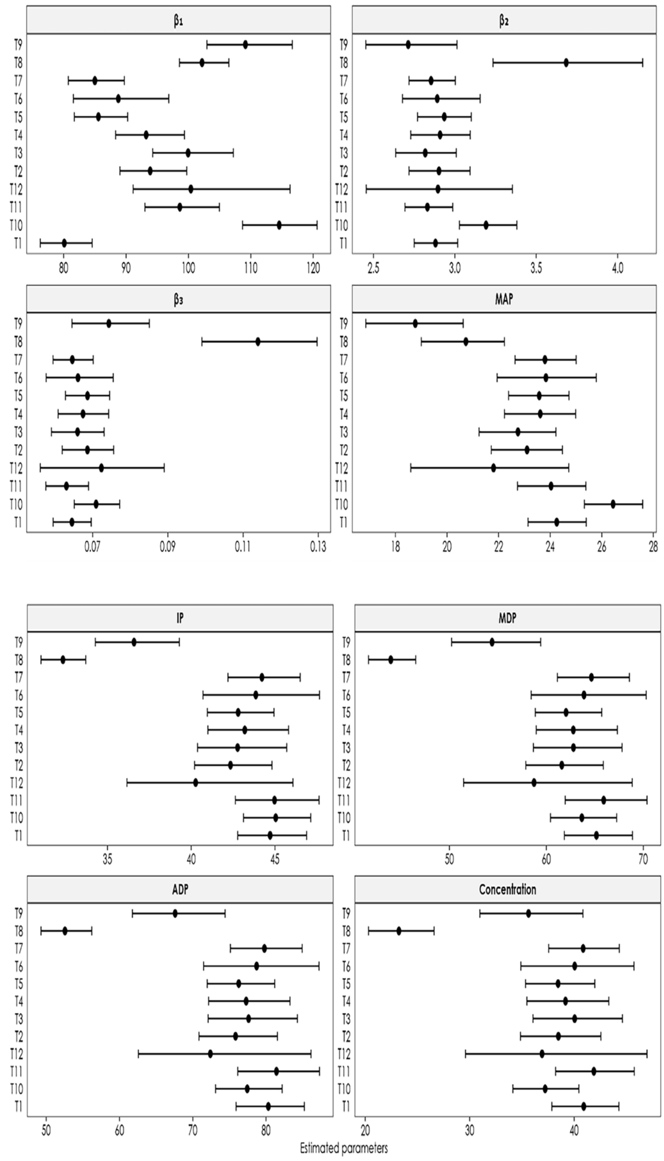

Figure 3. Confidence intervals of the parameters and critical points of the logistic model, estimated via bootstrap for the stem diameter (mm) variable, in the Santa Cruz Kada cultivar, Santa Maria, 2019. β_1 (represents height), β_2 (represents growth time), β_3 (represents growth rate), XMAP (maximum acceleration point), XIP (inflection point), XMDP (maximum deceleration point), XADP (asymptotic deceleration point) and Concentration (XMDP-XMAP)

take advantage of solar energy, resulting in a greater probability of it having a greater photosynthetically active area, and thus ensuring greater final productivity (San-Martín-Hernández et al., 2016).

Treatments T10 and T9 (**Figure 3**) presented the largest stem diameters, which is related to the better development of the aerial part and, mainly, of the root system, ensuring maximum capacity of translocation of nutrients and water to the aerial part (Santos et al., 2016). For PMA, treatment T10 had increases in stem diameter later than the others, as the benefits generated by the use of the Seed+ + Crop+ 2x biostimulants delayed the increase in stem diameter.

T8 presented a longer period of diameter growth and a higher rate of leaf expansion; according to Dantas et al. (2012), the increments may have different effects and can occur in parts or in the whole plant, during its growth. No difference was observed comparing T5 and T6 with T11 and T12 (Figure 3), that is, the application of the Seed+ and Crop+ biostimulants favors an increase in the efficiency of the use of mineral nutrients, which alter several physiological processes that contribute to stimulating plant development and reducing the effect of biotic and abiotic stresses on crops (Bulgari et al., 2015).

Figure 4 shows that water conditions affect the physiological and metabolic activities of plants, so treatment T1 had the smallest leaf width and length, plant height and stem diameter. The process that is most affected by water deficit is cell expansion, due to the need for water in the auxin-modulated growth process (Taiz et al., 2017). In addition, it is also observed that T6 presented greater leaf length. The stabilization of the growth of the analyzed variables occurred at 55 DAT.

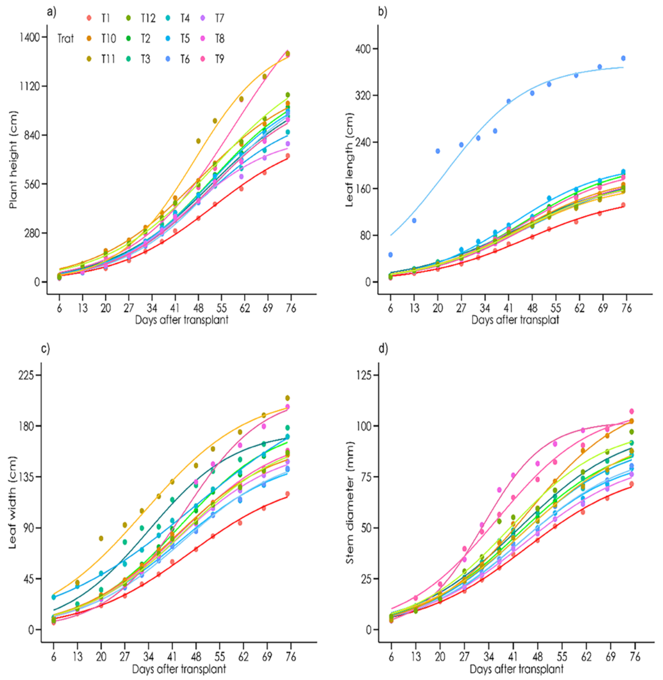

Figure 4. Growth curves observed using the nonlinear logistic regression model adjusted for plant height (a), leaf length (b), leaf width (c) and stem diameter (d), in the Santa Cruz Kada cultivar, Santa Maria, 2019.

Conclusions

The logistic model presented good fit to all treatments and variables analyzed, in the 50% and 100% conditions.

Treatment T9 (Seed+ + Crop+ 1x) was the one with the highest plant height, in the 100% soil WRC condition. Moreover, together with T10, it had the largest stem diameters.

Treatment T6 (Crop+ 2x, in the 50% soil WRC condition) presented a larger leaf area, which may mean a larger photosynthetically active area, and was the treatment with the longest growth time and greatest growth rate, even under a water deficit condition, which can directly influence productivity.

The use of the Seed+ and Crop+ biostimulants helped improve the morphology of tomato plants under the two tested water conditions and reduced the damages caused by water deficit.

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