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Production of tomato cultivated in different nutritive solutions

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Abstract

The objective this paper is determine the highest performance of fresh mass and number of fruits in tomato crops using different nutrient solution. An absolute hybrid with a semi-determined growth was used. It was grown in a protected environment using a fertigated substrate inside plastic bags containing ten liters of solution. The experiment was completely randomized with four levels of fertilization and five replications. Two experiments were carried out in two cultivation cycles (spring 2018 and autumn 2019) by performing an analysis of variance and Scott & Knott test and estimating the parameters of nonlinear logistic model and its critical points for both variables in each treatment. The mean fruit mass per plant was 3.70 kg for the spring experiment and 3.80 kg for the autumn experiment. The mean number of fruits per plant was 10.50 and 10.70 fruits for spring and autumn, respectively. There are significant differences between the treatments KO46, KO45 and KO56 compared to KO69 for fruit mass in the autumn experiment. For the other variables and cultivation cycles, the treatments did not show statistical differences. The logistic growth model fitted the weight and number of tomato fruits according to days after transplanting the seedlings and evidenced production cycle data, highlighting the main differences between the nutrient solutions. The nutritional solutions KO46, KO45 and KO56 are recommended for growing Gaúcho tomatoes in substrate. The nutrient solution KO56 has the best performance because it has a higher K availability, meets the balance of loads and antagonism between nutrients, provides equal response of means mass and number of fruits, and has a lower N:K ratio and balance of K over Ca and Mg, thus favoring fruit production, precocity, and development.
Keywords: logistic grown model, multiple harvests, nonlinear regression; plant nutrition, productivity

Introduction

Tomato is one of the main vegetables grown in the world. However, there is difficulty in growing tomatoes directly on the soil of protected environments (Moraes, 1997). Migration to growing crops on substrates has increased because substrates are an alternative means of employing the same production structure as that of protected environments. In this condition, there is only a change in the space for establishing the crop roots, making the activity viable due to crop safety.

Differences in yield can be influenced by hybrids, environmental conditions, management, stacking system, time to remove the buds from the nodes, and type of pruning. It should be noted that the earlier the shoots from the lateral nodes are removed, the less interference in the assessment of productivity levels. This fact influences the quality of the production systems (Andriolo, 2000).

For soil-less cultivation, it is necessary to use nutritional solutions to meet the nutritional requirements of plants. All nutrients must be supplied at levels compatible with the requirements of each species or cultivar and according to their stage of development. Thus, proper concentrations of nutrients in the solution are essential to increase productivity and improve product quality (Furlani et al., 2009).

The composition of the nutrient solution used in substrate cultivation must be determined according to the concentration of nutrient absorption by the plant and the interactions between the ions that compose the solution (Andriolo et al, 2003; Furlani et al, 2009). The nutritional status of plants indirectly produces a plant stand outside the standard of the cultivar, interfering with light interception, ventilation, and humidity inside the greenhouse.

Bio-based nonlinear growth models can be used to extract as much information as possible from a data

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set. They provide the reality of the production cycle in each experimental treatment, allowing inferences and interpretations not obtained in analysis of variance or complementary statistical tests such as comparisons of treatment means or linear regression analyses (Diel et al., 2017, 2020; Sari et al ., 2018, 2019).

As tomato produces it is possible to use regression models as a statistical tool for data analysis (Lúcio et al., 2015, Lúcio et al., 2016). The accumulation of values of productive variables in each harvest shows that production starts slowly and goes through an exponential growth that later decreases to a point at which it stabilizes. This type of response is sigmoidal and typical of nonlinear regression models known as growth models (Mischan et al., 2011).

Thus, this paper purpose to evaluate the production and the number of tomato fruits using non-linear logistic models and different nutrient solutions.

Material and Methods

The research was conducted in a greenhouse in the municipality of São Vicente do Sul (29°40'46.22” S and 54°40'08.09” W) in the state of Rio Grande do Sul, southern Brazil. Two experiments were installed, one in the spring of 2018 (August to December) and the other in the autumn of 2019 (February to June). The hybrid was the Gaúcho (Absoluto) of the company Feltrin® Sementes. It has a semi-determined growth.

Spring sowing took place on July 1, 2018, while autumn sowing took place on January 16, 2019. For this purpose, polystyrene trays with 128 cells were used. They were filled with Carolina® commercial substrate and one seed per cell was planted. The emergence occurred seven and five days after sowing (DAS) for the spring and autumn crops, respectively. At 35 and 29 DAS for spring and autumn, respectively, the seedlings were transplanted, one plant per cultivation container.

As a culture container, white polyethylene bags with a volume capacity of 10 liters each were used. The cultivation substrate was composed of 50% of superimposed litter for horses at an advanced stage of decomposition and 50% of carbonized rice husk. It should be noted that these materials are easily found in the region at a lower cost compared to commercial organic substrates. The aforementioned materials were mixed in a concrete mixer until homogenized. The bags were arranged in rows in the longitudinal direction of the greenhouse, with 1 m between rows and 0.4 m between bags, obtaining a density of 2.5 plants m^{-2}.

The experimental design was completely randomized with five replications and ten plants per plot. Four treatments were conducted according to the different levels of fertilization represented in (**Table 1**).

To stack tomatoes, a single stem was used and stacked by PVC tapes which kept the plant upright. Fifteen days after transplantation (DAT), the breeding phase started. The side shoots located next to leaves were manually removed. During the crop cycle, pests and diseases were monitored. Insecticide spraying was carried out to control tomato moth (*Tuta absoluta*) and whitefly (*Bemisia tabaci*). Fungal control was also carried out with applications every seven to 14 days with alternating active ingredients according to specific recommendations printed on the labels of pesticides recommended for the tomato crop.

The water used for irrigation and preparation of nutrient solutions was rainwater. This water was captured by the gutters of the greenhouse and driven through PVC pipes to two fiberglass boxes with a capacity of 20,000 liters each. The same levels of micronutrients were used for all treatments. The concentrations for 1,000 liters of nutrient solution were 30.0 g of 6% iron chelate, 7.0 g of boric acid, 6.0 g of manganese sulphate, 4.0 g zinc sulphate, 0.8 g of copper sulphate, and 0.3 g of sodium molybdate. The fertilizers used to prepare the nutrient solutions were calcium nitrate (18% Ca; 15.5% N), potassium nitrate (42%

Table 1: Composition of nutritional solutions (NS) in (mg L^{-1}) of fertilizers used and in $m.mol^{-1}$ of each macronutrient

Nutritional solution		Concentration of nutrients					
		$CaNO_3$	KNO_3	$MgSO_4$	MKP	MAP	K_2SO_4
KO69 (T1)		1,100	520	720	220	-	330
KO46 (T2)		650	546	370	82	46	-
KO45 (T3)		810	758	432	-	230	-
KO56 (T4)		810	1,162	432	-	230	-
	Macronutrients						
	NO_3^-	$H_2PO_4^-$	SO_4^{2-}	NH_4^+	K^+	Ca^{2+}	Mg^{2+}
KO69 (T1)	15.30	1.61	7.74	0.00	10.60	10.18	5.84
KO46 (T2)	12.00	1.00	3.00	1.00	6.00	6.00	3.00
KO45 (T3)	14.50	2.00	3.50	2.00	7.50	7.00	3.50
KO56 (T4)	18.50	2.00	3.50	2.00	11.50	7.00	3.50

Source: Authors.

K; 13% N), DAP (44% P; 32% K), magnesium sulfate (9.5% Mg; 12% S), potassium sulfate (51% K; 17% S), and MAP (61% P; 12% N).

The management of nutritive solutions took into account the electrical conductivity (EC) drained from the bags. In the four treatments, whenever the drained NS had an EC lower than 1.2 dS m^{-1}, the nutrient solution was applied to the plants; above this value, only water was supplied to the crop. For reading the EC in each treatment, NS collectors were built. They captured the NS drained from five consecutive bags and this NS was stored in a reservoir with a capacity of five liters.

For the preparation of the NS, the fertilizers were dissolved in water. They were separated into smaller containers and then inserted in 200-liter containers, homogenizing the nutrient solution up to an EC of 2.7 dS m^{-1}, verified by an EC measuring equipment (HANNA® combo). Irrigations and fertigation were carried out by micro spaghetti tube drippers with an outlet orifice per bag. The flow rate of each dripper was 9.0 L h^{-1}. The system was automated, composed of solenoid valves and a Hunter® automatic time controller. Irrigation was programmed according to the crop water requirement considering drainage of 20% of volume of water applied and following the recommendations of Alvarenga (2013). For fertigation and application of treatments, the equipment was used in manual mode.

The harvest began on September 22, 2018, and on May 2, 2019, for the spring and autumn experiments, respectively, with intervals of three to five days between one harvest and another. The fruits were harvested at an early stage of maturation considering their point of agronomic harvest from the greenish-pink color (Moraes, 1997). In each experiment, seven harvests were performed during the culture cycle. The evaluated parameters were fresh fruit weight (kg per plot), determined using a precision scale (NORTON TECH, Model: NT-SC40 digital 40-kg capacity), and number of fruits per plot.

The data obtained were submitted to analysis of variance. Means were compared by Scott-Knott test (p value < 0.05) and represented by box-plot graphs using the *Expdes* package in the software R (R Core Team, 2018).

The mass of fruits (kg $plot^{-1}$) and the number of fruits per plot obtained in each harvest were consecutively accumulated for each experimental plot (H1, H1 + H2, H1 + H2 + H3, ..., H1 + H2 +… H7). Then, a logistic model was fitted to each treatment and variable according to the following equation: $= \frac{\beta_1}{1 + e^{(\beta_2 - \beta_3 X_i)}}$ (I)

(I)

where Y_i is the mass of fruits or number of fruits (dependent variable); X_i is the days after transplantation (DAT, independent variable); β_1 is the asymptotic value, and its values represent the total production of treatments; β_2 is a parameter that reflects the distance between the initial value (observation) and the asymptote; and β_3 is the parameter associated with growth rate.

The parameter estimates were obtained using the ordinary least squares method with a Gauss-Newton algorithm. This procedure was performed using the *nls ()* function in software R (R Core Team, 2018). Later, the coefficient of determination (R2) and the intrinsic (c^I) and parametric (c^θ) non-linearity were calculated by the curve method as Bates and Watts (1988) suggested.

Then, $c^I \times \sqrt{F_{(\alpha;p,n-p)}}$ (II) and $c^\theta \times \sqrt{F_{(\alpha;p,n-p)}}$ (III) values were estimated, where $F_{(\alpha,p,\ np)}$ = F tabulated as a quantile of the F distribution, where α is 0.05, p is the number of parameters in the model and n is the number of observations. When these values are below 0.3 and 1.0, the parameters are nearly unbiased. The normality and homogeneity of residuals were assessed by the Shapiro-Wilk and Bartlett tests, respectively.

Due to the violation of the model's assumptions, the confidence intervals were obtained by a bootstrap approach. Using the *nlsboot()* function of the *nlstools* package in the software R (Baty et al., 2015), 1,000 estimates of each parameter were made for each treatment. The confidence intervals were obtained by the difference between the 97.5th and 2.5th percentiles of the bootstrap parameter estimates. When the confidence intervals did not cross, the treatments were considered different.

The coordinates (X and Y) of the critical points of the logistical model, known as the maximum acceleration point (XMAP), inflection point (XIP), maximum deceleration point (XMDP), and asymptotic deceleration point (XADP), were obtained by setting the following derivatives as equal to zero, according to methodology (Mischan et al., 2011) described:

inflection point (XIP) - $\frac{d^2 y(x)}{dx^2} = 0$ (IV);

point of maximum acceleration (XMAP) and point of maximum deceleration (XMDP) - $\frac{d^3 y(x)}{dx^3} = 0$ (V);

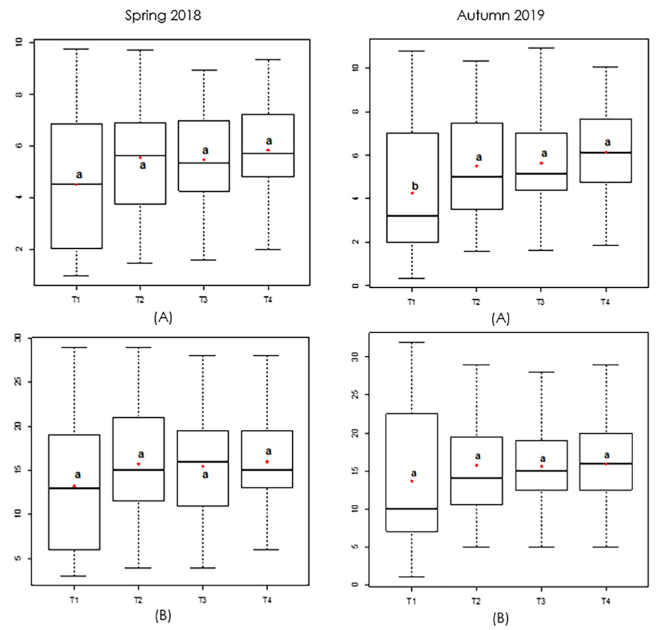
and point of asymptotic deceleration (XADP) - $\frac{d^4 y(x)}{dx^4} = 0$ (VI).

The precocity was defined when XIP was achieved (this point was related to the moment at which the fruit production rate was maximal). The concentration of production was defined by the difference between XMAP and XMPD, corresponding to the time during which the production increased exponentially (Sari et al., 2018).

Results and Discussions

There was a significant difference between nutrient solutions only for fruit mass in the autumn. The treatment (T1) had the worst performance (**Figure 1**). This treatment had an N:K ratio of 1:0.69, while the other treatments had a lower ratio. This indicates that the increase in K concentration promoted a significant difference for results of fresh weight of fruits per plant. This result partially corresponds to those Díaz et al. (2009) reported by cultivating fertigated tomatoes in the soil with N:K ratios in the nutrient solution of 1:0.45; 1:0.60; 1:0.75, and 1:0.90. The authors observed that both the highest (1:0.90) and the lowest ratios (1:0.45) hinder the production and number of fruits due to potassium concentrations. Thus, the authors concluded that the N:K ratio that most favored production and the number of fruits was 1:0.75. However, the results obtained in the present experiment differ from those Genuncio et al. (2010) obtained. Both in hydroponics and fertigated substrates, there were no differences in tomato production with different N:K ratios.

A hypothesis to explain the data of the present experiment is based on the high demand for calcium and magnesium by tomato mainly at the reproductive stage. Calcium and magnesium are cations antagonistic to potassium. Therefore, their concentrations must be observed so that an excess of potassium does not induce a deficiency in calcium and/or magnesium (Andriolo,



*** Means** not followed by the same letter for each variable and each growing season differ by Scott-Knott test (p value < 0.05).
Figure 1 - Box-plot for mass of fruits (A) and number of fruits (B) of tomatoes grown in different nutrient solutions KO69 (T1), KO46 (T2), KO45 (T3) and KO56 (T4) in two growing seasons.

1999). Thus, the antagonist relations between K/Ca+Mg and Ca/Mg for the treatments 2, 3, and 4 favored the equal response of means of fruit mass and number of fruits, in addition to the uniformity of fruits in the three treatments. The treatment 1, a solution widely used in the study region, does not meet the recommended standards.

For all treatments, the intrinsic and parametric nonlinearity were lower than 0.3 and 1.0, respectively. For non-linear regression models, the quality of the fitting must be defined based on the results of linearity measurements, as (Bates and Watts, 1988) proposed. The use of bootstrap confidence intervals (CI) to estimate parameters circumvents the non-compliance with the assumptions of regression models, normality, heterogeneity, and self-correlation of errors. It also allows for comparisons between the different treatments (Diel et al., 2020; Sari et al., 2019). However, the assumptions of nonlinear regression models were fully met. This fact validates the results of parameter estimates of the 16 fitted logistic models (**Figures 2** and **3**). The values of the 16 adjusted determination coefficients were also higher than 0.99, indicating an excellent quality of model fitting.

For fruit mass, as for number of fruits, the results obtained in the autumn experiment showed higher values of asymptote than those of the spring experiment, except for treatment 1 (Figures 2 and 3). The growth rate was higher in the spring experiment compared to that of the autumn experiment, except for treatment 2 (Figures 2 and 3). These results show that cultivation in autumn favors the production of tomato fruits. The hypothesis to explain this may be associated with the water condition of the plant in both growing seasons. In the autumn (February to June), the rate of transpiration of tomatoes tends to gradually decrease as the evaporative demand of the atmosphere decreases due to radiation. In this sense, the variation in water potential of the cultivation substrate tends to be smaller throughout the day, favoring the absorption and translocation of water and nutrients.

However, in the spring (August to December) the evaporative demand of the atmosphere tends to increase intensely due to solar radiation. This condition culminates in the maximum crop LAI, which consequently requires intense water absorption by the root system. When transpiration is more intense than the absorption of water by roots, the water potential of the plant tends to decrease rapidly. Thus, stomatal closure acts by regulating the water flow in the plant. Once the stomata close to decrease transpiration, photosynthesis is indirectly impaired by decreasing the concentration of CO_2 in the

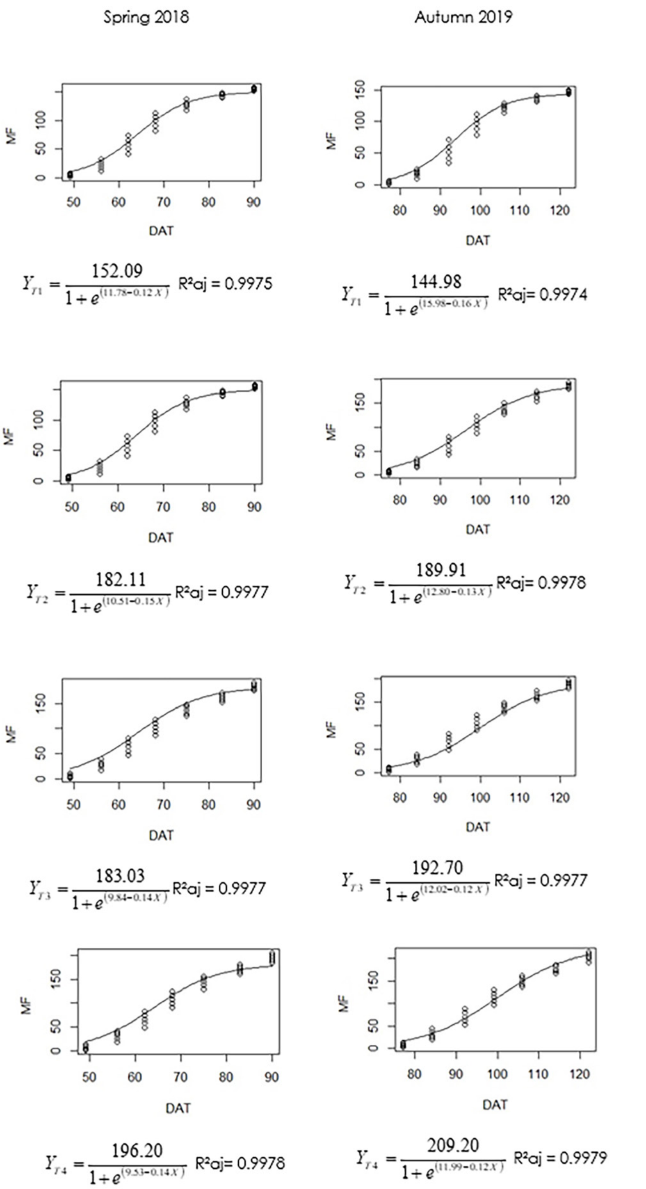


Figure 2 - Non-linear logistic model fitted for accumulated mass of tomato fruits (MF in kg), as a function of multiple harvests in days after transplanting the seedlings (DAT), grown in different nutrient solutions KO69 (T1), KO46 (T2), KO45 (T3) and KO56 (T4) in two growing seasons.

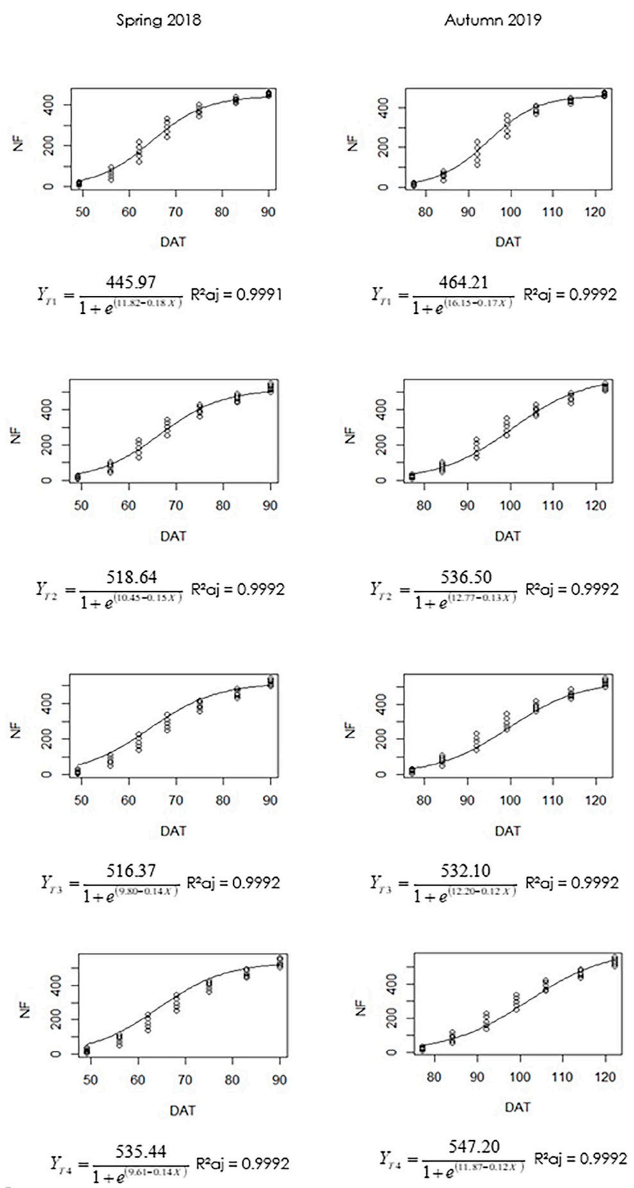


Figure 3 - Non-linear logistic model fitted for accumulated number of tomato fruits (NF), as a function of multiple harvests in days after transplanting the seedlings (DAT), grown in different nutrient solutions KO69 (T1), KO46 (T2), KO45 (T3) and KO56 (T4) in two growing seasons.

sub-stomatal chambers (Andriolo, 1999).

By observing the confidence intervals (**Figure 4**), the asymptotes of treatment 1 were significantly lower than those of the other treatments regardless of the growing season. These results confirm that the nutrient solution of T1 was unbalanced, disfavoring the mass of tomato fruits. As for the growth rate (Figure 4), T1 showed a higher mean value, but without a significant difference from the other treatments.

The scale parameter is that which, together with growth rate and points of maximum acceleration, indicates the early fruit production. There was no significant difference between nutrient solutions, according to the confidence interval, regardless of the variable and growing season (Figure 4). However, it appears that T1 had the highest absolute values of the scale parameter compared with the other treatments. It was higher for around two days in spring and five days in autumn.

The growth rate was higher in treatment 1 regardless of the variable and the growing season (Figure 4). However, this higher growth rate did not favor a greater fruit production because this was the treatment with the lowest estimated asymptotes and the lowest means (Figure 1). In addition, this treatment had the lowest inflection point and the lowest harvest concentration (Figure 4), indicating that it favors low production at a high speed in a shorter time.

Regarding the estimated critical points, what

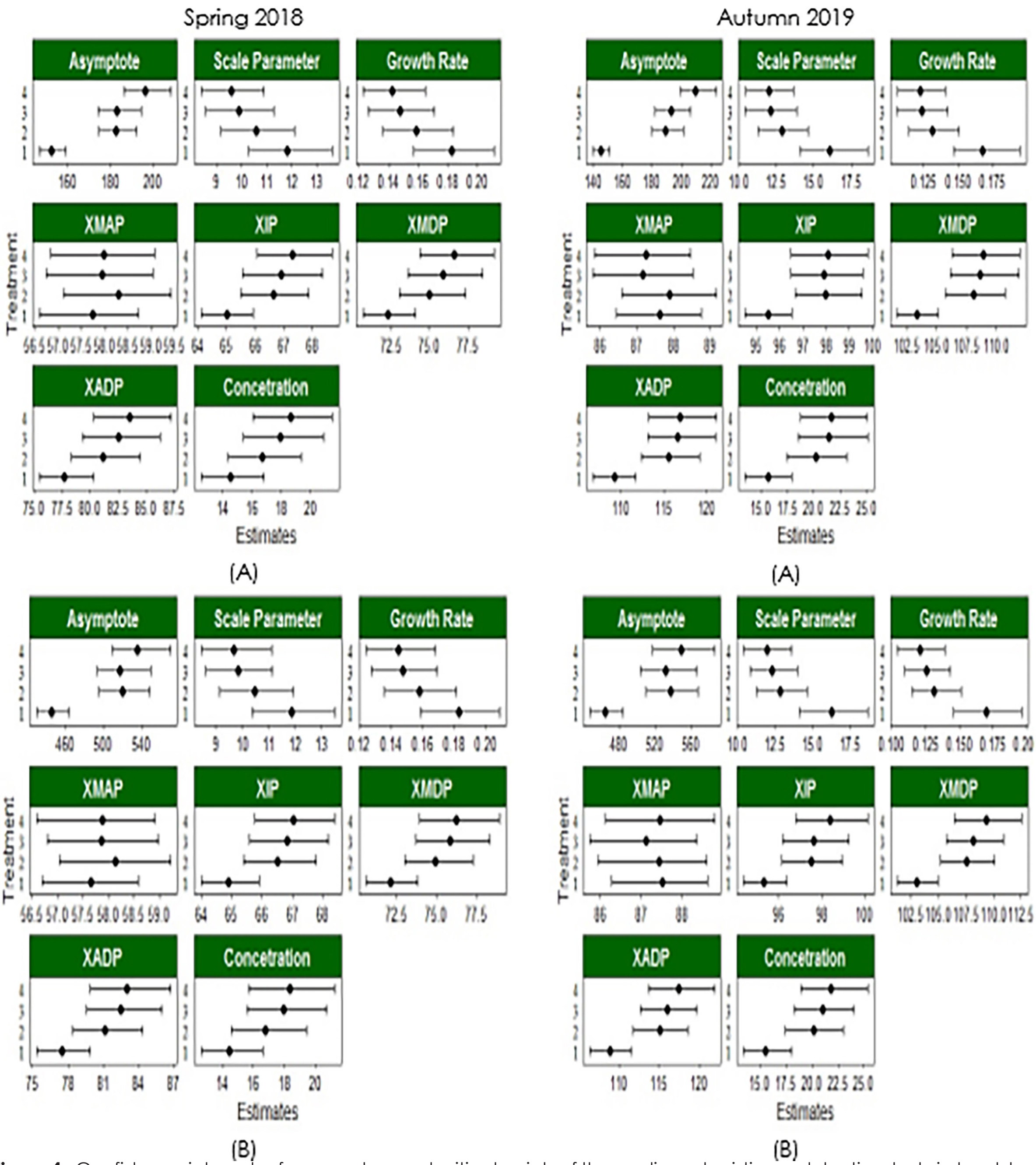


Figure 4 - Confidence intervals of parameters and critical points of the nonlinear logistic model estimated via bootstrap for mass of fruits (A) and number of fruits (B), asymptote (), scale parameter (), growth rate (), and XPAM (point of maximum acceleration).

is expected from favorable responses are nutritional solutions that have the shortest times of maximum acceleration, the longest times to reach the inflection point, the longest times of maximum deceleration and maximum asymptotic deceleration, and the highest concentration rates. There was a standard response where treatments represented by nutrient solutions 2, 3, and 4 showed absolute responses superior to the treatment with nutrient solution 1 (Figure 4).

These results can be interpreted by using the nonlinear logistic regression model, which has the critical points with biological interpretation. With the evaluation of only one variable it is possible to obtain several relevant data for the production and for the decision on which cultivar to choose according to the interests of the producer (Diel et al., 2020, 2019; Sari et al., 2018); otherwise, this information would not be identified.

The logistic growth model fitted for weight and number of tomato fruits according to days after transplanting the seedlings evidenced production cycle data, highlighting the main differences between the nutrient solutions.

The nutritional solutions 2, 3, and 4 are suitable for growing Gaúcho tomatoes in substrates. The nutritional solution 4 obtained the best performance because it has a higher K availability ratio in relation to the other nutrients. It meets the required load balance and antagonism between nutrients.

Conclusion

The nutritional solutions with the greatest availability of K and balance in relation to Ca and Mg provide a significant statistical increase in fruit mass in the autumn cycle and favor in both cycles gains in production, an earlier and longer production period. For number of fruits, there is no significant difference.

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