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*Scientific Article*

# Growth of oilseed flax described by nonlinear logistic model

# Crescimento da linhaça oleaginosa descrito por modelo não linear logístico

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**ABSTRACT** - Knowledge on plant-atmosphere interactions is essential to understand the growth and development of agricultural crops. Thus, fitting growth curves is an important methodology to model plant growth and phenological stages. The study aimed to describe the growth of four oilseed flax materials cultivated in six agricultural years and with different sowing dates through the nonlinear logistic model. Nine experiments were carried out in Curitibanos, SC, Brazil, between 2014 and 2020, considering different sowing dates. Throughout the crop cycle, the number of leaves, number of secondary stems, plant height and total dry mass were measured. Nonlinear logistic model was fitted to the data, with the growth variables as the dependent variables and the accumulated thermal sum as the independent variable. Model fit and parameter estimation were obtained by ordinary least method, using a Gauss-Newton algorithm. The goodness of fit was measured by intrinsic and parametric nonlinearity, adjusted coefficient of determination, random standard error, standard deviation of fit, Akaike information criterion, and Bayesian information criterion. The performance of the nonlinear logistic model differed between the varieties and cultivars studied, in different years and sowing times. However, the use of the nonlinear logistic model improves inferences about the growth of oilseed flax, and the estimates of its parameters and critical points allow a biological and practical interpretation to assist in crop planning. Furthermore, the study suggests that the oilseed flax cycle is directly related to genotype × environment interactions, and when sown at later times, the materials tend to shorten their cycle.

**Keywords**: *Linum usitatissimum* L. Edaphoclimatic conditions. Morphology. Growth curve.

**RESUMO** - O conhecimento das interações planta-atmosfera é essencial para compreender o crescimento e desenvolvimento das culturas. Assim, o ajuste de curvas de crescimento é metodologia importante para modelar o crescimento das plantas e seus estágios fenológicos. O estudo teve por objetivo descrever o crescimento de quatro materiais de linhaça cultivados em seis anos agrícolas e em diferentes épocas de semeadura por meio do modelo logístico. Nove experimentos foram conduzidos em Curitibanos, SC, Brasil, entre 2014 e 2020, considerando diferentes épocas de semeadura. Durante o ciclo da cultura, foram avaliados número de folhas, número de caules secundários, altura da planta e massa seca total. O modelo logístico foi ajustado considerando as variáveis de crescimento como dependentes e a soma térmica acumulada como independente. O ajuste do modelo e estimação dos parâmetros foram obtidos pelo método dos mínimos quadrados ordinários. A qualidade do ajuste foi mensurada por não linearidade intrínseca e paramétrica, coeficiente de determinação ajustado, erro padrão aleatório, desvio padrão do ajuste, critério de informação de Akaike e critério de informação Bayesiano. O desempenho do modelo logístico divergiu entre as variedades e cultivares, em diferentes anos e épocas de semeadura. Contudo, o uso do modelo logístico melhora as inferências sobre o crescimento da linhaça e, as estimativas de seus parâmetros e pontos críticos permitem uma interpretação biológica e prática a fim de auxiliar no planejamento da cultura. Ainda, o estudo sugere que o ciclo da linhaça está relacionado às interações genótipo× ambiente, sendo que em semeaduras tardias, os ciclos tendem a encurtar.

**Palavras-chave**: *Linum usitatissimum* L. Condições edafoclimáticas. Morfologia. Curva de crescimento.

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## INTRODUCTION

The principal commercial value of oilseed flax (*Linum usitatissimum* L.) is in the seeds, as they are rich in alpha-linolenic fatty acids (ALA), lignins, and soluble fibers (NADIMI; LOEWEN; PALIWAL, 2022). It is the raw material for the chemical and pharmaceutical industries, oil production, human and animal food (YAN; CHOUW; JAYARAMAN, 2014). The varieties cultivated in Brazil have golden and brown colored seeds, defined by pigments in the seed's outer coat, which are determined by environmental and genetic factors (BARROSO et al., 2014).

The oilseed flax crop is well adapted to the southern region of Brazil, where there is a predominance of cold weather, resulting in the production of seeds with high oil concentration and quality. Highly demanding in terms of appropriate climatic conditions, this crop needs low temperatures for its development (STANCK; BECKER; BOSCO, 2017), withstanding variations from 5 to 32 ºC throughout its cycle. Temperatures lower than -2 ºC, mainly in critical periods, germination and flowering, can cause plant death (CARVALHO et al., 2023). It requires a high-water regime, with 450-750 mm of rain evenly distributed during the cycle (STANCK; BECKER; BOSCO, 2017).

Knowledge on plant-atmosphere interactions is essential to understand the growth and development of agricultural crops. This knowledge generates information that will assist in planning, management, adaptability, product quality, and final yield (STANCK; BECKER; BOSCO, 2017). Thus, fitting growth curves is an important methodology to model plant growth and phenological stages (LEITE et al., 2017). Among the regression models, the nonlinear ones are suitable for describing biologically based growth curves because they have parameters with practical and biological interpretation.

The estimation of the parameters of a nonlinear regression model depends on how close to linear the model is, because the more linear, the more accurate the asymptotic results and the more reliable the inferences (CARINI et al., 2020; SILVA et al., 2021). According to Bates and Watts (1988), nonlinear models are generally adopted when the relationship between the response variable and the predictor variables follows a particular function. Nonlinear growth models are applied in several areas of knowledge, such as in agricultural sciences, in which they evaluate the cycle of a species or model growth according to the application of different treatments, e.g., the studies conducted by Akpo et al. (2014), Carson et al. (2014), Diel et al. (2019), Sari et al. (2019), Diel et al. (2020), Jane et al. (2020) and, Souza et al. (2017).

Additionally, in a pioneering study conducted by Peripolli et al. (2024), the performances of the Von Bertalanffy and Logistic nonlinear models were evaluated to characterize the growth of oilseed flax with different longitudinal, average, random, and transversal data collection scenarios. In general, the authors found that the logistic model performed better in the scenarios tested, even standing out as an interesting alternative for conditions with a reduced number of observations or in situations with losses of experimental units.

With the increase in demand for oilseed flax in the Brazilian and international markets, there is a need to generate knowledge to expand the possibilities of cultivation, following the indication of genetics and management adjusted for oilseed flax, as well as discussing models with flexibility of use in the face of different agricultural scenarios. Thus, the aim of this study was to describe the growth of oilseed flax varieties and cultivars grown in different agricultural years and with different sowing dates through the nonlinear logistic regression model.

## MATERIAL AND METHODS

### Study area and experimental design

The study was conducted with data from nine experiments carried out between the agricultural years 2014 and 2020 (Table 1), in the city of Curitibanos, in the state of Santa Catarina, southern Brazil, under geographic coordinates of 27°16'25" S and 50°30'12" W, with an altitude of 993 meters (m) above sea level. The climate in the region is of the Cfb type, humid subtropical with well-distributed rainfall throughout the year and subtropical from a thermal point of view, with average annual precipitation of around 1,480 mm, average maximum temperature of 22.0 °C and average minimum temperature of 12.4 °C (ALVARES et al., 2013). The soil is classified as *Cambissolo Húmico Háplico* (Inceptisol).

**Table 1**. Description of the nine experiments, sowing and harvesting dates, sowing time, genotypes, and growth variables evaluated, between 2014 and 2020, Curitibanos, SC, Brazil.

<table>
<tr><th>Year</th><th>Season</th><th>Genotypes</th><th>Sowing</th><th>Harvest</th><th>Cycle (days)</th><th>Variables</th></tr>
<tr><td rowspan="2">2014</td><td rowspan="2">S1</td><td>Brown. Var</td><td>08/14/2014</td><td>12/17/2014</td><td>125</td><td>PL, TDM and NL</td></tr>
<tr><td>Golden var.</td><td>08/14/2014</td><td>01/05/2014</td><td>144</td><td>PL, TDM and NL</td></tr>
<tr><td rowspan="2">2015</td><td rowspan="2">S2</td><td>Brown. Var</td><td>07/23/2015</td><td>12/12/2015</td><td>142</td><td>PL, TDM and NL</td></tr>
<tr><td>Golden var.</td><td>07/23/2015</td><td>12/12/2015</td><td>142</td><td>PL, TDM and NL</td></tr>
<tr><td rowspan="8">2016</td><td rowspan="3">S1</td><td>Aguará INTA cv.</td><td>04/26/2016</td><td>11/19/2016</td><td>207</td><td>PL, TDM, NL and NSS</td></tr>
<tr><td>Caburé INTA cv.</td><td>04/26/2016</td><td>11/19/2016</td><td>207</td><td>PL, TDM, NL and NSS</td></tr>
<tr><td>Golden var.</td><td>04/26/2016</td><td>11/19/2016</td><td>207</td><td>PL, TDM, NL and NSS</td></tr>
<tr><td rowspan="3">S2</td><td>Aguará INTA cv.</td><td>05/20/2016</td><td>12/06/2016</td><td>200</td><td>PL, TDM, NL and NSS</td></tr>
<tr><td>Caburé INTA cv.</td><td>05/20/2016</td><td>12/06/2016</td><td>200</td><td>PL, TDM, NL and NSS</td></tr>
<tr><td>Golden var.</td><td>05/20/2016</td><td>12/06/2016</td><td>200</td><td>PL, TDM, NL and NSS</td></tr>
<tr><td rowspan="2">S3</td><td>Aguará INTA cv.</td><td>06/24/2016</td><td>12/14/2016</td><td>173</td><td>PL, NL and NSS</td></tr>
<tr><td>Caburé INTA cv.</td><td>06/24/2016</td><td>11/19/2016</td><td>148</td><td>PL, NL and NSS</td></tr>
<tr><td rowspan="8">2018</td><td rowspan="4">S1</td><td>Aguará INTA cv.</td><td>04/13/2018</td><td>11/20/2018</td><td>221</td><td>PL and NSS</td></tr>
<tr><td>Caburé INTA cv.</td><td>04/13/2018</td><td>11/20/2018</td><td>221</td><td>PL and NSS</td></tr>
<tr><td>Golden var.</td><td>04/13/2018</td><td>10/22/2018</td><td>192</td><td>PL and NSS</td></tr>
<tr><td>Brown. Var</td><td>04/13/2018</td><td>11/20/2018</td><td>221</td><td>PL and NSS</td></tr>
<tr><td rowspan="4">S2</td><td>Aguará INTA cv.</td><td>05/24/2018</td><td>11/23/2018</td><td>183</td><td>PL and NSS</td></tr>
<tr><td>Caburé INTA cv.</td><td>05/24/2019</td><td>11/23/2019</td><td>183</td><td>PL and NSS</td></tr>
<tr><td>Golden var.</td><td>05/24/2020</td><td>11/23/2020</td><td>183</td><td>PL and NSS</td></tr>
<tr><td>Brown. Var</td><td>05/24/2021</td><td>11/23/2021</td><td>183</td><td>PL and NSS</td></tr>
<tr><td>2019</td><td>S1</td><td>Caburé INTA cv.</td><td>05/27/2019</td><td>12/22/2019</td><td>209</td><td>TDM</td></tr>
<tr><td>2020</td><td>S1</td><td>Brown. Var</td><td>09/06/2020</td><td>12/30/2020</td><td>115</td><td>PL and NSS</td></tr>
</table>

PL: plant height; TDM: total dry mass; NL; number of leaves; NSS: number of secondary stems.

The experimental design used was randomized complete blocks, with treatments varying over the years, composed of local varieties (Brown and Golden) and Argentine cultivars of brown color (Aguará INTA and Caburé INTA), with four repetitions (Table 1). The experimental units consisted of six sowing rows, 5.0 m long and 3.0 m wide, totaling 15 $m^2$. Sowing was carried out manually, at spacing of 0.02 m between plants and 0.35 m between rows, with a population of 143 plants $m^2$. The experimental area was under a no-tillage system.

### Weather conditions and measured growth variable

The data of air temperature (minimum, average and maximum) and accumulated rainfall were obtained from the automatic meteorological station linked to the National Meteorological Institute (INMET), located at Curitibanos airport, 5 km away from the experiments. The daily thermal sum (TSd) was calculated by the difference between the average daily temperature (T mean) and the lower basal temperature of the crop (Tb), TSd = (Tmean - Tb), considering 5º as the Tb of the oilseed flax crop (BERT, 2013). The accumulated thermal sum (TSa) was calculated from the emergence date by TSa= ∑TSd.

To carry out the growth analyses, the same methodology was adopted over the years. After emergence, 20 plants belonging to the usable area of each plot were randomly demarcated with colored wire. Twenty plants per treatment were evaluated weekly, counting the number of leaves (NL), number of secondary stems (NSS), and measuring plant height (PL), with the aid of a millimeter ruler, from the base to the apex of the plant. Total dry mass was measured every two weeks, collecting 12 plants per treatment, and placing them in paper bags. Subsequently, they were stored in an oven with air circulation at a temperature of 65 ° C, until they reached constant mass.

### Statistical analysis

The nonlinear logistic model considered the parameterization: $Y_i = \frac{\beta_1}{1+e^{(\beta_2-\beta_3 t_i)}} + \varepsilon_i$, where $Y_i$ is the measured variable; $t_i$ is the accumulated thermal sum, after emergence; $\beta_1$ is the horizontal asymptote; $\beta_2$ reflects the distance between the initial value (observation) and the asymptote; $\beta_3$ is associated with the growth rate; and $\varepsilon_i$ is associated with the experimental error.

Estimates of model parameters were obtained by the Gauss-Newton iterative method. Subsequently, the assumptions of normality, heteroscedasticity, and independence were tested by Shapiro-Wilk, Breusch-Pagan, and Durbin-Watson tests, respectively. Due to the violation of the model's assumptions, confidence intervals (CI) were obtained with 10000 bootstrap resamplings, using the *nlsboot ()* function of the *nlstools* package in R software.

To assess the goodness of fit, evaluators such as the adjusted coefficient of determination ($R^2_{adj}$), random standard error (RSE), standard deviation of fit (SDF), and Akaike (AIC) and Bayesian (BIC) information criteria were used. The interpretations of the values obtained for each evaluator were made based on their characteristics. The values of $R^2_{adj}$ vary from 0 to 1, and the closer to 1, the greater the amount of data variability is explained by the adjusted model. As for the RSE, SDF, AIC, and BIC evaluators, the lower the values obtained, the more accurate and parsimonious the model is in predicting the values of the dependent variable. In addition, the intrinsic and parametric nonlinearities obtained by the curvature method proposed by Bates and Watts (1988) were evaluated using the *nls()* function in R software (R DEVELOPMENT CORE TEAM, 2022).

The coordinates of the critical points were obtained through the partial derivatives of the selected model in relation to the independent variable (cumulative thermal sum), which are the inflection point (IP), calculated as $\frac{d^2y(t)}{dt^2}=0$; maximum acceleration point (MAP) and maximum deceleration point (MDP), calculated as $\frac{d^3y(t)}{dt^3}=0$; asymptotic deceleration point (ADP) calculated as $\frac{d^4y(t)}{dt^4}=0$ (MISCHAN; PINHO; CARVALHO, 2011) and Concentration (MDP-MAP) (SARI et al., 2019). All statistical analyses were performed using R software (R DEVELOPMENT CORE TEAM, 2022).

## RESULTS AND DISCUSSION

During the experimental period (2014 to 2020), the maximum air temperature was 34.5 °C (2020) and the minimum air temperature was -4.4 °C (2019) (Figure 1). Extremes of temperature can cause damage to the components of leaf photosynthesis, reducing the rate of carbon dioxide assimilation and increasing respiratory losses, especially if it occurs in critical periods, such as germination and flowering of oilseed flax. Values of air temperature above 32 °C during the flowering period causes a negative influence on yield, and temperatures below -4 to -7 °C during the vegetative period and -1 °C during the reproductive period cause irreversible damage to the plant (CARVALHO et al., 2023).

Air temperature influences the vegetative and reproductive stages of oilseed flax, so its cycle can be extended when subjected to lower temperatures and shortened under conditions of higher temperatures due to the faster fulfillment of the thermal demand of the plants (FLAX COUNCIL OF CANADA, 2022). The shortest cycle observed in the experimental period was 115 days, in the year 2020, coinciding with the cycle that had the highest air temperatures and latest sowing date (09/06/2020) compared to the other experiments (Figure 1 and Table 1). The lowest accumulated rainfall during the oilseed flax cycle, 440.8 mm, was observed in this growing season. The accumulated thermal sum (TSa) ranged from 1540.67 °C day (2020) to 2207.86 °C day (2018 Season 1).

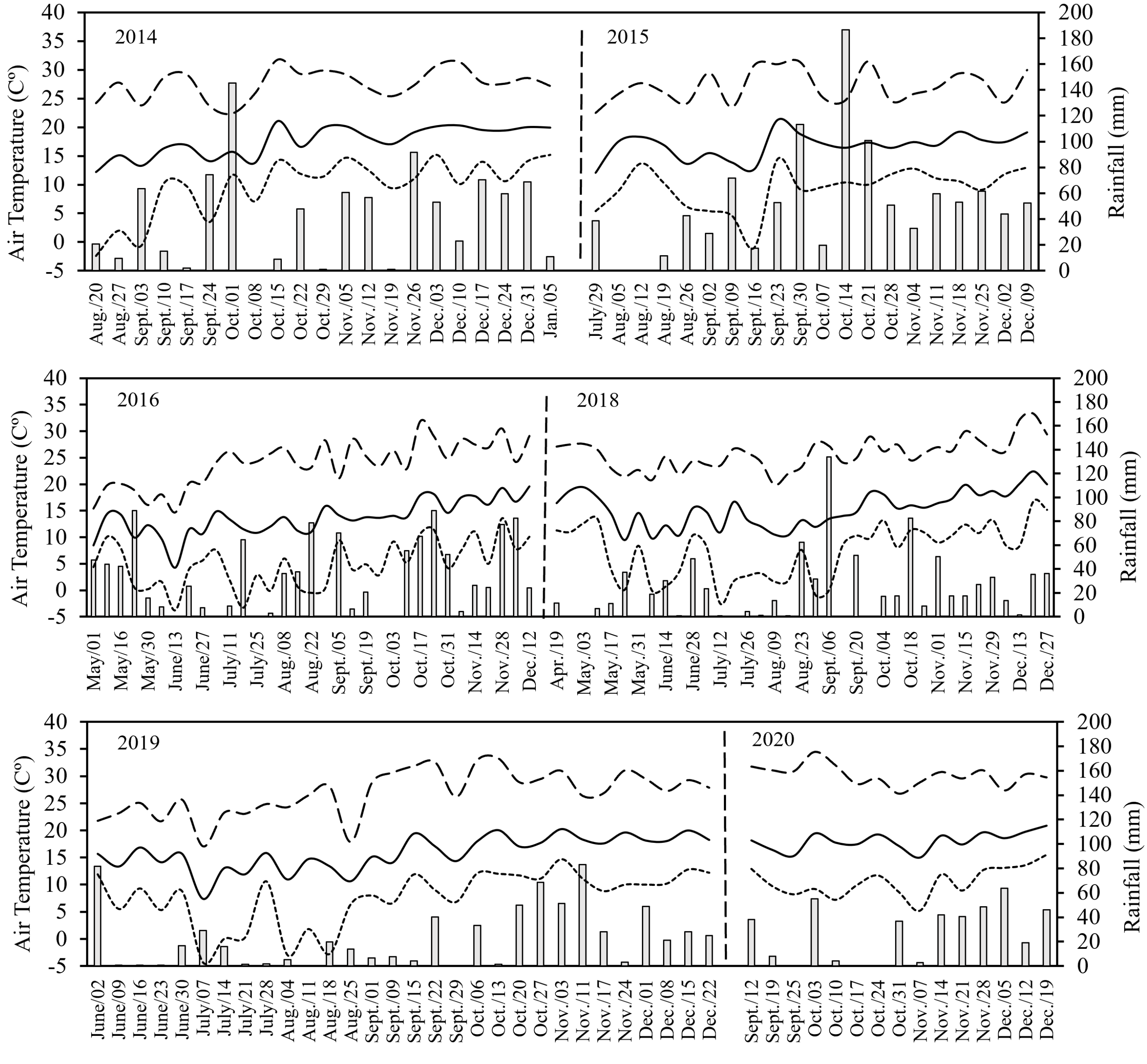


**Figure 1**. Air temperature, minimum (bottom lines), average (intermediate lines), and maximum (top lines) and accumulated rainfall (bars) from the sowing to harvesting of oilseed flax, cultivated during the years 2014, 2015, 2016, 2018, 2019, and 2020 for Curitibanos, SC, Brazil.

Regarding model fits, it was observed that model assumptions were not met for any of the variables, sowing time, agricultural year, and evaluated treatments. This is common in studies with repeated measures over time, in which heteroscedasticity and dependence on residuals may occur (YOKOO et al., 2014), and bootstrap resampling circumvents this bias. The values of intrinsic ($c^{I}$) and parametric ($c^{\theta}$) nonlinearity vary from 0.018 to 1.277, respectively, thus a variation from 0.018 to 0.513 ($c^{I}$) and from 0.083 to 1.277 ($c^{\theta}$) was observed, indicating that the parameter estimates were close to being impartial (Table 2), except for parametric nonlinearity, in the year 2016 Season 1, for the variables number of leaves and number of secondary stems.

The parameter estimates showed good quality in overall fit (Table 2). Only the total dry mass variable showed low values of $R^2_{adj}$, lower than 51.5%. According to Sari et al. (2019), it is advisable to use more than one quality evaluator together to better interpret the results obtained. Thus, most of the evaluated growth variables showed high values of $R^2_{adj}$ and low values of nonlinearity, RSE, SDF, AIC, and BIC, showing that the model is a good predictor and that the parameters can be used as explanatory variables.

**Table 2**. Indices of goodness of fit: intrinsic non-linearity ($c^I$) and parametric ($c^\theta$), adjusted coefficient of determination ($R^2_{adj}$), random standard error (RSE), standard deviation of fit (SDF), Akaike information criterion (AIC) and Bayesian information criterion (BIC), in the non-linear logistic model, in the growing years from 2014 to 2020, for the variables plant height, number of leaves, total dry mass and number of secondary stems.

| Year | $c^I$ | $c^\theta$ | $R^2_{adj}$ | RSE | SDF | AIC | BIC |
|---|---|---|---|---|---|---|---|
| Plant height | | | | | | | |
| 2014 | 0.034 | 0.124 | 0.951 | 6.337 | 3.659 | 3400.959 | 3417.974 |
| 2015 | 0.044 | 0.234 | 0.937 | 7.452 | 4.302 | 2308.176 | 2323.444 |
| 2016 Season 1 | 0.026 | 0.087 | 0.929 | 8.480 | 4.896 | 9394.553 | 9415.295 |
| 2016 Season 2 | 0.030 | 0.085 | 0.904 | 8.229 | 4.751 | 7622.584 | 7642.523 |
| 2016 Season 3 | 0.043 | 0.168 | 0.902 | 9.589 | 5.536 | 4126.140 | 4143.452 |
| 2018 Season 1 | 0.018 | 0.089 | 0.940 | 10.260 | 5.924 | 13644.740 | 13666.766 |
| 2018 Season 2 | 0.027 | 0.083 | 0.916 | 10.546 | 6.089 | 10876.188 | 10897.278 |
| 2020 | 0.069 | 0.509 | 0.873 | 7.306 | 4.218 | 1095.405 | 1107.706 |
| Number of leaves | | | | | | | |
| 2014 | 0.049 | 0.206 | 0.910 | 9.684 | 5.591 | 2661.372 | 2676.917 |
| 2015 | 0.052 | 0.499 | 0.924 | 9.973 | 5.758 | 1432.993 | 1446.023 |
| 2016 Season 1* | 0.021 | 1.277 | 0.917 | 9.234 | 5.331 | 5249.245 | 5267.562 |
| 2016 Season 2 | 0.032 | 0.213 | 0.879 | 13.808 | 7.972 | 6313.909 | 6332.546 |
| 2016 Season 3 | 0.054 | 0.160 | 0.842 | 13.233 | 7.640 | 3398.370 | 3414.569 |
| Total dry mass | | | | | | | |
| 2015 | 0.299 | 0.659 | 0.515 | 2.441 | 1.409 | 670.626 | 682.506 |
| 2016 Season 1 | 0.023 | 0.318 | 0.439 | 1.413 | 0.816 | 1240.221 | 1255.653 |
| 2016 Season 2 | 0.259 | 0.606 | 0.383 | 0.605 | 0.349 | 665.110 | 680.654 |
| 2019 | 0.513 | 1.000 | 0.361 | 2.178 | 1.257 | 848.684 | 861.714 |
| Number of secondary stems | | | | | | | |
| 2014 | 0.049 | 0.206 | 0.910 | 9.684 | 5.591 | 2661.372 | 2676.917 |
| 2015 | 0.052 | 0.499 | 0.924 | 9.973 | 5.758 | 1432.993 | 1446.023 |
| 2016 Season 1* | 0.021 | 1.277 | 0.917 | 9.234 | 5.331 | 5249.245 | 5267.562 |
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| 2016 Season 3 | 0.054 | 0.160 | 0.842 | 13.233 | 7.640 | 3398.370 | 3414.569 |

*non-compliance with parametric non-linearity.

The plant height variable is genetically determined, but highly influenced by environmental and climatic factors. It is observed in Figure 2 that plant height ranged from 71.629 cm (2020) to 127.166 cm (2018 Season 1). The years 2014, 2016 Season 2, and 2020 had lower values of $\beta 1$, indicating lower heights. These results corroborate those reported by Stanck, Becker, and Bosco (2017), who observed that delay in sowing linked to high temperatures reduces the height of oilseed flax plants due to their shorter vegetative period. Plants with lower height are preferred by growers as it reduces the likelihood of lodging, which impairs yield and makes harvesting difficult (HALL et al., 2016).

The inflection point (IP), which represents the moment when the plants are in maximum growth, differs between some years. In 2016 Season 3 the inflection point was obtained earlier than in most years (Figure 2), and in 2018 Season 1, this occurred later than in the other years (Figure 2). The maximum acceleration point (MAP) indicates the moment when the increase in rate (velocity) is maximum; in 2018 Season 1 this moment occurred later, and in 2016 Season 3, earlier. In addition, it was observed that 2014, 2016 Season 1, and 2018 Season 2 did not differ statistically in relation to MAP, as well as 2015 and 2020.

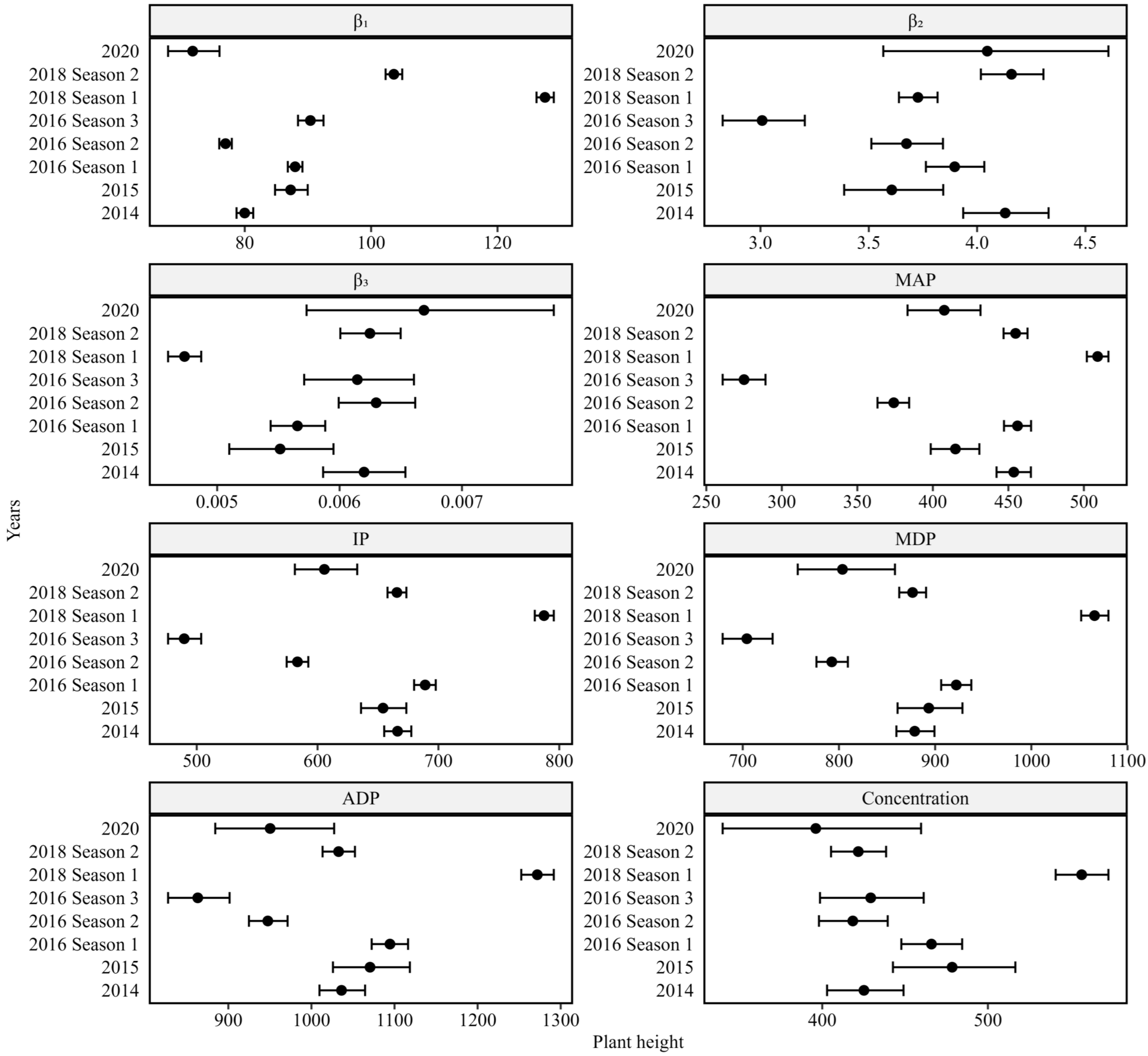


**Figure 2**. Confidence intervals of parameter estimates and critical points of the nonlinear logistic model for the plant height variable (cm): $\beta 1$ (represents height), $\beta 2$ (represents growth time), $\beta 3$ (represents growth rate), MAP (maximum acceleration point), IP (inflection point), MDP (maximum deceleration point), ADP (asymptotic deceleration point) and Concentration (MDP-MAP), in the growing years from 2014 to 2020.

The total dry mass showed a lower mean ($\beta 1$), 1.22 g in 2016 Season 2, and the highest average, 6.61 g, in 2015, that is, it obtained five times more total dry mass. In addition, in the latter it was the one that had the shortest cycle, with 139 days, compared to the others. This is directly related to climatic conditions, different sowing times, and agricultural years, which directly interfered with the morphology of oilseed flax plants. The years 2015 and 2019 did not differ statistically in relation to $\beta 3$, MAP, IP, and concentration (Figure 3).

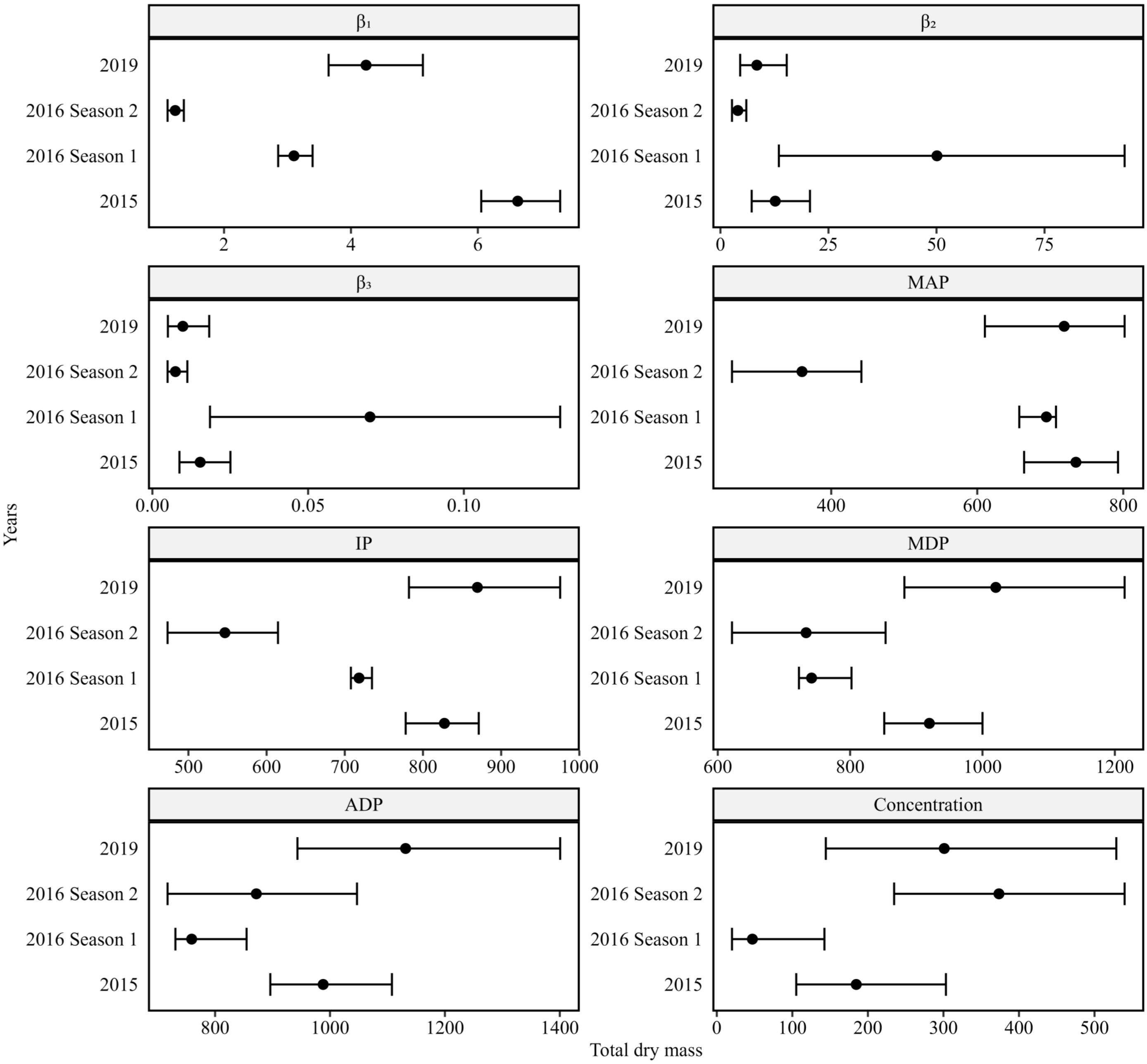


**Figure 3**. Confidence intervals of parameter estimates and critical points of the nonlinear logistic model for the variable total dry mass (g), $\beta 1$ (represents height), $\beta 2$ (represents growth time), $\beta 3$ (represents growth rate), MAP (maximum acceleration point), IP (inflection point), MDP (maximum deceleration point), ADP (asymptotic deceleration point) and Concentration (MDP-MAP), in the agricultural years 2014 to 2020.

The number of leaves in the year 2014 had a lower average (99 leaves) when compared to other years, with 120 (2015), 161 (2016 Season 1), 141 (2016 Season 2), and 117 (2016 Season 3) (Figure 4). Differences in the number of leaves may be a consequence of different planting times and weather conditions during the cycle (STANCK; BECKER; BOSCO, 2017). In a study conducted by the same authors, they found values that varied between 96 for sowing in August 2014 and 106 for sowing in July 2015.

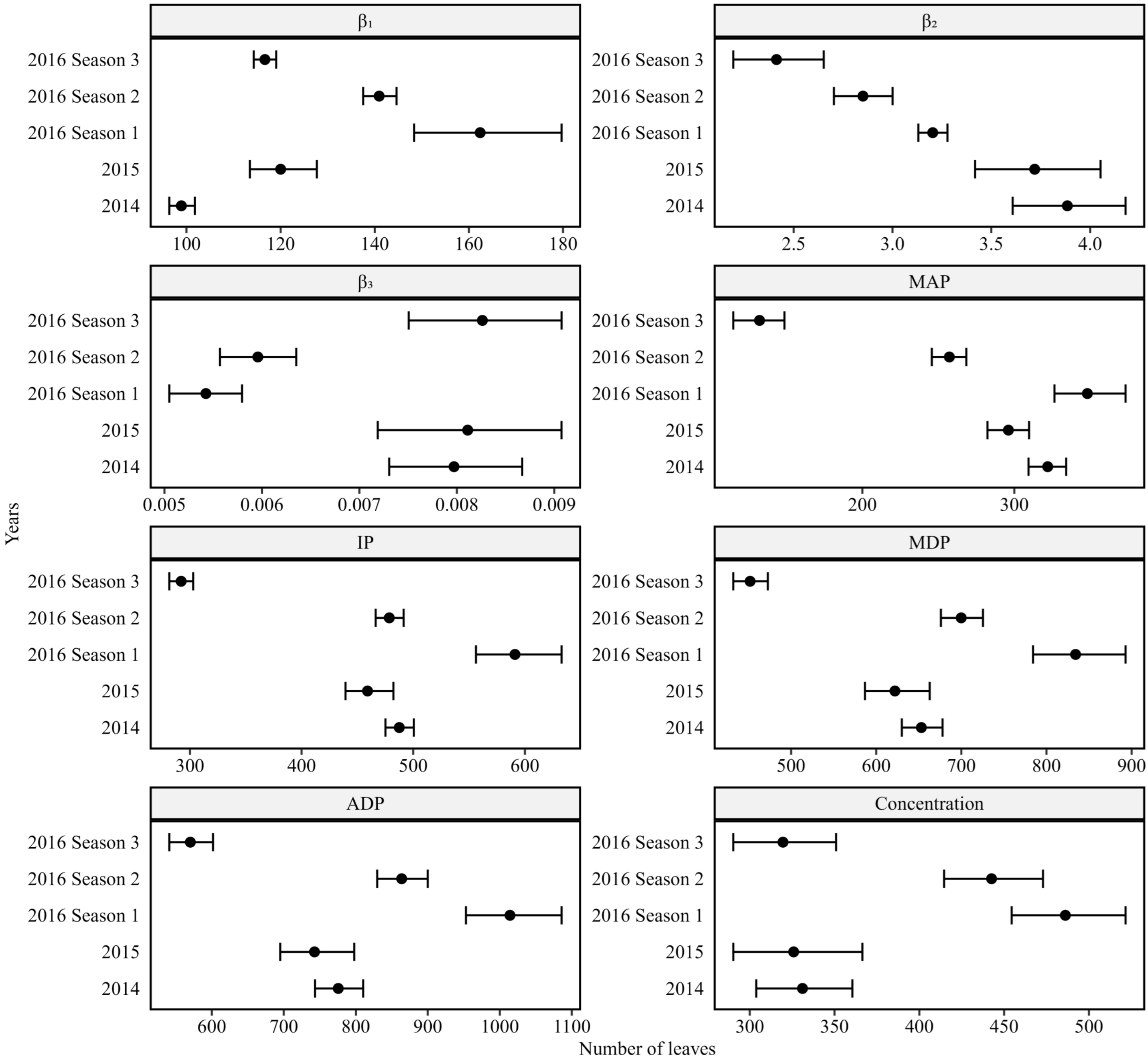


**Figure 4**. Confidence intervals of parameter estimates and critical points of the nonlinear logistic model for the variable number of leaves, $\beta 1$ (represents height), $\beta 2$ (represents growth time), $\beta 3$ (represents growth rate), MAP (maximum acceleration point), IP (inflection point), MDP (maximum deceleration point), ADP (asymptotic deceleration point) and Concentration (MDP-MAP), in the agricultural years 2014 to 2020.

Branches can appear from the main stem, also called secondary stems, which develop leaves, flowers, and capsules. The average number of secondary stems ($\beta 1$) ranged from 1.62 (2016 Season 2) to 4.17 (2020) per plant (Figure 5). $\beta 2$ and $\beta 3$ showed lower values for 2016 Season 1, 2018 Season 1, and 2020, which did not differ from each other, as well as 2016 Season 2, and 2018 Season 2. In addition, the year 2020 had the highest values for MAP, IP, MDP, ADP, and concentration, and 2016 Season 1 had the lowest values, while the others did not differ statistically from each other.

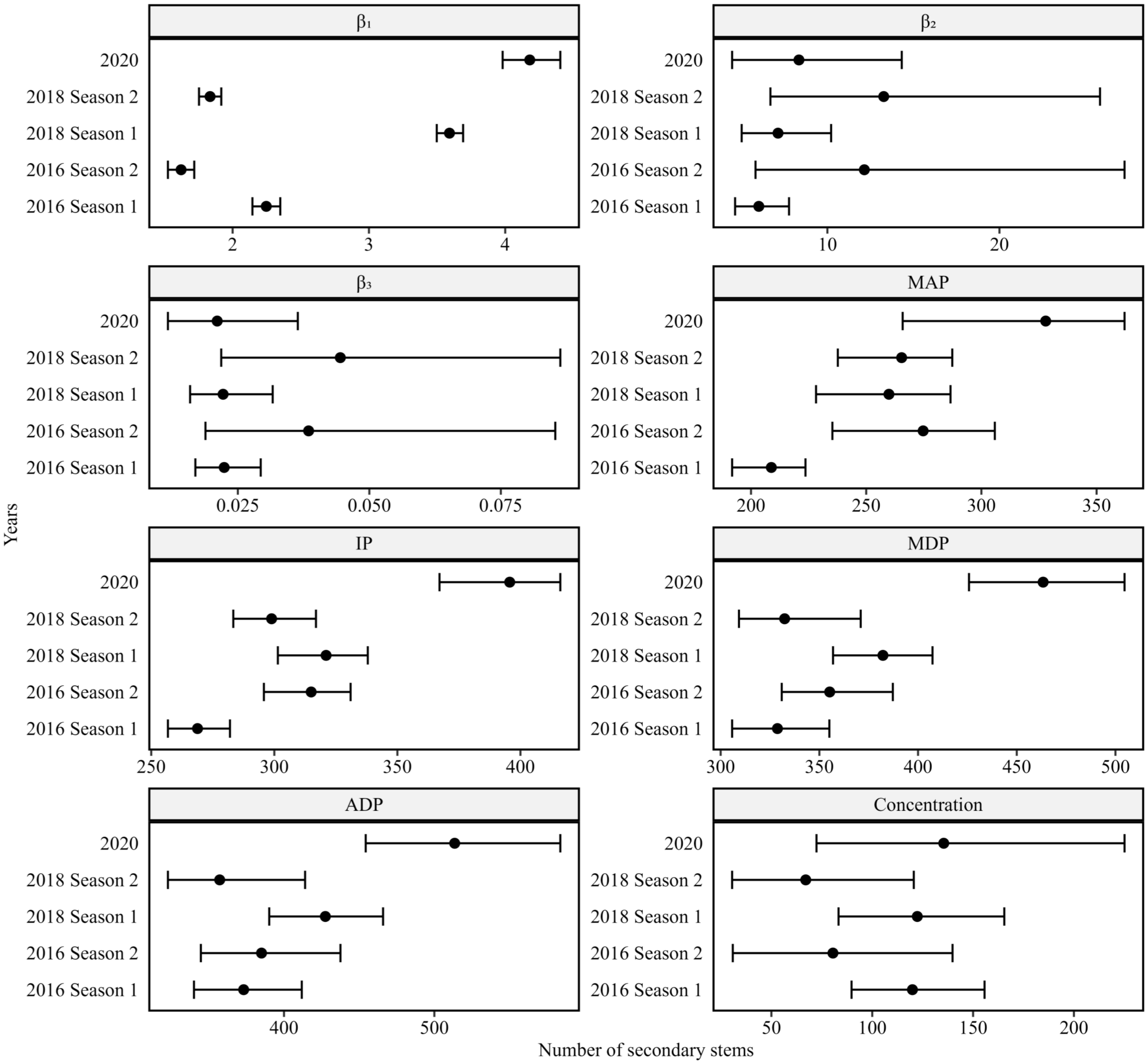


**Figure 5**. Confidence intervals of parameter estimates and critical points of the nonlinear logistic model for the variable number of secondary stems, *β1* (represents height), *β2* (represents growth time), *β3* (represents growth rate), MAP (maximum acceleration point), IP (inflection point), MDP (maximum deceleration point), ADP (asymptotic deceleration point) and Concentration (MDP-MAP), in the agricultural years 2014 to 2020.

In this study, the values for the number of secondary stems were within the expected range, as reported in most studies found in the literature. The number of stems per plant described in the literature varies between 1 and 4 stems per plant, varying according to genetics (CARGNELUTTI FILHO et al., 2016; ROSSETTO et al., 2012; SANTOS et al., 2013; TORRES et al., 2015). In studies conducted by Ahmad et al. (2014), the number of secondary stems ranged from 4.2 to 5.93, and Rossetto et al. (2012) found mean values of 2.86 and 2.75 stems per plant, for Golden and Brown cultivars, respectively.

When considering the variables separately, within cultivars and varieties, plant height showed values of intrinsic ($c^1$) and parametric ($c^\theta$) nonlinearity ranging from 0.025 to 0.074 and from 0.077 to 0.509, respectively, in addition to low values of RSE, SDF, AIC and BIC and high $R^2_{adj}$ (greater than 87%) for the variables and cultivars evaluated in different years and sowing times (Table 3).

**Table 3**. Indices of the goodness of fit: intrinsic ($c^I$) and parametric ($c^\theta$) non-linearity, adjusted coefficient of determination ($R^2_{adj}$), random standard error (RSE), standard deviation of fit (SDF), Akaike information criterion (AIC), and Bayesian information criterion (BIC), in the logistic non-linear model, for the Aguará INTA and Caburé INTA cultivars and Golden and Brown varieties, for the plant height variable.

| Year | $c^I$ | $c^\theta$ | $R^2_{adj}$ | RSE | SDF | AIC | BIC |
|---|---|---|---|---|---|---|---|
| Aguará Cultivar | | | | | | | |
| 2016 Season 1 | 0.051 | 0.180 | 0.903 | 10.457 | 6.037 | 3319.257 | 3335.604 |
| 2016 Season 2 | 0.053 | 0.158 | 0.892 | 8.798 | 5.079 | 2592.258 | 2607.802 |
| 2016 Season 3 | 0.051 | 0.180 | 0.929 | 8.500 | 4.908 | 1998.045 | 2012.584 |
| 2018 Season 1 | 0.025 | 0.130 | 0.969 | 7.643 | 4.413 | 3181.494 | 3198.019 |
| 2018 Season 2 | 0.048 | 0.151 | 0.933 | 9.901 | 5.716 | 2677.300 | 2692.845 |
| Caburé Cultivar | | | | | | | |
| 2016 Season 1 | 0.040 | 0.132 | 0.946 | 7.141 | 4.123 | 2983.558 | 2999.905 |
| 2016 Season 2 | 0.048 | 0.156 | 0.913 | 7.309 | 4.220 | 2458.809 | 2474.354 |
| 2016 Season 3 | 0.054 | 0.241 | 0.920 | 8.159 | 4.711 | 1975.122 | 1989.661 |
| 2018 Season 1 | 0.033 | 0.188 | 0.945 | 10.020 | 5.785 | 3430.673 | 3447.198 |
| 2018 Season 2 | 0.045 | 0.136 | 0.942 | 9.119 | 5.265 | 2618.111 | 2633.655 |
| Golden Variety | | | | | | | |
| 2014 | 0.040 | 0.153 | 0.966 | 5.159 | 2.978 | 1595.970 | 1610.213 |
| 2015 | 0.050 | 0.271 | 0.958 | 5.866 | 3.387 | 1076.202 | 1088.698 |
| 2016 Season 1 | 0.035 | 0.105 | 0.962 | 5.952 | 3.436 | 2823.360 | 2839.707 |
| 2016 Season 2 | 0.031 | 0.077 | 0.968 | 4.914 | 2.837 | 2172.893 | 2188.437 |
| 2018 Season 1 | 0.034 | 0.106 | 0.961 | 7.100 | 4.099 | 2978.543 | 2994.890 |
| 2018 Season 2 | 0.054 | 0.152 | 0.915 | 9.703 | 5.602 | 2662.803 | 2678.348 |
| Brown Variety | | | | | | | |
| 2014 | 0.052 | 0.176 | 0.945 | 6.850 | 3.955 | 1743.434 | 1757.677 |
| 2015 | 0.074 | 0.372 | 0.922 | 8.685 | 5.014 | 1208.028 | 1220.524 |
| 2018 Season 1 | 0.034 | 0.156 | 0.951 | 9.883 | 5.706 | 3417.939 | 3434.464 |
| 2018 Season 2 | 0.049 | 0.154 | 0.939 | 9.033 | 5.215 | 2611.235 | 2626.779 |
| 2020 | 0.069 | 0.509 | 0.873 | 7.306 | 4.218 | 1095.405 | 1107.706 |

The $\beta 1$ parameter had greater variability (71.629 to 136.716), reflecting climatic conditions, and thus interfering with the evaluated growth variables (Table 4). When compared separately, the same years and sowing times with each other, it is observed that the cultivar Aguará had higher plant heights ($\beta 1$) than Caburé (ranging from 79.565 to 136.716 and from 72.340 to 132.346 respectively), as observed for the Brown variety compared to Golden (with 71.629 to 132.374 and 78.967 to 104.584, respectively).

In 2016 Season 2, the lowest plant heights occurred in the Aguará and Caburé cultivars ($\beta 1$= 79.565 and 72.340, respectively), whereas the highest plant heights ($\beta 1$= 132.346 and 136.716, respectively) were observed in 2018 Season 1, which shows the interference of climatic conditions on this variable, as the sowing times were very close (Table 4). The Golden and Brown varieties also had the highest plant heights in 2018 Season 1 ($\beta 1$= 104.584 and 132.374, respectively), but the lowest heights for the Golden variety occurred in 2014 ($\beta 1$= 78.967) and for the Brown variety in 2020 ($\beta 1$= 71.629), that is, they coincided with the years whose sowings were carried out later, 08/14/2014 and 09/06/2020, respectively, and had the highest air temperatures. The parameters $\beta 2$ and $\beta 3$ do not vary much within each cultivar or variety.

The variable total dry mass showed a violation of the fit quality indices for the parametric nonlinearity, in 2016 Season 2 in the cultivars Aguará and Caburé (Table 5). The Golden variety showed violations in the years 2014 and 2016 Season 1 and the Brown variety showed no fit. For the other agricultural years and seasons, the model fitting assumptions were met. However, the values of $R^2_{adj}$ were lower than 0.67, that is, low explanatory power of the biological data.

For the parameters and critical points of the varieties and cultivars that showed adequate goodness-of-fit indices, there was high variability for the variable total dry mass (Table 6). In the year 2016 Season 1, the Aguará cultivar obtained a higher total dry mass ($\beta 1$), about 23.84%, when compared to Caburé, which may be a consequence of the higher plant height of Aguará compared to Caburé. The Golden variety obtained an increase of 31.74% in 2015 when compared to 2016 Season 2. The $\beta 2$ parameter varied according to the year (from 3.912 to 55.679), and this may be related to the variable having greater variability in the results.

**Table 4**. Estimation parameters $\beta1$, $\beta2$, and $\beta3$ and critical points: inflection point (IP), maximum acceleration point (MAP), maximum deceleration point (MDP), and asymptotic deceleration point (ADP), in the logistic non-linear model, for the Aguará INTA and Caburé INTA cultivars and Golden and Brown varieties, for the plant height variable.

| Aguará Cultivar | | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | $\beta1$ | $\beta2$ | $\beta3$ | IP | MAP | MDP | ADP |
| 2016 Season 1 | 93.099 | 3.675 | 0.005 | 678.316 | 435.237 | 921.396 | 1101.426 |
| 2016 Season 2 | 79.565 | 3.479 | 0.006 | 578.002 | 359.171 | 796.833 | 958.904 |
| 2016 Season 3 | 94.816 | 3.022 | 0.006 | 468.216 | 264.188 | 672.245 | 823.353 |
| 2018 Season 1 | 136.716 | 3.616 | 0.004 | 808.004 | 513.711 | 1102.297 | 1320.257 |
| 2018 Season 2 | 109.328 | 4.114 | 0.006 | 669.376 | 455.100 | 883.651 | 1042.349 |
| Caburé Cultivar | | | | | | | |
| 2016 Season 1 | 85.686 | 3.959 | 0.006 | 699.577 | 466.833 | 932.322 | 1104.697 |
| 2016 Season 2 | 72.340 | 3.575 | 0.006 | 620.279 | 391.756 | 848.802 | 1018.052 |
| 2016 Season 3 | 86.119 | 3.009 | 0.006 | 515.310 | 289.773 | 740.848 | 907.885 |
| 2018 Season 1 | 132.346 | 3.661 | 0.004 | 836.195 | 535.414 | 1136.975 | 1359.739 |
| 2018 Season 2 | 107.268 | 4.155 | 0.006 | 657.839 | 449.325 | 866.352 | 1020.782 |
| Golden Variety | | | | | | | |
| 2014 | 78.967 | 4.153 | 0.006 | 684.863 | 467.667 | 902.059 | 1062.919 |
| 2015 | 85.623 | 3.453 | 0.005 | 642.547 | 397.467 | 887.627 | 1069.138 |
| 2016 Season 1 | 84.287 | 4.105 | 0.006 | 685.676 | 465.686 | 905.667 | 1068.597 |
| 2016 Season 2 | 79.447 | 4.036 | 0.007 | 560.253 | 377.434 | 743.071 | 878.470 |
| 2018 Season 1 | 104.584 | 4.231 | 0.006 | 654.735 | 450.934 | 858.535 | 1009.475 |
| 2018 Season 2 | 94.267 | 4.052 | 0.007 | 614.062 | 414.469 | 813.655 | 961.478 |
| Brown Variety | | | | | | | |
| 2014 | 80.971 | 4.139 | 0.006 | 647.984 | 441.818 | 854.150 | 1006.842 |
| 2015 | 88.701 | 3.764 | 0.006 | 663.970 | 431.677 | 896.263 | 1068.304 |
| 2018 Season 1 | 132.374 | 4.043 | 0.005 | 824.534 | 555.941 | 1093.127 | 1292.053 |
| 2018 Season 2 | 102.433 | 4.522 | 0.006 | 714.993 | 506.753 | 923.232 | 1077.459 |
| 2020 | 71.629 | 4.030 | 0.007 | 604.852 | 407.186 | 802.517 | 948.913 |

**Table 5**. Indices of the goodness of fit: adjusted coefficient of determination ($R^2_{adj}$), random standard error (RSE), standard deviation of fit (SDF), Akaike information criterion (AIC), and Bayesian information criterion (BIC), in the logistic non-linear model, for the Aguará INTA and Caburé INTA cultivars and Golden and Brown varieties, for the total dry mass variable.

| Aguará Cultivar | | | | | | | |
|---|---|---|---|---|---|---|---|
| Year | $c^I$ | $c^\theta$ | $R^2_{adj}$ | RSE | SDF | AIC | BIC |
| 2016 Season 1 | 0.008 | 0.528 | 0.447 | 1.557 | 0.899 | 489.063 | 500.533 |
| 2016 Season 2 | 0.533 | 1.239 | 0.327 | 0.548 | 0.316 | 201.131 | 212.281 |
| Caburé Cultivar | | | | | | | |
| 2016 Season 1 | 0.141 | 0.535 | 0.445 | 1.239 | 0.715 | 396.875 | 408.025 |
| 2016 Season 2 | 0.654 | 1.278 | 0.398 | 0.377 | 0.217 | 111.166 | 122.316 |
| Golden Variety | | | | | | | |
| 2014 | 0.552 | 2.094 | 0.777 | 7.211 | 4.163 | 167.736 | 172.448 |
| 2015 | 0.337 | 0.934 | 0.671 | 1.517 | 0.876 | 269.270 | 278.377 |
| 2016 Season 1 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 | 0.000 |
| 2016 Season 2 | 0.284 | 0.641 | 0.607 | 0.622 | 0.359 | 231.400 | 242.550 |
| Brown Variety | | | | | | | |
| 2014 | 0.339 | 10.557 | 0.783 | 7.955 | 4.593 | 172.448 | 177.161 |
| 2015 | 0.293 | 1.205 | 0.493 | 2.993 | 1.728 | 367.146 | 376.253 |
| 2019 | 0.513 | 1.000 | 0.361 | 2.178 | 1.257 | 848.684 | 861.714 |

**Table 6**. Estimation parameters $\beta1$, $\beta2$, and $\beta3$ and critical points: inflection point (IP), maximum acceleration point (MAP), maximum deceleration point (MDP) and asymptotic deceleration (ADP), in the non-linear logistic model, after meeting the quality indices, for the Aguará INTA and Caburé INTA cultivars and Golden variety, for the variable total dry mass.

| Year | $\beta1$ | $\beta2$ | $\beta3$ | IP | MAP | MDP | ADP |
|---|---|---|---|---|---|---|---|
| Aguará Cultivar | | | | | | | |
| 2016 Season 1 | 3.490 | 55.679 | 0.078 | 712.346 | 695.497 | 729.195 | 741.674 |
| Caburé Cultivar | | | | | | | |
| 2016 Season 1 | 2.658 | 38.209 | 0.053 | 721.035 | 696.182 | 745.888 | 764.295 |
| Golden Variety | | | | | | | |
| 2015 | 6.236 | 6.704 | 0.008 | 844.270 | 678.417 | 1010.123 | 1132.957 |
| 2016 Season 2 | 1.979 | 3.912 | 0.006 | 611.578 | 405.688 | 817.467 | 969.954 |

For the variable number of leaves, the year 2016 Season 1 did not show parametric nonlinearity fit for any of the treatments studied (Table 7). In general, the results showed high values of $R^2_{adj}$, ranging from 81.8% to 93.6%, and low values of RSE, SDF, AIC, and BIC, regardless of variety and cultivar, demonstrating reliability in the results.

Among the cultivars (Aguará and Caburé), based on the analysis of $\beta1$, it is observed that 2016 Season 2 had a higher number of leaves per plant, when compared to 2016 Season 3, with values varying from 151.274 (Caburé) to 156.048 (Aguará) in season 2 and from 114.408 (Caburé) to 122.298 (Aguará) in season 3 (Table 8). In addition, Aguará had higher values when compared to Caburé ($\beta1$= 118.408 to 153.349 and 114.342 to 151.241, respectively). The Golden variety in 2016 Season 1 obtained 37.61% more leaves than in 2014, when there was the lowest amount. For the Brown variety, the years in which it was evaluated (2014 and 2015) were very similar, with values ranging from 100.314 to 116.917, respectively.

**Table 7**. Indices of the goodness of fit: adjusted coefficient of determination ($R^2_{adj}$), random standard error (RSE), standard deviation of fit (SDF), Akaike information criterion (AIC), and Bayesian information criterion (BIC), in the logistic non-linear model, for the Aguará INTA and Caburé INTA cultivars and Golden and Brown varieties, for the variable number of leaves.

| Year | $c^I$ | $c^\theta$ | $R^2_{adj}$ | RSE | SDF | AIC | BIC |
|---|---|---|---|---|---|---|---|
| Aguará Cultivar | | | | | | | |
| 2016 Season 1 | 0.032 | 1.755 | 0.936 | 8.263 | 4.771 | 1699.741 | 1713.664 |
| 2016 Season 2 | 0.059 | 0.466 | 0.862 | 16.056 | 9.270 | 2186.403 | 2200.646 |
| 2016 Season 3 | 0.066 | 0.202 | 0.861 | 12.730 | 7.349 | 1907.156 | 1921.079 |
| Caburé Cultivar | | | | | | | |
| 2016 Season 1 | 0.034 | 2.881 | 0.922 | 8.510 | 4.913 | 1713.852 | 1727.774 |
| 2016 Season 2 | 0.046 | 0.416 | 0.908 | 12.404 | 7.162 | 2052.219 | 2066.462 |
| 2016 Season 3 | 0.089 | 0.261 | 0.818 | 13.790 | 7.962 | 1492.767 | 1505.626 |
| Golden Variety | | | | | | | |
| 2014 | 0.061 | 0.273 | 0.927 | 8.520 | 4.919 | 1287.059 | 1299.831 |
| 2015 | 0.076 | 0.726 | 0.924 | 10.337 | 5.968 | 725.849 | 736.106 |
| 2016 Season 1 | 0.041 | 2.070 | 0.904 | 10.318 | 5.957 | 1806.321 | 1820.244 |
| 2016 Season 2 | 0.046 | 0.180 | 0.931 | 9.194 | 5.308 | 1896.489 | 1910.731 |
| Brown Variety | | | | | | | |
| 2014 | 0.075 | 0.300 | 0.900 | 10.516 | 6.071 | 1362.831 | 1375.602 |
| 2015 | 0.073 | 0.694 | 0.927 | 9.540 | 5.508 | 710.440 | 720.697 |

**Table 8**. Estimation parameters $\beta 1$, $\beta 2$, and $\beta 3$ and critical points: inflection point (IP), maximum acceleration point (MAP), maximum deceleration point (MDP) and asymptotic deceleration (ADP), in the logistic non-linear model, after meeting the quality indices, for the Aguará INTA and Caburé INTA cultivars and Golden and Brown varieties, for the variable number of leaves.

| Year | $\beta 1$ | $\beta 2$ | $\beta 3$ | IP | MAP | MDP | ADP |
|---|---|---|---|---|---|---|---|
| Aguará Cultivar | | | | | | | |
| 2016 Season 2 | 153.349 | 2.849 | 0.006 | 511.083 | 274.810 | 747.357 | 922.346 |
| 2016 Season 3 | 118.408 | 2.374 | 0.008 | 291.990 | 129.988 | 453.992 | 573.974 |
| Caburé Cultivar | | | | | | | |
| 2016 Season 2 | 151.241 | 2.808 | 0.005 | 528.688 | 280.739 | 776.637 | 960.273 |
| 2016 Season 3 | 114.342 | 2.479 | 0.008 | 292.457 | 137.110 | 447.805 | 562.859 |
| Golden Variety | | | | | | | |
| 2014 | 97.354 | 3.845 | 0.008 | 493.094 | 324.218 | 661.970 | 787.044 |
| 2015 | 122.614 | 3.729 | 0.008 | 459.991 | 297.513 | 622.468 | 742.802 |
| 2016 Season 1 | 156.048 | 3.372 | 0.006 | 581.491 | 354.395 | 808.586 | 976.779 |
| 2016 Season 2 | 122.298 | 3.147 | 0.008 | 408.124 | 237.342 | 578.906 | 705.391 |
| Brown Variety | | | | | | | |
| 2014 | 100.314 | 3.921 | 0.008 | 481.612 | 319.860 | 643.364 | 763.161 |
| 2015 | 116.917 | 3.693 | 0.008 | 456.783 | 293.876 | 619.691 | 740.344 |

Table 9 presents the goodness-of-fit indices for the variable number of secondary stems. It is observed that 2016 Season 1 was the only one that had adequate fit of the model in all evaluated treatments, and the Brown variety had adequate indices in the years 2018 Season 1 and 2020. Despite this, $R^2_{adj}$ was low and the other quality indices did not follow a pattern, demonstrating high variability in the data.

**Table 9**. Indices of the goodness of fit: adjusted coefficient of determination ($R^2_{adj}$), random standard error (RSE), standard deviation of fit (SDF), Akaike information criterion (AIC) and Bayesian information criterion (BIC) in the logistic non-linear model, for the Aguará INTA and Caburé INTA cultivars and Golden and Brown varieties, for the variable number of secondary stems.

| Year | $c^I$ | $c^\theta$ | $R^2_{adj}$ | RSE | SDF | AIC | BIC |
|---|---|---|---|---|---|---|---|
| Aguará Cultivar | | | | | | | |
| 2016 Season 1 | 0.255 | 0.507 | 0.493 | 0.720 | 0.415 | 528.087 | 542.010 |
| 2016 Season 2 | 1.262 | 2.095 | 0.113 | 0.915 | 0.528 | 696.617 | 710.860 |
| 2016 Season 3 | 0.082 | 123.495 | 0.251 | 1.106 | 0.638 | 734.285 | 748.207 |
| 2018 Season 1 | 0.543 | 2.053 | 0.152 | 1.418 | 0.819 | 1631.958 | 1648.483 |
| 2018 Season 2 | 1.876 | 2.795 | 0.095 | 1.224 | 0.707 | 1172.134 | 1187.679 |
| Caburé Cultivar | | | | | | | |
| 2016 Season 1 | 0.217 | 0.456 | 0.522 | 0.843 | 0.487 | 603.988 | 617.911 |
| 2016 Season 2 | 0.079 | 2.493 | 0.104 | 0.944 | 0.545 | 713.059 | 727.301 |
| 2016 Season 3 | 0.280 | 0.512 | 0.367 | 1.266 | 0.731 | 799.387 | 813.310 |
| 2018 Season 1 | 9.528 | 24.661 | 0.000 | 1.462 | 0.844 | 1659.844 | 1676.369 |
| 2018 Season 2 | 1.294 | 3.051 | 0.012 | 1.487 | 0.859 | 1312.280 | 1327.825 |
| Golden Variety | | | | | | | |
| 2016 Season 1 | 0.416 | 0.823 | 0.359 | 0.835 | 0.482 | 599.679 | 613.601 |
| 2016 Season 2 | 0.051 | 0.329 | 0.528 | 0.783 | 0.452 | 615.739 | 629.982 |
| 2018 Season 1 | 1.124 | 5.376 | 0.006 | 1.457 | 0.841 | 1584.651 | 1600.998 |
| 2018 Season 2 | 1.318 | 2.019 | 0.049 | 1.084 | 0.626 | 1084.678 | 1100.223 |
| Brown Variety | | | | | | | |
| 2018 Season 1 | 0.381 | 0.586 | 0.211 | 2.279 | 1.316 | 2068.422 | 2084.946 |
| 2018 Season 2 | 0.499 | 1.026 | 0.215 | 1.458 | 0.842 | 1297.974 | 1313.519 |
| 2020 | 0.274 | 0.612 | 0.337 | 1.082 | 0.625 | 484.348 | 496.649 |

The results of the parameters and critical points for the variable number of secondary stems differed between cultivars when compared to the other evaluated variables (Table 10). It is observed that Caburé obtained higher numbers of secondary stems ($\beta1$= 3.062 and 3.515) when compared to Aguará ($\beta1$= 2.025), that is, Caburé was an exception because shorter plants, with fewer leaves and lower dry mass, developed greater number of secondary stems. The Brown variety had the highest number of secondary stems per plant ($\beta1$= 5.076 and 4.170), when compared to the other cultivars and varieties.

**Table 10**. Estimation parameters $\beta1$, $\beta2$, and $\beta3$ and critical points: inflection point (IP), maximum acceleration point (MAP), maximum deceleration point (MDP) and asymptotic deceleration (ADP), in the logistic non-linear model, after meeting the quality indices, for the Aguará INTA and Caburé INTA cultivars and Golden and Brown varieties, for the variable number of secondary stems.

| Year | $\beta1$ | $\beta2$ | $\beta3$ | IP | MAP | MDP | ADP |
|---|---|---|---|---|---|---|---|
| Aguará Cultivar | | | | | | | |
| 2016 Season 1 | 2.025 | 5.713 | 0.020 | 287.001 | 220.838 | 353.164 | 402.165 |
| Caburé Cultivar | | | | | | | |
| 2016 Season 1 | 3.062 | 4.466 | 0.017 | 257.891 | 181.847 | 333.934 | 390.253 |
| 2016 Season 3 | 3.515 | 3.555 | 0.015 | 229.556 | 144.513 | 314.598 | 377.582 |
| Golden Variety | | | | | | | |
| 2016 Season 1 | 1.672 | 11.719 | 0.044 | 266.583 | 236.623 | 296.544 | 318.733 |
| 2016 Season 2 | 2.651 | 31.046 | 0.100 | 310.498 | 297.326 | 323.670 | 333.425 |
| Brown Variety | | | | | | | |
| 2018 Season 1 | 5.076 | 6.662 | 0.018 | 367.872 | 295.151 | 440.593 | 494.452 |
| 2020 | 4.170 | 7.959 | 0.020 | 396.343 | 330.756 | 461.931 | 510.507 |

The variations found in this study occurred due to the different sowing times and cultivars/varieties used, corroborating the study by Bosco et al. (2020). Thus, the nonlinear logistic regression model can be used to compare the treatments, in the different years and times of sowing of the oilseed flax crop, describing the stages of the growth and development cycle, thus allowing greater knowledge of the responses of the plant and based on biological interpretation of parameter estimates. The results of this study provided a greater understanding of the growth of oilseed flax, contributing to future research and seeking more supporters of commercial cultivation, since the demand for grains and their derivatives tends to increase.

## CONCLUSIONS

The use of the nonlinear logistic regression model improves the inferences about the growth of oilseed flax, and the estimates of its parameters and critical points allow a biological and practical interpretation in order to assist in crop planning and management.

The duration of the development cycle of oilseed flax is influenced by air temperature and sowing time, so later sowings tend to shorten the cycle and, consequently, reduce growth variables.

Taller plants have a greater number of leaves and total dry mass, as occurred for the Aguará cultivar and the Brown variety, regardless of year and sowing time.

The number of secondary stems diverged; shorter plants, with lower dry mass and number of leaves, produced a greater number of stems in the Caburé cultivar, whereas the opposite occurred in the Golden variety.

Furthermore, further research should be conducted to study the performance of other models, as well as the use of other parameterizations to characterize the growth of oilseed flax and other agricultural crops, to make the results more reliable compared to those observed under field conditions.

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