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Comparison of the Gompertz and Verhulst Models in the Accumulation of Calcium in Common Bean Cultivar Jalo

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Abstract: *One of the ways to evaluate the biomass accumulation of common bean by means of some physiological process is to find an equation that expresses growth over time. The objective of this study was to model the macronutrient accumulation calcium, in the common bean cultivar Jalo, throughout its vegetative growth in five densities of with the use of nonlinear models of Gompertz and Verhulst. Through the regression equations obtained by fitting the nonlinear models of Gompertz and Verhulst, asymptotic weight parameter estimates indicate that as increased plant populations there was an increase in calcium accumulation over the days. Considering the Akaike criterion and the properties of both models, the nonlinear model of Verhulst presented better adjustment in all seeding densities, being more suitable for to describe the accumulation data of the total calcium nutrient of Jalo bean.*

Keywords: *Biomass accumulation, growth curve, Gompertz, nonlinear model, Phaseolus vulgaris L., Verhulst.*

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I. INTRODUCTION

Common bean (*Phaseolus vulgaris L.*) is one of the main crops produced and consumed in Brazil and in the world, with Brazil standing out as the world´s largest grain producer in the year 2016, a productive capacity to reestablish increase of bean productivity due to production collapses in renowned in the country, mainly due to climatic factors such as drought and frost. In this way, producers investments in this crop due to the favorable prices above. For the year 2017, bean production is estimated at 1.38 million tons in the first harvest, 1.22 million tons in the second harvest and 672.6 thousand tons in the third harvest (CONAB, 2017). Moreover per capita consumption tends to grow from 17 to 22 kg/inhabitant/year until the year 2022 (FRANCO, 2016) Due to the short cycle of the bean, the modeling of its growth is important to aid in the practices, inference about physiological processes, in the best fertilization, among others (BENINCASA, 2003). The description of growth through the accumulation of biomass over time is essential for proper management and detection of factors that affect the growth of the plant. In the bean crop, little emphasis has been given on the modeling of accumulation of nutrients. Responsible for maintaining membrane and cell wall integrity, calcium ions are related to the preservation and quality of vegetables, processed and fresh (BUREN, 1980) it is important to evaluate the accumulation of this nutrient. The objective of this work was to model the accumulation of macronutrient calcium, non-common bean cultivar Jalo, along its vegetative growth in five densities with the use of nonlinear Verhulst and Gompertz models.

II. MATERIAL AND METHODS

The nutrient accumulation data calcium (Ca), in $kg.ha^{-1}$, are derived from experiment carried out in the experimental area of the Department of Agriculture, Federal University of Lavras, with the common bean, cultivate Jalo, using the randomized block design, with three repetitions, and the treatments were arranged in a 5x7 factorial scheme to verify the effect of the factors planting density (75, 145, 215, 285 and 355 thousand plants per ha^{-1}) in different periods (13, 23, 33, 43, 53, 63, and 73 days after emergence). The accumulation data total calcium were submitted to analysis of the variance, being verified the homogeneity of variances by Bartlett test and the normality of the errors by the Shapiro-Wilk test. Subsequently, regression analysis to evaluate

growth, in calcium accumulation, according to the days after, at each sowing density, using nonlinear regression models, of Gompertz and Verhulst.

For the description of the accumulation of calcium according to the epochs of evaluation, of regression using nonlinear Gompertz models (DOMINGUES, 2011; BOYCE et al., 1999)

$$y_t = \alpha e^{(-e^{(\beta - rt)})} + \varepsilon$$

and Verhulst (BASSANEZZI, 2002), represented by

$$y_t = \frac{\alpha}{1 - \left(1 - \frac{\alpha}{\beta}\right) e^{-rt}} + \varepsilon$$

in which, for both models, is the accumulation of calcium at time t, in kg/ha^{-1}; α is the relative parameter the maximum accumulation or maximum asymptotic weight that the plant can accumulate; β is the parameter of location; r growth rate, kg/ha^{-1}; t represents the evaluation times in days after the emergency; ε represents the experimental error, with mean zero and constant variance. The Akaike criterion (AIC) was used to compare the models of the growth curves, being considered as best, the model that presented the lowest estimate for AIC. Statistical analyzes were performed using the R (R Development Core Team, 2017) software, using the nls function to estimate the regression models.

III. RESULTS AND DISCUSSION

The growth period was carried out within each sowing density in order to evaluate the behavior of total calcium accumulation for each population. Magellan (2017) when applying the highest dose of chicken manure in his experiment observed that the accumulation of Ca in the bean-pod bean cultivar was 13% and this macronutrient was driven by the pods. This is due to the fact that the low content of Ca found in the pods is justified because there is little locomobility of this nutrient that has the tendency of accumulation in the aerial part and precarious translocation to the fruits. Through the regression equations (Figures 1, 2 and 3) obtained by fitting the nonlinear regressions of Gompertz and Verhulst, it was observed that the estimates of the weight parameter indicate that, as sowing density increases, there was an increase in accumulation of calcium, and this is easy to see by the Verhulst model. Lower values for parameter r indicate that the plants take longer to reach maturity, with more development occurring plants.

IV. FIGURES AND TABLES

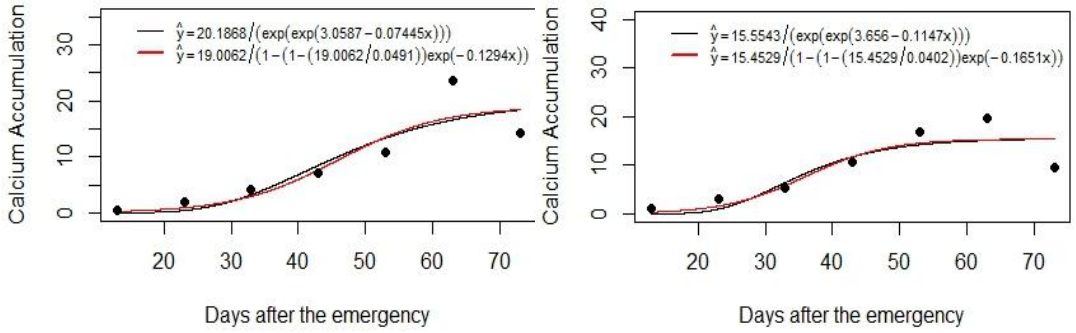


Figure1. Adjustment of nonlinear Gompertz and Verhulst models to calcium accumulation in common bean cultivar Jalo at no-tillage at seeding density 75 and 145, respectively.

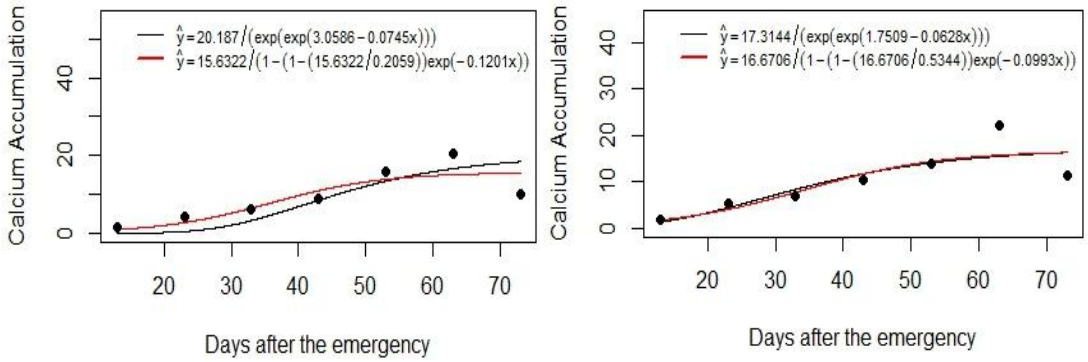
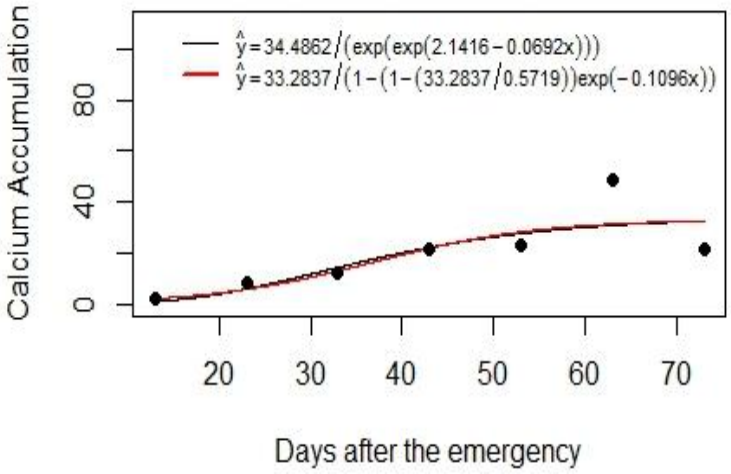


Figure2. Adjustment of nonlinear Gompertz and Verhulst models to calcium accumulation in common bean cultivar Jalo at no-tillage at seeding density 215 and 285, respectively.



F**igure3**. Adjustment of nonlinear Gompertz and Verhulst models to calcium accumulation in common bean cultivar Jalo at no-tillage at sowing density 355.

T**able**. Value of the Akaike information criterion (AIC) and adjusted coefficient of determination for the Gompertz (G) and Verhulst (V) models in adjusting the total calcium accumulation of Jalo bean, for each seeding density.

Density	75		145		215		285		355	
Model	G	V	G	V	G	V	G	V	G	V
AIC	44.75	44.00	43.89	43,11	44.75	43.71	44.44	44.06	57.25	56.98
R_a^2	0.748	0.768	0.725	0.735	0.748	0.668	0.602	0.625	0.517	0.625

V. CONCLUSION

Considering the Akaike criterion and the properties of both models, the nonlinear model of Verhulst presented better adjustment in all seeding densities, being more to describe the accumulation data of the total calcium nutrient of Jalo bean. An acknowledgement section may be presented after the conclusion, if desired.

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