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**Research Paper**

# Didactic tool for experimental demonstration with 'Gigante' forage cactus pear

**Bruno Vinícius Castro Guimarães[1]* • Sérgio Luiz Rodrigues Donato[2] • Ignacio Aspiazú[3] • Alcinei Mistico Azevedo[4] • Abner José de Carvalho[3]**

[1]Departamento de Ciências Agrárias, Instituto Federal do Amazonas, São Gabriel da Cachoeira, Amazonas, Brazil.
[2]Setor de Agricultura, Instituto Federal Baiano, Guanambi, Bahia, Brazil.
[3]Departamento de Ciências Agrárias, Universidade Estadual de Montes Claros, Janaúba, Minas Gerais, Brazil.
[4]Instituto de Ciências Agrárias, Universidade Federal de Minas Gerais, Montes Claros, Minas Gerais, Brazil.

*Corresponding author. E-mail: bvinicius20@yahoo.com.br. Tel: 55-77-99121-4608.

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***Abstract.*** To make scientific knowledge easier to grasp, interpret and understand, the researcher must make an effort using didactic resources and innovative tools to meet the purposes of research. The art of representing the scientific knowledge as an alternative to the traditional model renders the pedagogical process more efficient. This work aimed to present a model representing the optimum experimental plot size for 'Gigante' forage cactus pear, defined using the linear response plateau method, by an *in vivo* model with the species *Opuntia brasiliensis*. We developed a model with 28 basic units arranged in a 4 × 7 grid of which ten basic units are plants for measurements arranged in a 2 × 5 *grid* or 40 $cm^2$ with the species *Opuntia brasiliensis*. The *in vivo* model scale, 1:10, represents a ten basic unit optimum plot size (40 $cm^2$), which in the field corresponds to 4 $m^2$ of the forage crop. Using the experimental model as a didactic and strategic resource was successful in improving the practical understanding of agronomic concepts; therefore, the *in vivo* model may be developed not only for thesis qualification and defense, but also for any teaching, research and extension environment as an innovative tool.

**Keywords:** Experimentation, education, teaching, model, *Opuntia*.

## INTRODUCTION

Agricultural trials are founded on the statistical definition of a suitable plot size, which is one of the main strategies for increasing experimental precision, reducing error, and improving the reliability of inferences drawn from the experimental design (Sampaio Filho *et al*., 2019). Generally, one selects a method for estimating the optimum plot size that is easy to use, highly precise and allows an effective visualization of results (Tedford *et al*., 2017).

However, the success of methods in estimating plot size should not be solely based on the theoretical representation of the results. From a pedagogical standpoint, to make the scientific knowledge easier to assimilate, interpret and effectively understand, the researcher must make an effort through didactic resources and innovating tools to meet the purposes of a study. The art of representing the scientific knowledge as an alternative to the traditional model renders the pedagogical process more efficient (Alves and Barros, 2019).

In defining plot size and shape for field trials, the results are quantitative, with values expressed as a number of basic units or unit area, thereby limiting the practical understanding of the reader. Nonetheless, demonstrating knowledge using an actual didactic instrument enables visually grasping the spatial context provided by a three-dimensional model. In turn, it favors a better understanding between what is observed in the model and what was algebraically estimated (Sharma, 2019).

Aiming at selecting from the family Cactaceae the most similar species to the 'Gigante' cactus pear (*Opuntia ficus-indica* Mill), using morphological, anatomical and physiological characteristics, *Opuntia brasiliensis* (Willd) Haw was chosen for its importance in representing *Opuntia ficus-indica* Mill (Azevedo *et al*., 2013). Phyllotaxy of cladodes, modified leaves (spines), parallelocytic stomata, crassulacean acid metabolism (CAM), and arrangement and thickness of epidermis and cuticle were the main characteristics taken into account, which are related to the natural adaptation of the species to arid and semiarid environments (Rosas *et al*., 2012).

Furthermore, Silva *et al.* (2001) reported similar stomata frequency between *Opuntia brasiliensis* (Willd) Haw, with 46 stomata $mm^{-2}$, and *O. ficus-indica* Mill, with 50 stomata $mm^{-2}$. Therefore, in comparing both species, *Opuntia brasiliensis* can harvest $CO_2$ as efficiently as *O. ficus-indica*, favoring carbon fixation for photosynthesis and thus positively affecting the vegetative growth.

This study aimed to present a model representing the experimental optimum plot size for 'Gigante' forage cactus pear, determined by the linear response plateau method (LRP), using an *in vivo* model with the species *Opuntia brasiliensis* (Willd) Haw.

## MATERIALS AND METHODS

The work was conducted in an experimental area at Baiano Federal Institute, campus Guanambi, state of Bahia, Brazil. The soil is a Litolic Neosol and mean annual rainfall and temperature are 670.2 mm and 25.9°C, respectively.

Based on a blank trial, plants, each one considered a basic unit (BU), were subjected to homogenous agronomic practices throughout the area. For evaluation purposes, eight central rows consisting of 48 plants each were used, totaling 384 'Gigante' forage cactus plants. The following vegetative characteristics were measured in the third production cycle: plant height (m), cladode length (cm), cladode width (cm), cladode thickness (mm), cladode number (unit), cladode area ($cm^2$), cladode total area ($cm^2$) and yield (Mg $ha^{-1}$). The distribution of the 384 BUs on the area allowed designing 15 specific plot sizes, thereby they fully occupied an area of 153.60 $m^2$.

The linear response plateau model was defined as:

$$CV_i=\begin{cases} \beta X_0+\beta_1 X_i+\varepsilon i & \text{if, } X_i \le X_c \\ P+\varepsilon i & \text{if, } X_i>X_c \end{cases}, \ i = 1,...15 \quad (1)$$

where, $CV_i$ is the coefficient of variation between plot sizes $X_i$; $X_i$ is the plot size in basic units; $X_c$ is the optimum plot size in basic units; P is the coefficient of variation on the plateau; $\beta_0$ is the intercept; $\beta_1$ is the angular coefficient; and εi is the random error associated with $CV_i$ (Sampaio Filho *et al*., 2019). The optimum plot size was calculated using the function $X_c=\frac{(\hat{P}-\hat{\beta}_O)}{\hat{\beta}_1}$,where, $\hat{\beta}_0$, $\hat{\beta}_1$ and P are parameters of model (1).

Based on plot sizes (BU) estimated by the linear response plateau method for 'Gigante' forage cactus pear, an *in vivo* model was designed with the species *Opuntia brasiliensis*, according to the virtual model built using SketchUp Application (Figure 1A). The growing medium was confined to rectangular-shaped boxes made of wood from a commercial forest of *Pinus* sp. The boxes measured 70, 22 and 7 cm in length, width and depth, respectively (Figure 1B). A model having the same dimensions as the wooden box was built using marble stone (Figure 1C). A natural growing medium was used at a ratio of 70, 25 and 5% of dirt, sand and cattle manure, respectively.

The cladodes planted in the model were selected based on their vigor, uniformity and overal health, thus reflecting an actual forage cactus pear plantation. Cladodes were collected from a single, representative plant with 28 cladodes (Figure 2A). Afterwards, the cladodes were placed in shade for 15 days for healing the wound resulted from the detachment from the plant, called curing (Figure 2B).

Aiming at the maximum similarity between growth and development parameters, the *in vivo* model growing the species *Opuntia brasiliensis* was conducted under soil and climate conditions akin to the field trial with the species *O. ficus-indica*; therefore, an improved didactic comparison between both species in an academic environment was obtained. Statistical procedures for determining plot size in the field as well as *in vivo* were carried out using R (R Development Core Team, 2012).

## RESULTS

Using the relationship between the 15 plot sizes estimated on the field trial and their respective coefficient of variation, optimum plot sizes for every measured characteristic were estimated using the linear response plateau method. A 0.9 BU variation occurred across plot sizes. The smallest plot size was for plant height with 8.55 BUs, followed by cladode number (8.81 BUs), yield (8.83 BUs), total cladode area (8.84 BUs), cladode length (9.07 BUs), cladode thickness (9.23 BUs), cladode area (9.27 BUs) and cladode length (9.46 BUs).

However, determining plot sizes is a quantitative discrete process, that is, integer values are used (Guimarães *et al*., 2019), and one usually measures all aforementioned characteristics in field trials with 'Gigante'

A B C

**Figure 1. A.** Schematic design of the box representing the soil and model with the species *O. brasiliensis.* **B.** Wooden box in which the growing medium was placed. **C.** Marble stone used for building the model. Source: materials created by the authors

A B

**Figure 2.** A. Representative *Opuntia brasiliensis* plant from which cladodes were collected, after harvesting. B. Cladodes selected and left for wound healing - curing. Source: materials created by the authors.

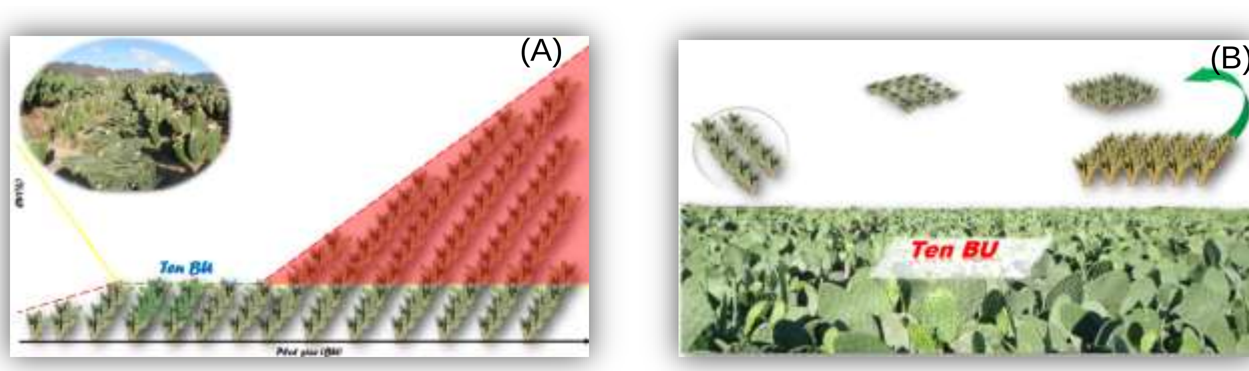


**Figure 3.** (A) Relationship between the coefficient of variation and the optimum experimental plot sizes. (B) Agronomic dynamic for defining the optimum size of experimental plots. Source: materials created by the authors.

cactus pear; therefore, a single plot size should be selected. When conducting agricultural experiments or field trials, it is necessary that the researcher or instructor defines what the experimental basic unit will consist of, thereby aiming at the highest precision by reducing the experimental error. The optimum plot size for Opuntia ficus-indica was represented on the model by 10 basic units using the species Opuntia brasiliensis. With the in vivo model, students should have a better understanding of it. This plot size was selected due to the stabilization of the coefficient of variation, which means an improved use of resources, as illustrated in Figure 3.


**Figure 4.** Doctoral thesis qualification using didactic resources for demonstrating the optimum plot size for 'Gigante' forage cactus. Professors, coordinators and students of the professional Master's program signed an informed consent form by which they authorized publishing their images on academic media. **Source:** Materials created by the authors.

The linear response plateau regression model has been used for estimating the optimum plot size for several crops, such as forest species (Bhering *et al*., 2015), papaya (Celanti *et al*., 2016; Silva *et al*., 2019), castor bean (Sampaio Filho *et al*., 2019), among other crops. This method is considered among researchers as an efficient method as it is possible, using a single model, to have precision, an effective visualization, and practical determination.

For concretely visualizing the effect of a field trial, the optimum plot size was defined using the linear response plateau method and, then, this effect was illustrated by the *in vivo* model with the species *Opuntia brasiliensis* in a grid with four rows, seven plants per row, totaling 28 BUs. Plants used for measurements were those within central rows with 10 BUs for all measured characteristics. Figure 4 depicts a didactic-pedagogical representation of the optimum plot size for forage cactus pear determined using the linear response plateau model.

The *in vivo* model used in this study helped students to grasp concepts related to agricultural research; thus, the model is an adequate resource in developing theory and practical classes (Figure 4). Using this method, students followed the growth, development, and crop interactions with the atmosphere. Didactic resources similar to the one presented herein have been developed in several fields of higher education, with focus on increasing accessibility, permanence, and academic success.

## DISCUSSION

The use of didactic tools has made the access to information and professional education easier, especially when the model of education in place permits broadening the comprehension of academic contents in an efficient and contextualized manner; hence, using models represents an alternative approach that provides a way of overcoming possible barriers between teaching and learning. Such pedagogical tools are essential during times of insecurity brought about by the Covid-19 pandemic; therefore, building complementary, alternative teaching tools is necessary for education to be successful (Figure 5).

In this regard, Duval (2017) stresses how important building models is as a didactic resource by which the authors involved in it developed numerous abilities from planning, discussion, organization, material acquisition, scheduling, and content. The validation of a differentiated pedagogical model is done by the student body who, according to Stumbles (2018), are immediate agents in a classroom setting, and their basic interests, background diversity, life experience and learning expectations should be met, respected and valued.


**Figure 5.** Trends, dynamics, and contextualization of teaching-learning process. Image composed by the authors.

The theoretical-practical robustness of research when teaching agricultural sciences must be planned for supporting the professional education at every level. Sinclair *et al*. (2016), studying knowledge construction and the importance of scientific discussion, added that the development of an innovative, high-quality educational products should be constant over the educational qualification process.

The spread of papers and educational products maximizes knowledge acquisition and breakdown of interpretations; thus, education products should be reproduced, licensed and applied according to multiple needs in academic works (Sarpkaya and Kırdök, 2019). Therefore, a research professor, working with professional qualification, can offer a more concrete practical demonstration of an investigated phenomenon (Alves, 2018).

The search for teaching alternatives has been valued in many multidisciplinary scientific fields (Alves, 2018). Paula and Andreola (2016) identified a strategic dynamic by building models from techniques commonly used by smallholder farmer, thereby promoting a self-sustainable and productive community, where making three-dimensional models is an important and successful didactic-pedagogical tool.

Moreover, Paula and Andreola (2016) reported that group work contributes to the cognitive, psychomotor and affective development of participants and the presentation of a concrete teaching-learning model enabled teachers involved in professional qualification the opportunity of a technical analysis of 3D proposals regarding nature-friendly management and conservation of soil.

Gunčaga *et al*. (2017) developed an interdisciplinary didactic strategy in building models for physical and virtual demonstration of geometry in a math degree classroom. For the authors, the pedagogical proposal had significant and favorable results in teaching. Besides reaffirming technical concepts in exact and environmental sciences, the model led to a historical and cultural analysis by the academic community. Based on students' opinions, building the model was motivated by the inseparability between theory and practice, thereby allowing a palpable expression of knowledge.

For Alves and Barros (2019), organizing the knowledge as a model allows closely representing the investigated object. A three-dimensional model on a smaller scale, either virtual or physical, serves as support for all areas of knowledge, providing the student with a holistic and isometric vision about the object while giving the teacher insight into students' understanding of the subject being taught.

Creating, describing and interpreting a topic in a critical and innovative way expand one's horizon as well as providing a high-quality professional qualification (Alves, 2018). Such understanding challenges the research professor to seek didactic tools such as models for attaining a better visualization provided by the three-dimensional thematic model, contrasting with the logic of the limited traditionalism that perpetuates in classroom settings with presentation of contents.

Sousa (2014) elaborated didactic-pedagogical workshops on building geographical relief models to aid teachers of several educational levels. According to the researcher, the qualification of students as critical readers of maps is essential for emancipating them from the passive dependence on cartographic works, thus ensuring students the ability of acting as thinkers that can change academia.

As models represent a practical knowledge, they can assume a static or dynamic nature, as reported by Paula and Andreola (2016) and Sousa (2014), respectively. A static model represents a limited observation of objects inserted in the model, while a dynamic model, in addition to observation, allows combining elements composing the model, which favors the development of the reader's critical thinking. However, an *in vivo* model, such as the one presented herein, allows a real analysis of a living organism in the face of farming factors directly interfering with the phenotypic expression and development of the crop.

*In vivo* models illustrate natural characteristics of the species, such as spines, phylotaxy of cladodes, similarity to vegetative growth and reproductive development, as well as interactions with soil and atmosphere, water relations, and defense mechanisms against pathogens (Rosa *et al*., 2012; Azevedo *et al*., 2013). Accordingly, these are reliable models for a didactic-pedagogical characterization of the utmost importance for teaching agricultural sciences. They establish a three-dimensional agronomic representation on which *Opuntia brasiliensis* can undergo a detailed analysis, thereby drawing inferences from the crop of interest, *O. ficus-indica* (Figure 4).

This study offers the research professor a teaching tool that contributes to professional and academic qualification, not only by presenting an education product, with wide use in classrooms and other educational settings, but also improving teaching practice and educational quality. Rôças and Bomfim (2018) emphasize the importance of the criteria used to validate an educational product as these products must emerge in response to a problem, with proper theoretical and statistical support, as performed for the pedagogical proposal reported in this paper.

As discussed by Resende *et al*. (2002), acquiring and communicating information in agricultural sciences should be open to a broader contribution, including texts, games, models, etc. These didactic tools, particularly for statistics and agricultural sciences, seemingly complex subjects, can constitute a communication bridge for a better understanding, popularization and use of these subjects. These may help to demystify the notion that only a few "geniuses" are able to understand these subjects, and teachers holding this knowledge are often the ones perpetuating this notion. These alternatives would positively contribute to a better qualification of lecturers teaching statistics applied to agricultural sciences, regardless of the level.

The main goal of this study is building an *in vivo* model for representing the optimum plot size for 'Gigante' forage cactus pear, further providing teachers and advisors with an actual, practical demonstration of a basic experimental unit, with the maximum representation of the crop. Therefore, we believe that this didactic resource can be used in agricultural sciences not only in teaching statistics but also soil fertility analysis, planting arrangement, irrigation and drainage, pest and disease control, germplasm bank, and species conservation.

## CONCLUSION

Based on the linear response plateau regression method, we developed a rectangular-shaped model consisting of 28 basic units arranged in a 4 × 7 grid of which ten basic units are plants for measurements arranged in a 2 × 5 grid or 40 $cm^2$ with the species *Opuntia brasiliensis*. The *in vivo* model scale, 1:10, represents a ten basic unit optimum plot size (40 $cm^2$), which in the field corresponds to 4 $m^2$ of the forage crop.

Using the experimental model as a didactic and strategic resource was successful in improving the practical understanding of agronomic concepts; therefore, the *in vivo* model can be developed not only for thesis qualification and defense, but also for any teaching, researching and extension environment as an innovative tool.

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