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Short communication

Regression plateau for plot size estimation with 'Gigante' forage cactus pear

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'Gigante' cactus pear (*Opuntia ficus indica* Mill. cv. Gigante) is a forage crop grown under semi-arid climates and because of its' resilience to water-limiting conditions it can produce a high biomass yield. The objective of this study was to estimate the optimum experimental plot size for 'Gigante' using the linear Response Plateau Model. The study was carried out at Baiano Federal Institute, Guanambi Campus, state of Bahia, Brazil. A uniformity trial in which plants were subjected to the same cultural practices and spaced 2.0 m × 0.2 m apart was conducted. Each plant was considered as a basic unit. The Linear Response Plateau Method allowed fitting models with coefficients of determination ranging from 0.0772 to 0.881. Plot sizes ranged from 7.30 to 9.46 basic units for the evaluated characteristics. Using the Linear Response Plateau Regression model, a plot size of 10 basic units (4.0 m²) was estimated to be sufficient for field experiments with 'Gigante' forage cactus pear.

Keywords: agronomic characters, evaluation, *Opuntia*

Introduction

The cactus pear (*Opuntia fícus indica* Mill. cv. Gigante) is one of the best-performing forage crops grown under semi-arid climates. An important aspect in determining the success of field experiments is defining the experimental unit (Guimarães et al. 2019). Generally, field experiments with forage cactus pear are conducted using plots of different sizes based on the reseacher's experience, available resources, and genetic material, among others (Queiroz et al. 2015; Padilha Júnior et al. 2016; Silva et al. 2016). Therefore, the aim of this study was to estimate the optimum plot size for 'Gigante' forage cactus pear using the Linear Response Plateau (LRP) model.

The study was conducted between 2009 and 2011 at the Baiano Federal Institute, Guanambi Campus, state of Bahia, Brazil, on a predominately flat soil classified as Litholic Neossol. The region has a tropical, hot semi-arid climate according to the Köppen classification. The mean annual rainfall and temperature during this period were 670.2 mm and 25.9 °C, respectively.

For each characteristic evaluated on an area consisting of 384 basic units, several plot sizes were combined so that plants could cover the whole experimental area; hence, 15 different pre-established rectangular-shaped plot sizes were evaluated, ranging in number from 1, 2, 3 up to 192 BU.

The LRP model, defined by a linear plateau function, is characterized by two segments: increasing or decreasing curve and a plateau response (the curve levels out), that assumes a constant value (P) (Schabenberger and Pierce 2002). The model is explained as follows:

$$CV_i = \begin{cases} \hat{a}_0 + \hat{a}_1 X_i + \varepsilon_i & if, X_i \le X_c \\ P + \varepsilon_i & if, X_i > X_c \end{cases}, \; i = 1,...,15 \quad (1)$$

where CV_i is the coefficient of variation between plot sizes
X_i is the plot size in basic units
X_c is the optimum plot size in basic units
P is the coefficient of variation at the point where the curve turns into a plateau
β_0 is the intercept
β_1 is the angular coefficient
ε_i is the random error associated with the CV_i (Castro et al. 2016).
The optimum plot size was estimated using the equation

$$X_c = \frac{\left(\hat{P} - \hat{\beta}_0\right)}{\hat{\beta}_1},$$

where $\hat{\beta}_0$, $\hat{\beta}_1$ and P are parameters of Eq. 1.
Statistical analyzes were performed using the software R (R Development Core Team 2012).

The coefficients of variation (CV) were estimated for the following eight characteristics: Y = yield; PH = plant height; CTA = cladode total area; NC = number of cladodes; CT = cladode thickness; CA = cladode area; CL = cladode

Table 1: Estimates of coefficients of variation (%) as a function of plot size in basic units (*X*) for phenotypic descriptors of 'Gigante' forage cactus pear

X	*Y*	PH	TCA	NC	CT	CA	CL	CW
1	49.92	18.82	40.13	36.58	37.01	13.63	6.91	8.05
2	33.79	13.72	27.38	26.64	29.83	9.73	5.15	5.69
3	27.95	11.47	21.66	22.44	26.37	8.17	4.33	4.83
4	24.72	10.47	19.56	20.77	25.93	7.42	3.96	4.40
6	22.12	9.49	17.00	18.43	23.97	6.72	3.46	4.04
8	15.29	5.85	12.98	11.29	14.77	4.00	2.35	2.18
12	19.00	7.93	14.33	15.96	21.43	5.35	2.68	3.36
16	11.18	5.58	9.84	10.61	16.08	3.29	1.92	1.98
24	17.43	6.66	12.25	14.50	19.60	4.02	1.98	2.55
32	6.49	3.81	5.32	5.38	12.15	1.63	1.11	0.96
48	6.36	3.54	4.75	4.94	11.74	1.39	0.77	0.90
64	6.09	3.70	4.73	4.70	11.58	1.34	0.82	0.91
96	6.06	3.62	4.65	5.04	11.13	0.50	0.30	0.46
128	5.49	3.95	5.17	5.13	12.82	0.83	0.86	0.37
192	3.93	2.18	5.12	6.21	13.16	1.84	1.28	0.68

Y = yield; PH = plant height; CTA = cladode total area; NC = number of cladodes; CT = cladode thickness; CA = cladode area; CL = cladode length; and CW = cladode width.

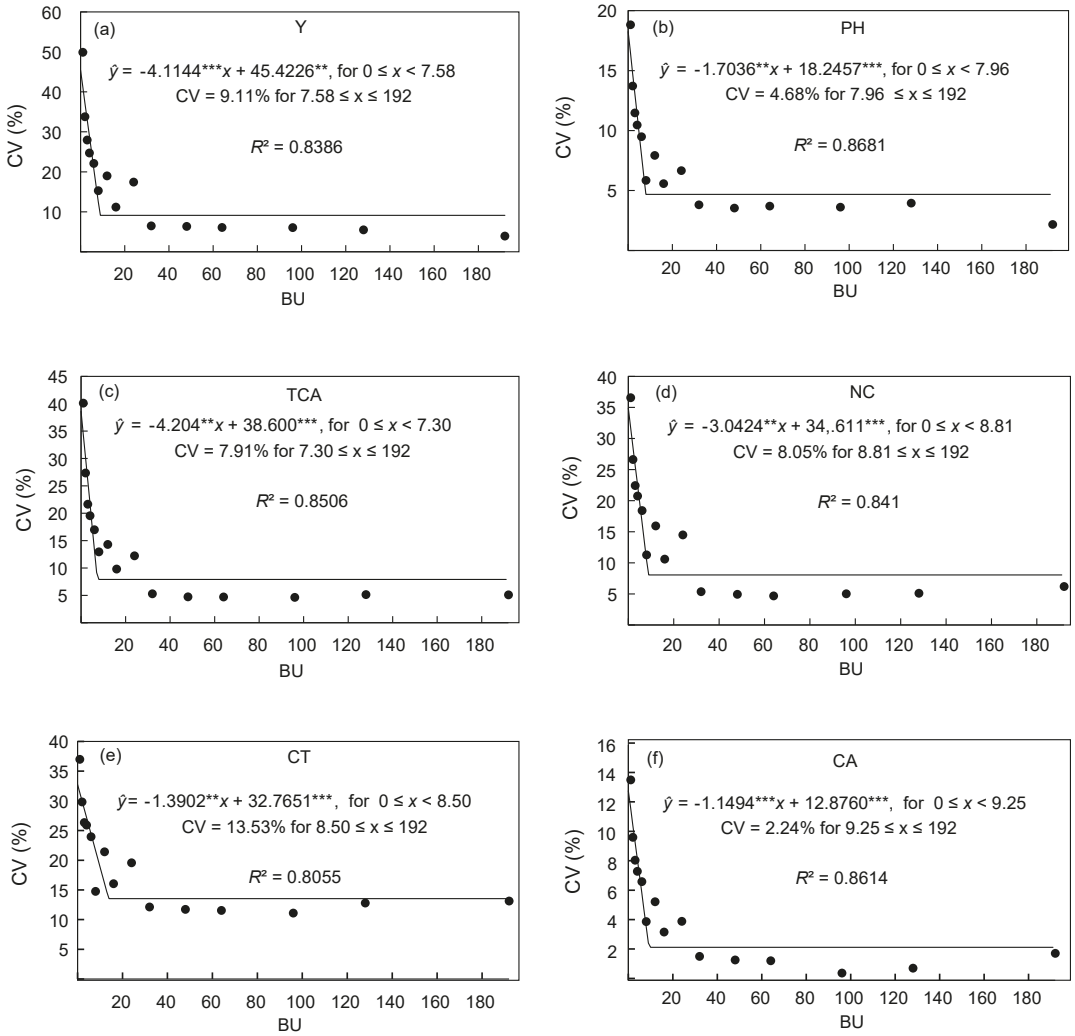

Figure 1: Linear representation of the relationship between the coefficient of variation (CV) and optimum plot size (X_c), in basic units (BU), for the characteristics: (a) yield - *Y*; (b) plant height - PH; (c) total cladode area - TCA; (d) number of cladodes - NC; (e) cladode thickness - CT; (f) cladode area - CA; (g) cladode length - CC; and (h) cladode width - CW in forage cactus pear. ***p = 0.0001; **p = 0.001; *p = 0.01

length; and CW = cladode width. These were evaluated in respect to the 15 plot sizes arranged in the experimental area (Table 1). The CV values fluctuated across measured characteristics and plot sizes. Cladode length had the lowest CV (0.30%) while yield the highest (49.92%).

Using the LRP method for estimating the optimum plot size allowed fitting models with coefficients of determination ranging from 0.772 (Figure 1H) to 0.881 (Figure 1G). Plot sizes (X_c) estimated by this method were similar across evaluated characteristics. The smallest plot (7.30 BU) was for total cladode area (Figure 1C) and the largest plot (9.46 BU) for cladode length (Figure 1G). For these two characteristics, the CV estimates leveled off on the plateau (P) with CVs of 7.91 and 1.30%, respectively.

Leonardo et al. (2014) reported 10 to 20 basic unit plots for pineapple, Peixoto et al. (2011) reported three to eight basic unit plots for passion fruit, and Silva et al. (2012) 1 to 21 basic unit plot sizes for radish. Sousa et al. (2015) estimated plot sizes using the LRP method, and the authors reported plot sizes ranging from 4 to 5 basic units for experimental evaluation with sunflower cultivation, which is more consistent with this study where the basic units range from 8 to 10 (Figure 1).

The maximum number of basic units tested in this study was 192, occupying an area of 76,8 m^2. As indicated in Figure 1A, when the CV for yield becomes constant at 9.11%, the optimum plot size has 7.58 basic units. Increasing the number of basic units does not decrease the CV, thus, there is no further increase in experimental precision.

Optimum plot sizes were 7.96, 7.30, 8.82, 8.50, 9.25, 9.46 and 9.07 basic units for plant height, total cladode area, number of cladodes, cladode thickness, area, length and width, respectively. These plot sizes are associated with the CV at the following points corresponding to the plateau formation: 4.68, 7.91, 8.05, 13.53, 2.24, 1.30 and 1.67%, respectively (Figure 1).

Results from this study using the Linear Response Plateau Regression model allow us to estimate that a 10 basic unit experimental plot size (40 m²) is sufficient for field experiments with 'Gigante' forage cactus pear to measure all the evaluated characteristics adequately.

Geolocation information

Brazil: 14°13′30″ S; 42°46′5″ W.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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