Original Research Article

Optimum size and shape of experimental units for cassava cropping

Abstract

In agricultural experimentation, the right size and shape of experimental units increase the precision of the experiment. This study determines the optimum size and shape of the experimental unit for field experimentation with cassava. For this, we carried out a uniformity test in Pacajús, Ceará, under dry conditions, with the cultivar 'Mastruço' planted at a spacing of 1.00 m x 0.60 m. The root yields were collected in 15 rows with 40 plants each, comprising 31 types of experimental units of 23 different pre-established sizes. The optimum size of the experimental unit was estimated by the Hatheway method, and the shape was determined by the relative information method. The Hatheway method indicated several optimum sizes of experimental units, many of which were applicable for evaluation experiments of cassava cultivars. The 15 x 1 rectangular experimental unit (15 rows with one plant and 9.00 m² of useful area) was considered the ideal shape for assessment of cassava production, which was smaller than the size suggested in surveys with of cassava cropping. There was a continuous nonlinear reduction of the coefficient of variation with the increase in plot size.

Key words: *Manihot esculenta* Crantz, Hatheway's method, Method of relative information.

1. INTRODUCTION

The cassava (*Manihot esculenta* Crantz) stands out in the world socioeconomic context due to its high adaptability to soil and climatic conditions and large starch production per unit area. This plant is primarily produced in northeastern Brazilian region.

Cassava shows wide genetic variability and is cultivated in small farms throughout tropical regions [1]. This variability, coupled with the differences in vigor between plants of the same variety and variations of production per plant [2], have made it difficult to establish an optimal size of experimental unit for field experiments with this crop. In Brazil, the fourth largest producer of cassava in the world [3], field research with this crop is done in quite different environments. Often, the heterogeneity of local conditions has led to experimental errors, which makes it difficult to prove the statistical differences between the evaluated treatments.

Generally, soil heterogeneity is due to pre-existing conditions or characteristics related to soil formation and its interactions with flora, fauna and crop management. Land use in agricultural crops introduces new sources of heterogeneity, such as the irregular distribution of crop residues, insects, diseases, weeds, applied fertilizers, cultivated species or genotypes and irrigation [7], and in the literature [22]. The experimental area, even if it appears to be homogeneous, presents variations both horizontally and vertically, which can hardly be controlled only with the use of an appropriate design [15]. The soil heterogeneity index, represented by the crop productivity, is the main characteristic that determines the optimal plot size in trials and consequently the experimental precision through the value of the coefficient of variation [7][17]. The calculation of soil heterogeneity index (b) was proposed by [27].

Because the differences between genotypes of improved species tend to decrease, the success of a breeding program demands accurate experiments. Therefore, the maintenance of genetic gains with selection depends on the increase in experimental precision. However, planning is necessary to carry out trials with high accuracy. Within this context, one of the fundamental questions in experimental design relates to the optimum size of the experimental plot or unit [4].

The smaller the difference between the studied materials, the greater the size of the experimental units should be so that these differences exceed the variation caused by sampling error. Therefore, in advanced cycles of selection, there is demand for larger experimental units [5]. However, the increase in experimental accuracy due to increasing the size of the experimental unit is asymptotic and therefore, the larger the size of the experimental unit the smaller the efficiency in improving accuracy. The implication is that, above a given size, the progress of accuracy does not compensate for the increase in size. From this point, additional increases in accuracy will be obtained by increasing the number of replicates [6].

Several factors are involved in choosing the size and shape of the experimental unit. Among these, soil heterogeneity is the most critical factor, and information about the experimental area is essential [7]. [8] mentioned that the size and shape of the experimental unit should not be generalized, as they vary with soil, climatic conditions, and crop under study.

Several studies report the optimal size of the experimental unit for different situations and different crops, such as for tomato [9,10,], lettuce [11], candeia [12], bean [13], rice [6], coffee [5], and sunflower [14,15,16]. However, there is little information about the size and shape of the experimental unit for cassava.

Due to the above, this work aimed to determine the optimum size and shape of experimental units or plots for field experimentation with the cassava crop.

Material and Methods

The data production from the 'Mastruço' cultivar were collected in a uniformity test at the Coastal Research Unit of the Agricultural Research Company of Ceará (Unidade de Pesquisa do Litoral da Empresa de Pesquisa Agropecuária do Ceará - EPACE), located in Pacajus (4°10'S-38º27'W; 60m of altitude), Ceará. The soil of the region is classified as Dystrophic Red-Yellow Podzolic with sandy texture [17]. The area has an average annual precipitation of 1027 mm and two seasons, the rainy season, from January to June, which concentrates 85% of the rainfall, and a dry season, from July to December. There are high temperatures throughout the year, with averages ranging from 23°C to 32°C. The average air humidity varies from 70% during the dry season to 90% in the rainy season [18].

We planted fifteen rows (24 m long) with 40 plants each at a spacing of 1.00 m x 0.60 m, covering a total area of 360 m², where the 600 basic units (BUs) were collected, each consisting of 1.00 m x 0.60 m (1 plant), with an area of 0.6 m².

Each plot size consisted of X_1 BUs of width (lines) and X_2 BUs of length (columns), comprised by the grouping of contiguous BUs, so that product $X_1.X_2$ corresponded to X (plot size in BUs).

For the choice of different types of plots, we used only the groupings of BUs with parcel sizes that allowed the use of 100% of the area of uniformity test. In this way, the number of repetitions of each plot was limited by the respective total area, and the BUs were grouped in 31 different ways: : 1x1, 1x2, 1x4, 1x5, 1x8, 1x10, 1x20, 1x40, 3x1, 3x2, 3x4, 3x5, 3x8, 3x10, 3x20, 3x40, 5x1, 5x2, 5x4, 5x5, 5x8, 5x10, 5x20, 5x40, 15x1, 15x2, 15x4, 15x5, 15x8, 15x10, and 15x20, thus obtaining 23 different plot sizes (X): 1, 2, 3, 4, 5, 6, 8, 10, 12, 15, 20, 24, 25, 30, 40, 50, 60, 75, 100, 120, 150, 200, and 300 UBs , which corresponded respectively to areas of 0.60, 1.20, 1.80, 2.40, 3.00, 3.60, 4.80, 6.00, 7.20, 9.00, 12.00, 14.40, 15.00, 18.00, 24.00, 30.00, 36.00, 45.00, 60.00, 72.00, 90.00, 120.00, and 180.00 m².

Remembering that not just one but several sizes of plots are suitable to each research condition [19], we determined the optimum size of plot by the formula proposed by [20]:

$$X = \sqrt[b]{\frac{2(t_1 + t_2)^2 CV^2}{rd^2}} \qquad (1)$$

Where X is the optimum size of the plot in BUs; b is the coefficient of soil heterogeneity [21]; t_1 is the critical value of Student's t-distribution, at the α_1 level of significance of probability of error, found in the table of bilateral significance; t_2 is the critical value of t-distribution, at $\alpha_2 = 2(1 - P)$ probability level, where P is the probability of obtaining a significant result; CV is the coefficient of variation (%) of plots with 1 BU; r is the number of repetitions needed to detect true unit difference between two treatments; and *d* is the true difference between two treatments measured as a percentage of the mean.

The coefficient of soil heterogeneity (*b*), which measures the degree of association between adjacent BUs, was estimated after the linearization of the equation [21]:

$$V_x = \frac{V_1}{X^b} \qquad (2)$$

Where V_x is the variance per unit area of plots comprising X BUs of size; V_1 is the variance of the plots with 1 BU; and X is the number of BUs that compose the plot (plot size), using the weighted estimate of the degrees of freedom associated with each plot size X_i planned, i.e.,

$$\hat{b} = -\frac{\sum W_i(\log V_{xi})(\log X_i) - \frac{(\sum W_i \log V_{xi})(\sum W_i \log X_i)}{\sum W_i}}{\sum W_i(\log X_i)^2 - \frac{(\sum W_i \log X_i)^2}{\sum W_i}} \qquad (3)$$

In which W_i is the number of degrees of freedom associated with the variance, i.e., it is the total size of all plots with X_i size minus 1 (one). The variance per unit area (V_{xi}) was calculated by the formula:

$$V_{xi} = \frac{S^2_{xi}}{X_i^{\ 2}} \qquad (4)$$

Where S^2_{xi} is the variance between plots with X_i BUs. The value of $\hat{V}_1$ was obtained as follows:

$$\log \hat{V}_1 = \hat{V} \Rightarrow \hat{V}_1 = 10^{\hat{V}} \qquad (5)$$

In which:

$$\hat{V} = \frac{\sum W_i \log V_{xi}}{\sum Wi} + \hat{b}\frac{\sum W_i \log X_i}{\sum Wi} \qquad (6)$$

The significance level of 5% ($\alpha_1 = 0{,}05$) and the probability of obtaining significant differences between averages of 80% (P = 0.80) were used for the calculation of the optimum size of the plot by the [21] formula. We tested the combinations among the following experimental conditions: numbers of cultivars (4, 8, 12, and 15); numbers of replicates (3, 5, and 7); coefficients of variation (6, 12, 17, 23, and 30% plus the CV of plots with 1 BU); and expected differences between averages of two cultivars (10, 15, and 20%); considering the randomized block design.

The influence of the shape of experimental plot, which is the relationship between length and width, on the experimental precision was assessed through the method of relative information proposed by [22] and the observation of the behavior of the coefficients of variation of the different shapes of plots with the same size.

First, we calculated the variance of cassava production between plots of size X BUs for each type of plot:

$$S_x^2 = \frac{\sum_i (x_i - M(X))^2}{N - 1} \tag{7}$$

Where x_i is the cassava production of the i-th plot,

$$M(X) = \frac{\sum_i x_i}{N} \tag{8}$$

the average cassava production of the plots with X BUs of size, and

$$N = \frac{12}{X} \tag{9}$$

is the number of plots with X BUs. Subsequently, this variance was divided by its corresponding number of BUs, which refers to the variance per BU, thus obtaining, according to [22], a comparable variance (Vc) with the variance of the plot consisting of 1 BU (V_1), that is, the relative information (IR (%) was calculated by:

$$IR(\%) = \frac{V_1}{Vc} x100 \tag{10}$$

Considering that, according to [22], the variance of the plot with 1 BU provides 100% of relative information, dividing this variance by the comparable variance of each plot shape, we obtained the percentage of relative information corresponding to each plot shape, from this relative information, the best shape of plot to evaluate cassava production was determined.

Results

Table 1 shows the coefficients of variation (CV) for the plot of different sizes. The smallest parcel size (1 UB) resulted in the highest CV value. The CVs decreased with the increase in parcel sizes but with a non-linear rate. This reduction of the CV (precision gain) by adding more area was significant when the plot size was small.

Table 1. Size, number of plots, degrees of freedom, and coefficient of variation among plots.[1]

Plot size (Number of BUs)	Number of plots	Degrees of freedom	Coefficient of variation (%)
1	600	599	41.28
2	300	299	30.50
3	200	199	24.35
4	150	149	22.72

5	120	119	19.86 *
6	100	99	17.49
8	75	74	14.27
10	60	59	13.22 *
12	50	49	13.53
15	40	39	12.14 *
20	30	29	10.38 *
24	25	24	6.19
25	24	23	9.64
30	20	19	7.32 *
40	15	14	5.76 *
50	12	11	6.23
60	10	9	5.92 *
75	8	7	5.96
100	6	5	5.69
120	5	4	2.82 *
150	4	3	4.56
200	3	2	4.01
300	2	1	4.97

[1]BU = 0.60 m² (1.00 m x 0.60 m); * Arithmetic mean of the coefficients of variation of plots with different shapes but with the same size.

Table 2 shows the different optimum plot sizes for evaluating of cassava production, using a significance level of 5% of probability. It was used various combinations of cultivar numbers (I = 4, 8, 12 and 16), number of replicates (r = 3, 5 and 7), coefficients of variation (CV = 6, 12, 18, 24 and 30% plus the CV of plots constituted of 1 UB), and differences between means of two cultivars that are expected to detect (d) equal to 10, 15 and 20%. The experiment was done in randomized block design and the coefficient b estimated in the uniformity test.

Table 2. Optimum size of plots in BUs for evaluation of cassava production estimated in different combinations of cultivar (I), repetition (r), coefficients of variation (CV), and differences between averages of two cultivars, in % of the mean (d).[1]

d (%)	CV (%)	I = 4			I = 8			I = 12			I = 16		
		r = 3	r = 5	r = 7	r = 3	r = 5	r = 7	r = 3	r = 5	r = 7	r = 3	r = 5	r = 7
10	6	2.79	1.35	0.91	2.24	1.22	0.84	2.11	1.19	0.83	2.06	1.17	0.82
	12	11.69	5.68	3.83	9.37	5.12	3.53	8.86	4.98	3.47	8.63	4.92	3.45
	18	27.03	13.12	8.85	21.67	11.83	8.16	20.48	11.52	8.02	19.96	11.38	7.97
	24	48.98	23.79	16.05	39.27	21.45	14.79	37.12	20.89	14.54	36.18	20.62	14.44
	30	77.69	37.73	25.45	62.29	34.02	23.47	58.87	33.13	23.06	57.39	32.70	22.91
	41.86	154.66	75.10	50.66	123.99	67.72	46.71	117.20	65.95	45.91	114.24	65.09	45.61
15	6	1.21	0.59	0.40	0.97	0.53	0.36	0.91	0.51	0.36	0.89	0.51	0.36
	12	5.06	2.46	1.66	4.05	2.21	1.53	3.83	2.16	1.50	3.73	2.13	1.49
	18	11.69	5.68	3.83	9.37	5.12	3.53	8.86	4.98	3.47	8.63	4.92	3.45
	24	21.19	10.29	6.94	16.99	9.28	6.40	16.05	9.03	6.29	15.65	8.92	6.25
	30	33.60	16.32	11.01	26.94	14.71	10.15	25.46	14.33	9.97	24.82	14.14	9.91
	41.86	66.89	32.48	21.91	53.63	29.29	20.20	50.69	28.52	19.86	49.41	28.15	19.73
20	6	0.67	0.32	0.22	0.53	0.29	0.20	0.50	0.28	0.20	0.49	0.28	0.20
	12	2.79	1.35	0.91	2.24	1.22	0.84	2.11	1.19	0.83	2.06	1.17	0.82
	18	6.45	3.13	2.11	5.17	2.82	1.95	4.89	2.75	1.91	4.76	2.71	1.90

24	11.69	5.68	3.83	9.37	5.12	3.53	8.86	4.98	3.47	8.63	4.92	3.45
30	18.54	9.00	6.07	14.86	8.12	5.60	14.05	7.91	5.50	13.70	7.80	5.47
41.86	36.91	17.92	12.09	29.59	16.16	11.15	27.97	15.74	10.96	27.26	15.53	10.88

[1]BU = 0.60 m² (1.00 m x 0.60 m); b (coefficient of soil heterogeneity) = 0.9675; CV of plots consisting of 1 UB = 41.86%.

Table 3 shows the results concerning the influence of plot shape on the variability of cassava production evaluated through the comparable variance (Vc), relative information (IR), and coefficient of variation (CV_{LxC}).

Table 3. Comparable Variance (Vc), relative information (IR), and coefficient of variation (CV) of cassava production for different shapes and sizes of plot.[1]

Plot size (LxC)	Number of BUs	Number of plots	Area (m^2)	DF	Vc	IR (%)	CV_{LxC} (%)
1x1	1	600	0.60	599	542314	100.00	41.28
1x2	2	300	1.20	299	591948	91.62	30.50
3x1	3	200	1.80	199	566145	95.79	24.35
1x4	4	150	2.40	149	657211	82.52	22.72
1x5	5	120	3.00	119	678654	79.91	20.65
5x1	5	120	3.00	119	577910	93.84	19.06
3x2	6	100	3.60	99	583869	92.88	17.49
1x8	8	75	4.80	74	518296	104.63	14.27
1x10	10	60	6.00	59	590759	91.80	13.63
5x2	10	60	6.00	59	522698	103.75	12.82
3x4	12	50	7.20	49	699371	77.54	13.53
3x5	15	40	9.00	39	714921	75.86	12.24
15x1	15	40	9.00	39	690945	78.49	12.03
1x20	20	30	12.00	29	769387	70.49	11.00
5x4	20	30	12.00	29	606280	89.45	9.76
3x8	24	25	14.40	24	292418	185.46	6.19
5x5	25	24	15.00	23	738598	73.42	9.64
3x10	30	20	18.00	19	418581	129.56	6.62
15x2	30	20	18.00	19	614730	88.22	8.02
1x40	40	15	24.00	14	386349	140.37	5.51
5x8	40	15	24.00	14	460035	117.89	6.01
5x10	50	12	30.00	11	618373	87.70	6.23
3x20	60	10	36.00	9	452905	119.74	4.87
15x4	60	10	36.00	9	924877	58.64	6.96
15x5	75	8	45.00	7	848917	63.88	5.96
5x20	100	6	60.00	5	1031162	52.59	5.69
3x40	120	5	72.00	4	178582	303.68	2.16
15x8	120	5	72.00	4	459238	118.09	3.47
15x10	150	4	90.00	3	990480	54.75	4.56
5x40	200	3	120.00	2	1021273	53.10	4.01
15x20	300	2	180.00	1	2357520	23.00	4.97

[1]BU=0,60 m^2 (1,00 m x 0,60 m)

Discussion

However, as it approaches the optimum size, there is little gain in precision with further increases in the area. The authors [23,19,12,24,25,16] evaluated different plot sizes also reported CV reduction with increasing plot size, but when reaching the optimum size, the gain in precision decreased rapidly with the addition of more area.

The coefficient of soil heterogeneity (b = 0.9675) indicated a high heterogeneity, which suggests an absence of correlation between adjacent BUs. The Hatheway method estimated several optimum plot sizes from which the researcher can choose the one that suits him best, from pre-defined experimental conditions.

According to [26], experimental units with up to 20 BUs (12.00 m^2) can be used as basic units of practical size and therefore used for discussion purposes. We verified that to detect a 10% difference between averages of cultivars, it is possible obtaining plots of practical size with CV up to 18%, except for 4, 8, and 12 cultivars combined with three for the CV of 24%, using 4, 8, 12, and 16 treatments with seven replicates and for the CVs of 30 and 41.86% (CV of one BU) none combinations should be recommended. The practical size of the plot to detect a difference of 15% is possible for CV up to 24%, except for 4 cultivars with three replicates, for the CV of 30%, using 4, 8, 12, and 16 cultivars with five and seven replicates and for the CV of 41.46%, using 12 and 16 cultivars with seven replicates. Finally, to detect a difference of 20%, except for the CV of 41.86%, with 4, 8, 12, and 16 cultivars with three replicates, any values of CVs, numbers of replicates, and cultivars allow obtaining plots of practical size.

In general, a careful evaluation of the values obtained from optimum plot sizes indicates that some sizes are not practically feasible because values are very small or very large, especially when the ratio $(CV/d)^2$ is too small or too large, respectively.

The results in table 2 show the influence of the coefficient of variation, number of repetitions, experimental precision desired, and number of cultivars on the optimum size of plots, which proves the importance of considering these factors in experimental planning.

The CV was the most influential factor affecting the optimum size since large increases were observed in the optimum size with the increase in CV in any combination of d, I, and r. These results resemble those obtained by [26,27,12,16], with melon, eucalyptus, candeia, and sunflower, respectively.

The number of replicates also strongly influenced the optimal plot size. When kept fixed the values of d, I, and CV, significant reductions in optimum sizes were observed with increasing number of replicates. This confirms the effect of the increase in the number of repetitions in the improvement of the experimental precision [29,27,17], which enhances the efficiency of small plots with many replications to detect small percentage differences between cultivars than the use of large plots with few replications [27,16].

The optimum sizes decreased considerably when the values of d (the lowest experimental precision) were increased when maintaining values of CV, I, and r constant [12,27,16]. On the other hand, there were little changes in the size of plots with the variation of number of cultivars, which indicates a low influence of this factor [12,27,16].

In general, combining the values of CV, d, I, and r, we estimated 216 different optimum plot sizes, most of which were of practical sizes, which can be useful in the experimental planning for evaluation of cassava cultivars.

The relative information decreased and the comparable variance increased with the increase in plot size, a fact also observed by [22], [9], and [16]).

The method of relative information is based on the principle that comparable variance and relative information result in the same best shape of plot (Keller, 1949). In this way, the choice of the optimum shape can be made considering only the relative information.

Comparing the variability indices used in this study (Vc, IR, and CV_{LxC}) among plots of the same size, we verified the influence of plot shape on experimental precision (Table 3). Most plots with rectangular shape showed the highest IR and lowest CV_{LxC}. The best shapes comprised plots with 15 BUs (9.00 m²) and shape 15 x 1 (15 rows with 1 plant), with high CV (12.03%), which had greater precision than the shape 3 x 5 (3 rows with 5 plants), also with high CV (12.24%), being more efficient in the control of variability to assess cassava production. Also, a high value of relative information was verified in the 15 x 1 shape when compared to the 3 x 5 shape. The experimental plot shape indicated in this work (rectangular) is in agreement with the results found by [28] and [16].

The production of cassava cultivars was evaluated by [26] in plots with an area of 12.00m². However, according to our results, this plot size could be reduced significantly without compromising the information obtained, since the experimental unit size of 9.00 m² of useful area proved to be suitable for evaluation of cassava cultivars.

In conclusion, the Hatheway method allows to estimate several optimum sizes of experimental units considering the conditions, characteristics, and limitations of the experiment. Experimental unit in the rectangular shape 15 x 1 (15 rows with 1 plant and 9.00 m² of useful area) was indicated as most adequate to evaluate the production of cassava. There was a continuous nonlinear reduction of the coefficient of variation with the increase in plot size.

References

1. Bellotti AC, Kawano K. Improvement for varietal resistance in cassava cultivation. In: Centro Internacional de Agricultura Tropical. Yuca, control integrado de plagas. Cali, Colombia: CIAT/PNUD. 1983. 171-194. Spanish. Available:htt://ciatlibrary.ciat.cgiar.org/...ciat/.../Mejoramiento_genetico_de_la_yuca_en_America_Lat...

2. Lozano JC, Toro JC, Castro A, Bellotti AC. Production of cassava planting material. Cali, Colombia: Centro Internacional de Agricultura Tropical. 1977. 28 p. (Série GP, 17). Spanish. Available:https://cgspace.cgiar.org/handle/10568/69720
3. Fao (2016). Statistics Division. Available:https://www.fao.org/3/a-br622e.pdf
4. Silva JR. Portion size and border effect in experiments with melon. Thesis (PhD in Agronomy: Phytotechny), Federal Rural Semi-Arid University (UFERSA), 2009; 142f. Portuguese. Available:https://www2.ufersa.edu.br/portal/view/uploads/setores/82/teses_2009/Tese_Robson.pdf
5. Moraes BFX. Portion size and sample size in the yield evaluation of arabica coffee beans. Master (Agronomy: Phytotechny), Universidade Federal de Lavras, Lavras-MG, 2013. Brazil. Available:https://www.sbicafe.ufv.br/handle/123456789/6856
6. Cargnelutti Filho A, Marchesan E, Silva LS, Toebe M. Measures of experimental precision and number of replicates in genotype trials of irrigated rice. Pesquisa Agropecuária Brasileira, 2012; 47 (3): 336- 343. Portuguese. Available:http://dx.doi.org/10.1590/S0100-204X2012000300004
7. Chacín Lugo, F. Tamaño de parcela experimental y su forma. Revista Facultad Agronomia, v.9, p.55-74, 1977.
8. Gomez, K.A.; Gomez, A.A. A statistical procedure for agricultural research. 2.ed. New York: John Wiley, 1984. 680p.
9. Storck L, Garcia DC, Lopes SJ, Estefanel V. Plant experimentation. 2. ed. Santa Maria: UFSM, 2006, 198p. Available:http://www.scielo.br/scielo.php?script=sci_arttext&pid=S0100204X2012000300004
10. Oliveira PH, Estefanel V. Optimum size and shape of the plot for yield evaluation in potato experiments. Ciência Rural, 1995; 25 (2): 205-208. Portuguese. Available:http://dx.doi.org/10.1590/S0103-84781995000200004
11. Lúcio AD, Carpes RH, Storck L, Zanardo B, Toebe M, Puhl OJ, Santos JRA. Clustering of tomato crops and plot size estimates in protected cultivation. Horticultura Brasileira, 2010; 28 (2): 190-196. Portuguese. Available:http://dx.doi.org/10.1590/S0102-05362010000200009.1.
12. Lúcio AD, Haesbaert FM, Santos D, Schwertner DV, Brunes RR (2012). Sample and plot sizes for growth and productive variables of tomato. Horticultura Brasileira, 2012; 30 (2): 660-668. Portuguese. Available:http://www.scielo.br/scielo.php?pid=S010205362012000400016&script=sci...tlng..
13. Lúcio AD, Haesbaert FM, Santos D, Benz V. Estimation of plot size for experiment with lettuce. Horticultura Brasileira, 2011; 29 (4): 510-515. Portuguese. Available:http://dx.doi.org/10.1590/S0102-05362011000400011
14. Oliveira GMV, Mello JM, Lima RR, Scolforo JRS, Oliveira AD (2011). Size and shape of experimental plots for *Eremanthus erythropappus*. Cerne, 2011; 17 (1): 327-338. Available:http://www.scielo.br/scielo.php?pid=S010477602011000300006&script=sci...tlng
15.Ramalho, M.A.P.; Ferreira, D.F.; Oliveira, A.C. de. A experimentação em genética e melhoramento de plantas. Lavras: Ufla, 2000. 326p.
16. Resende, MDV. Genética biométrica e estatística no melhoramento de plantas perenes. Brasília: Embrapa Informação Tecnológica, 2002. 975p.
17. Rossetti, A.G.; Pimentel Gomes, F. Determinação do tamanho ótimo de parcelas em ensaios agrícolas. Pesquisa Agropecuária Brasileira, v.18, p.477-487, 1983.
18. Santos D, Haesbaert FM, Lúcio AD, Storck L, Cargnelutti Filho A. Great plot size for the bean-pod culture. Revista Ciência Agronômica, 2012; 43 (2): 119-128. Portuguese. Available:http://www.scielo.br/scielo.php?pid=S180666902012000100015&script=sci...tlng..

19. Sousa RP, Silva PSL, Assis JP, Silva J, Oliveira VR, Oliveira AMP (2015a). Optimum plot size for evaluating sunflower grain yield. Revista Brasileira de Engenharia Agrícola e Ambiental, 2015a; 19 (2): 21-26.Portuguese.
Available:http://DOI: http://dx.doi.org/10.1590/1807-1929/agriambi.v19n1p21-26
20. Sousa RP, Silva PSL, Assis JP, Silva J, Silva, PIB, Silva, JCV (2015b). Optimum plot size for experiments with the sunflower. Revista Ciência Agronômica, 2015b; 46 (1): 170-175. Portuguese. Available:http://www.ccarevista.ufc.br
21. Sousa RP, Silva PSL, Assis JP (2016). Size and shape of plots for experiments with sunflower. Revista Ciência Agronômica, 2016; 47 (4): 683-690. Portuguese.
Available:http:// www.ccarevista.ufc.br
22. Stell, RGD.; Torrie, JH.; Dickey, DA. Principles and procedures of statistics: a biometrical approach. New York: McGraw-Hill Book, 1997. 666 p.
23.Jacomine PRT, Almeida JC, Medeiros LAR (1973). Exploratory survey-Soil reconnaissance in the State of Ceará. Recife, Ministério da Agricultura-Divisão de Pesquisa pedológica, 1973. 2v. (Boletim Técnico, 28). Portuguese.
Available:http://www.bdpa.cnptia.embrapa.br/.../busca?...%22JACOMINE...%22JACOMINE ...
24. Frota PCE, Parente JIG, Costa JTA, Melo FIO. Influence of climatic factors on cashew phenophases. /s.n.t./ (Paper presented at the 1st National Encounter of Cajun Agroindustry and 28 Week in Ceará, Caju, 1984, Fortaleza, Ce). Portuguese
Available:http://www.scielo.br/scielo.php?script=sci_arttext&pid=S01002945200200030008
25. Donato SLR, Siqueira DL, Silva SO, Cecon PR, Silva JA, Salomão LCC (2008). Plots size estimates for evaluation of phenotypic descriptors in banana. Pesquisa Agropecuária Brasileira, 2008; 43 (8): 957-969. Portuguese
Available:http://dx.doi.org/10.1590/S0100-204X2008000800003.
26. Hatheway EH (1961). Convenient plot size. Agronomy Journal 53: 279-280
Available:https://dl.sciencesocieties.org › Publications › Agronomy Journal
27. Smith HF (1938). An empirical law describing heterogeneity in yields of agricultural crops. Journal Agricultural Science, 1938; 28 (1): 1-23.
Available:https://www.scielo.br/scielo.php?script=sci_nlinks&ref=000072&pid=S1413...lng..
28. Keller KR (1949). Uniformity trials on hops (*Humulus lupulus* L.) for increasing the precision of field experiments. Agronomy Journal, 1949; 41 (2): 389-392.
Available:http://www.nal.usda.gov/
29. Henriques Neto D, Sediyama T, Souza MA, Cecon PR, Yamanaka CH, Sediyama MAN, Viana AES. Size of plots in experiments with wheat irrigated under no-tillage and conventional tillage. Pesquisa Agropecuária Brasileira, 2004; 39 (6): 517-524. Portuguese.
Available:https://www.scielo.br/pdf/pab/v39n6/v39n6a01.pdf
30. Humada-González GG, Liska GR, Mendoza CAC, Morais AR (2013). Methods of estimation of optimal plot size in potato experiment. In: Annual meeting of the Brazilian region of the international society of biometrics, 58th, and statistical symposium applied to agronomic experimentation, 15º, Campina Grande, Anais..., Campina Grande: UEPB, CD-ROM. Portuguese.
Available:https://www.ccsenet.org/journal/index.php/jas/article/download/0/0/36820/36862
31. Brum B, Brandelero FD, Oliveira Vargas T, Storck L, Zanini PPG (2016). Great plot size for mass and diameter of broccoli heads. Ciência Rural, 2016; 46 (3): 447-463. Portuguese.
Available:http://dx.doi.org/10.1590/0103-8478cr20150236.
32. Muniz JA, Aquino LH, Simplício E, Soares AR. Study of the size of experimental plots in Eucalyptus grandis Hill stands, using linear plots. Ciência e Agrotecnologia, 2009; 33 (4): 1002-1010. Portuguese.
Available:http://dx.doi.org/10.1590/S1413-70542009000400009.

33. Storck L, Ribeiro ND, Lopes SJ, Cargnelutti Filho A, Carvalho MP, Jost E (2007). Persistence of the experimental plan in elite bean germplasm evaluation trials. Ciência Rural, 2007; 37 (6): 1549-1553. Portuguese.
Available:http://www.scielo.br/pdf/cr/v37n6/a07v37n6.pdf
34. Cocco C, Boligon AA, Andriolo JL, Oliveira CS, Lorentz LH (2009). Size and shape of plot in experiments with strawberry cultivated in soil or in hydroponics. Pesquisa Agropecuária Brasileira, 2009; 44 (7): 681-686. Portuguese.
Available:http://www.scielo.br/pdf/pab/v44n7/05.pdf