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Optimal plot size in buckwheat

Tamanho ótimo de parcela em trigo mourisco

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Highlights

The three methods for determining the optimal plot size generate different results.
A plot size of 7.60 m^2 is the reference for experiments with buckwheat.
Information is provided for improving experimental precision in buckwheat.

Abstract

The aim of this work was to compare three methods of estimating the optimal plot size for evaluating fresh matter in the IPR91-Baili and IPR92-Altar cultivars of buckwheat (*Fagopyrum esculentum* Moench). Sixteen uniformity trials (blank experiments) were conducted, eight with the IPR91-Baili cultivar and eight with the IPR92-Altar cultivar. The trials were carried out at eight different sowing times. The fresh matter was evaluated in 576 basic experimental units (BEU), each 1 m × 1 m in size (36 BEU per trial). The optimal plot size was determined using the method of modified maximum curvature, the linear response plateau model and the quadratic response plateau model. The optimal plot size differs between methods, and decreases in the following order: quadratic response plateau model, linear response plateau model and modified maximum curvature. The optimal plot size for evaluating fresh matter in the IPR91-Baili and IPR92-Altar cultivars of buckwheat is 7.60 m^2. This size can be used as a reference for future experiments with buckwheat.
Key words: Soil cover crop. Experimental design. Uniformity trial. *Fagopyrum esculentum* Moench.

Resumo

O objetivo deste trabalho foi comparar três métodos de estimação do tamanho ótimo de parcela para avaliar a massa de matéria fresca de trigo mourisco (*Fagopyrum esculentum* Moench) das cultivares IPR91-Baili e IPR92-Altar. Foram conduzidos 16 ensaios de uniformidade (experimentos em branco), sendo oito com a cultivar IPR91-Baili e oito com a cultivar IPR92-Altar. Os ensaios foram realizados em oito épocas de semeadura. Foi avaliada a massa de matéria fresca em 576 unidades experimentais básicas (UEB) de 1 m × 1 m (36 UEB por ensaio). Foi determinado o tamanho ótimo de parcela por meio dos métodos da curvatura

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máxima modificado, do modelo linear de resposta com platô e do modelo quadrático de resposta com platô. O tamanho ótimo de parcela difere entre os métodos e decresce na seguinte ordem: modelo quadrático de resposta com platô, modelo linear de resposta com platô e curvatura máxima modificado. O tamanho ótimo de parcela para avaliar a massa de matéria fresca de trigo mourisco, das cultivares IPR91-Baili e IPR92-Altar é de 7,60 m^2. Esse tamanho pode ser utilizado como referência para futuros experimentos com trigo mourisco.

Palavras-chave: Cultura de cobertura de solo. Dimensionamento experimental. Ensaio de uniformidade. *Fagopyrum esculentum* Moench.

Introduction

Buckwheat (*Fagopyrum esculentum* Moench) is an annual plant of family Polygonaceae, originally from Central Asia and grown in Europe, Asia and America (Accame & Ortega, 2019). It displays fast growth, a short cycle, high tolerance to acidity and the ability to grow in low-fertility soils (Gonçalves et al., 2016). Important properties of buckwheat related to its use in human and animal nutrition, as a medicinal plant and as ground cover have been highlighted (Accame & Ortega, 2019; Gonçalves et al., 2016; Görgen et al., 2016; Menezes & Leandro, 2004; Mikhailovich, 2019; Pereira et al., 2017; Skora & Campos, 2017; Yilmaz, Ayhan, & Meriç, 2020; Ziech et al., 2015).

The buckwheat cultivars, IPR91-Baili and IPR92-Altar, are widely used experimental materials. It is important to know the variability of the soil and of the experimental material in order to correctly plan the plot size and choose the genetic base with the least variability. By using an appropriate plot size and least-variable genetic base, it is possible to minimise the experimental error and, consequently, increase the accuracy of the inferences. Smaller plot sizes require a smaller experimental area, but can generate less-reliable results due to the reduced representativeness of the experiment (sample). On the other hand, larger plot sizes can make it difficult to conduct the experiment due to the necessary size of the experimental area, but would have the advantage of being more representative and, as a result, having greater experimental precision. Proper plot sizing optimises resources involved in the research, such as labour, time, financial resources and the experimental area.

Research in buckwheat together with other species of ground cover has been conducted with different plot sizes, such as: 25 m^2 with a working area of 12 m^2 (Menezes & Leandro, 2004); 25 m^2 (Ziech et al., 2015); 20 m^2 (Görgen et al., 2016); 4 m^2 (Pereira et al., 2017) and 24 m^2 (Skora & Campos, 2017). These surveys point out promising aspects of buckwheat and other species of ground cover, and no reference is made to defining the plot size for evaluating fresh matter. It is therefore important to determine the optimal plot size to be used as a reference in planning future experiments with buckwheat.

Among the various methods for estimating optimal plot size, the method of modified maximum curvature (Meier & Lessman, 1971), the linear response plateau model (Paranaíba, Ferreira, & Morais, 2009a) and the quadratic response plateau model (Peixoto, Faria, & Morais, 2011) stand out. Comparative studies involving these methods and others have been carried out with rice (Paranaíba et al., 2009a), wheat and cassava (Paranaíba, Morais,

& Ferreira, 2009b), passion fruit (Peixoto et al., 2011) and papaya (Brito, Faria, Morais, Sousa, & Dantas, 2012), with different results between methods.

In uniformity trials (blank experiments), it is possible to divide the experimental area into basic experimental units (BEU) of the smallest possible size compatible with the evaluations (Storck, Garcia, Lopes, & Estefanel, 2016). With the data collected in these BEUs, it is possible to form different plot sizes (X) by grouping adjacent BEUs, and then estimate the coefficient of variation ($CV_{(X)}$) between the BEUs. The values of $CV_{(X)}$ and X can be related using these three methods for determining the optimal plot size (Xo) and the coefficient of variation at the optimal plot size (CV_{Xo}).

Carrying out uniformity trials for different sowing times and with different cultivars is important to increase the representativeness of the results, as it submits the crop to scenarios of environmental and genetic variability. Therefore, an analysis of this set of uniformity trials generates useful information to be used as a reference in planning experiments with buckwheat aiming at greater experimental precision. It is assumed that the optimal plot size differs between cultivars and between the methods of estimation. As such, the aim of this study was to compare three methods of estimating the optimal plot size for evaluating fresh matter in two cultivars (IPR91-Baili and IPR92-Altar) of buckwheat [*Fagopyrum esculentum* (Moench)].

Materials and Methods

Sixteen uniformity trials were conducted using buckwheat [*Fagopyrum esculentum* (Moench)], eight with the IPR91-Baili cultivar and eight with the IPR92-Altar cultivar, in an experimental area located at 29º42’ S and 53º49’ W, at an altitude of 95 m. According to the Köppen classification, the climate is type Cfa, humid subtropical, with hot summers and no dry season (Alvares, Stape, Sentelhas, Gonçalves, & Sparovek, 2013); the soil is a Distrophic Arenic Red Argisol (Santos et al., 2018). A physical and chemical analysis of the soil at a depth of 0-20 cm revealed: pH_{H2O} 1:1:5.5, Ca: 4.7 $cmol_c$ dm^{-3}, Mg: 1.9 $cmol_c$ dm^{-3}, Al: 0.0 $cmol_c$ dm^{-3}, H+Al: 4.4 $cmol_c$ dm^{-3}, SMP index: 6.0, organic matter: 2.3%, clay content: 29.0%, S: 1.5 mg dm^{-3}, P (Mehlich): 32.8 mg dm^{-3}, K: 0.532 $cmol_c$ dm^{-3}, CEC_{pH7}: 11.6 $cmol_c$ dm^{-3}, Cu: 2.2 mg dm^{-3}, Zn: 1.01 mg dm^{-3}, and B: 0.2 mg dm^{-3}. These results were used to define the type of fertilisation (Comissão de Química e Fertilidade do Solo [CQFS], 2016).

On each of the following days (18/12/2017, 03/01/2018, 14/03/2018, 06/11/2018, 28/12/2018, 30/01/2019, 22/02/2019 and 28/03/2019), two uniformity trials were set up, one with the IPR91-Baili cultivar and the other with the IPR92-Altar cultivar, giving a total of 16 uniformity trials. In each trial, sowing was carried out in rows spaced 0.5 m apart at a density of 50 kg ha^{-1} and with a base fertilisation of 35 kg ha^{-1} N, 135 kg ha^{-1} P_2O_5 and 135 kg ha^{-1} K_2O. The fresh matter (FM) was evaluated on 15/02/2018, 14/03/2018, 10/05/2018, 27/12/2018, 14/02/2019, 03/04/2019, 15/04/2019 and 20/05/2019 respectively, i.e. 59, 70, 57, 51, 48, 63, 52 and 53 days after sowing, to coincide with the final flowering period and the start of grain formation.

During the uniformity trials, the daily data for minimum (Tmin) and maximum (Tmax) air temperature, in ºC; insolation, in hours day^{-1}; solar radiation, in MJ m^{-2} day^{-1}; and rainfall, in mm were recorded by the Weather Station of the 8th Meteorological District of the National Institute of Meteorology, located 100 m from the experimental area. The average daily air temperature (Tave), in °C, was calculated from the expression: Tave = (Tmin + Tmax)/2.

For each uniformity trial measuring 8 m × 8 m (64 m^2), the central area, 6 m × 6 m (36 m^2) in size was divided into 36 basic experimental units (BEU), each of 1 m × 1 m (1 m^2), forming a matrix of six rows and six columns (Figure 1). In each BEU, the plants were cut close to the ground, and the FM was immediately determined, in g m^{-2}, on a digital scale (accuracy: 1 g). Weighing was carried out immediately after cutting in order to minimise possible variations in plant moisture. Samples of fresh matter were collected and weighed (FMS, in g $sample^{-1}$) from six randomly chosen BEU in each uniformity trial. The samples were packed in paper packages, identified by BEU, and dried in a forced air ventilation oven at 65 ± 3°C to constant weight, i.e. the dry matter weight (DMS, in g $sample^{-1}$). The dry matter content, in %, was calculated for each uniformity trial using the expression: DM(%) = DMS/FMS × 100.

For each uniformity trial, plots with X_R adjacent BEUs on a row and X_C adjacent BEUs in a column were projected, using the FM data of the 36 BEUs. Plots of different sizes and/or shapes were projected ($X = X_R \times X_C$), i.e. (1×1), (1×2), (1×3), (1×6), (2×1), (2×2), (2×3), (2×6), (3×1), (3×2), (3×3), (3×6), (6×1)), (6×2) and (6×3). The abbreviations X_R, X_C and X, refer, respectively, to the number of adjacent BEUs in a row, the number of adjacent BEUs in a column and the plot size in number of BEUs. For each plot size (X), the following were determined: n - number of plots with a size of X BEU (n = 36/X), $M_{(X)}$ – mean value for plots with a size of X BEU, and $CV_{(X)}$ - coefficient of variation (in %) between plots with a size of X BEU. In each of the 16 trials, the optimal plot size (Xo) was determined using the methods of modified maximum curvature (MMC) (Meier & Lessman, 1971), the linear response plateau model (LRP) (Paranaíba et al., 2009a) and the quadratic response plateau model (QRP) (Peixoto et al., 2011). In these three methods, models of the dependent variable ($CV_{(X)}$, in %) are adjusted as a function of the independent variable (X, in BEU).

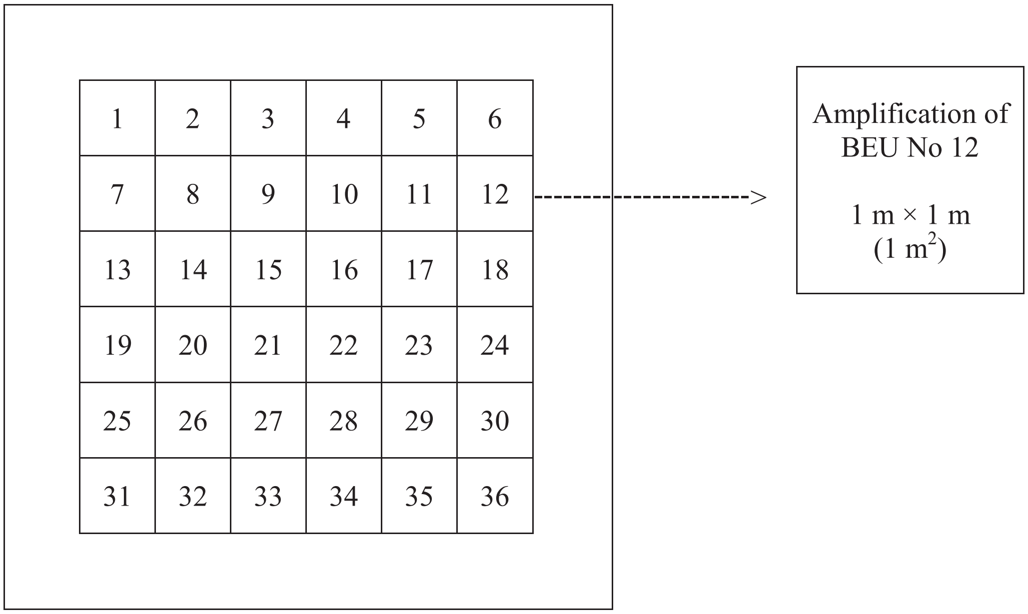

Figure 1. Sketch of one uniformity trial measuring 8 m × 8 m (64 m^2) with the central area of 6 m × 6 m (36 m^2) divided into 36 basic experimental units (BEU) of 1 m × 1 m (1 m^2), forming a matrix of six rows and six columns.

With reference to the method of modified maximum curvature (MMC) (Meier & Lessman, 1971), the parameters a and b were estimated, together with the coefficient of determination (R^2) of the model $CV_{(X)} = a/X^b + ε$. These parameters were estimated through the logarithmic transformation and linearisation of $CV_{(X)} = a / X^b + ε$, i.e. $\log CV_{(X)} = \log a - b \log X + ε$, where the estimate was weighted by the degrees of freedom (DF = n-1) associated with each plot size (Steel, Torrie, & Dickey, 1997). The point corresponding to the optimal plot size (Xo) was algebraically determined using the expression: $Xo = [a^2\ b^2\ (2b+1)/(b+2)]^{1/(2b+2)}$. The coefficient of variation corresponding to the optimal plot size (CV_{Xo}) was determined by $CV_{Xo} = a/Xo^b$.

For the linear response plateau model (LRP) (Paranaíba et al., 2009a), two segmented lines were adjusted and estimates of the parameters a, b and p, and the coefficient of determination (R^2) were obtained. The first line ($CV_{(X)} = a + bX + ε$) is adjusted to the point corresponding to the optimal plot size (Xo) with a non-zero slope *(b)*. The second line ($CV_{(X)} = p + ε$) starts at Xo and has zero slope, i.e. it is a line parallel to the abscissa, where p = the plateau, i.e. p corresponds to CV_{Xo}. The LRP model was as follows:

$$CV_{(X)} = \begin{cases} a + bX + ε & \text{if } X \leq Xo \\ p + ε & \text{if } X > Xo. \end{cases}$$

In the LRP model, the optimal plot size was determined by *Xo = (p-a)/b*, and the coefficient of variation at the optimal plot size by $CV_{Xo} = a + bXo$.

For the quadratic response plateau model (QRP) (Peixoto et al., 2011), the adjustment was made using two segmented equations. Estimates of parameters a, b, c and p, and of the coefficient of determination (R^2) were obtained. The quadratic part of the model was adjusted up to point *Xo* ($CV_{(X)} = a + bX + cX^2 + ε$). From Xo the model becomes a straight line with zero slope, called the plateau, whose model is described by ($CV_{(X)} = p + \varepsilon$) where p = the plateau, i.e. $p = CV_{Xo}$. Therefore, the QRP model was as follows:

$$CV_{(X)} = \begin{cases} a + bX + cX^2 + \varepsilon & \text{if } X \leq Xo \\ p + \varepsilon & \text{if } X > Xo. \end{cases}$$

In the QRP model, the optimal plot size was determined by $Xo = -b/2c$ and the coefficient of variation at the optimal plot size by $CV_{Xo} = a - b^2/4c$. In the LRP and QRP models, the point of union between the two segments corresponds to Xo on the abscissa and CV_{Xo} on the ordinate. In the three models (MMC, LRP and QRP), ε represents the residual or random error of the model.

Therefore, for each uniformity trial within each cultivar, estimates of the coefficient of determination (R^2), the optimal plot size (Xo) and the coefficient of variation at the optimal plot size (CV_{Xo}) were obtained relative to the MMC, LRP and QRP methods. The mean values of the estimates for R^2, Xo and CV_{Xo}, in relation to the MMC, LRP and QRP methods, were compared between the buckwheat cultivars (IPR91-Baili versus IPR92-Altar) within each method (n = 8 uniformity trials), using Student's t-test (unilateral) for independent samples, at a significance level of 5%. Comparisons were made between the methods (MMC versus LRP, MMC versus QRP and LRP versus QRP) within each buckwheat cultivar (n = 8 uniformity trials) and overall, i.e. irrespective of the cultivar (n = 16 uniformity trials), using Student's t-test (unilateral) for dependent samples, at a significance level of 5%. The results of these comparisons were represented by letters at the side of each mean value. The statistical analysis was carried out with the aid of Microsoft Office Excel® and the R (R Development Core Team [R], 2020) and Genes (Cruz, 2016) software.

Results and Discussion

Among the uniformity trials, the fresh matter (FM) of the IPR91-Baili buckwheat cultivar ranged from 459 to 3336 g m^{-2} (4.59 and 33.36 Mg ha^{-1}) with a mean value of 1870 g m^{-2} (18.70 Mg ha^{-1}), and from 474 to 3311 g m^{-2} (4.74 and 33.11 Mg ha^{-1}) with a mean value of 1833 g m^{-2} (18.33 Mg ha^{-1}) for the IPR92-Altar cultivar (Tables 1 and 2). The difference between the mean values for FM in the cultivars was not significant (t = 0.068; p-value = 0.9467; 14 degrees of freedom). The dry matter weight (DM) obtained for the sowing times of 18/12/2017, 03/01/2018, 14/03/2018, 06/11/2018, 28/12/2018, 30/01/2019, 22/02/2019, 28/03/2019 were 505, 591, 134, 177, 259, 515, 533 and 107 g m^{-2} respectively, for the IPR91-Baili cultivar, and 490, 557, 174, 202, 99, 482, 494 and 92 g m^{-2}, for the IPR92-Altar cultivar. Therefore, the DM ranged between 1.07 and 5.91 Mg ha^{-1}, with a mean value of 3.53 Mg ha^{-1} for the IPR91-Baili cultivar and between 0.92 and 5.57 Mg ha^{-1}, with a mean of 3.24 Mg ha^{-1} for the IPR92-Altar cultivar; the difference between mean values was not significant (t = 0.286; p-value = 0.7787; 14 degrees of freedom). As such, it can be inferred that between the IPR91-Baili and IPR92-Altar cultivars there were similar amounts of FM and DM.

Table 1
Planned plot size ($X = X_R \times X_C$), in basic experimental units (BEU), with X_R adjacent BEUs in a row and X_C adjacent BEUs in a column; number of plots with a size of X BEU (n = 36/X); mean value for plots with a size of X BEU [$M_{(X)}$], in g; and coefficient of variation (in %) between plots with a size of X BEU [$CV_{(X)}$]. Fresh matter data in buckwheat (*Fagopyrum esculentum* Moench) 'IPR91-Baili', obtained in uniformity trials conducted at eight sowing times

X_R	X_C	X	n	$M_{(X)}$	$CV_{(X)}$	$M_{(X)}$	$CV_{(X)}$	$M_{(X)}$	$CV_{(X)}$	$M_{(X)}$	$CV_{(X)}$
				18/12/2017		03/01/2018		14/03/2018		06/11/2018	
1	1	1	36	3336	19.37	3105	14.19	901	26.84	1227	30.53
1	2	2	18	6673	12.69	6210	12.54	1802	22.52	2455	23.75
1	3	3	12	10009	9.03	9314	11.01	2703	17.26	3682	18.98
1	6	6	6	20019	7.01	18629	10.38	5405	7.69	7365	16.28
2	1	2	18	6673	14.59	6210	10.85	1802	23.29	2455	26.42
2	2	4	9	13346	9.07	12419	9.20	3604	21.31	4910	19.91
2	3	6	6	20019	5.94	18629	7.86	5405	15.46	7365	14.86
2	6	12	3	40038	1.88	37258	7.66	10811	7.43	14729	13.37
3	1	3	12	10009	15.21	9314	8.15	2703	23.37	3682	24.47
3	2	6	6	20019	9.30	18629	7.11	5405	22.07	7365	17.46
3	3	9	4	30028	7.09	27943	5.50	8108	15.85	11047	11.74
3	6	18	2	60057	6.08	55887	6.10	16216	5.15	22094	10.00
6	1	6	6	20019	10.48	18629	6.33	5405	22.84	7365	24.10
6	2	12	3	40038	7.71	37258	4.86	10811	22.90	14729	17.35
6	3	18	2	60057	5.37	55887	2.85	16216	16.29	22094	10.22
				28/12/2018		30/01/2019		22/02/2019		28/03/2019	
1	1	1	36	1397	17.17	2470	23.17	2067	16.30	459	41.40
1	2	2	18	2795	11.98	4940	15.26	4135	13.96	918	36.18
1	3	3	12	4192	10.41	7409	11.08	6202	11.29	1377	31.49
1	6	6	6	8384	7.65	14819	9.87	12405	7.67	2753	22.15
2	1	2	18	2795	14.04	4940	15.90	4135	11.50	918	24.69
2	2	4	9	5589	8.90	9879	10.38	8270	9.39	1836	22.13
2	3	6	6	8384	7.94	14819	6.84	12405	9.69	2753	20.11
2	6	12	3	16767	4.18	29638	5.95	24809	5.00	5507	21.34
3	1	3	12	4192	11.32	7409	13.83	6202	10.43	1377	22.75
3	2	6	6	8384	7.03	14819	8.60	12405	8.87	2753	21.38
3	3	9	4	12575	6.88	22228	3.23	18607	9.05	4130	19.02
3	6	18	2	25151	5.16	44457	1.49	37214	4.87	8260	23.03
6	1	6	6	8384	9.48	14819	13.66	12405	9.84	2753	15.13
6	2	12	3	16767	5.12	29638	9.33	24809	8.90	5507	12.77
6	3	18	2	25151	6.64	44457	3.66	37214	9.86	8260	3.51

(1) Each uniformity trial of 6 m × 6 m (36 m2) was divided into 36 BEU of 1 m × 1 m (1 m^2), forming a matrix of six rows and six columns.

The FM evaluated at 90 days after plant emergence in buckwheat by Menezes and Leandro (2004) was 3.58 Mg ha^{-1}. At 93 days after sowing, i.e. at the full flowering stage, Ziech et al. (2015) obtained a DM of 2.8 Mg ha^{-1}. In cuts made at 47, 57 and 67 days after sowing buckwheat, Görgen et al. (2016) obtained DM of 2.301, 3.144 and 4.471 Mg ha^{-1} respectively. At 71 days after sowing buckwheat, during the reproductive period between flowering and the grain milk stage, Pereira et al. (2017) obtained values for FM and DM of 26.97 and 6.78 Mg ha^{-1} respectively. Fresh matter weights in buckwheat of less than 3.00 Mg ha^{-1} were obtained by Skora and Campos (2017). The different environmental conditions, management, cultivars and evaluation times make comparisons difficult. Even so, in general, it can be seen that the values obtained in this study were similar to those reported in the above studies, and demonstrated good plant development under the environmental conditions of the area (Table 3).

Table 2

Planned plot size ($X = X_R \times X_C$), in basic experimental units (BEU), with X_R adjacent BEUs in a row and X_C adjacent BEUs in a column; number of plots with a sized of X BEU (n = 36/X); mean value for plots with a size of X BEU [$M_{(X)}$], in g; and coefficient of variation (in %) between plots with a size of X BEU [$CV_{(X)}$]. Fresh matter data in buckwheat (*Fagopyrum esculentum* Moench) 'IPR92-Altar', obtained in uniformity trials conducted at eight sowing times

X_R	X_C	X	n	$M_{(X)}$	$CV_{(X)}$	$M_{(X)}$	$CV_{(X)}$	$M_{(X)}$	$CV_{(X)}$	$M_{(X)}$	$CV_{(X)}$
				18/12/2017		03/01/2018		14/03/2018		06/11/2018	
1	1	1	36	3253	17.53	3311	21.26	1009	23.41	1245	33.59
1	2	2	18	6505	13.14	6621	13.26	2019	20.89	2490	29.37
1	3	3	12	9758	9.76	9932	10.67	3028	19.67	3735	24.49
1	6	6	6	19516	4.78	19863	8.20	6056	14.44	7471	17.63
2	1	2	18	6505	11.82	6621	15.49	2019	15.02	2490	27.69
2	2	4	9	13011	10.68	13242	7.92	4038	13.84	4981	25.49
2	3	6	6	19516	4.85	19863	3.77	6056	13.40	7471	20.85
2	6	12	3	39032	5.17	39726	2.51	12113	4.79	14942	11.79
3	1	3	12	9758	11.48	9932	14.98	3028	14.69	3735	22.67
3	2	6	6	19516	10.45	19863	7.50	6056	13.28	7471	20.88
3	3	9	4	29274	4.14	29795	2.62	9085	13.56	11206	15.49
3	6	18	2	58548	4.79	59589	0.86	18169	8.87	22413	11.23
6	1	6	6	19516	10.24	19863	14.25	6056	12.90	7471	16.11
6	2	12	3	39032	10.22	39726	7.54	12113	12.51	14942	17.29
6	3	18	2	58548	1.56	59589	3.07	18169	14.01	22413	14.71
				28/12/2018		30/01/2019		22/02/2019		28/03/2019	
1	1	1	36	621	32.57	2635	24.81	2117	20.97	474	29.96
1	2	2	18	1242	20.93	5269	15.82	4234	17.20	948	24.11
1	3	3	12	1863	22.05	7904	15.10	6350	14.45	1422	21.61
1	6	6	6	3727	8.33	15807	9.65	12701	13.08	2844	12.72
2	1	2	18	1242	26.24	5269	15.54	4234	16.81	948	23.98
2	2	4	9	2484	16.72	10538	7.56	8467	14.71	1896	18.97
2	3	6	6	3727	20.10	15807	8.07	12701	11.69	2844	19.71
2	6	12	3	7453	7.40	31614	3.21	25401	10.33	5688	11.39
3	1	3	12	1863	25.78	7904	14.81	6350	11.00	1422	21.89
3	2	6	6	3727	17.96	15807	6.66	12701	7.89	2844	18.07
3	3	9	4	5590	21.62	23711	4.22	19051	5.97	4266	19.65
3	6	18	2	11180	10.27	47421	0.05	38102	3.12	8533	12.54
6	1	6	6	3727	23.03	15807	8.95	12701	8.64	2844	17.57
6	2	12	3	7453	16.88	31614	4.86	25401	6.62	5688	15.00
6	3	18	2	11180	24.38	47421	0.18	38102	3.70	8533	16.85

(1) Each uniformity trial of 6 m × 6 m (36 m^2) was divided into 36 BEU of 1 m × 1 m (1 m^2), forming a matrix of six rows and six columns.

Table 3

Monthly mean value for the minimum (Tmin), maximum (Tmax) and average (Tave) air temperature, in °C; monthly mean value for daily insolation, in hrs day^{-1}; monthly mean value for daily solar radiation, in MJ m^{-2} day^{-1}; total rainfall, in mm, for the evaluation periods of buckwheat (*Fagopyrum esculentum* Moench) 'IPR91-Baili' and 'IPR92-Altar', and the climate normal for 1981-2010

Month	Year	Tmin (°C)	Tmax (°C)	Tave (°C)	Insolation (hrs day^{-1})	Radiation (MJ m^{-2} day^{-1})	Rainfall (mm)
2017/2018 agricultural year (sown on 18/12/2017, 03/01/2018 and 14/03/2018)							
November	2017	14.8	28.1	21.4	9.0	24.4	70.0
December	2017	19.2	30.9	25.1	8.5	24.1	83.9
January	2018	19.9	30.3	25.1	7.8	22.2	122.2
February	2018	18.4	29.9	24.1	8.5	22.7	108.9
March	2018	17.3	28.9	23.1	7.1	17.7	167.6
April	2018	18.5	28.8	23.6	6.0	13.1	167.6
May	2018	13.6	22.2	17.9	4.4	9.7	59.9
2018/2019 agricultural year (sown on 06/11/2018, 28/12/2018, 30/01/2019, 22/02/2019 and 28/03/2019)							
November	2018	17.7	28.8	23.3	7.9	22.8	245.1
December	2018	18.7	30.0	24.4	8.3	24.4	176.2
January	2019	21.9	30.8	26.4	5.3	19.0	266.1
February	2019	19.1	30.0	24.6	8.1	21.7	83.4
March	2019	17.2	28.1	22.7	7.2	18.3	136.3
April	2019	17.3	26.4	21.8	5.1	12.6	210.4
May	2019	15.4	22.5	19.0	3.6	8.2	260.2
Climate normal 1981-2010							
November		16.4	27.8	21.6	7.3	-	132.7
December		18.6	30.3	24.1	8.1	-	154.3
January		19.8	30.9	24.9	7.9	-	166.3
February		19.4	29.9	24.0	7.1	-	139.6
March		18.5	29.1	22.9	6.8	-	127.7
April		15.0	25.7	19.4	5.8	-	170.1
May		12.0	22.0	16.0	5.0	-	154.4

From the FM data of the 36 basic experimental units (BEU) of 1 m × 1 m (1 m^2), the coefficient of variation (CV) varied between 14.19 and 41.40% for the IPR91-Baili cultivar and between 17.53 and 33.59% for the IPR92-Altar cultivar (Tables 1 and 2). This variations in the CV may be associated with environmental and genotypic variability, and the genotype interaction with the environment. The mean coefficient of variation was 23.62% and 25.51% respectively, for the IPR91-Baili and IPR92-Altar cultivars, and the difference between the mean values was not significant (t = -0.494; p-value = 0.6287; 14 degrees of freedom). According to the classification bands of the coefficients of variation established by Pimentel-Gomes (2009) for agricultural field trials, the values obtained are classified as of medium (between 10 and 20%), low (between 20 and 30%) and very low (>30%) experimental precision, which shows that it is necessary to use a plot size greater than 1 m^2 to improve the experimental precision.

This wide variability in FM and CV between the uniformity trials is possibly associated with the different environmental conditions between the years and sowing times (Table 3). Furthermore, this scenario of wide variability gives credibility to the study of plot size, since it includes real situations of variability that occur in experiments conducted in the field. The non-significant difference between cultivars, in relation to FM and CV, suggests that the plot size for experiments with these two buckwheat cultivars may be similar.

In each uniformity trial conducted with the IPR91-Baili and IPR92-Altar cultivars, there was an increase in the mean value of the plots [$M_{(X)}$] and a reduction in the coefficient of variation [$CV_{(X)}$] for an increase in the planned plot size (X) (Tables 1 and 2). These results indicate an improvement in experimental precision (a reduction in $CV_{(X)}$) with the increase in plot size. Although it is possible to evaluate fresh matter (FM) in plots of 1 m^2, based on the methodology used in this study, it is important to evaluate the precision of larger-sized plots, i.e. it is essential to plan the experiment at the optimal plot size to ensure proper discrimination of the treatments under evaluation and the reliability of the inferences. In addition, smaller sizes may not represent plant development, while larger sizes make it possible to evaluate the plants in the central area of each plot (working area) and disregard the borders, thereby reducing interference from the plants of adjacent plots, e.g. inter-plot competition (Storck et al., 2016).

For the methods of modified maximum curvature (MMC), the linear response plateau model (LRP) and the quadratic response plateau model (QRP), the mean values for the coefficient of determination (R^2), the optimal plot size (Xo) and the coefficient of variation at the optimal plot size (CV_{Xo}) did not differ between the two cultivars (IPR91-Baili and IPR92-Altar) (Tables 4 and 5). As such, based on these results and on the lack of difference in FM, DM and CV between the cultivars, it can be inferred that the experimental planning of plot size is similar for both cultivars.

Table 4

Estimates of the coefficient of determination (R^2), optimal plot size (Xo, in m^2) and coefficient of variation at the optimal plot size (CV_{Xo}, in %), in relation to the methods of modified maximum curvature (MMC), the linear response plateau model (LRP) and the quadratic response plateau model (QRP), obtained from the fresh matter of buckwheat (*Fagopyrum esculentum* Moench) 'IPR91-Baili' and 'IPR92-Altar', in eight uniformity trials

Trial	Sown	MMC			LRP			QRP		
		R^2	Xo	CV_{Xo}	R^2	Xo	CV_{Xo}	R^2	Xo	CV_{Xo}
Cultivar IPR91-Baili (n = 8 uniformity trials)										
1	18/12/2017	0.78	4.28	9.27	0.74	7.17	5.63	0.77	9.31	5.73
2	03/01/2018	0.82	3.03	9.69	0.76	8.21	5.39	0.77	11.51	5.39
3	14/03/2018	0.48	4.39	17.82	0.39	8.07	13.52	0.41	19.06	11.33
4	06/11/2018	0.83	5.03	18.26	0.77	8.57	12.54	0.77	11.68	12.66
5	28/12/2018	0.94	3.76	9.65	0.88	7.35	5.60	0.91	9.99	5.60
6	30/01/2019	0.83	4.96	9.17	0.76	8.20	4.73	0.78	10.52	5.03
7	22/02/2019	0.85	3.08	11.05	0.67	6.94	7.54	0.71	8.05	7.75
8	28/03/2019	0.73	6.73	18.56	0.61	6.83	15.93	0.64	8.29	16.32
Mínimum		0.48	3.03	9.17	0.39	6.83	4.73	0.41	8.05	5.03
Maximum		0.94	6.73	18.56	0.88	8.57	15.93	0.91	19.06	16.32
Mean		0.78	4.41	12.93	0.70	7.67	8.86	0.72	11.05	8.73
Cultivar IPR92-Altar (n = 8 uniformity trials)										
1	18/12/2017	0.75	3.99	8.91	0.67	7.41	5.17	0.69	9.72	5.30
2	03/01/2018	0.76	4.93	7.63	0.74	8.23	3.32	0.76	11.03	3.48
3	14/03/2018	0.70	3.98	14.82	0.62	7.51	10.75	0.64	11.76	10.38
4	06/11/2018	0.91	5.50	19.69	0.89	7.81	14.10	0.90	11.46	13.87
5	28/12/2018	0.58	5.24	17.83	0.40	6.20	16.11	0.44	5.75	16.65
6	30/01/2019	0.68	5.56	6.48	0.87	7.96	2.50	0.90	11.43	2.33
7	22/02/2019	0.82	4.47	11.14	0.80	8.37	5.95	0.81	16.88	4.39
8	28/03/2019	0.87	4.66	18.82	0.75	6.68	15.08	0.78	8.11	15.28
Mínimum		0.58	3.98	6.48	0.40	6.20	2.50	0.44	5.75	2.33
Maximum		0.91	5.56	19.69	0.89	8.37	16.11	0.90	16.88	16.65
Mean		0.76	4.79	13.16	0.72	7.52	9.12	0.74	10.77	8.96
Overall (n= 16 uniformity trials)										
Mínimum		0.48	3.03	6.48	0.39	6.20	2.50	0.41	5.75	2.33
Maximum		0.94	6.73	19.69	0.89	8.57	16.11	0.91	19.06	16.65
Mean		0.77	4.60	13.05	0.71	7.60	8.99	0.73	10.91	8.84

Table 5

Mean estimates of the coefficient of determination (R^2), optimal plot size (Xo, in m^2) and coefficient of variation at the optimal plot size (CV_{Xo}, in %), in relation to the methods of modified maximum curvature (MMC), the linear response plateau model (LRP) and the quadratic response plateau model (QRP), obtained from the fresh matter of buckwheat (*Fagopyrum esculentum* Moench) 'IPR91-Baili' and 'IPR92-Altar', in eight uniformity trials

Cultivar	MMC	LRP	QRP
	Coefficient of determination (R^2)		
IPR91-Baili	0.78 A a	0.70 A c	0.72 A b
IPR92-Altar	0.76 A ab	0.72 A a	0.74 A b
Overall	0.77 a	0.71 c	0.73 b
	Optimal plot size (Xo, in m^2)		
IPR91-Baili	4.41 A c	7.67 A b	11.05 A a
IPR92-Altar	4.79 A c	7.52 A b	10.77 A a
Overall	4.60 c	7.60 b	10.91 a
	Coefficient of variation for optimal plot size (CV_{Xo}, in %)		
IPR91-Baili	12.93 A a	8.86 A b	8.73 A b
IPR92-Altar	13.16 A a	9.12 A b	8.96 A b
Overall	13.05 a	8.99 b	8.84 b

* Mean values not followed by the same uppercase letter in a column (comparing cultivars within each method; n = 8 uniformity trials) differ by Student's t-test (unilateral) for independent samples, at a level of 5% significance. Mean values not followed by the same lowercase letter on a line (comparing methods within each cultivar, n = 8 uniformity trials; and overall, i.e. irrespective of the cultivar, n = 16 uniformity trials) differ by Student's t-test (unilateral) for dependent samples, at a level of 5% significance.

The mean values for R^2 varied between 0.70 (LRP - 'IPR91-Baili') and 0.78 (MMC - 'IPR91-Baili'). It should be considered that 0.00 ≤ R2 ≤ 1.00, interpreted as the closer R^2 is to 1.00 the better the model fits the data. Generally, between the MMC, LRP and QRP methods, the MMC values for R^2 were higher, the QRP values were intermediate and the LRP values were lower in the uniformity trials with the IPR91-Baili and IPR92-Altar cultivars, and overall (irrespective of cultivar) (Table 5). Specifically, in comparing methods within the IPR92-Altar cultivar, the R^2 value for MMC did not differ from that of LRP or QRP, however the R^2 for LRP and QRP differed from each other. This result can be explained by the dependent samples being compared in pairs (MMC versus LRP, MMC versus QRP and LRP versus QRP). As such, it can be inferred that although the adjustments were different, each method showed R^2 close to one ($R^2 \geq 0.70$).

In relation to the IPR91-Baili cultivar, the optimal plot size (Xo) differed between the three methods, with 11.05 m^2 for QRP, 7.67 m^2 for LRP and 4.41 m^2 for MMC. There was also a difference between methods for the IPR92-Altar cultivar, of 10.77 m^2 for QRP, 7.52 m^2 for LRP and 4.79 m^2 for MMC (Table 5). When comparing the cultivars within each method the differences were not significant. It can therefore be inferred that the plot size might be the same for these cultivars and depends on the method of estimation.

The coefficient of variation at the optimal plot size (CV_{Xo}, in %) for both cultivars was higher with the MMC method compared to LRP and QRP, which did not differ from each other (Table 5). Between cultivars within each method, the differences in CV_{Xo} were not significant. These results indicate better experimental precision when using plot sizes determined by the LRP and QRP methods compared to the MMC method, irrespective of the cultivar.

Regardless of the cultivar, the mean values for R^2 differed between methods (MMC = 0.77; LRP = 0.71; QRP = 0.73). The mean values for Xo decreased in the following order: QRP = 10.91 m^2; LRP = 7.60 m^2; and MMC = 4.60 m^2, whereas CV_{Xo} was higher with MMC (13.05%), and there was no difference between LRP (8.99%) and QRP (8.84%). Therefore, despite the plot size being different between the LRP (7.60 m^2) and QRP (10.91 m^2) methods, they result in similar experimental precision, as CV_{Xo} did not differ. This lack of difference can be explained by the fact that, for a given plot size, any gains in precision (reduction in CV_{Xo}) from additions to the area of the plot are not significant. As such, it can be inferred that plots of 7.60 m^2 are suitable for experimental planning. This suggestion for plots of 7.60 m^2 is supported by practical feasibility in the field, and stabilised precision starting from that size, and can be used as a reference when planning experiments with buckwheat. This plot size is slightly larger than the 4 m^2 used by Pereira et al. (2017), and smaller than the 25 m^2 used by Menezes and Leandro (2004), the 25 m^2 used by Ziech et al. (2015), the 20 m^2 used by Görgen et al. (2016) and the 24 m^2 used by Skora and Campos (2017) in research with buckwheat and other species of ground cover.

Higher estimates for R^2, lower for Xo and higher for CV_{Xo} were obtained with the MMC method compared to the LRP in rice (Paranaíba et al., 2009a), wheat and cassava (Paranaíba et al., 2009b) and papaya (Brito et al., 2012). In passion fruit, greater values for R^2 and Xo, and lower values for CV_{Xo} were obtained with the QRP method compared to the LRP method (Peixoto et al., 2011). In general, the above research, comparing different methods to determine optimal plot size, found similar results to the those of present study.

Conclusion

The optimal plot size differs between methods, and decreases in the following order: quadratic response plateau model, linear response plateau model and modified maximum curvature. The optimal plot size for evaluating fresh matter in buckwheat 'IPR91-Baili' and 'IPR92-Altar' is 7.60 m^2.

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