

Plot size and number of replications to assess the vegetable matter in oat

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Abstract

The determination of the optimum plot size in agricultural crops is important for obtaining accurate inferences in the treatments in question. This study aimed at determining the optimum plot size (X_o) and the number of replications to evaluate the fresh matter (FM) and the dry matter (DM) of oat and at verifying the variability of X_o among cultivars and sowing dates. Ninety-six uniformity trials of 3×3 m were performed and each assay was divided into 36 basic experimental units (BEU) of 0.5×0.5 m. The 96 uniformity trials were distributed in four cultivars and three sowing dates. At the flowering stage, FM and DM were determined in each BEU. Then, the X_o was determined in each uniformity assay, using the maximum curvature method of the coefficient of variation model. In oat, there is variability of X_o among cultivars and sowing dates to measure FM and DM. For the four cultivars on the three sowing dates, the X_o of 1.66 m² and of 1.73 m² are suitable to evaluate FM and DM, respectively. Four replications to evaluate the maximum of 50 treatments in completely randomized design and randomized blocks design are sufficient so that the differences among treatment means of 44.75% of the experiment mean may be significant, using the Tukey test at 5% probability to measure FM and DM in oat.

Keywords: *Avena sativa* L., experimental design, uniformity trials

Introduction

The oat (*Avena sativa* L.) is the main winter grass sown in southern Brazil and it is the fifth most cultivated cereal (IBGE, 2014). It is an economically viable alternative for cultivation in the winter/spring period, occupying part of the agricultural areas that would lie fallow this time of the year. It is an annual herbaceous plant with great potential to be used as food for both humans and animals. The oat can also be used in the crop rotation system due to its soil restoration properties, having an aggressive root system and a large amount of matter. Furthermore, this plant influences the development of the soil biota, as observed in the study by Cardoso et al. (2014),

thus improving the microbiological soil conditions.

Due to the relevance of the oat cultivation, several studies have been conducted (Floss et al., 2007; Grecco et al., 2011; Demétrio et al., 2012; Meinerz et al., 2012; Tafernaberi Júnior et al., 2012; Ferrazza et al., 2013; Soares et al., 2013; Iqbal et al., 2014; Khan et al., 2014) in order to improve knowledge and to investigate the productivity of fresh and dry matter. Nevertheless, researchers have been using different plot sizes in these experiments, ranging from 0.25 m² (Soares et al., 2013) to 10.8 m² (Iqbal et al., 2014).

The fresh matter on plants is an important property to be assessed, for it reveals the potential and the performance of plants and their benefits

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for the soil and for the succeeding crops. According to Cardoso et al. (2014), in a study of soil covering plants, which includes oat, they provided a 10% increase in soybean productivity. Likewise, the dry matter, which is a percentage related to the fresh matter, has the same benefits.

The determination of the optimum plot size and of the number of replications from data collected in uniform trials (trials without treatments) allows the researcher to obtain a precise inference in the experiments, serving as a base to carrying out future research with cultivation. Thus, theoretically, based on the literature, the researcher can be guided on which plot size and number of replications one should use.

The optimum plot size can be determined by the maximum curvature method of the coefficient of variation model proposed by Paranaíba et al. (2009). It is assumed that the optimum plot size and the number of replications differ among cultivars and sowing dates of oat. Therefore, this study aimed at determining the optimum plot size and the number of replications to evaluate the fresh matter and the dry matter of oat and at verifying the variability of the optimal plot size among cultivars and sowing dates.

Material and Methods

Field experiments

Ninety-six uniformity trials were conducted with the oat crop (*Avena sativa* L.) in an experimental area of 90 × 60 m (5,400 m²), from the Department of Phytotechnology of the Santa Maria Federal University, Santa Maria, State of Rio Grande do Sul, located at 29°42'S, 53°49'W and 95 m high, in the agricultural year of 2014. The sowing density was 350 plants m⁻², with throwing sowing. The base fertilization was 21 kg ha⁻¹ N, 88 kg P₂O₅ ha⁻¹ and 88 kg ha⁻¹ of K₂O and later two 45 kg ha⁻¹ N covering fertilizations were performed. The cultivation tracts were carried out homogeneously throughout the experimental area.

The 96 uniformity trials were conducted as follows: eight uniformity trials with the URS Charrua cultivar, eight with the URS Taura cultivar, eight with the URS Estampa cultivar and eight with the URS Corona cultivar in each of the

three sowing dates (date 1 - 04/28/2014, date 2 - 05/28/2014 and date 3 - 07/14/2014). Each uniformity assay of size 3 × 3 m (9 m²) was divided in 36 basic experimental units (BEU) of 0.5 × 0.5 m (0.25 m²), forming a matrix of six lines and six columns.

Measurement of variables

At the flowering stage, at each BEU of 0.25 m², the plants were cut off at the surface of the soil. After that, they were weighed to obtain the fresh matter (FM) in kg per 0.25 m². Subsequently, five plants from each BEU were randomly collected. The FM of these five plants was weighed and placed into an air forced circulation greenhouse at 338.15 ± 276.15 K until constant matter was attained. Then, the dry matter (DM) was weighed and converted in kg per 0.25 m².

Estimation of optimum plot size and comparison of means

For each uniformity assay, with the data of FM and DM of 36 BEU, the first-order spatial autocorrelation coefficient (ρ), the variance (s^2), the mean (m) and the coefficient of variation of the assay (CV) were determined in percentage. The estimate of ρ was obtained in the direction of the columns, according to the methodology of Paranaíba et al. (2009). To this end, a path was followed from the BEU located in line 1, column 1 to line 6, column 1, returning from line 6, column 2 to line 1, column 2, and so on until the completion of the path on the BEU line 1, column 6.

Subsequently, in each of the 96 trials, the optimum plot size (X_o) was determined by the maximum curvature method of the coefficient of variation model using the expression of the Paranaíba et al. (2009)

$$X_o = \left(10 \sqrt[3]{2(1-\rho^2)s^2m}\right)/m \quad (1)$$

Next, the coefficient of variation of the optimum plot size (CV X_o) was determined in percentage by the expression

$$CV_{X_o} = \left(\sqrt{(1-\rho^2)s^2/m^2}\right)/\sqrt{X_o} \times 100 \quad (2)$$

Thus, for each cultivar on each sowing date, eight ρ estimates, s^2 , m , CV, X_o and CV X_o

were obtained. The comparison of the statistics means of ρ , s^2 , m , CV , X_o and CVX_o among cultivars (URS Charrua, URS Taura, URS Estampa and URS Corona) and among sowing dates (date 1 - 04/28/2014, date 2 - 05/28/2014 and date 3 - 07/14/2014), with $n = 8$ uniformity trials per cultivar on each sowing date, was carried out using the Scott Knott test via bootstrap analysis with 10,000 resampling with a 5% probability.

Estimation of number of replications

The minimum significant difference (d) of the Tukey test, expressed in percentage of the experiment mean was estimated by the expression

$$d = (q_{\alpha(i;GLE)} \sqrt{QME/r}) / m \times 100 \quad (3)$$

in which $q_{\alpha(i;GLE)}$ is the critical value of the Tukey test at the α level of error probability ($\alpha = 0.05$ in this study), i is the number of treatments, GLE is the number of degrees of freedom for error, i.e., $i (i-1)$ for a completely randomized design and $(i-1)(r-1)$ for a randomized blocks design, QME is the squared mean of the error, r is the number of replications and m is the experiment mean. Substituting the expression of the experimental coefficient of variation

$$(CV = \sqrt{QME} / m \times 100) \quad (4)$$

in percentage, in the expression to calculate d and isolate r resulting in

$$r = (q_{\alpha(i;GLE)} CV / d)^2 \quad (5)$$

The experimental coefficient of variation of the expression corresponds to CVX_o and it is expressed in percentage, for it is the expected CV to the experiment with the determined optimum plot size (X_o). From the highest means of CVX_o of the cultivars and of the three dates of evaluation, the number of replications (r) was determined by iterative process until convergence, for experiments in completely randomized design and randomized blocks design, in scenarios formed by combinations of i ($i = 3, 4, \dots, 50$) and d ($d = 10\%, 15\%, 20\%, 25\%, 30\%, 35\%, 40\%, 45\%$ and 50%).

Resources used for the calculations

Statistical analyzes were performed using the Microsoft Office Excel® application and the Sisvar® software (Ferreira, 2014).

Results

Descriptive statistics

Variability was found on the following statistics: first-order spatial autocorrelation coefficient (ρ), variance (s^2), mean (m) and coefficient of variation of the assay (CV). Accordingly, there was variability of the estimates of the optimum plot size (X_o) and of the coefficient of variation of the optimum plot size (CVX_o), because by using the maximum curvature method of the coefficient of variation model (Paranaíba et al., 2009), the X_o and the CVX_o are calculated based on ρ , s^2 and m .

Analysis of variance

Based on the Scott Knott test via bootstrap analysis, it was observed that the first-order spatial autocorrelation coefficient (ρ) did not differ among cultivars for the properties of fresh and dry matter, with the exception of the property of dry matter at the date 3. Among the sowing dates, differences were observed in the ρ with the data of the properties of fresh matter from the URS Taura cultivar and dry matter from the URS Charrua and URS Taura cultivars (Table 1).

Concerning the data of the fresh and dry matter of oat, differences among cultivars and among sowing dates were found on the variance (s^2), mean (m), coefficient of variation (CV) and, consequently, on the optimum plot size (X_o) and coefficient of variation of the optimum plot size (CVX_o) (Table 1).

Average fresh matter

The mean of fresh matter among cultivars of oat from the URS Charrua cultivar, with 0.80431 kg 0.25 m⁻², 0.87205 kg 0.25 m⁻² and 0.83615 kg 0.25 m⁻² for the dates 1, 2 and 3, respectively, was higher than the URS Taura, URS Estampa and URS Corona cultivars (Table 1). Regarding the sowing dates, the mean of the fresh matter of oat in the URS Charrua and URS Taura cultivars was higher on the date 2, with 0.87205 kg 0.25 m⁻² and 0.686.75 kg 0.25 m⁻², respectively, differing

from the other dates. In the URS Estampa and URS Corona cultivars, the sowing dates did not differ in the production of fresh matter (Table 1).

Table 1. First-order spatial autocorrelation coefficient (ρ), variance (s^2), mean (m), coefficient of variation of the assay (CV, in %), optimum plot size (X_o , in number of BEU of 0.25 m²) and coefficient of variation of the optimum plot size (CV _{x_o} , in %), to the aerial part of fresh matter (kg 0.25 m²) and the aerial part of dry matter (kg 0.25 m²) of four cultivars of oat (URS Charrua, URS Taura, URS Estampa and URS Corona) sown on three dates⁽¹⁾

Date	Fresh matter				Dry matter			
	URS Charrua	URS Taura	URS Estampa	URS Corona	URS Charrua	URS Taura	URS Estampa	URS Corona
First-order spatial autocorrelation coefficient (ρ)								
(04/28/2014)	0.13 Aa	0.34 Aa	0.28 Aa	0.13 Aa	0.07 Aa	0.30 Aa	0.28 Aa	0.16 Aa
(05/28/2014)	0.11 Aa	0.24 Aa	0.13 Aa	0.18 Aa	0.16 Aa	0.20 Aa	0.14 Aa	0.13 Aa
(07/14/2014)	-0.03 Aa	0.10 Ba	0.10 Aa	0.17 Aa	-0.10 Bb	0.04 Ba	0.15 Aa	0.04 Aa
variance (s^2)								
(04/28/2014)	0.02788 Bb	0.04197 Aa	0.02671 Ab	0.02676 Bb	0.00124 Cb	0.00186 Aa	0.00131 Bb	0.00098 Bb
(05/28/2014)	0.04731 Aa	0.05559 Aa	0.03781 Aa	0.05004 Aa	0.00175 Ba	0.00187 Aa	0.00129 Bb	0.00199 Aa
(07/14/2014)	0.03815 Aa	0.02413 Ba	0.03700 Aa	0.03336 Ba	0.00254 Aa	0.00163 Ab	0.00232 Aa	0.00270 Aa
average (m)								
(04/28/2014)	0.80431 Ba	0.49591 Bd	0.64266 Ac	0.72662 Ab	0.15367 Ba	0.09787 Ac	0.12916 Ab	0.13303 Bb
(05/28/2014)	0.87205 Aa	0.68675 Ab	0.68845 Ab	0.64852 Ab	0.15532 Ba	0.11732 Ab	0.11552 Bb	0.12389 Bb
(07/14/2014)	0.83615 Ba	0.51149 Bc	0.63320 Ab	0.68204 Ab	0.17944 Aa	0.11830 Ac	0.13881 Ac	0.16256 Ab
coefficient of variation of the trial (CV, in %)								
(04/28/2014)	20.78 Bb	41.51 Aa	25.85 Ab	22.47 Cb	22.90 Bb	44.13 Aa	28.34 Ab	23.54 Bb
(05/28/2014)	24.87 Ab	34.55 Ba	28.17 Ab	35.75 Aa	26.77 Ac	36.50 Aa	31.01 Ab	37.57 Aa
(07/14/2014)	23.20 Ac	31.07 Ba	30.28 Aa	26.65 Bb	27.76 Aa	34.71 Aa	34.28 Aa	31.59 Aa
optimal plot size (X_o , in the number of BEU of 0,25 m ²)								
(04/28/2014)	4.27 Bb	6.62 Aa	4.86 Ab	4.59 Cb	4.64 Bb	6.93 Aa	5.17 Bb	4.70 Bb
(05/28/2014)	4.94 Ab	6.00 Aa	5.32 Ab	6.17 Aa	5.17 Ac	6.28 Aa	5.65 Ab	6.42 Aa
(07/14/2014)	4.71 Ab	5.66 Aa	5.55 Aa	5.10 Bb	5.30 Aa	6.11 Aa	6.07 Aa	5.78 Aa
coefficient of variation of optimal plot size (CV _{x_o} , in %)								
(04/28/2014)	9.55 Bb	14.80 Aa	10.86 Ab	10.26 Cb	10.37 Bb	15.50 Aa	11.57 Bb	10.52 Bb
(05/28/2014)	11.05 Ab	13.41 Aa	11.90 Ab	13.79 Aa	11.56 Ac	14.03 Aa	12.64 Ab	14.36 Aa
(07/14/2014)	10.52 Ab	12.67 Aa	12.41 Aa	11.41 Bb	11.86 Aa	13.67 Aa	13.58 Aa	12.92 Aa

(1) To each statistic (p, s², m, CV, X_o e CV X_o) the means that are not followed by the same letter, lowercase in the line (comparison of means among cultivars on each date) and uppercase in the column (comparison of means among dates in each cultivar), differ at a 5% probability using the Scott Knott test via bootstrap analysis with 10,000 resampling.

Average dry matter

The means of the dry matter of oat among cultivars that were sown at three sowing dates differed among themselves (Table 1). On the three sowing dates (date 1, date 2 and date 3), the dry matter of oat was higher in the URS Charrua cultivar, with 0.15367 kg 0.25 m², 0.15532 kg 0.25 m² and 0.17944 kg 0.25 m², respectively, differing from the URS Taura, URS Estampa and URS Corona cultivars. In reference to sowing dates, the mean of the dry matter of oat in the URS Charrua and URS Corona cultivars was higher on the date 3, with 0.17944 kg 0.25 m² and 0.16256 kg 0.25 m², respectively, differing from dates 1 and 2; concerning the URS Taura cultivar, the sowing dates did not differ in relation to the dry matter; in the URS Estampa cultivar, the highest mean was obtained on the date 1 (0.12916 kg 0.25 m²) and the date 3 (0.13881 kg 0.25 m²) and did not differ among themselves, nevertheless,

they differed from the date 2 (0.11552 kg 0.25 m²) (Table 1).

Coefficient of variation

The means of the coefficient of variation (CV) oscillated between 20.78% and 22.90% for the URS Charrua cultivar on the date 1 and 41.51% and 44.13% for the URS Taura cultivar on the date 1 (Table 1) for the data of fresh and dry matter of oat, respectively.

Optimum plot size and coefficient of variation of optimum plot size

Regarding the means of the optimum plot size (X_o) and of the coefficient of variation of the optimum plot size (CV x_o), for measuring the fresh matter of oat, significant differences among cultivars were observed, resulting in the obtainment of a larger optimum plot size and a higher coefficient of variation of the optimum

plot size in the URS Taura cultivar ($X_o = 6.62$ and $CV_{x_o} = 14.80\%$) on the date 1, in the URS Taura ($X_o = 6.0$ and $CV_{x_o} = 13.41\%$) and URS Corona cultivars ($X_o = 6.17$ and $CV_{x_o} = 13.79\%$) on the date 2, and in the URS Taura ($X_o = 5.66$ and $CV_{x_o} = 12.67\%$) and URS Estampa cultivars ($X_o = 5.55$ and $CV_{x_o} = 12.41\%$) on the date 3. The sowing dates also differ significantly among themselves, with higher values on dates 2 ($X_o = 4.94$ and $CV_{x_o} = 11.05\%$) and 3 ($X_o = 4.71$ and $CV_{x_o} = 10.52\%$), without a significant difference among themselves, however, higher than the date 1 ($X_o = 4.27$ and $CV_{x_o} = 9.55\%$) in the URS Charrua cultivar, and on the date 2 ($X_o = 6.17$ and $CV_{x_o} = 13.79\%$) in the URS Corona cultivar (Table 1).

Concerning the measurement of dry matter, the means of the optimum plot size (X_o) and the coefficient of variation of the optimum plot size (CV_{x_o}) also differed, with higher values of $X_o = 6.93$ and $CV_{x_o} = 15.50\%$ in the URS Taura cultivar, sown on the date 1, of $X_o = 6.28$ and 6.42 , and $CV_{x_o} = 14.03\%$ and 14.36% in the URS Taura and URS Corona cultivars, respectively, sown on the date 2. The highest values among the sowing dates were obtained on dates 2 and 3, when the URS Charrua, URS Estampa and URS Corona cultivars were sown (Table 1).

Another finding was that the largest optimum plot size obtained to evaluate the fresh and the dry matter of oat was 6.62 and 6.93 basic experimental units of 0.25 m^2 (1.66 m^2 and 1.73 m^2), respectively, and the coefficient of variation of the optimum plot size was 14.80% and 15.50% , respectively (Table 1). These values were considered adequate, for they encompass all the variability existent among the cultivars and the sowing dates.

Number of replications

In scenarios formed by combinations of i treatments ($i = 3, 4, \dots, 50$) and minimal differences among the treatment means to be detected as significant at a 5% probability by the Tukey test, expressed in percentage of the experiment mean ($d = 10\%, 15\%, 20\%, 25\%, 30\%, 35\%, 40\%, 45\%$ and 50%), to evaluate the fresh matter of oat in the completely randomized design (CRD), the number of replications oscillated from 2.34 ($i = 3$ and $d = 50\%$) to 69.96 ($i = 50$ and $d = 10\%$)

(Table 2) and in the randomized blocks design (RBD) they oscillated from 2.44 ($i = 3$ and $d = 50\%$) to 69.96 ($i = 50$ and $d = 10\%$) (Table 3). Regarding the measurement of dry matter of oat in the completely randomized design (CRD), the number of replications ranged from 2.40 ($i = 3$ and $d = 50\%$) to 76.72 ($i = 50$ and $d = 10\%$) (Table 4) and in the randomized blocks design (RBD) they ranged from 2.50 ($d = 3$ $i = 50\%$) to 76.72 ($i = 50$ and $d = 10\%$) (Table 5).

In experiments with 50 treatments and higher experimental precision ($d = 10\%$), the required number of replications is the same in the completely randomized design and in the randomized blocks design, i.e., 69.96 and 76.72 replications for the measurement of fresh and dry matter, respectively. Thus, due to the high number of replications these experiments are not feasible. Nevertheless, whoever uses the information of this study can choose the combination of experimental design, number of treatments, minimal differences among the treatment means and the number of replications suitable to carry out one's experiment (Tables 2, 3, 4 and 5). It is important to note that the information provided on this study is from the X_o and CV_{X_o} defined according to Paranaíba et al. (2009) methodology. Although the gain in the accuracy from the increasing of the X_o is not very expressive, it is possible to opt for the increasing of the X_o to reduce the CV_{X_o} , and, thus, improve the experimental accuracy.

By fixing X_o , CV_{X_o} and d , with the increase of the number of treatments, regardless of the experimental design CRD or RBD, the number of replications increases, as was also confirmed by Cargnelutti Filho et al. (2014a) (Tables 2, 3, 4 and 5). Furthermore, with the increase of the number of treatments, the number of replications for RBD and for CRD get closer. For fixed values of X_o , CV_{X_o} , i and d , the number of replications in the RBD is higher than the number of replications in the CRD, which confirms a higher efficiency of the CRD in relation to the RBD when there is no variability in the experimental units (plots) (Storck et al., 2016).

Thus, to evaluate a large number of treatments ($i = 50$) and $d = 45\%$, 3.63 replications in CRD and in RBD are required for

Table 2. Number of replications to evaluate the aerial part of fresh matter of oat (*Avena sativa* L.), in a completely randomized design experiment, in scenarios formed by combinations of *i* treatments (*i* = 3, 4, ..., 50) and *d* minimum differences among treatment means to be detected as significant at a 5% probability, using the Tukey test, expressed in percentage of the experiment mean (*d* = 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% e 50%), from the optimum plot size ($X_o = 1.66 \text{ m}^2$) and the coefficient of variation of the optimum plot size ($CV_{x_o} = 14.80\%$)

<i>i</i>	10%	15%	20%	25%	30%	35%	40%	45%	50%
3	25.08	11.75	7.11	4.99	3.86	3.19	2.82	2.59	2.34
4	29.77	13.73	8.14	5.58	4.20	3.40	2.88	2.60	2.34
5	33.34	15.25	8.94	6.04	4.48	3.55	2.98	2.61	2.36
6	36.24	16.49	9.59	6.42	4.71	3.70	3.06	2.63	2.37
7	38.67	17.53	10.15	6.74	4.91	3.82	3.13	2.67	2.39
8	40.78	18.44	10.63	7.03	5.09	3.94	3.20	2.71	2.38
9	42.64	19.24	11.06	7.29	5.25	4.04	3.26	2.75	2.39
10	44.31	19.96	11.45	7.52	5.40	4.13	3.33	2.78	2.41
11	45.82	20.61	11.80	7.73	5.53	4.22	3.38	2.82	2.43
12	47.19	21.21	12.12	7.93	5.66	4.30	3.44	2.85	2.45
13	48.46	21.76	12.42	8.11	5.78	4.38	3.49	2.89	2.47
14	49.63	22.27	12.70	8.28	5.89	4.45	3.54	2.92	2.49
15	50.72	22.74	12.96	8.43	5.99	4.52	3.58	2.95	2.51
16	51.75	23.19	13.20	8.58	6.08	4.59	3.63	2.98	2.53
17	52.71	23.61	13.43	8.72	6.18	4.65	3.67	3.01	2.55
18	53.62	24.00	13.64	8.86	6.26	4.71	3.71	3.03	2.56
19	54.48	24.38	13.85	8.98	6.35	4.77	3.75	3.06	2.58
20	55.29	24.73	14.04	9.10	6.42	4.82	3.79	3.09	2.60
21	56.07	25.07	14.23	9.22	6.50	4.87	3.82	3.11	2.61
22	56.81	25.40	14.41	9.33	6.57	4.92	3.86	3.14	2.63
23	57.52	25.71	14.58	9.43	6.64	4.97	3.89	3.16	2.65
24	58.20	26.00	14.74	9.53	6.71	5.02	3.92	3.18	2.66
25	58.85	26.29	14.90	9.63	6.77	5.06	3.95	3.21	2.68
26	59.47	26.56	15.05	9.72	6.84	5.10	3.99	3.23	2.69
27	60.08	26.83	15.19	9.81	6.90	5.15	4.01	3.25	2.71
28	60.66	27.08	15.33	9.90	6.96	5.19	4.04	3.27	2.72
29	61.22	27.33	15.47	9.99	7.01	5.22	4.07	3.29	2.74
30	61.76	27.56	15.60	10.07	7.07	5.26	4.10	3.31	2.75
31	62.29	27.80	15.73	10.15	7.12	5.30	4.13	3.33	2.76
32	62.79	28.02	15.85	10.22	7.17	5.34	4.15	3.35	2.78
33	63.29	28.23	15.97	10.30	7.22	5.37	4.18	3.36	2.79
34	63.76	28.44	16.09	10.37	7.27	5.41	4.20	3.38	2.80
35	64.23	28.65	16.20	10.44	7.32	5.44	4.23	3.40	2.82
36	64.68	28.85	16.31	10.51	7.36	5.47	4.25	3.42	2.83
37	65.12	29.04	16.42	10.58	7.41	5.50	4.27	3.43	2.84
38	65.55	29.23	16.52	10.64	7.45	5.53	4.29	3.45	2.85
39	65.96	29.41	16.62	10.70	7.49	5.56	4.32	3.47	2.87
40	66.37	29.59	16.72	10.77	7.54	5.59	4.34	3.48	2.88
41	66.77	29.76	16.82	10.83	7.58	5.62	4.36	3.50	2.89
42	67.15	29.94	16.91	10.89	7.62	5.65	4.38	3.51	2.90
43	67.53	30.10	17.00	10.94	7.66	5.68	4.40	3.53	2.91
44	67.90	30.26	17.09	11.00	7.69	5.71	4.42	3.54	2.92
45	68.26	30.42	17.18	11.06	7.73	5.73	4.44	3.56	2.93
46	68.62	30.58	17.27	11.11	7.77	5.76	4.46	3.57	2.94
47	68.96	30.73	17.35	11.16	7.80	5.78	4.48	3.58	2.95
48	69.30	30.88	17.44	11.22	7.84	5.81	4.49	3.60	2.96
49	69.63	31.03	17.52	11.27	7.87	5.83	4.51	3.61	2.97
50	69.96	31.17	17.60	11.32	7.91	5.86	4.53	3.62	2.98

the measurement of fresh matter (tables 2 and 3) and 3.96 replications for the measurement of dry matter (Tables 4 and 5). In practice, in field experiments these values cannot be used,

then the right action to follow is to round them, using four replications to measure fresh and dry matter of oat. It is possible to calculate the minimum significant difference (*d*) of the Tukey

Table 3. Number of replications to evaluate the aerial part of fresh matter of oat (*Avena sativa* L.), in a randomized blocks design experiment, in scenarios formed by combinations of *i* treatments (*i* = 3, 4, ... 50) and *d* minimum differences among treatment means to be detected as significant at a 5% probability, using the Tukey test, expressed in percentage of the experiment mean (*d* = 10%, 15%, 20%, 25%, 30%, 35%, 40%, 45% and 50%), from the optimum plot size (*X*_o = 1.66 m²) and the coefficient of variation of the optimum plot size (CVX_o = 14.80%)

<i>i</i>	10%	15%	20%	25%	30%	35%	40%	45%	50%
3	25.58	12.25	7.59	5.46	4.32	3.33	3.08	2.73	2.44
4	30.05	14.02	8.43	5.86	4.48	3.65	3.10	2.74	2.45
5	33.53	15.44	9.12	6.22	4.67	3.74	3.14	2.75	2.45
6	36.37	16.62	9.72	6.55	4.84	3.83	3.18	2.76	2.46
7	38.77	17.63	10.25	6.85	5.02	3.93	3.23	2.77	2.46
8	40.86	18.52	10.71	7.11	5.17	4.02	3.28	2.79	2.46
9	42.71	19.30	11.12	7.35	5.32	4.10	3.33	2.82	2.46
10	44.36	20.01	11.50	7.57	5.45	4.19	3.38	2.84	2.47
11	45.86	20.65	11.84	7.78	5.58	4.27	3.43	2.87	2.48
12	47.23	21.24	12.16	7.97	5.70	4.34	3.48	2.89	2.49
13	48.49	21.79	12.45	8.14	5.81	4.42	3.52	2.92	2.51
14	49.66	22.29	12.73	8.31	5.91	4.48	3.57	2.95	2.52
15	50.75	22.77	12.98	8.46	6.01	4.55	3.61	2.98	2.54
16	51.77	23.21	13.22	8.61	6.11	4.61	3.65	3.00	2.55
17	52.73	23.63	13.45	8.74	6.20	4.67	3.69	3.03	2.57
18	53.64	24.02	13.66	8.87	6.28	4.73	3.73	3.06	2.58
19	54.49	24.39	13.86	9.00	6.36	4.78	3.77	3.08	2.60
20	55.31	24.75	14.06	9.12	6.44	4.84	3.80	3.10	2.62
21	56.08	25.09	14.24	9.23	6.52	4.89	3.84	3.13	2.63
22	56.82	25.41	14.42	9.34	6.59	4.93	3.87	3.15	2.65
23	57.53	25.72	14.59	9.44	6.66	4.98	3.90	3.17	2.66
24	58.21	26.01	14.75	9.54	6.72	5.03	3.94	3.20	2.68
25	58.86	26.30	14.91	9.64	6.79	5.07	3.97	3.22	2.69
26	59.48	26.57	15.06	9.73	6.85	5.11	4.00	3.24	2.70
27	60.08	26.84	15.20	9.82	6.91	5.15	4.02	3.26	2.72
28	60.67	27.09	15.34	9.91	6.96	5.19	4.05	3.28	2.73
29	61.23	27.33	15.48	9.99	7.02	5.23	4.08	3.30	2.75
30	61.77	27.57	15.61	10.07	7.07	5.27	4.11	3.32	2.76
31	62.29	27.80	15.73	10.15	7.13	5.31	4.13	3.34	2.77
32	62.80	28.02	15.86	10.23	7.18	5.34	4.16	3.35	2.79
33	63.29	28.24	15.98	10.30	7.23	5.38	4.18	3.37	2.80
34	63.77	28.45	16.09	10.38	7.28	5.41	4.21	3.39	2.81
35	64.23	28.65	16.20	10.45	7.32	5.44	4.23	3.41	2.82
36	64.69	28.85	16.31	10.51	7.37	5.48	4.25	3.42	2.84
37	65.12	29.05	16.42	10.58	7.41	5.51	4.28	3.44	2.85
38	65.55	29.23	16.52	10.65	7.46	5.54	4.30	3.46	2.86
39	65.97	29.42	16.63	10.71	7.50	5.57	4.32	3.47	2.87
40	66.38	29.59	16.72	10.77	7.54	5.60	4.34	3.49	2.88
41	66.77	29.77	16.82	10.83	7.58	5.63	4.36	3.50	2.89
42	67.16	29.94	16.92	10.89	7.62	5.65	4.38	3.52	2.90
43	67.54	30.11	17.01	10.95	7.66	5.68	4.40	3.53	2.92
44	67.91	30.27	17.10	11.00	7.70	5.71	4.42	3.55	2.93
45	68.27	30.43	17.19	11.06	7.74	5.74	4.44	3.56	2.94
46	68.62	30.58	17.27	11.11	7.77	5.76	4.46	3.57	2.95
47	68.97	30.73	17.36	11.17	7.81	5.79	4.48	3.59	2.96
48	69.31	30.88	17.44	11.22	7.84	5.81	4.50	3.60	2.97
49	69.64	31.03	17.52	11.27	7.88	5.84	4.52	3.62	2.98
50	69.96	31.17	17.60	11.32	7.91	5.86	4.53	3.63	2.99

test, expressed in percentage of the experiment mean with the expression

$$d = a_{\alpha(i;GLE)} CV / \sqrt{r} \quad (6)$$

with *i* = 50 treatments, $\alpha = 0.05$, CVX_o = 14.80% and 15.50% (coefficient of variation of the optimum plot size) to fresh and dry matter,

respectively, and *r* = 4 replications. In these conditions, it was obtained for the fresh matter *d* = 42.71% in a completely randomized design and *d* = 42.73% in a randomized blocks design. As for the dry matter, *d* = 44.73% was determined in a completely randomized design and *d* = 44.75%, in a randomized blocks design.

Table 4. Number of replications to evaluate the aerial part of dry matter of oat (*Avena sativa* L.), in a completely randomized design experiment, in scenarios formed by combinations of *i* treatments ($i = 3, 4, \dots, 50$) and *d* minimum differences among treatment means to be detected as significant at a 5% probability, using the Tukey test, expressed in percentage of the experiment mean ($d = 10\%, 15\%, 20\%, 25\%, 30\%, 35\%, 40\%, 45\%$ and 50%), from the optimum plot size ($X_o = 1.73 \text{ m}^2$) and the coefficient of variation of the optimum plot size ($CV_{x_o} = 15.50\%$)

<i>i</i>	10%	15%	20%	25%	30%	35%	40%	45%	50%
3	27.41	12.78	7.68	5.35	4.10	3.36	2.98	2.70	2.40
4	32.57	14.97	8.84	6.02	4.50	3.61	3.05	2.73	2.45
5	36.50	16.65	9.72	6.54	4.82	3.80	3.15	2.72	2.47
6	39.68	18.02	10.45	6.96	5.08	3.97	3.26	2.79	2.49
7	42.36	19.17	11.07	7.33	5.31	4.11	3.35	2.84	2.48
8	44.68	20.17	11.60	7.65	5.52	4.24	3.43	2.89	2.51
9	46.73	21.05	12.08	7.94	5.70	4.36	3.51	2.93	2.53
10	48.55	21.85	12.51	8.19	5.86	4.47	3.58	2.98	2.56
11	50.21	22.56	12.90	8.43	6.02	4.57	3.65	3.02	2.59
12	51.72	23.22	13.25	8.65	6.16	4.67	3.71	3.07	2.62
13	53.11	23.82	13.58	8.85	6.29	4.75	3.77	3.10	2.64
14	54.40	24.39	13.89	9.04	6.41	4.84	3.82	3.14	2.67
15	55.60	24.91	14.17	9.21	6.52	4.91	3.88	3.18	2.69
16	56.73	25.40	14.44	9.38	6.63	4.99	3.93	3.21	2.71
17	57.78	25.86	14.69	9.53	6.74	5.06	3.98	3.25	2.73
18	58.78	26.30	14.93	9.68	6.83	5.12	4.02	3.28	2.76
19	59.72	26.71	15.16	9.82	6.93	5.19	4.07	3.31	2.78
20	60.62	27.10	15.37	9.95	7.01	5.25	4.11	3.34	2.80
21	61.47	27.47	15.58	10.08	7.10	5.31	4.15	3.37	2.82
22	62.29	27.83	15.77	10.20	7.18	5.36	4.19	3.40	2.84
23	63.06	28.17	15.96	10.32	7.26	5.42	4.23	3.43	2.86
24	63.81	28.50	16.14	10.43	7.33	5.47	4.27	3.45	2.88
25	64.52	28.81	16.31	10.54	7.40	5.52	4.30	3.48	2.89
26	65.21	29.11	16.48	10.64	7.47	5.57	4.34	3.50	2.91
27	65.87	29.40	16.64	10.74	7.54	5.61	4.37	3.53	2.93
28	66.51	29.68	16.80	10.84	7.60	5.66	4.40	3.55	2.95
29	67.13	29.95	16.95	10.93	7.67	5.70	4.44	3.57	2.96
30	67.72	30.21	17.09	11.02	7.73	5.75	4.47	3.60	2.98
31	68.30	30.47	17.23	11.11	7.79	5.79	4.50	3.62	3.00
32	68.85	30.71	17.37	11.19	7.84	5.83	4.53	3.64	3.01
33	69.40	30.95	17.50	11.27	7.90	5.87	4.55	3.66	3.03
34	69.92	31.18	17.62	11.35	7.95	5.90	4.58	3.68	3.04
35	70.43	31.40	17.75	11.43	8.00	5.94	4.61	3.70	3.06
36	70.93	31.62	17.87	11.51	8.06	5.98	4.63	3.72	3.07
37	71.41	31.83	17.99	11.58	8.10	6.01	4.66	3.74	3.09
38	71.88	32.04	18.10	11.65	8.15	6.05	4.69	3.76	3.10
39	72.34	32.24	18.21	11.72	8.20	6.08	4.71	3.78	3.11
40	72.78	32.44	18.32	11.79	8.25	6.11	4.73	3.79	3.13
41	73.22	32.63	18.43	11.86	8.29	6.15	4.76	3.81	3.14
42	73.64	32.82	18.53	11.92	8.34	6.18	4.78	3.83	3.15
43	74.06	33.00	18.63	11.99	8.38	6.21	4.80	3.84	3.16
44	74.46	33.18	18.73	12.05	8.42	6.24	4.83	3.86	3.18
45	74.86	33.35	18.83	12.11	8.46	6.27	4.85	3.88	3.19
46	75.25	33.53	18.93	12.17	8.50	6.30	4.87	3.89	3.20
47	75.63	33.69	19.02	12.23	8.54	6.32	4.89	3.91	3.21
48	76.00	33.86	19.11	12.29	8.58	6.35	4.91	3.92	3.22
49	76.36	34.02	19.20	12.34	8.62	6.38	4.93	3.94	3.24
50	76.72	34.17	19.29	12.40	8.66	6.41	4.95	3.95	3.25

Table 5. Number of replications to evaluate the aerial part of dry matter of oat (*Avena sativa* L.), in a randomized blocks design experiment, in scenarios formed by combinations of *i* treatments (*i* = 3, 4 ..., 50) and *d* minimum differences among treatment means to be detected as significant at a 5% probability, using the Tukey test, expressed in percentage of the experiment mean (*d* = 10%, 15%, 20%, 25 %, 30%, 35%, 40%, 45% and 50%), from the optimum plot size ($X_o = 1.73 \text{ m}^2$) and the coefficient of variation of the optimum plot size ($CV_{x_o} = 15.50\%$)

<i>i</i>	10%	15%	20%	25%	30%	35%	40%	45%	50%
3	27.91	13.28	8.18	5.84	4.57	3.69	3.20	2.90	2.50
4	32.85	15.26	9.12	6.29	4.78	3.88	3.27	2.91	2.55
5	36.68	16.84	9.91	6.72	5.00	3.99	3.33	2.93	2.58
6	39.81	18.15	10.58	7.10	5.22	4.10	3.39	2.92	2.64
7	42.46	19.27	11.17	7.43	5.41	4.21	3.45	2.94	2.59
8	44.76	20.25	11.68	7.73	5.60	4.33	3.51	2.97	2.59
9	46.79	21.12	12.14	8.00	5.76	4.43	3.57	3.00	2.60
10	48.61	21.90	12.56	8.25	5.92	4.53	3.63	3.03	2.62
11	50.25	22.61	12.94	8.48	6.06	4.62	3.69	3.07	2.64
12	51.76	23.26	13.29	8.69	6.20	4.71	3.75	3.11	2.66
13	53.14	23.86	13.61	8.88	6.32	4.79	3.80	3.14	2.68
14	54.43	24.41	13.92	9.07	6.44	4.87	3.86	3.17	2.70
15	55.63	24.93	14.20	9.24	6.55	4.94	3.91	3.21	2.72
16	56.75	25.42	14.46	9.40	6.66	5.01	3.95	3.24	2.74
17	57.80	25.88	14.71	9.55	6.76	5.08	4.00	3.27	2.76
18	58.80	26.31	14.95	9.70	6.85	5.14	4.04	3.30	2.78
19	59.74	26.72	15.17	9.84	6.94	5.21	4.09	3.33	2.80
20	60.63	27.11	15.39	9.97	7.03	5.26	4.13	3.36	2.82
21	61.49	27.49	15.59	10.09	7.11	5.32	4.17	3.38	2.84
22	62.30	27.84	15.79	10.21	7.19	5.38	4.21	3.41	2.85
23	63.07	28.18	15.97	10.33	7.27	5.43	4.24	3.44	2.87
24	63.82	28.51	16.15	10.44	7.34	5.48	4.28	3.46	2.89
25	64.53	28.82	16.32	10.55	7.41	5.53	4.31	3.49	2.91
26	65.22	29.12	16.49	10.65	7.48	5.58	4.35	3.51	2.92
27	65.88	29.41	16.65	10.75	7.55	5.62	4.38	3.54	2.94
28	66.52	29.69	16.80	10.84	7.61	5.67	4.41	3.56	2.96
29	67.13	29.96	16.95	10.94	7.67	5.71	4.44	3.58	2.97
30	67.73	30.22	17.10	11.03	7.73	5.75	4.47	3.60	2.99
31	68.30	30.47	17.24	11.11	7.79	5.79	4.50	3.63	3.00
32	68.86	30.72	17.37	11.20	7.85	5.83	4.53	3.65	3.02
33	69.40	30.96	17.50	11.28	7.90	5.87	4.56	3.67	3.03
34	69.93	31.19	17.63	11.36	7.96	5.91	4.59	3.69	3.05
35	70.44	31.41	17.75	11.44	8.01	5.95	4.61	3.71	3.06
36	70.93	31.63	17.87	11.51	8.06	5.98	4.64	3.73	3.08
37	71.41	31.84	17.99	11.59	8.11	6.02	4.67	3.74	3.09
38	71.88	32.05	18.11	11.66	8.16	6.05	4.69	3.76	3.10
39	72.34	32.25	18.22	11.73	8.21	6.09	4.72	3.78	3.12
40	72.79	32.44	18.33	11.80	8.25	6.12	4.74	3.80	3.13
41	73.22	32.64	18.43	11.86	8.30	6.15	4.76	3.82	3.14
42	73.65	32.82	18.54	11.93	8.34	6.18	4.78	3.83	3.16
43	74.06	33.00	18.64	11.99	8.38	6.21	4.81	3.85	3.17
44	74.47	33.18	18.74	12.05	8.43	6.24	4.83	3.87	3.18
45	74.86	33.36	18.83	12.11	8.47	6.27	4.85	3.88	3.19
46	75.25	33.53	18.93	12.17	8.51	6.30	4.87	3.90	3.20
47	75.63	33.70	19.02	12.23	8.55	6.33	4.89	3.91	3.22
48	76.00	33.86	19.11	12.29	8.59	6.36	4.91	3.93	3.23
49	76.37	34.02	19.20	12.35	8.62	6.38	4.93	3.94	3.24
50	76.72	34.18	19.29	12.40	8.66	6.41	4.95	3.96	3.25

Discussion

Descriptive statistics

Plot size studies with soil covering plants found scenarios with wide variability of statistics ρ , s^2 , m , CV , X_o and CVX_o among uniformity trials (Cargnelutti Filho et al., 2014a, Burin et al., 2015), as observed in this study. According to these authors, this scenario of variability is important in studies of optimum plot size and of number of replications, for it reflects real conditions of the field cultivation.

Average fresh matter and dry matter

Overall, the means of fresh and dry matter of oat in the four cultivars on the three sowing dates were respectively 0.68568 kg 0.25 m⁻² (27,430 kg ha⁻¹) and 0.13541 kg 0.25 m⁻² (5,420 kg ha⁻¹). These fresh and dry matter of oat productivities were inferior than 51,160 kg ha⁻¹ and 8,900 kg ha⁻¹, respectively, and were obtained in the Iqbal et al. (2014) study. Values higher than the study of fresh and dry matter of 80,000 kg ha⁻¹ and 10,950 kg ha⁻¹, respectively, were also observed by Khan et al. (2014). Lower values of fresh and dry matter of 5,150 kg ha⁻¹ and 1,170 kg ha⁻¹, respectively, were obtained in the study of Grecco et al. (2011). In Meinerz et al. study (2011), the authors obtained values of 33,280 kg ha⁻¹ for the fresh matter and of 11,910 kg ha⁻¹ for the dry matter of oat, which are higher than the values of this study. Higher values of fresh matter, 42,890 kg ha⁻¹, and of dry matter, 10,080 kg ha⁻¹, were also verified by Floss et al. (2007). Differences in cultivation, climate, soil, management and sowing dates may explain the different results between the mentioned studies and the present study. Thus, it can be said that, in general, the cultivation had an adequate development and a high productive potential, reflecting the real conditions of the field. Furthermore, a set of substantial data (3,456 BEU) with four cultivars in three sowing dates, and a wide variability scenario, give, combined with all of the above, credibility to the study of the dimensioning of the optimum plot size and the number of replications in oat cultivation.

Coefficient of variation

Coefficients of variation of this

magnitude observed in the study are above the observed value of 8.52%, present in a study conducted by Meinerz et al. (2011), which evaluates the production and the content of dry matter of oat. These values are also above the 14.91% coefficient of variation obtained by Floss et al. (2007) for the yield of dry matter of oat. It is also important to point out that these high values of the coefficient of variation obtained on this study may indicate low precision in conducting the experiment, however, these values are acceptable because the experiments conducted in the field usually exhibit higher estimates of the coefficient of variation, due to the less control of the experimental error (Smiderle et al., 2014).

Optimum plot size and coefficient of variation of optimum plot size

The purpose of the estimate portion size according to Frazer et al. (2011) is to minimize the experimental error, increase forecast accuracy and the variables and reduce the measurement effort. For this purpose was obtained optimum plot size in this study $X_o = 1.66\text{m}^2$ for fresh matter, and $X_o = 1.73\text{m}^2$ dry matter, which includes the maximum variability in this scenario (cultivars and seasons seeding), in which, from these values, the increase in variability is negligible. Still, it was found dissimilarity in estimating the optimum plot size between the mass variables of fresh and dry matter of oat. In a study by Lombardi et al. (2015) on the effect of plot size in the estimation of forest indicators was also observed difference between the estimated variables, which corroborates the information in this study.

Throughout the investigation of the literature, no studies were found on the dimensioning of the optimum plot size to assess the fresh matter ($X_o = 6.62\text{ BEU}$ or 1.66m^2 and $CVx_o = 14.80\%$) and the dry matter ($X_o = 6.93\text{ BEU}$ or 1.73m^2 and $CVx_o = 15.50\%$) of oat to be faced with these data obtained on this study. Nevertheless, in cultivations from the same family (Poaceae), such as the black oat, Cargnelutti Filho et al. (2014a), in order to evaluate the fresh matter, defined X_o of 4.14m^2 and CVx_o of 9.25%, and to measure the fresh matter of millet, Burin et al. (2015) established X_o of 4.46m^2 and CVx_o of

9.96%. Within this context, it was verified that in the evaluation of the aerial part of fresh matter of these cultivations, the estimates of X_o and CV_{X_o} were different. Therefore, it can be inferred that the use of the plot size of a certain cultivation when used in another cultivation may produce results with low experimental precision. In this case, when these crops are analyzed together, in the same experiment, it is suggested to scale the plot size based on the highest estimate in order to provide the desired accuracy for all the cultivations.

In studies that measure fresh and dry matter of oat, the plot sizes used by Floss et al. (2007), Grecco et al. (2011), Demétrio et al. (2012) and Ferrazza et al. (2013), Khan et al. (2014) and Iqbal et al. (2014) were larger than the plot size of this study, which suggests that the information attained on these studies were obtained from plots with sufficient size. However, on the studies of Tafernaberi Júnior et al. (2012), Meinerz et al. (2012) and Soares et al. (2013), the plot sizes were inferior to that obtained on the present study. The use of a smaller plot size than the optimal plot size may increase the experimental error, and thus conceal the effect of treatment. The comparison between the optimum size obtained on this study and the plot sizes used in the aforementioned studies should be considered with caution, for there are differences concerning the useable area of the plot used in the evaluations.

Number of replications

The number of repetitions determined to measure the fresh weight and dry matter of oat that study was replicated four times. Studies have been conducted with four (Demétrio et al., 2012; Tafernaberi Júnior et al., 2012; Soares et al., 2013) and three (Floss et al., 2007; Meinerz et al., 2012; Ferrazza et al., 2013; Khan et al., 2014; Iqbal et al., 2014) replications, showing the feasibility of conducting experiments with these numbers of replications. A proper scaling of the plot size and the proper number of replications, as mentioned by Cargnelutti Filho et al. (2014b), is critical to perform accurate inferences in the experiments.

Can infer that to evaluate the aerial part of fresh and dry matter of oat in a CRD or a RBD, with the maximum of 50 treatments, using

the Tukey test at 5% probability, four replications are sufficient to identify significant differences among the treatment means of 44.75% of the experiment mean.

Conclusions

There is variability of the plot size among cultivars and sowing dates in order to measure the fresh and dry matter in oat.

The optimum plot size of 6.62 and 6.93 basic experimental units (1.66 and 1.73 m²) are suitable to assess the fresh and dry matter of oat in the four cultivars and on the three sowing dates, respectively.

Four replications to evaluate the maximum of 50 treatments in completely randomized design and randomized blocks design are sufficient so that the differences among treatment means of 44.75% of the experiment mean may be significant, using the Tukey test at 5% probability to measure the fresh and dry matter in oat.

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