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Plot size and number of repetitions in forage wheat

Tamanho de parcela e número de repetições em trigo forrageiro

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ABSTRACT - Forage wheat (*Triticum aestivum* L.) is an annual crop, alternative for use as a ground cover crop in the winter period, in production systems in southern Brazil. Given its magnitude, research with field experiments is carried out and plot size definition is of great importance in the experimental design. The objectives of this study were to estimate the plot size and number of repetitions to evaluate the fresh matter of forage wheat and to investigate the variability of plot size among agricultural years, sowing dates and cultivars. Thirty-six uniformity trials were conducted (two agricultural years × three sowing dates × two cultivars × three repetitions). Plot size was determined by the method of maximum curvature of the coefficient of variation model. The number of repetitions was determined for experiments in completely randomized and randomized block designs in scenarios formed by the combinations of i treatments (i=3, 4, …, 50) and d least significant differences among treatment means to be detected as significant by the Tukey test, at 5% of significance, expressed as a percentage of the overall mean of the experiment (d=5%, 10%, …, 30%). The plot size to evaluate the fresh matter of forage wheat is 4.05 m². Seven repetitions are sufficient to identify the fresh matter in completely randomized designs and randomized block designs with up to 50 treatments, making it possible to obtain least significant difference lower than or equal to 20% of the mean of the experiment.

Keywords: *Triticum aestivum* L. Soil cover crop. Uniformity trial. Experimental planning.

RESUMO - O trigo forrageiro (*Triticum aestivum* L.) é uma cultura anual, alternativa de utilização como cultura de cobertura de solo no período de inverno, em sistemas produtivos da região Sul do Brasil. Dada sua magnitude, pesquisas com experimentos a campo são desenvolvidas e a definição do tamanho de parcela tem grande importância no planejamento experimental. Os objetivos deste trabalho foram estimar o tamanho de parcela e o número de repetições para avaliar a matéria fresca de trigo forrageiro e investigar a variabilidade de tamanho de parcela entre anos agrícolas, épocas de semeadura e cultivares. Foram conduzidos 36 ensaios de uniformidade (dois anos agrícolas × três épocas de semeadura × duas cultivares × três repetições). O tamanho de parcela foi determinado por meio do método da curvatura máxima do modelo do coeficiente de variação. O número de repetições foi determinado para experimentos nos delineamentos inteiramente casualizado e blocos ao acaso em cenários formados pelas combinações de i tratamentos (i=3, 4, ..., 50) e d diferenças mínimas entre médias de tratamentos detectadas como significativas pelo teste de Tukey, a 5% de significância, expressas em percentagem da média do experimento (d=5%, 10%, ..., 30%). O tamanho de parcela para avaliar a matéria fresca de trigo forrageiro é 4,05 m^2. Sete repetições são suficientes para avaliar a matéria fresca em delineamentos inteiramente casualizado e blocos ao acaso com até 50 tratamentos, possibilitando obter diferença mínima significativa menor ou igual a 20% da média do experimento.

Palavras-chave: *Triticum aestivum* L. Cultura de cobertura de solo. Ensaio de uniformidade. Planejamento experimental.

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INTRODUCTION

Forage wheat (*Triticum aestivum* L.) is an alternative to be used as a ground cover crop in the winter period in production systems in southern Brazil (FONTANELI et al., 2016). This crop has fast initial establishment, high tillering capacity, relatively long cycle and high fresh matter production and can be sown immediately after the harvest of summer crops (MANFRON; FONTANELI, 2019).

Producers have at their disposal forage wheat cultivars registered for the production of silage, pre-dried silage, double purpose (forage and grain) and ground cover crop (BIOTRIGO GENÉTICA, 2019). The cultivars TBIO Energia I and TBIO Energia II are intended for use as cover crop, for the production of silage and pre-dried silage, and are not recommended for grazing. They have morphological characteristics such as absence of awns, tolerance to lodging, and high production of fresh matter (BIOTRIGO GENÉTICA, 2019).

In experimental planning, determining plot size and number of repetitions is important for proper sizing of experiments. According to Storck et al. (2016), the plots must have dimensions that allow precise estimation of the traits under evaluation. Plot size can be determined from data obtained in uniformity trials, that is, trials without any treatment (STORCK et al., 2016).

Plot size estimation can be performed by the method of maximum curvature of the coefficient of variation model, proposed by Paranaíba, Ferreira and Morais (2009). This method has been used by Lavezo et al. (2017), Chaves et al. (2018a) and Toebe et al. (2020a, b) in the determination of plot size to estimate fresh matter per experimental unit in white oat, rye, triticale and ryegrass crops, respectively. In studies with wheat crop, plot sizes of 6.48 m^2 (LORENTZ et al., 2007), 0.68 m² (PARANAÍBA; MORAIS; FERREIRA, 2009) and 1.6 m^2 and 2.4 m^2 (HENRIQUES NETO et al., 2009) were recommended for evaluation of mass and/or grain yield.

Defining the number of repetitions is fundamental for the minimization of the experimental error, that is, the reduction of variance between experimental units of the same treatment. In experiments with forage wheat crop, three (CARVALHO et al., 2015; MANFRON; FONTANELI, 2019) four (BECKER; GAI, 2019) and five (CARLETTO et al., 2020) repetitions have been used. These different numbers of repetitions recommended and used show that there is no consensus regarding this situation, which may lead to different results in relation to experimental precision.

Studies on the plot size and number of repetitions to evaluate the fresh matter of forage wheat were not found in the literature. It is assumed that the plot size and the number of repetitions vary with the agricultural year, sowing date and cultivar. Thus, it is essential to obtain information on these characteristics in these scenarios so that they can be used as a reference in future planning of experiments with the crop. Therefore, the objectives of this study were to estimate the plot size and number of repetitions to evaluate the fresh matter of forage wheat and investigate the variability of plot size among agricultural years, sowing dates and cultivars.

MATERIAL AND METHODS

Thirty-six uniformity trials were conducted with forage wheat crop in the experimental area of the Plant Science Department of the Federal University of Santa Maria, located at 29º42'S, 53º49' W and 95 m altitude. The climate of the region is humid subtropical - Cfa, according to Köppen's classification, with hot summers and no dry season (ALVARES et al., 2013) and the soil is classified as *Argissolo vermelho distrófico arênico* (Ultisol) (SANTOS et al., 2018).

The trials were formed by the combination of two agricultural years, three sowing dates, two cultivars (TBIO Energia I and TBIO Energia II) and three repetitions. These cultivars were selected because they have high fresh matter production, being recommended as a ground cover crop. Of these, 30 uniformity trials were divided into 36 basic experimental units (BEU) of 1 m^2 (1 m × 1 m), forming a matrix of six rows and six columns (6 m × 6 m), totaling 36 m^2 (Figure 1). Due to the excess rainfall during the establishment of the plant stand, the sizing of the trials with the cultivar TBIO Energia I (three trials for the first sowing date of the year 2019) and with the cultivar TBIO Energia II (three trials for the third date of the year 2019) was formed with matrices of 9 × 4 and 5 × 6, totaling 36 and 30 BEU, respectively.

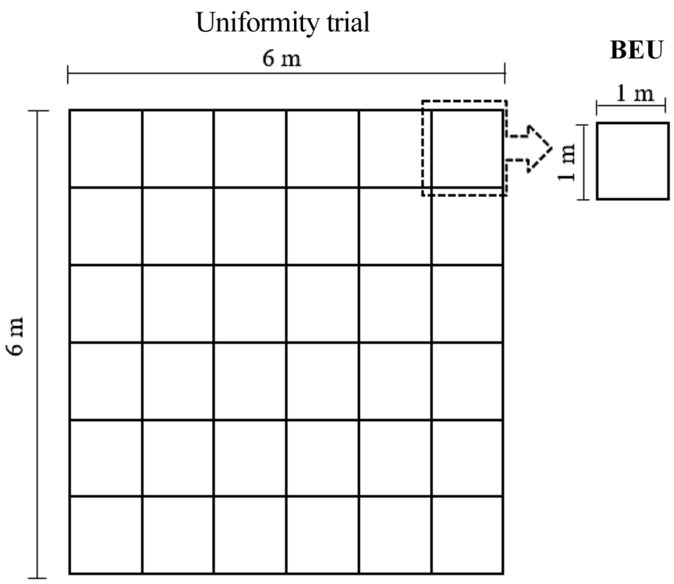
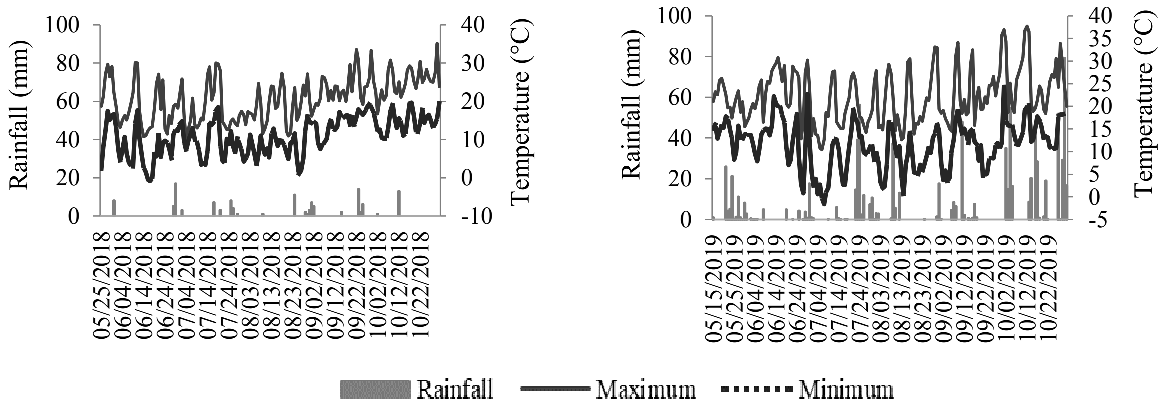


Figure 1. Representation of a uniformity trial with dimensions of 6 m × 6 m and the subdivision into 36 basic experimental units (BEU) of 1 m^2 (1 m × 1 m).

In all trials, mechanized sowing was performed at the density of 420 seeds m^{-2}. Basal fertilization was 9 kg ha^{-1} of N, 36 kg ha^{-1} of P_2O_5 and 36 kg ha^{-1} of K_2O, and subsequently two top-dressing fertilizations of 41 kg ha^{-1} of N were performed in the development stages V3 (three expanded leaves) and V6 (six expanded leaves).

In 2018, sowing was carried out on May 28 (date 1), June 20 (date 2) and July 7 (date 3). In 2019, sowing was carried out on June 7 (date 1), June 27 (date 2) and July 18 (date 3). Cultural management practices were performed homogeneously throughout the experimental area.

The meteorological data of rainfall and air temperatures (maximum and minimum) recorded during the trials were collected by the weather station of the Federal University of Santa Maria, located 100 m away from the experiment (Figure 2).



	TBIO Energia I			TBIO Energia II		
	D1	D2	D3	D1	D2	D3
Cycle (days)*	101 | 120	93 | 99	76 | 93	87 | 99	78 | 99	71 | 93
Rainfall (mm)	80 | 465	78 | 432	68 | 493	78 | 344	55 | 432	68 | 493
Maximum temperature (°C)	30 | 36.9	33.5 | 36.9	33.5 | 37.7	30 | 34.1	30 | 36.9	33.5 | 37.7
Minimum temperature (°C)	-0.9 | -1.6	1 | -1.6	1 | 0.4	-0.9 | -1.6	1 | -1.6	1 | 0.4

Figure 2. Daily rainfall (mm) and daily maximum and minimum air temperatures (°C) during the months from May to October in the years 2018 and 2019, in experiments conducted with two wheat cultivars in Santa Maria, RS. *Number of days from emergence to harvest. Information regarding the cycle, rainfall and air temperatures presented below the graph refers to the values recorded during the months of 2018 (left of the bar - |) and 2019 (right of the bar), in relation to the sowing dates (D1=first date, D2=second date and D3=third date) for each cultivar (TBIO Energia I and TBIO Energia II).

In each trial, the evaluations were carried out when the crop was at the dough grain development stage (85: soft dough), according to the decimal scale of cereal development proposed by Zadoks, Chang and Konzak (1974). In each BEU of 1 m², the plants were cut near the soil surface and, immediately after the cut, fresh matter was determined with a digital scale (accuracy: 1 g), thus obtaining the value of mass in g m^{-2}.

For each uniformity trial, the fresh matter data of the basic experimental units were used to estimate the mean (m), variance (s^2), coefficient of variation of the trial (CV, in %) and first-order spatial autocorrelation coefficient (ρ). The estimate of ρ was obtained by a walk along the rows, according to the methodology proposed by Paranaíba, Ferreira and Morais (2009).

Based on the method of maximum curvature of the coefficient of variation model proposed by Paranaíba, Ferreira and Morais (2009), the plot size (Xo) was determined in each of the 36 uniformity trials by the expression:

$$\mathrm{Xo} = \frac{10\sqrt[3]{2(1-\rho^2)s^2\,\mathrm{m}}}{\mathrm{m}}$$

where: m is the mean, s^2 is the variance and ρ is the first-order spatial autocorrelation coefficient.

Next, the coefficient of variation of plot size (CVXo) was determined, as a percentage, using the expression:

$$\mathrm{CVXo} = \frac{\sqrt{(1-\rho^2)s^2/m^2}}{\sqrt{\mathrm{Xo}}} \times 100$$

For the statistics m, s^2, CV, ρ, Xo and CVXo, the following comparisons of means were performed, using Student's t-test (two-tailed), for independent samples, with 5% significance level: a) comparisons of agricultural years, regardless of sowing dates and cultivar (n=18 trials per year); b) comparisons of sowing dates within each agricultural year, regardless of cultivar (n=six trials per sowing date); and, c) comparisons of cultivars within agricultural years and sowing dates (n=three trials or repetitions per cultivar) and comparisons of sowing dates within agricultural years and cultivars (n=three trials per sowing date).

The number of repetitions was determined according to Steel, Torrie and Dicky (1997), applied by Cargnelutti Filho et al. (2014) and described below. The least significant difference (d) of the Tukey test, expressed as a percentage of the overall mean of the experiment, was estimated by the expression:

$$d = \frac{q_{\alpha(i;DFE)}\sqrt{\frac{MSE}{r}}}{m} \times 100$$

where qα(i;DFE) is the critical value of the Tukey test at the α probability level of error (α =0.05, in this study), i is the number of treatments, DFE is the number of degrees of freedom of the error, that is, i (r - 1) for the completely randomized design and (i - 1) (r - 1) for the randomized block design, MSE is the mean square of the error, r is the number of repetitions, and m is the mean of the experiment.

Replacing the expression of the experimental coefficient of variation $CV = \frac{\sqrt{MSE}}{m} \times 100$, in percentage, in the expression for the calculation of d and isolating r lead to the expression to determine the number of repetitions:

$$r = \left(\frac{q_{\alpha(i;DFE)}CV}{d}\right)^2$$

In this study the experimental coefficient of variation corresponds to CVXo and is expressed as a percentage, because this is the CV expected for the experiment with the determined plot size.

Next, the number of repetitions (r) was estimated for experiments in completely randomized and randomized block designs, considering the CVXo referring to the highest mean of the Xo estimate among agricultural years, sowing dates and cultivars. The number of repetitions was determined in different scenarios formed by the combinations of i treatments (i=3, 4, ..., 50) and d least significant differences between treatment means detected as significant by the Tukey test, at 5% significance level, expressed as a percentage of the overall mean of the experiment (d=5%, 10%, ..., 30%). Statistical analyses were performed with the Microsoft Office Excel® application and R software version 4.2.0 (R CORE TEAM, 2022).

RESULTS AND DISCUSSION

There was a significant difference in the estimates of mean (m), variance (s^2) and first-order spatial autocorrelation coefficient (ρ) between the agricultural years 2018 and 2019 (Table 1).

Table 1. Mean (m), variance (s^2), coefficient of variation (CV, in %), first-order spatial autocorrelation coefficient (ρ), plot size (Xo, in m^2) and coefficient of variation of plot size (CVXo, in %) for the fresh matter of forage wheat, in g m^{-2}, in the agricultural years 2018 and 2019.

Year	m	s^2	CV (%)	ρ	Xo (m^2)	CVXo (%)
2018	2,231.07 A[(1)]	125,403.77 A	15.85 A	0.28 A	3.51 A	7.84 A
2019	1,364.78 B	40,974.87 B	14.52 A	0.04 B	3.40 A	7.61 A

[(1)]Means not followed by the same letter in the column (comparison of agricultural years, regardless of sowing date and cultivar) differ from each other at 5% probability of error by Student's t-test for independent samples, with 34 degrees of freedom.

In plot size studies (Xo) with ground cover crops carried out by Cargnelutti Filho et al. (2014) and Burin et al. (2015), scenarios of variability in the estimates of the statistics m, s^2, coefficient of variation (CV), ρ, Xo and coefficient of variation of plot size (CVXo) among the uniformity trials were also observed. According to these authors, variability scenarios are important in studies of Xo and number of repetitions, as they reflect the actual conditions of the crop in the field.

The mean of fresh matter, obtained in soft dough grain stage according to the scale described by Zadoks, Chang and Konzak (1974), was higher in 2018 than in 2019 (Table 1). This difference may have been influenced by the occurrence of climatic conditions more favorable to the development of the crop during 2018. During the months of the trials in 2019, the superiority in rainfall volume (852.00 mm) compared to the previous year (124.00 mm) (Figure 2) and oscillations in air temperature hampered the development of the crop. Higher air temperature oscillations occurred in 2019, with maximum of 37.7 °C and minimum of -1.6 °C. In 2018, there were lower oscillations between the maximum and minimum temperatures recorded, with values of 35.1°C and -0.9 °C, respectively. According to Zilio, Peloso and Mantovani (2017), the excess of rains and high temperatures reduce the duration of the plant growth period, thus advancing the elongation stage, which may have contributed to the lower fresh matter production of forage wheat in 2019.

There were differences in the estimates of m and s^2 in the comparisons between sowing dates within the year 2018. In this year, differences in m and s^2 were observed between the first and third date, and only for m between the second and third date. In 2019, there were differences between the estimates of m, s^2, CV, ρ, Xo and CVXo (Table 2). In that year, no differences were observed in the estimates of m between the second and third date and in the estimates of s^2, CV, Xo and CVXo between the first and third date.

Table 2. Mean (m), variance (s^2), coefficient of variation (CV, in %), first-order spatial autocorrelation coefficient (ρ), plot size (Xo, in m^2) and coefficient of variation of plot size (CVXo, in %) for the fresh matter of forage wheat, in g m^{-2}, as a function of sowing dates and agricultural years.

Date	m	s^2	CV (%)	ρ	Xo (m^2)	CVXo (%)
			Year 2018			
1	2,446.64 A[(1)]	121,308.49 A	14.19 A	0.40 A	3.20 A	7.16 A
2	2,524.23 A	175,053.02 A	16.11 A	0.16 A	3.59 A	8.03 A
1	2,446.64 A	121,308.49 A	14.19 A	0.40 A	3.20 A	7.16 A
3	1,722.34 B	79,849.81 B	17.24 A	0.31 A	3.73 A	8.33 A
2	2,524.23 A	175,053.02 A	16.11 A	0.16 A	3.59 A	8.03 A
3	1,722.34 B	79,849.81 A	17.24 A	0.31 A	3.73 A	8.33 A
			Year 2019			
1	1,648.69 A	58,549.10 A	14.85 A	-0.07 A	3.48 A	7.78 A
2	1,243.54 B	21,196.19 B	11.26 B	0.00 A	2.91 B	6.50 B
1	1,648.69 A	58,549.10 A	14.85 A	-0.07 B	3.48 A	7.78 A
3	1,202.11 B	43,179.31 A	17.46 A	0.17 A	3.83 A	8.55 A
2	1,243.54 A	21,196.19 B	11.26 B	0.00 A	2.91 B	6.50 B
3	1,202.11 A	43,179.31 A	17.46 A	0.17 A	3.83 A	8.55 A

[(1)]Means not followed by the same letter in the column (comparison of sowing dates within each agricultural year, regardless of cultivar), differ from each other at 5% probability of error by Student's t-test for independent samples, with 10 degrees of freedom.

Differences in the means of fresh matter of white oats were also observed among three sowing dates (LAVEZO et al., 2017). The authors found that the differences in the means of fresh matter of white oat could be attributed to temperature and water availability oscillations throughout the growing period. This is consistent with the behavior observed between the sowing dates in 2019, when there were greater differences between the estimates, which can be attributed to the greater oscillations of temperature and water availability (Figure 2) compared to the climatic conditions of cultivation for the sowing dates of 2018. Significant differences were identified between the estimates of m, s^2, CV, ρ, Xo and CVXo, between cultivars within agricultural years and sowing dates and between sowing dates within agricultural years and cultivars (Table 3).

The mean of fresh matter (m) of the cultivar TBIO Energia II was 428.32 g m^{-2} higher than that of TBIO Energia I for the second sowing date in 2018. In 2019, higher estimates of fresh matter were observed for the cultivar TBIO Energia II in the first sowing date and for TBIO Energia I in the second and third sowing dates.

The values of fresh matter production of forage wheat in the present study were higher than those found by Carletto et al. (2015). These authors observed in forage wheat a fresh matter production of 13,096 kg ha^{-1}, a value much lower than that found for the cultivars TBIO Energia I (23,100.7 kg ha^{-1}) and TBIO Energia II (27,383.9 kg ha^{-1}), in the second sowing date of 2018. This greater amount of fresh matter results from the characteristics of the genetic basis of these cultivars. According to the company which owns the registration of the cultivars, the fresh matter production can vary from 25,000 to 30,000 kg ha^{-1} (BIOTRIGO GENÉTICA, 2019), justifying their use as an option of ground cover crop, as well as for the production of silage and pre-dried silage.

The means of s^2, CV, Xo and CVXo did not differ statistically between the cultivars in 2018. Significant difference was found only in the mean estimates of the first-order spatial autocorrelation coefficient between the first and second sowing date (Table 3).

In 2019, the means of s² and ρ did not differ between cultivars for all sowing dates. The means of CV, Xo and CVXo for the first sowing date of the cultivar TBIO Energia I was higher than those of TBIO Energia II. For the same sowing date, Xo was equal to 3.82 and 3.14 m² for the cultivars TBIO Energia I and TBIO Energia II, respectively (Table 3). Gains in experimental precision can be observed when using the plot size in the estimation of fresh matter, which can be noticed when comparing the coefficient of variation (CV), obtained in the uniformity trials, with the coefficient of variation of plot size (CVXo). The significant reduction indicates gains in experimental precision with the use of the plot size (CHAVES et al., 2018b).

Table 3. Mean (m), variance (s^2), coefficient of variation (CV, in %), first-order spatial autocorrelation coefficient (ρ), plot size (Xo, in m^2) and coefficient of variation of plot size (CVXo, in %) for the fresh matter of forage wheat, in g m^{-2}, in uniformity trials with two cultivars (TBIO Energia I and TBIO Energia II) sown on three dates in the agricultural years 2018 and 2019.

Year 2018							
TBIO Energia I				TBIO Energia II			
Date	m	s^2	CV (%)	Date	m	s^2	CV (%)
1	2,399.19 Aa[(1)]	126,251.27 Aa	14.72 Aa	1	2,494.08 Aa	116,365.71 Aa	13.67 Aa
2	2,310.07 Ba	116,588.00 Aa	14.84 Aa	2	2,738.39 Aa	233,518.04 Aab	17.38 Aa
3	1,736.93 Aa	87,096.15 Aa	18.73 Aa	3	1,707.75 Ab	72,603.48 Ab	15.75 Aa
Date	ρ	Xo (m^2)	CVXo (%)	Date	ρ	Xo (m^2)	CVXo (%)
1	0.49 Aa	3.18 Aa	7.11 Aa	1	0.31 Ba	3.23 Aa	7.22 Aa
2	-0.04 Bb	3.50 Aa	7.82 Aa	2	0.36 Aa	3.68 Aa	8.24 Aa
3	0.31 Aab	3.93 Aa	8.79 Aa	3	0.30 Aa	3.52 Aa	7.88 Aa
Year 2019							
Date	m	s^2	CV (%)	Date	m	s^2	CV (%)
1	1,480.25 Ba[(1)]	64,171.75 Aa	17.08 Aa	1	1,817.13 Aa	52,926.46 Aa	12.62 Ba
2	1,364.33 Aa	28,268.26 Ab	12.22 Ab	2	1,122.74 Bb	14,124.12 Ab	10.31 Aa
3	1,376.73 Aa	46,358.04 Aab	15.63 Aab	3	1,027.49 Bb	40,000.59 Aab	19.28 Aa
Date	ρ	Xo (m^2)	CVXo (%)	Date	ρ	Xo (m^2)	CVXo (%)
1	-0.12 Aa	3.82 Aa	8.54 Aa	1	-0.02 Aa	3.14 Ba	7.01 Ba
2	-0.12 Aa	3.08 Ab	6.88 Ab	2	0.11 Aa	2.74 Aa	6.12 Aa
3	0.12 Aa	3.60 Aab	8.05 Aab	3	0.25 Aa	4.05 Aa	9.06 Aa

[(1)]Means not followed by the same uppercase letter in the row (comparison of cultivars within agricultural years and sowing dates) and lowercase letter in the column (comparison of sowing dates within agricultural years and cultivars) differ at 5% probability of error by Student's t-test for independent samples, with 4 degrees of freedom.

In the comparison between sowing dates within agricultural years and cultivars, a significant difference was observed in the first-order spatial autocorrelation coefficient for the cultivar TBIO Energia I in 2018. For the cultivar TBIO Energia II in the same year, a lower mean of fresh matter in the third sowing date (1,707.75 g m^{-2}) and higher s^2 estimate in the second date were observed.

For the cultivar TBIO Energia I, in 2019, statistical differences were observed between the sowing dates in relation to the estimates of s^2, CV, Xo and CVXo. In the same year, only the mean and variance showed statistical differences between the sowing dates for the cultivar TBIO Energia II, with higher estimates in the first sowing date (Table 3).

The Xo values for the estimation of fresh matter in forage wheat did not differ significantly by the Student's t-test between agricultural years (Table 1). However, they differed significantly in the comparison of means between sowing dates in 2019 (Table 2), as well as between cultivars within the same sowing date and between sowing dates within the same cultivar, in 2019 (Table 3).

Given the variability in the estimation of Xo between sowing dates and between cultivars, it was decided to use the highest mean of plot size, in order to contemplate the maximum variability of all scenarios (agricultural years, sowing dates and cultivars). Thus, the plot size to evaluate the fresh matter of forage wheat is 4.05 m² and can be used as a reference for future studies with this crop, with an estimated coefficient of variation of 9.06%.

In the literature, there are studies which determined the plot size for winter cereals. Cargnelutti Filho et al. (2014) determined the plot size of 4.14 m^2 as ideal for evaluation of fresh matter in black oat. For white oat, Lavezo et al. (2017) determined the plot sizes of 1.66 and 1.73 m² as ideal for estimating fresh matter and dry matter, respectively. In the rye crop, Chaves et al. (2018a) determined plot sizes of 3.43, 3.82 and 6.08 m² to evaluate fresh matter, dry matter and grain yield, respectively.

Toebe et al. (2020a) defined the plot size of 3.12 m^2 to evaluate fresh matter in triticale. In studies with wheat crop, plot sizes of 6.48 m^2 (LORENTZ et al., 2007), 0.68 m^2 (PARANAÍBA; MORAIS; FERREIRA, 2009) and 1.6 m^2 and 2.4 m^2 (HENRIQUES NETO et al., 2009) were determined for evaluation of mass and/or grain yield, respectively.

In practice, studies have been carried out with different plot sizes in experiments with forage wheat crop. Carvalho et al. (2015), Zilio, Peloso and Mantovani (2017) and Carletto et al. (2020) used plots of 4.08, 4.25 and 15.00 m², respectively. This highlights the importance of the adequate sizing of the plot size for the crop, since Carvalho et al. (2015) and Zilio, Peloso and Mantovani (2017) used plot sizes very close to that determined in the present study, but Carletto et al. (2020) could have saved financial resources, labor and time in their trials, without compromising the precision of their results with the use of smaller plot size.

Regarding the number of repetitions, in studies to evaluate fresh and dry matter in rye, Chaves et al. (2018b) recommend using six repetitions, identifying significant differences (α=0.05) between treatment means equal to 18 and 20% of the overall mean of the experiment, in completely randomized design and randomized block design, respectively. According to Cargnelutti Filho et al. (2014), four repetitions are sufficient to evaluate the fresh matter of black oat in up to 50 treatments, in completely randomized design and randomized block design with differences between treatment means of 26.7% of the mean of the experiment, significant at 5% probability level by Tukey test.

To determine the number of repetitions to evaluate fresh matter in forage wheat, one should start from scenarios formed by the combination of i treatments (i=3, 4, ..., 50) and d least significant differences between the treatment means to be detected as significant by the Tukey test at 5% significance level, expressed as a percentage of the overall mean of the experiment (d=5%, 10%, ..., 30%), using the Xo of 4.05 m² and CVXo of 9.06%.

The number of repetitions oscillated between 2.31 (three treatments and d=30%) and 104.80 (50 treatments and d=5%) for experiment in completely randomized design (CRD) and between 2.41 (three treatments and d=30%) and 104.80 (50 treatments and d=5%) for experiment in randomized block design (RBD) (Table 4).

Table 4. Number of repetitions for experiments in completely randomized design (CRD) and randomized block design (RBD) in scenarios formed by combinations of i treatments (i=3, 4, ..., 50) and d least significant differences between treatment means detected as significant at 5% probability level, by the Tukey test, expressed as a percentage of the overall mean of the experiment (d=5%, 10%, ..., 30%), to evaluate the fresh matter in forage wheat, from the plot size (Xo=4.05 m²) and coefficient of variation of plot size (CVXo=9.06%).

	CRD						RBD					
i	5%	10%	15%	20%	25%	30%	5%	10%	15%	20%	25%	30%
3	37.08	10.07	5.14	3.49	2.79	2.31	37.58	10.60	5.62	3.91	2.93	2.41
4	44.19	11.73	5.77	3.74	2.86	2.33	44.50	12.00	6.04	4.00	2.99	2.43
5	49.61	12.99	6.25	3.93	2.92	2.35	49.80	13.17	6.44	4.12	3.10	2.45
6	53.98	14.01	6.64	4.11	2.97	2.38	54.11	14.15	6.79	4.24	3.12	2.47
7	57.68	14.88	7.00	4.27	3.05	2.40	57.77	14.98	7.08	4.38	3.14	2.48
8	60.86	15.65	7.29	4.41	3.10	2.42	60.94	15.72	7.38	4.49	3.19	2.50
9	63.67	16.31	7.56	4.54	3.16	2.45	63.74	16.37	7.63	4.60	3.23	2.51
10	66.19	16.91	7.80	4.65	3.23	2.47	66.24	16.97	7.86	4.71	3.28	2.53
11	68.46	17.45	8.03	4.75	3.28	2.50	68.50	17.49	8.07	4.80	3.33	2.54
12	70.53	17.95	8.23	4.85	3.32	2.52	70.57	17.99	8.27	4.89	3.37	2.56
13	72.44	18.41	8.42	4.95	3.37	2.54	72.48	18.44	8.45	4.99	3.41	2.58
14	74.21	18.83	8.60	5.04	3.42	2.56	74.24	18.87	8.63	5.07	3.45	2.59
15	75.86	19.23	8.76	5.12	3.46	2.58	75.89	19.26	8.79	5.15	3.49	2.61
16	77.40	19.61	8.92	5.20	3.50	2.60	77.43	19.63	8.95	5.29	3.52	2.63
17	78.85	19.96	9.07	5.27	3.54	2.63	78.87	19.98	9.08	5.29	3.56	2.65
18	80.22	20.29	9.20	5.34	3.58	2.65	80.24	20.31	9.22	5.36	3.60	2.67
19	81.51	20.60	9.34	5.41	3.61	2.66	81.53	20.62	9.35	5.43	3.63	2.68
20	82.74	20.90	9.46	5.47	3.65	2.68	82.76	20.92	9.48	5.49	3.67	2.70
21	83.93	21.19	9.58	5.54	3.68	2.70	83.94	21.20	9.60	5.55	3.70	2.72
22	85.03	21.46	9.70	5.60	3.72	2.72	85.04	21.47	9.71	5.61	3.73	2.73
23	86.09	21.72	9.81	5.66	3.75	2.74	86.10	21.73	9.82	5.66	3.76	2.75
24	87.11	21.97	9.91	5.71	3.78	2.75	87.12	21.98	9.92	5.72	3.79	2.77
25	88.10	22.20	10.01	5.76	3.81	2.77	88.10	22.21	10.02	5.77	3.82	2.78
26	89.04	22.43	10.11	5.81	3.84	2.78	89.04	22.44	10.12	5.82	3.85	2.80
27	89.94	22.66	10.21	5.86	3.86	2.80	89.95	22.66	10.21	5.87	3.87	2.81
28	90.82	22.87	10.30	5.91	3.89	2.82	90.84	22.88	10.31	5.92	3.90	2.83
29	91.66	23.07	10.38	5.95	3.92	2.83	91.67	23.08	10.39	5.96	3.93	2.84
30	92.48	23.28	10.47	6.00	3.94	2.85	92.48	23.28	10.48	6.01	3.95	2.86
31	92.26	23.47	10.55	6.04	3.87	2.86	93.27	23.48	10.56	6.05	3.98	2.87
32	94.03	23.65	10.63	6.09	3.99	2.88	94.03	23.66	10.64	6.09	4.00	2.88
33	94.77	23.84	10.71	6.13	4.02	2.89	94.77	23.84	10.72	6.13	4.02	2.90
34	95.49	24.01	10.79	6.17	4.04	2.90	95.49	24.02	10.79	6.17	4.05	2.91
35	96.19	24.18	10.86	6.21	4.06	2.92	96.19	24.19	10.87	6.21	4.07	2.92

Table 4. Continuation.

	CRD						RBD					
i	5%	10%	15%	20%	25%	30%	5%	10%	15%	20%	25%	30%
36	96.86	24.35	10.93	6.24	4.09	2.93	96.87	24.36	10.94	6.25	4.09	2.94
37	97.53	24.51	11.00	6.28	4.11	2.94	97.53	24.52	11.01	6.29	4.11	2.95
38	98.17	24.67	11.07	6.32	4.13	2.96	98.17	24.68	11.07	6.32	4.14	2.96
39	98.80	24.83	11.13	6.35	4.15	2.97	98.80	24.83	11.14	6.36	4.16	2.97
40	99.41	24.98	11.20	6.39	4.17	2.98	99.41	24.98	11.20	6.39	4.18	2.99
41	100.00	25.12	11.26	6.42	4.19	2.99	100.00	25.13	11.27	6.43	4.20	3.00
42	100.58	25.27	11.32	6.45	4.21	3.00	100.58	25.27	11.33	6.46	4.22	3.01
43	101.15	25.41	11.38	6.49	4.23	3.02	101.16	25.41	11.39	6.49	4.24	3.02
44	101.71	25.54	11.44	6.52	4.25	3.03	101.71	25.55	11.45	6.52	4.25	3.03
45	102.25	25.68	11.50	6.55	4.27	3.04	102.26	25.68	11.51	6.55	4.27	3.04
46	102.78	25.81	11.56	6.58	4.29	3.05	102.79	25.81	11.56	6.58	4.29	3.06
47	103.30	25.93	11.61	6.61	4.30	3.06	103.31	25.94	11.62	6.61	4.31	3.07
48	103.81	26.06	11.67	6.64	4.32	3.07	103.81	26.06	11.67	6.64	4.32	3.08
49	104.31	26.18	11.72	6.67	4.34	3.08	104.31	26.19	11.72	6.67	4.34	3.09
50	104.80	26.30	11.77	6.69	4.35	3.09	104.80	26.31	11.78	6.70	4.36	3.10

Therefore, for experiments in CRD and RBD, it can be observed that there is an increase in the number of repetitions as the number of treatments increases, when the value of d is fixed. With the increase in the number of treatments, the difference in the number of repetitions for experiments in CRD and RBD gradually decreased, tending to be insignificant. For example, an experiment with i=50 treatments, $\alpha=0.05$, r=7 repetitions and CVXo=9.06% for fresh matter in forage wheat, has d=19.548% (CRD) and 19.552% (RBD) ≅20%.

According to Cargnelutti Filho et al. (2014), lower d values indicate higher experimental precision, that is, smaller differences between treatment means are significant. It is up to the user of the information from the present study to choose the combination of the desired experimental design, number of treatments, least significant difference between treatment means and number of repetitions suitable for the experiment. In practice, experiments with the crop have been conducted with three (CARVALHO et al., 2015; MANFRON; FONTANELI, 2019), four (BECKER; GAI, 2019) and five (CARLETTO et al., 2020) repetitions, respectively. However, it can be inferred that the use of adequate and sufficient plot size, together with the number of repetitions obtained from this study, can contribute to the sizing of future experiments with forage wheat crop, with higher experimental precision.

CONCLUSION

Plot size of 4.05 m^2 can be used as a reference in future experiments with forage wheat.

Seven repetitions are sufficient to evaluate fresh matter in completely randomized design and randomized block design with up to 50 treatments, making it possible to obtain a least significant difference lower than or equal to 20% of the overall mean of the experiment.

There is variability in plot size to evaluate the fresh matter of forage wheat between sowing dates and between the cultivars TBIO Energia I and TBIO Energia II.

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